Cognitive Impairment After Unilateral Hemispheric Injury of Congenital or Adult Origin

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OBJECTIVE. The purpose of this study was to assess and compare cognitive functioning in adults with unilateral hemispheric injury due to either congenital damage or an ischemic event in young adulthood.

METHOD. Adults with cerebral palsy resulting from left hemispheric brain damage were compared with adults who had a unilateral stroke in either the left or the right hemisphere. Our primary interest was to determine the impact on hemispheric dominance as revealed by dichotic listening, a task that assesses the bias for preferential listening and processing of sounds. Performance also was determined on a language-related task (word finding) and a spatial task (dot localization).

RESULTS. Scores on the Quick Neurological Screening Test indicated that all participants demonstrated significant neuromotor deficits, whereas scores on the Barthel Index indicated that the participants were functional in basic activities of daily living. On cognitive assessments, healthy control participants demonstrated a pronounced left-hemisphere dominance and right-ear advantage; participants with injury to the left hemisphere showed a strong shift toward a right-hemisphere and left-ear dominance. In particular, injury of congenital origin appeared to foster this neural reorganization and localization of language-related functions into the healthy hemisphere. This shift was associated with a deterioration of performance on both the language and the spatial tasks.

CONCLUSION. The importance of appreciating subtle deficits after unilateral injury is important in therapy. The dichotic listening test may provide a simple and useful means for evaluating persistent unilateral brain dysfunction in the clinical setting.


Health care professionals need a comprehensive understanding of the deficits caused by congenital and acquired brain injury as necessary to better assist clients and to design more effective treatments. In addition to the overt neuromotor impairments, subtle cognitive, sensory, and emotional ramifications exist that often are undetected by current evaluation methods but can still interfere with normal functioning. Specifically, subtle cognitive deficits, if unidentified, can prevent persons with disabilities from participating in their desired occupational roles to the fullest. Understanding how the brain reorganizes functional capacities after neurological damage is critical for evaluating a person’s recovery process toward attainment of their optimal occupational ability. Identification of subtle cognitive impairments would enable occupational therapists to introduce environmental modifications and implement compensatory treatment strategies for the remediable aspects of the impairment.

One exemplary condition in this regard is unilateral hemispheric damage, which presents unique challenges because of the asymmetric localization of functions in the brain. At least since the time of Broca (1865), language has been believed to be localized predominantly in one hemisphere, and scientists have speculated subsequently on how this relates to handedness and affects the allocation of
other cognitive and sensory processes (Broca, 1865; Geschwind & Levitsky, 1968; Wada & Rasmussen, 1960). Hearing, especially the auditory processing of words, is one cognitive–sensory system known to be affected by hemispheric asymmetry, which is typically manifested as a right-ear, left-hemisphere bias for sound input in right-handed people (Broadbent, 1954). Many investigators have explored this phenomena using the intriguing task of dichotic listening, which assesses the processing of sounds or words presented simultaneously to both ears (Kimura, 1967). Most right-handed people typically have a bias to hear only the sound presented to the right ear, which is usually interpreted as reflecting the more rapid neural transmission to the left hemisphere (Hugdahl, Andersson, Asbjornsen, & Dalen, 1990). In addition, an inhibition of the ipsilateral signal induced at the level of the brainstem or midbrain relay nuclei may exist (Hugdahl & Wester, 1992).

Performance on the dichotic listening task has been used to explore alterations in brain asymmetry in both healthy and neurologically affected populations. Children with epilepsy and several learning disorders have been found to differ from healthy peers; similarly, adults with schizophrenia often do not manifest the strong right-ear advantage found in 60% to 80% of right-handed people (Duvellorey-Hommet et al., 1995; Martinez & Sanchez, 1999; Wexler, Giller, & Southwick, 1991). Of particular relevance to the present study are the prior evaluations of persons who experienced unilateral damage, especially to the left hemisphere. In keeping with the predictions, persons typically manifest a marked decrement in their right-ear advantage after a stroke in the left hemisphere (Bergman, Costeff, Korne, Korfman, & Reshef, 1984; Hugdahl & Wester, 1992; Korkman & von Wendt, 1995; Sparks, Goodglass, & Nickel, 1970; Woods, 1984). This observation has led other investigators to consider whether congenital damage has a differential impact when compared with unilateral hemorrhage or infarction strokes experienced as an adult (Isaacs, Christie, Varga-Khadem, & Mishkin, 1996). In general, the findings have been in keeping with the Kinnard Principle: There is typically more recovery following early brain trauma (Schneider, 1979). However, this conclusion has remained somewhat controversial because congenital damage may force more brain reorganization and the “crowding” of functions into one hemisphere (Nass, Sadler, & Sidtis, 1992; Rasmussen & Milner, 1977; Satz, Strauss, Wada, & Orsini, 1988). We investigated this question further by comparing performance on the dichotic listening task in adults who had experienced a unilateral lesion in the perinatal period with the performance of those who had experienced a unilateral lesion as young adults.

Many studies using the dichotic listening task have explored other factors contributing to performance, including the role of selective attention (Boliek, Obrazt, & Shaw, 1988; Kinsborne, 1970). For example, some hypothesized that the right-ear advantage is determined in part by a preferential bias for the left hemisphere to attend to word sounds. Although this interpretation of the ear bias in dichotic listening has fallen into disfavor, the attention issue has been partially resolved by a methodological refinement, which requires the participant to attend specifically to the sound presented in each ear during some test trials. We used the protocol developed by Hugdahl and colleagues that compares performance on free-listening trials to “forced-right or left-ear” trials (Hugdahl, 1988). This comparison permits one to assess specifically deficits in performance by the nondominant ear. Researchers have speculated that word sounds projected to the left ear may first have to be transmitted to the right hemisphere before being transferred back through the corpus callosum for final processing in the left hemisphere where language functions are located in right-handed people. This view was based on the observation that surgical transection of the callosum for the treatment of epilepsy resulted in a decrement in left-ear performance. Thus, it seemed possible that we might find that persons with exclusively right-hemisphere damage would still show a deficit in left-ear processing, even though their left hemisphere was the dominant one for language and had remained healthy and intact.

Finally, some articles have attempted to correlate performance on the dichotic listening task with other measures, including overall language and intellectual ability and the capacity to perceive complex sound attributes such as pitch (Hariri, Lakshmi, Larner, & Connolly, 1994; Sidtis & Volpe, 1988; Strauss, 1986). In our study, we used two additional tasks presumed to be sensitive to hemispheric asymmetry. One was a word-finding task that requires the participant to provide the term best defined by a phrase stimulus, a linguistic function believed to be associated with the hemisphere dominant for language (Davidson, Chapman, Chapman, & Henriques, 1990; Fujioka, 1986; Miller, Fujioka, Chapman, & Chapman, 1995a). The second task assessed an aspect of spatial ability—the participant’s capacity to visualize and remember the location of two dots—and presumed to reflect right-hemisphere functioning in right-handed people (Hannay, Varney, & Benton, 1976; Henriques & Davidson, 1997). Scalp electroencephalography–recording studies have indicated increases in right temporal lobe activity during the performance of this task (Davidson et al., 1990).

The purpose of this study was to compare performance on these three tasks—dichotic listening, word-finding, and
dot localization—in adults who had a unilateral hemispheric stroke and adults with spastic hemiparesis of congenital origin. One goal was to evaluate the extent of hemispheric reorganization after perinatal versus adult-onset trauma. Additionally, we were interested in whether impaired abilities on the cognitive tasks would be related to functional impairment and other assessments of neurological functioning. A prior article by our group already described undetected alterations in immune responses in persons with cerebral palsy and after a stroke (Rogers, Coe, & Karaszewski, 1998). Thus, the current study was directed to possible alterations of cognitive functioning in a set of tasks specifically chosen for their relevance to left-hemispheric or right-hemisphere capabilities.

Method

Participants and Procedure

Forty-four young adults (mean age = 35 years) were recruited and divided into three groups: (a) unilateral brain injury incurred in the prenatal or perinatal period (i.e., cerebral palsy, left hemispheric injury [LHI], n = 8), (b) unilateral brain injury due to hemorrhagic or infarction stroke in adulthood (LHI, n = 8; right hemispheric injury [RHI], n = 9), and (c) healthy adults (n = 19). The stroke group had experienced a single ischemic event a minimum of 9 months before our evaluation, with the range extending 5 years post-stroke. The healthy participants were age and gender matched to the study participants in both the stroke and the cerebral palsy groups. Neither the gender distribution nor the mean age differed between groups. On most test days, when a participant from the stroke or cerebral palsy groups was assessed, a participant from the control group also was evaluated. The control participants provided a baseline for how persons with no known neurological deficits would perform on three cognitive tasks (dichotic listening, word-finding, dot localization), a neuromotor assessment (Quick Neurological Screening Test [QNST]), and a functional assessment (Barthel Index of Independent Living). To ensure the selection of generally healthy participants, our inclusion criteria were no history of multiple infarctions, alcohol abuse, severe infections, malignant and autoimmune diseases, or use of immunosuppressive and antipsychotic drugs. Additionally, persons who were institutionalized or significantly receptive-impaired were excluded. Participants were 23 women and 21 men, all Caucasian except for 2 African-American participants in the stroke group.

Participant recruitment was approved by the university Institutional Review Board, and all participants signed a form indicating informed consent. All evaluations took place in a private research room of an outpatient clinic between 8:00 a.m. and 11:00 a.m. The testing procedure took approximately 1.5 hr per participant. Each participant received a financial remuneration of $20 for participation.

Because past medical records were not accessible, it was essential to quantify the participants’ neuromotor, functional, and sensory impairments as both evidence of neurological trauma and an establishment of general levels or absence of impairment. Thus, each participant, including the control participants, was evaluated with the Barthel Index and QNST (Collin, Wade, Davies, & Horne, 1988; Fricke & Unsworth, 1996; Mahoney & Barthel, 1965; Multti, Sterling, & Spalding, 1978). The participants were then asked to complete three cognitive tasks: dichotic listening, word-finding, and dot localization. The word-finding and dot localization tasks were presented with a rear-projected slide format in a semidarkened room. The order of task presentation counterbalanced across participants.

Instruments

**Barthel Index of Independent Living.** The Barthel Index, a standard index of independence, assesses a person’s level of functioning in basic activities of daily living (Mahoney & Barthel, 1965). This instrument reliably measures self-care abilities and has been found to have some predictive validity (Fortinsky, Granger, & Seltzer, 1981; Granger, Dewis, Peters, Sherwood, & Baret, 1979; Korner-Bitsky & Wood-Dauphinee, 1995; Letts & Bosch, 2001; Shah, Vanclay, & Cooper, 1989; Shinar et al., 1987). The Barthel Index consists of 10 items: feeding, bathing, grooming, dressing, bowel and bladder control, toilet transfers, chair and bed transfers, ambulation, stair climbing. Each item is rated on a 2-point or 3-point ordinal scale. Participants receive a final score between 0 and 100 in increments of 5. Healthy participants with no impairments typically receive a total score of 100 on the Barthel Index. Research has indicated that persons who live alone score above 75, whereas those scoring below 60 are considered to be dependent in self-care. Persons who have had a stroke and achieve scores greater than 45 are more likely to go home after hospitalization (Granger et al., 1979; Hasselkus, 1982).

**QNST.** The QNST determines the severity of neurological impairment (Multti et al., 1978). The standardized, norm-referenced assessment evaluates motor skills, asymmetry, muscle tone, sensory deficits, spatial organization, perceptual skills, balance, and attention. Low scores indicate better nervous system functioning; thus, healthy participants should score 24 or less. Participants scoring between 25 and 75 are considered to be minimally to moderately impaired, and those scoring above 75 are considered to be severely impaired. The QNST also was used to verify that the brain damage was unilateral and of a delimited nature.
**Word finding.** The word-finding task used was modeled after the Boston Naming Test (Davidson et al., 1990; Fujioka, 1986; Miller et al., 1995a). Each participant was presented with a series of phrases and asked to provide the word best defined by each phrase. The phrases were presented as a black-and-white image on a screen directly in front of the participant. An example test phrase is “a box or house for bees to live in.” In this case, the correct answer is “hive.” Five practice items with correct answers were provided, followed by the 24 test items. Word items of similar difficulty were selected. Participants were instructed to vocalize the word to the examiner, who wrote it on an answer sheet.

**Dot localization.** The dot localization task was adapted from a measure developed by Hannay et al. (1976). Each participant was shown an image of two open rectangles, one above the other. The top rectangle contained two dots, and the bottom rectangle contained an array of numbers. The bottom rectangle was increasingly offset to the right or left of the top rectangle. Participants were asked to indicate the numbers that would be covered by the two dots if the rectangles were superimposed. The difficulty of the task was manipulated by using five differently sized arrays of numbers, with the smallest containing 8 numbers and the largest containing 50 numbers. There were 20 scored items in addition to the 5 sample items. This task is believed to be largely a nondominant hemisphere function according to findings in persons with unilateral lesions (Davidson et al., 1990; Fujioka, 1986; Hannay et al., 1976; Miller, Fujioka, Chapman, & Chapman, 1995b).

**Dichotic listening.** The dichotic listening test was administered as recommended by Wester and Hugdahl (1995). Stimuli were presented simultaneously to the right and left ears through a headset. Six syllables consisting of the stop-consonants [b], [d], [g], [p], [t], and [k] combined with the vowel [a] were presented in pairs, including all possible combinations ([ba], [pa], etc.). These combinations generated 36 pairs of syllables, including the homonyms ([ba]-[ba], [pa]-[pa], etc.). The 6 homonymic pairs were included to ensure that the participant heard acoustical stimuli normally. The syllables in each presentation were the same in each ear, so a participant could choose only the correct syllable. In the statistical analyses, homonymic data were not included. Each syllable was presented for approximately 350 msec, with an intertrial interval of 4 sec between presentations. The 36 pairs of syllables were recorded 3 times on the tape, generating a total of 108 presentations. Order of presentation of the consonant–vowel syllables was randomized.

The dichotic listening task was presented in three conditions: nonforced, forced-right, and forced-left. Standardized instructions were given for each, and a prolonged pause marked the beginning of a different condition. In the nonforced condition, the participant was told to simply report which syllable was heard after each trial. For the forced-right or forced-left conditions, they were asked to listen to and report only the syllable heard from the specified ear. For more details on the dichotic listening task and verification of the methodology, see Hugdahl (1988, 1995).

**Statistical Analysis**

One-way analyses of variance (ANOVAs) were used to evaluate group differences on the Barthel Index, QNST, and dot localization and word-finding tasks. Two-way repeated-measures ANOVAs were used to analyze group differences on the dichotic listening task for each of the three test conditions. Scores for the left and right ears were analyzed as the repeated measure. Post hoc tests were performed with the Tukey honesty significant difference comparison, although for repeated measures, t tests were conducted (Welkowitz, Ewen, & Cohen, 2000).

Because of an inability to recruit sufficient numbers of participants with cerebral palsy who had right hemispheric damage, two sets of analyses were performed for each dependent variable. First, group differences were examined between participants in the control and stroke groups, comparing those with LHI to those with RHI after stroke. Second, ANOVAs were done to compare participants with cerebral palsy to only participants with left hemispheric stroke damage and control participants. Correlations between different test scores were determined with the Pearson product-moment correlation.

**Results**

**Barthel Index**

As expected, scores on the Barthel Index for participants with stroke or cerebral palsy differed from their healthy counterparts. All control participants scored 100, which is significantly above the values for those who had a stroke in adulthood, $F(2, 33) = 19.69$, $p < .001$. Post hoc tests indicated that both LHI (cerebral palsy and stroke groups) and RHI (stroke group only) resulted in scores below normal ($p < .001$). On this measure, side of lesion did not significantly influence the scores (see Table 1).

The ANOVA comparing Barthel Index scores for participants with LHI cerebral palsy with those with LHI stroke and control participants also indicated a significant difference between groups, $F(2, 32) = 23.00$, $p < .001$. Post hoc analysis revealed that values for participants with LHI stroke were significantly below those of the control participants ($p < .001$) as well as below the scores for participants...
with cerebral palsy ($p < .001$). This difference was primarily due to the decreased mobility of participants after stroke and the need for some modification in their daily self-care or the use of adaptive equipment. Nevertheless, it should be emphasized that all participants were able to complete most tasks independently without physical assistance and that all scored above 75 on the Barthel Index. In fact, the functioning of the participants with LHI cerebral palsy was so high that their scores did not differ significantly from the control participants (see Table 1).

**QNST**

Participants with stroke or cerebral palsy had elevated scores on the QNST primarily due to differences in muscle tone (spasticity), asymmetry (bilateral limb control), sensory deficits, and balance impairment. All control participants received a score below 25, which is typical for persons without disabilities. Participants with LHI and RHI stroke had higher scores, which is indicative of poorer performance, $F(2, 33) = 240.03, p < .001$. Side of lesion did not significantly influence the QNST scores (see Table 1).

Similarly, the analysis comparing QNST scores after LHI stroke with the ratings for LHI cerebral palsy indicated a significant difference, $F(2, 32) = 306.89, p < .001$. Both the cerebral palsy and the stroke groups had higher scores than the control group (see Table 1). The spastic hemiparesis in participants with cerebral palsy indicated that the left hemisphere was affected primarily and that they were all now functionally left-handed. Participants in the stroke group were mixed: 8 had ischemic damage on the left side and 9 on the right side. According to the classification standards set by Hachinsky (1990), these participants would be classified as having had a minor stroke. This designation reflects a person who is discharged home, can walk without physical assistance, and copes unaided with self-care activities within 1 month after the stroke.

**Word Finding**

Participants with LHI (cerebral palsy and stroke) and participants with RHI stroke performed poorer on the word-finding task, $F(2, 33) = 11.37, p < .001$, than the control participants. Post hoc tests indicated that both participants with LHI stroke and participants with RHI stroke ($p < .004$) had significantly more difficulty on this task than control participants ($p < .001$), but surprisingly, the reduced ability of those with RHI stroke was equivalent to those with LHI stroke (see Table 1). In keeping with predictions, only the participants with LHI stroke tended to have a higher mean error rate. Similarly, the ANOVA comparing the participants with LHI stroke and the participants with cerebral palsy indicated that both made significantly more errors on the word-finding task, $F(2, 32) = 14.12, p < .001$, than the control participants. However, this task did not reveal an effect of age at the time of injury (see Table 1). Overall, an impaired performance on the word-finding task was significantly correlated with a poor rating on the QNST ($r = .59, p < .001$) but was unrelated to level of functioning on the Barthel Index ($r = -.13$).

**Dot Localization**

Compared with control participants, performance of the spatial task was below normal for the participants with LHI and RHI stroke, $F(2, 33) = 13.77, p < .001$. Both an LHI and an RHI stroke caused more difficulty in visualizing the placement of the two dots, but side of lesion did not differentially impair performance. In keeping with the predictions, the participants with RHI stroke tended to have a slightly higher error rate than those with LHI stroke (see Table 1). All control participants demonstrated error rates that were within normal limits for a healthy population.

Analysis of the performance by participants with LHI cerebral palsy indicated that they also had some trouble with the dot localization task (see Table 1). Both the participants with LHI stroke and the participants with LHI cerebral palsy performed more poorly than the control participants, $F(2, 32) = 8.98, p < .001$. Age at the time of brain injury, again, did not influence performance of the task. However, difficulty with dot localization was correlat-
ed overall with having lower scores on both the Barthel Index (r = -.46, p < .002; scores 75–85) and the QNST (r = .57, p < .001). In addition, poor performance on this spatial task was associated with a high error rate on the word-finding task (r = .48, p < .001).

**Dichotic Listening**

**LHI versus RHI stroke.** Analysis of dichotic listening performance during the nonforced condition revealed an overall strong right-ear advantage for all participants, F(1, 33) = 11.05, p < .001, but a significant interaction term in the ANOVA indicated that this ear bias was manifest differentially by participants with LHI and RHI stroke, F(2, 33) = 5.96, p < .003 (see Figure 1). In fact, a right-ear advantage was not clearly shown after an LHI. These participants actually manifested signs of a left-ear advantage. An analysis of the bias to hear correctly sounds presented to the left ear indicated that they had a significant left-ear advantage when just scores from the left ear in the participants with LHI stroke were compared with the left ear in the participants with RHI stroke (t = 2.69, p < .02) (see Figure 1A).

When asked to listen preferentially to sounds presented in the left ear in the forced-left condition, overall the participants no longer revealed a significant side bias (see Figure 1B). However, now a statistical interaction existed between ear bias and side of injury, F(2, 33) = 2.63, p < .08. The forced-left task accentuated the left-ear advantage in participants with LHI stroke (t = 2.41, p < .03), whereas participants with RHI stroke were unable to use their left ear volitionally and continued to manifest their prior right-ear advantage (t = -2.72, p < .02). Control participants were intermediate and showed some diminution in their right-ear advantage and an enhanced left-ear performance when asked to do so (see Figure 1B).

The forced-right condition strongly accentuated the right-ear advantage and resulted in a significant ear bias, F(1, 33) = 73.12, p < .001. However, an interaction continued to exist between the magnitude of the ear advantage and injury location, F(2, 33) = 6.73, p < .004. Post hoc analysis indicated that the right-ear scores remained significantly higher in the participants with RHI stroke than in the participants with LHI stroke (t = 5.77, p < .008). Similarly, an analysis of the left-ear scores indicated that participants with LHI stroke were still attending more to their left ear, even when asked to listen with the right ear. Thus, they had higher left-ear scores than the participants with RHI on the forced-right task (t = 3.0, p < .009) (see Figure 1C).

**LHI stroke versus LHI cerebral palsy.** Performance by participants with cerebral palsy revealed similar results, but now the atypical tendency for a left-ear advantage was manifest even more strongly than after an LHI stroke. For the nonforced condition, a significant interaction existed between brain injury and ear preference, F(2, 32) = 16.48, p < .001 (see Figure 2A). Post hoc comparisons indicated that the right-ear advantage in control participants was significantly greater than that of both the participants with LHI stroke (t = 2.32, p < .03) and the participants with cerebral palsy (t = 4.38, p < .001). In contrast, participants with LHI stroke (t = 3.62, p < .001) and participants with cerebral palsy (t = 6.23, p < .001) manifested a significant left-ear advantage compared with control participants.

When asked to attend only to their left ear, all three

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**Figure 1.** Performance of participants with stroke (left hemispheric injury [LHI] and right hemispheric injury [RHI]) and control participants on the dichotic listening task. Percentage of correct sounds heard by the left ear (LE) and right ear (RE) during the three conditions are presented as follows: nonforced (A), forced-left (B), and forced-right (C). **++Significant right-ear advantage (p < .001). *Significant right-ear advantage (p < .05). ++Significant left-ear advantage (p < .001). +Significant left-ear advantage (p < .05).**
groups (i.e., control, LHI stroke, cerebral palsy) showed a significant bias for a left-ear advantage, $F(1, 32) = 7.18, p < .012$. There was no longer a significant interaction term because control participants were able to switch their focus, and the participants with LHI stroke and cerebral palsy continued to show their typical left-ear bias (see Figure 2B). It should be noted, though, that the control participants still did not evince the very pronounced left-ear advantage found in participants with cerebral palsy.

During the forced-right trials, the pattern of results was quite different. Now control participants accentuated their right-ear advantage, but neither the participants with LHI stroke nor the participants with cerebral palsy were able to do so. This inability to switch resulted in a significant interaction between ear advantage and type of injury, $F(2, 32) = 22.76, p < .001$. Post hoc analysis indicated that right-ear scores were highest in the control participants, whereas right-ear performance in the participants with stroke was somewhat better than that in the participants with cerebral palsy ($t = 3.40, p < .004$). The intermediate performance of the participants with stroke reflected the fact that participants with cerebral palsy retained their strong left-ear bias; that is, their left-ear scores were higher on the forced-right task than for participants with stroke ($t = 1.98, p < .068$) (see Figure 2C).

To consider the relationship between performance on the dichotic listening task and the other instruments used in this study, a quotient of the right-ear advantage divided by the left-ear advantage was determined for all participants on the basis of scores during the nonforced condition. This ratio was then used to test the correlation among performance on the three cognitive tasks. The control group had a mean ratio of 1.33 (right ear/left ear = 48.9/36.7). A reduction in this ratio was associated with poorer performance on the word-finding task ($r = .49, p < .001$) but was unrelated to the dot localization task. Similarly, a shift away from the right-ear advantage was correlated with a greater impairment on the QNST ($r = .36, p < .02$) but was not related to level of functioning as assessed by the Barthel Index.

**Discussion**

Our study has confirmed the importance of appreciating the subtle effects of unilateral hemisphere injury on cognitive and sensory ability in addition to the gross impact on neuromotor functioning. This point is highlighted by the fact that abnormal performance was found on all three cognitive tasks in both the participants with RHI and the participants with LHI, even though these participants, especially those who had experienced a congenital injury, were high functioning. Participants with stroke and cerebral palsy scored above 75 on the Barthel Index, and the independent functioning of the participants with cerebral palsy was so high that it did not differ significantly from that of control participants. The stroke group did have somewhat lower scores on the Barthel Index but primarily because of decreased mobility. These findings are consistent with other reports indicating that a good functional outcome does not necessarily exclude cognitive deficits (Hutter & Gilsbach, 1993). Not surprisingly, participants in the cerebral palsy and stroke groups did not do as well as the control participants on the QNST. They showed signs of spasticity and a lack of bilateral limb control, which provided confirmatory evi-

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**Figure 2.** Performance of participants with cerebral palsy on the dichotic listening task compared with control participants and participants with left hemispheric injury stroke. Percentage of correct consonant–vowel sounds heard by the left ear (LE) and right ear (RE) during the three conditions are presented as follows: nonforced (A), forced-left (B), and forced-right (C). *Significant right-ear advantage ($p < .05$). **Significant right-ear advantage ($p < .001$). ++Significant left-ear advantage ($p < .05$). +Significant left-ear advantage ($p < .05$).
dence for the unilateral nature of their hemispheric injury. The value of the QNST as a predictive instrument was shown further by the fact that the scores correlated significantly with performance on all three cognitive tasks. This power for predicting level of cognitive functioning was not seen for scores on the Barthel Index.

In keeping with prior studies of dichotic listening, we confirmed that this task is an extremely sensitive index for assessing unilateral brain injury and, further, that healthy persons have a strong right-ear bias (Bergman et al., 1984; Hugdahl & Wester, 1992; Isaacs et al., 1996; Korkman & von Wendt, 1995; Sparks et al., 1970; Woods, 1984). Whereas healthy, right-handed persons, and even many left-handed persons, will show a strong right-ear advantage, this hearing bias becomes disrupted after unilateral brain injury (Hugdahl & Carlsson, 1994). Damage to the left hemisphere resulted in the most dramatic change because a clear loss of the right-ear advantage was found. In our study, the alteration was shown more markedly by participants with LHI cerebral palsy because they also now manifested a left-ear advantage to a greater degree than the participants with stroke. Even when asked to focus on their right ear, the participants with left-hemisphere damage had difficulty doing so, concurring with Hugdahl and Carlsson's (1994) findings. This inability to shift focus and the continued retention of a strong left-ear advantage suggest that the deficit is not simply a matter of selective attention. Our findings also would appear to support a more complex view of neural plasticity after injury than just considering age at the time of injury (Kinnard Principle). That is, to understand recovery of function, we also need to consider how the functions are now represented bilaterally in both hemispheres, even if only one side is predominantly used for a task in healthy persons (Gazzaniga, 2000; Kastrup, Leonhardt, Kurthen, & Hufnagel, 2000; Lazar et al., 2000; Simos et al., 2000).

Participants with RHI stroke had a different pattern of results and evinced a more mild impairment in the dichotic listening task. In the nonforced and forced-right conditions, they appeared quite similar to control participants and manifested a strong right-ear advantage. However, when asked to listen selectively with their left ear, they were less able to do so and retained a relative bias for the right ear. Evaluation of their impaired left-ear performance in the forced-left condition could be viewed as somewhat supportive of the hypothesis that word sounds may have to travel via the damaged contralateral hemisphere before being processed by the intact left hemisphere. This finding also would support other studies that proposed that the lexical–semantic capacities of the right hemisphere are underestimated in persons without disabilities and suggests that a dynamic systems model framework may better explain the development of skills and the subsequent recovery after damage (Querne, Eustache, & Faure, 2000).

Unilateral hemispheric damage also was associated with impaired performance on the word-finding task. In keeping with expectations, participants with LHI stroke and participants with cerebral palsy had some difficulty discerning the correct word defined by the phrases. However, it is still not clear that this is exclusively a left-hemisphere task because some deficit also was found in participants with RHI stroke. Overall, however, a participant's ability to do well on the word-finding task was highly associated with a more normal performance on the dichotic listening task (i.e., correlated with the degree to which a right-ear advantage was evident). Also of interest was that the dichotic listening results proved to be strongly associated with a participant's ability to process information correctly on the spatial task. Although the dot localization condition is purported to be primarily a task performed by the nondominant hemisphere (i.e., right side in right-handed persons), we found that errors occurred more frequently in participants with any type of brain injury. A significant deterioration also was evident in participants with LHI stroke. Of potential clinical importance is that poor performance on the dot localization task correlated significantly with both the QNST and the Barthel Index, suggesting that it may be assessing attributes important in motor planning and day-to-day functioning.

Our study did not fully resolve the question of whether congenital brain injury has a larger or smaller impact on left hemispheric cognitive functioning than a comparable insult in adulthood. However, the participants with cerebral palsy manifested a particularly strong left-ear advantage, suggesting significant neural reorganization and a permanent shift in language functioning to the right hemisphere (Papanicolaou, Moore, Deutsch, Levin, & Eisenberg, 1988). However, this transfer of function was also evident to some degree in the participants with LHI stroke. It should be acknowledged that the ischemic event ranged from 9 months to 5 years before testing, and the duration of recovery likely would have affected the extent of reorganization that occurred. One theory supported by the strong left-ear advantage displayed by participants with cerebral palsy is that of ongoing neural reorganization, which appears to be possible throughout life and after neurological damage (Nudo, 1997; Nudo & Milliken, 1996; Nudo, Milliken, Jenkins, & Merzenich, 1996; Nudo, Wise, SiFuentes, & Milliken, 1996). These findings thus have important implications and support some current motor intervention approaches.

One factor limiting our ability to draw definitive conclusions about the impact of trauma during the perinatal
period was the absence of participants with right hemispheric lesions in the cerebral palsy group. This omission reflected a natural tendency for cerebral palsy to be more commonly manifest as an LHI, resulting in a higher prevalence of spastic hemiparesis on the right side of the body (Grether, Cummins, & Nelson, 1992). Given the relatively small city from which we were recruiting participants, we were unable to recruit sufficient persons interested in filling the missing condition. However, our general conclusions on the impact of unilateral hemispheric damage on cognitive functioning are in keeping with studies that had larger and more complete sample sizes (Isaacs et al., 1996).

Implications for Occupational Therapy Practice

Beyond demonstrating the possible use of dichotic listening as a simple diagnostic test, some implications exist for clinicians working with clients with cerebral palsy or stroke. The deficits we observed could affect one’s ability to perform many day-to-day tasks, such as driving, listening on the telephone with one ear, or attending to a conversation in a noisy room. These clients might be particularly sensitive to distracting sounds in general and could be advised on how best to direct their attention to a particular ear. Korkman and von Wendt (1995) also believed that this hemispheric bias could be associated with a person’s predilection to evaluate emotions expressed on the right and left side of another’s face. By knowing the skills that are affected and how neural reorganization may influence and limit functioning, therapists can advise their clients more effectively and thereby promote a more complete recovery. ▲

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