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Use of the dichotic listening technique with learning disabilities

John E. Obrzut *, Emery B. Mahoney

Department of Disability and Psychoeducational Studies, College of Education, University of Arizona, Tucson, AZ 85721-0069, United States

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ABSTRACT

Dichotic listening (DL) techniques have been used extensively as a non-invasive procedure to assess language lateralization among children with and without learning disabilities (LD), and with individuals who have other auditory system related brain disorders. Results of studies using DL have indicated that language is lateralized in children with LD and that the lateralized language asymmetries do not develop after age 6 nor are they affected by gender. Observed differences in lateralized language processes between control children and those with LD were found not due to delayed cerebral dominance, but rather to deficits in selective attention. In addition, attention factors have a greater influence on auditory processing of verbal than nonverbal stimuli for children with LD, and children with LD exhibit a general processing bias to the same hemisphere unlike control children. Furthermore, employing directed attention conditions in DL experiments has played an important role in explaining learning disabled children's performance on DL tasks. We conclude that auditory perceptual asymmetries as assessed by DL with children who experience LD are the result of the interaction of hemispheric capability and attention factors.

1. Introduction

Although many theories have been advanced over decades regarding the underlying etiology of learning disabilities (LD), evidence to date indicates that a developmental failure in neural integration may be responsible for this specific cognitive disability as suggested by Benton as far back as 1975. Specifically, poorly established cerebral dominance for language function has been implicated as a correlate of poor reading achievement (Orton, 1937; Zangwell, 1962). However, due to the fact that lateral hand preference seemed to be relatively stable by the time normal children began to read (Gesell & Ames, 1947), experimenters began to examine the associations between reading disorders and lateral preferences in hand, foot, eye, and ear processes.

The dichotic listening (DL) technique has been used extensively as a stable measure of cerebral processing and auditory reception as it relates to language functions (Hugdahl, Carlsson, Uvebrant, & Lundervold, 1997; Zatorre, 1989). According to Bryden (1982), DL techniques have provided us with some of the most robust effects available in contemporary neuropsychological research. This technique was originally conceived by Broadbent (1956) as an experimental paradigm to investigate a mechanical model of memory. The DL task consists of a series of paired stimuli presented simultaneously, one to each ear. The stimuli reported by the subject will usually be evidence of an "ear effect" such that a greater proportion of the dichotic stimuli are correctly reported favoring one ear. The dichotic stimuli may consist of digits, filtered speech or competing sentences, words, consonant–vowel (CV) syllables, or any combination of linguistic stimuli.

Working with both normal and brain damaged adult subjects, Kimura (1961a, 1961b) demonstrated that the majority of right-handed subjects correctly identified more stimuli presented to the right-ear when the stimuli were verbal and more stimuli presented to the left-ear when the stimuli were nonverbal. Based on studies of neurological patients in whom cerebral dominance had been established by the sodium amytal test (Wada & Rasmussen, 1960), the DL procedure appeared to be a reliable and stable measure of cerebral dominance for central auditory and language related functions. Those with known left hemisphere representation of language function displayed the normal right-ear advantage (REA) on verbal material, and those with known right hemisphere representation for language function displayed a left-ear advantage (LEA). This suggests that crossed or prepotent contralateral auditory pathways transmit information more quickly (or have an inhibitory effect on ipsilateral pathways) than ipsilateral pathways to the auditory cortex (Godfrey, 1974; Kimura, 1967). Therefore, the ear opposite the dominant cerebral hemisphere will perceive correctly a greater number of the dichotically presented stimuli. However, it must be acknowledged that most dichotic studies do not employ external validation measures in conjunction with their research, making it difficult to decipher whether results are reflective of the individual's different information processing strategies or different patterns of cerebral organization (Obrzut & Boliek, 1986). Some research has been performed in order to determine the level of agreement between

* Corresponding author. Fax: +1 520 621 382.
E-mail address: jobrzut@u.arizona.edu (J.E. Obrzut).

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the Wada test and DL measures. Results suggest that a high-level of concordance exists between the measures (Hugdahl et al., 1997; Hung-Georgiadis, Lex, Friederici, & Yves von Cramon, 2002; Van Ettinger-Veenstra et al., 2010).

Following the work of Kimura, other investigators used the paradigm to study the normal development of dichotic ability in infancy and young children. In this regard, cerebral asymmetries have been found in infant auditory perception by Glanville, Best, and Levenson (1977), and an REA has been found as early as age three in Canadian (Ingram, 1975) and Japanese children (Nagafuchi, 1970) age four with a different sample of Canadian children (Kimura, 1963) and age five with American children Berlin, Hughes, Lowe-Bell, and Berlin (1973). Further, Hynd and Obrzut (1977) provided normative DL data obtained from kindergarten, second, fourth, and sixth grade children and found that the magnitude of the dichotic ear advantage did not increase as a function of age or sex.

However, one of the more significant applications of this clinical procedure has been in the assessment of school age children who experience specific LD. The learning disabled subjects in these studies were classified on the basis of an extensive evaluation in which each subject had to (1) possess average intellectual abilities on a standardized test of intelligence with a Full Scale IQ > 85; (2) show evidence of a processing deficit in reception, discrimination, association, organization/integration, retention or application of information; and (3) demonstrate a two-year achievement deficit in reading as defined by IQ/achievement discrepancies of more than one standard deviations corrected for regression scores across IQ levels. These criteria are legally recognized under the "Individuals with Disabilities Education Improvement Act".

In this regard, the laboratory at the University of Georgia under the direction of Hynd and the laboratories at the University of Northern Colorado and the University of Arizona under the direction of Obrzut have provided some of the most compelling data on the issues of whether LD can be attributed to incomplete or delayed language lateralization, and whether cerebral lateralization follows a developmental course as assessed by the DL paradigm. Although, these issues were prominent in DL assessment, other demographic variables such as gender and handedness were being investigated, and controlled for, in relation to cerebral lateralization for language. At the same time other studies using subtypes of learning-disabled children, studies employing bilingual children, and those individuals who experience other language related brain disorders (i.e. elderly, stutterers, aphasics, and those with early focal brain damage) were being assessed with the DL technique and seemingly provide information that can be used as a model for understanding LD.

For example, several studies have been performed to examine the language lateralization in individuals with aphasic disorders. Perhaps the most frequently discussed finding in these studies is that individuals with damage to only one hemisphere of their brain tend to exhibit a significantly poorer performance on conditions assessing the contralateral ear than on those assessing the ipsalateral ear in relation to the lesion site (Niccum, Rubens, & Selnes, 1983). As a group, individuals with aphasic disorders seem to exhibit a unique pattern of performance on DL assessments, namely, the demonstration of a left-ear effect that is contrary to the pattern exhibited by control participants. Additionally, some studies have shown that aphasic individuals often demonstrate an increase in the amount of engagement demonstrated by the right hemisphere during tasks, which require language processing (Gowers, 1893; Kinsbourne, 1971; Nielsen, 1936; Papanicolaou, Moore, Levin, & Eisenberg, 1984). Whether these patterns are due to a shift in cerebral dominance or due to a break down of messages received auditorally prior to being analyzed is a question that has been debated within the literature (Bavosi & Rupp, 1984; Johnson, Sommers, & Weidner, 1977; Johnson, Sommers, & Weidner, 1978; Niccum et al., 1983; Petit & Noll, 1979). Interestingly, research in this area has also indicated that the scores an individual earns on DL tasks that direct attention to the right ear will also provide information regarding the extent of damage present in central auditory processing structures (Niccum et al., 1983).

Dichotic listening procedures have also shed some light on the reorganization of language functions following early focal brain damage. Some research in this area has indicated that childrens' language processing shifts to the right hemisphere following congenital lesions to the left hemisphere (Brizzolara et al., 2002; Carlsson, Hugdahl, Uverbrant, Wiklund, & Von Wendt1992; Isaacs, Christie, Vargha-Khadem, & Mishkin, 1996). Other research has indicated that whether or not language is reorganized within the same hemisphere seems to depend largely on the child's age and the type of lesion (Brizzolara et al., 2002). Similarly, research by Chilosi et al. (2005) found that children with left-hemisphere damage showed a LEA, while children with right-hemisphere damage demonstrated a REA. This study also found that children with left hemisphere lesions experience a delay in language development.

While the free recall technique in DL studies primarily has been used to assess auditory perception, the directed attention paradigm (stimulus pre-cuing task) has been used to assess selective attention or, what some may call, auditory-executive function. Thus, differences between learning disabled individuals' performance versus their control counterparts in selective attention may be explained by the top-down and bottom-up processing model. In essence, the forced left task demands top-down processing, as performance on this task involves suppression of the automatic response (reduction in report of automatic right ear input), and an increase of the reporting of the redundant signal in the left ear (shift to a left-ear advantage) (see, Tallus, Hugdahl, Alho, Medvedev, & Hamalainen, 2007). It is thought that the forced left ear task is a more sensitive test for attention deficits that some learning-disabled children experience.

Directed attention tasks have also been used in an effort to gain a better understanding of developmental stuttering. One study by Foundas, Corey, Hurley, and Heilman (2004) examined 18 adults who were developmental stutters and 28 control participants. Participants were given three DL conditions, attend left, attend right, and free recall. The participants were grouped by sex and dominant hand. By so doing, the researchers were able to make several conclusions. While the control participants and right-handed male stutterers demonstrated a REA during free recall and a LEA under the directed left condition, a significantly different pattern was found for left-handed men with developmental stuttering and right-handed female developmental stutterers. These individuals demonstrated the inverse pattern. More specifically, they showed a REA in left-ear directed condition and a REA during free recall. In contrast, right-handed female developmental stutterers showed a tendency to report hearing sounds that had not been presented. Additionally, they also showed no ear effect under free recall and seemed to find shifting attention from one ear to another more challenging than the other participants.

Directed attention tasks have also been used to assess individuals with auditory processing disorders. Results have shown that the DL procedure is able to accurately detect a variety of auditory system related brain disorders (Jerger & Martin, 2006). In a study by Jerger and Martin (2006) a group of 172 elderly individuals with auditory processing disorders were assessed in order to determine the magnitude of difference in performance on a divided vs. directed attention dichotic listening task. The participants were simultaneously presented with a pair of sentences in each ear. After being presented with the sentences, they were to select their response from a list of six target sentences. In one condition, the participant was asked to report which sentences were heard, while in the second condition he or she was asked to report only what was heard in either the left or the right ear. Results revealed that 58% of the participants in the study showed a poorer performance on the free recall task. With the addition of the directed attention condition, only 19% of the participants showed a normal performance on both conditions, whereas the remaining 23% showed abnormal performances on both conditions. The authors stated that the results seem to indicate that performance on such tasks may be affected by their individual differences in domains of memory, attention and processing speed.

Thus, in this article, we summarize the DL findings as they relate to the theoretical issues of whether LD can be attributed to incomplete or delayed auditory lateralization, and whether cerebral lateralization follows a developmental course. Clinical studies conducted that relate DL data with findings from intelligence and achievement instruments as well as studies controlling for the variables of gender, handedness, and selective attention in the assessment of LD also are presented.

2. Theoretical and clinical issues in DL with LD

2.1. Can LD result from Incomplete or abnormal cerebral dominance?

The development of cerebral dominance and its relationship to language functioning in children with LD has been an area of interest in neuropsychology since the 1970s. Traditionally, these children were thought to have minimal brain dysfunction although the neurological basis of their learning difficulties had not been established. In the past, children with known cerebral damage have been studied and inferences regarding the role of the left and right hemisphere in language functioning have been drawn. Although left hemisphere language abnormality has long been suspected in adult cases with the identification of both Broca's and Wernicke's aphasia, Witelson (1977) reviewed the child literature on cases with unilateral brain damage and estimated that approximately twice as many children with left than right lesions have associated speech loss. This suggests a greater participation of the left than right hemisphere in mediating language.

One approach to the study of hemisphere specialization involves populations such as the learning disabled who are presumed to be belatedly or inadequately lateralized for language (Orton, 1937). This clinical group exhibits disturbances primarily in the reading process which represents one of the many complex linguistic-cognitive functions subserved by the left cerebral hemisphere. Only with the advent of special laterality assessment procedures such as the DL technique has a direct evaluation of Orton's theory been made. For example, Satz (1976) extensively reviewed dichotic studies relating cerebral dominance and reading disability and found several of these studies (Bryden, 1970; Leong, 1976; Satz, Rardin, & Ross, 1971; Sparrow & Satz, 1970) revealed a REA in reading-disabled children. However, other studies which revealed no perceptual asymmetry (REA) in these readers were marred by procedural artifacts (Witelson & Rabinnovitch, 1972; Zurif & Carson, 1970). Since the evidence that poor readers exhibit deficits in cerebral lateralization for language was inconclusive, Obrzut, Hynd and their associates conducted research using DL techniques with learning-disabled children designed to determine if they are less lateralized than their normal counterparts in language functioning (as originally suggested by Orton, 1937), and to determine if there is any evidence of a developmental increase in functional lateralization with increasing age (see, Hynd & Obrzut, 1981; Hynd, Obrzut, Weed, & Hynd, 1979; Obrzut, Hynd, Obrzut, & Leitgeb, 1980; Obrzut, Hynd, Obrzut, & Pirozzolo, 1981). The results of these studies of an auditory nature tend to contradict the hypothesis that learning-disabled children are not as well lateralized for language functioning as are normal control children. Therefore, it was proposed that there is little support for the hypothesis that the nature of dysfunction in LD is incomplete lateralization which directly affects intellectual or cognitive processes. It is more likely that language is lateralized in both normal and learning-disabled children, but the efficiency of the language processor is less functional in those with LD and may represent one aspect of a more general maturational lag (Obrzut & Boliek, 1986). Despite these findings, the debate continues to be somewhat ongoing. For example, Hugdhal, Helland, Faerevaag, Lyssand, and Asbjornsen (1995) did not find the expected REA in right handed dyslexic adolescents and adults, but did find a REA in the left handed dyslexic group. Still others claim that individuals defined as learning disabled do not actually manifest a brain based disability, instead these individuals experience reading difficulties due to lack of exposure and training in reading and socioeconomic factors (Samuelsson & Lundberg, 1996).

The basic notion underlying the maturational lag hypothesis stems from the work of Lennenberg (1967) who contended that the left hemisphere becomes increasingly specialized for language during development. Therefore, in normal children, between-hemisphere differences in language mediation should increase as the child advances in age (Rourke, Bakker, Fisk, & Strang, 1983). This theory predicts a lag in the maturation of the central nervous system in LD. In essence, learning-disabled children experience a delay of left-hemisphere specialization that may have a negative impact on their ability to acquire normal age-related cognitive skills. From this theory, Bakker and associates (Bakker, 1973; Bakker, Smink, & Reitsma, 1973; Bakker, Teunissen, & Bosch, 1976) as well as Satz and colleagues (Sparrow & Satz, 1970; Satz & Van Nostrand, 1973) hypothesized that visual-motor and auditory integration skills that presumably develop earlier would be delayed in younger dyslexic readers while linguistic skills that develop later would be more delayed in older dyslexic children. This theory, however, is based on the assumption that speech processes become more completely lateralized with increasing age. These studies found that good readers displayed a consistent increase in magnitude of the REA with increasing age, but poor readers displayed little evidence of a shift in ambilaterality with age. Satz et al. (1971) concluded that deficits in performance may be associated with younger children, but that these deficits tend to attenuate with age in learning-disabled children. Conversely, other studies (Schulman-Galambos, 1977; Ullman, 1977) indicated no developmental trend in the establishment of cerebral dominance and that the left hemisphere was predisposed for the processing of language at birth.

2.2. Is there a developmental increase in functional lateralization with normal children and those who experience LD?

In an effort to investigate the developmental hypothesis, Obrzut, Hynd and associates carried out a series of studies in an effort to investigate the developmental hypothesis using groups of children with specific LD (as defined earlier in this paper) and their normal counterparts (Hynd & Obrzut, 1981; Hynd et al., 1979; Obrzut et al., 1980, 1981). For example, in the study by Obrzut et al. (1980), the REA in 48 normal control and 48 children with LD was assessed. Both groups were matched according to age, gender, and handedness and were divided into three age groups in order to examine possible developmental differences. Results of this study showed that both the normal and learning-disabled children demonstrated a significant REA, although the normal subjects reported right ear stimuli more accurately. Also, no developmental trend was evidenced between the groups indicating that while there may be differences between the performance of learning disabled and normal children on the dichotic task, both are lateralized for speech representation and do not evidence a developmental lag or delay (see Table 1).

The above referenced studies suggest that lateralized language capabilities exist in normal children from ages 6 to 12. Furthermore, it appears as though these lateralized language asymmetries do not develop after age 6 nor are they affected by gender. Because these studies controlled for selective attention, the differences in lateralized language processes between the two groups may not be due to delayed cerebral dominance, but rather to deficits in selective attention. Hynd et al. (1979) contended that the differences between the groups of children were attributed to deficits in the ability to selectively attend. In the subjects who experience LD this deficit resulted from a higher rate of guessing during the task. The variability in performance due to differing abilities to attend selectively had been suggested previously by Bryden and Allard (1978) in their review of DL studies. These authors suggested that children may have difficulties in disentangling simultaneously occurring sounds and, therefore, resort to random guessing in their responses.

2.3. Can attention mechanisms in DL provide insight into how normal children differ from children with LD?

In contrast to Lennenberg's (1967) developmental theory of speech lateralization, Kinsbourne (1975) argued that left-hemisphere specialization for language exists at birth. Relative to a structural model, most researchers have interpreted the magnitude of differences in laterality as direct indices of the degree of cerebral lateralization. Thus, they implied a one-to-one relationship between the demonstrated performance in laterality to brain specialization and lateralization. However, the available research suggests strongly that cerebral dominance does not develop (e.g., Hynd & Obrzut, 1977; Kinsbourne & Hiscock, 1977, 1978; Ullman, 1977). Since the structural-developmental model is questionable, it was thought that another conceptual model might be better suited in attempting to understand how normal children and those who experience LD differ neuropsychologically.

Kinsbourne (1970) first proposed an attention model for functional asymmetry. He proposed that each hemisphere is dominant for interpretation of different stimuli. The expectation of incoming stimuli will activate the appropriate hemisphere and will cause a shift in attention toward the opposite side of space. At the same time, the perception of stimuli in the other hemisphere is suppressed. Thus, awareness and expectancy of verbal stimuli activates the left hemisphere and shifts or biases attention toward the right side of space. Conversely, a set for nonverbal stimuli would activate the right hemisphere and bias attention to the left side of space. However, if children with LD have attention deficits, as suggested by Hynd et al. (1979), they may not have the ability to suppress the non-dominant hemisphere in verbally related tasks and will, therefore, be unable to focus attention appropriately for linguistic tasks.

In an effort to test the attention hypothesis, Obrzut et al. (1981) conducted a study with normal and learning disabled youngsters employing a prestimulus cuing paradigm in addition to the standard free recall condition. In the cued condition, each child was told to listen carefully and report only stimuli received in the one (target) ear. These preliminary cuing conditions were used in an attempt to control for the effects of variability in selective attention. In the free recall condition, both groups clearly demonstrated a significant REA, and no developmental effect existed. However, it was interesting to note that when asked to direct attention to the left ear only, the learning disabled group was able to reverse the ear effect and showed a dramatic LEA, while the normal group continued to show a REA. Also, when attention was directed toward the right ear, both groups showed a significant REA, but the learning disabled subjects could increase the magnitude of the between-ear difference significantly over the normal subjects (Obrzut et al., 1981). Although their performance generally was deficient when total accuracy was examined, the learning-disabled children were able to increase correct recognition of left-and right-ear presentations on cue from the examiner. However, it is likely that performance by the learning-disabled children in this study may have been due to an artifact of the verbal cuing by the examiner. Overall, the results suggest that learning-disabled children probably do not suffer from developmental delays but rather from a defect in callosal functioning that interferes with their ability to simultaneously process verbal information. This is consistent with research done by Westerhausen and Hugdahl (2008) who found "an overall pattern of results that strongly supports the notion that naturally occurring interindividual variability in the corpus collosum influences dichotic listening performance" (p. 1051). Additionally, results suggested that children who experience LD have not developed the ability to suppress the non-dominant hemisphere during verbal tasks (Kinsbourne, 1974) and that these children may not have developed the ability to verbally mediate appropriate perceptual events. Therefore, these children perform as if the two cerebral hemispheres interact minimally in processing. This leads to interference from the non-dominant hemisphere and difficulty in focusing attention unlike that found for normal children (see Hynd, Cohen, & Obrzut, 1983).

Subsequent studies have provided varied results some supportive of the attention shifting hypothesis with children who experience LD (Cohen, Riccio, & Hynd, 1999; Tallal, Merzenich, Miller, & Jenkins, 1998; Obrzut, Hynd, & Obrzut, 1983; Obrzut, Obrzut, Bryden, & Bartels, 1985) and others failing to find attentional shifts in dyslexic individuals. For example, Obrzut, Boliek, and Obrzut (1986) determined that the *type of stimuli* used in dichotic paradigms (words, digits, CV syllables, and melodies) and experimental conditions (free recall, directed left, and directed right) can influence perceptual asymmetry as reflected by the REA. While the expected REA for words and CV syllables and the expected LEA for melodies were found under free recall, the directed conditions produced varied results depending on the nature of the stimuli. Directed condition had no effect on recall of CV syllables but had a dramatic effect on recall of digits. Research by Asbjornsen and Bryden (1998) also failed to find significant attentional shifts in reading-disabled children when presented with consonant–vowel syllables during selected attention conditions.

In order to further understand the construct of selective attention as it relates to perceptual asymmetries in children with LD, Obrzut, Mondor, and Uecker (1993) designed a study using the pre-cuing paradigm developed by Mondor and Bryden (1991) to

Table 1
Mean number of correctly reported CV syllables for each ear by diagnostic group and developmental level.

Developmental level (age range)	N	Left ear		Right ear	
		$\bar{X}$	SD	$\bar{X}$	SD
Normal					
Level I (7.0–8.5)	16	8.69	2.33	15.50	3.06
Level II (8.6–10.4)	16	9.88	2.55	13.88	3.14
Level III (10.5–11.11)	16	9.31	2.68	14.19	2.29
Learning Disabled					
Level I (7.0–8.5)	16	10.61	2.31	11.19	3.06
Level II (8.6–10.4)	16	9.13	2.94	12.50	2.83
Level III (10.5–11.11)	16	8.56	4.15	12.25	6.04

Note: A total score of 30 was possible for each ear.
From "Time-Sharing and Dichotic Listening Asymmetry in Normal and Learning-Disabled Children" by J. E. Obrzut, G. W. Hynd, A. Obrzut, and J.L Leitgeb, 1980, *Brain and Language, 11*, p. 189. *Copyright 1980* by Academic Press, Inc. Reprinted by permission.

investigate the possibility that, for adults, attention factors influence the magnitude of the REA for CV syllable identification. This technique was based largely on studies of visual-spatial attention. In studies of visual attention, a cue is presented that indicates the position in which a stimulus will be displayed. The cue may be presented in a location that approximates the location of the forthcoming stimulus (a pull cue). In contrast, the cue (usually an arrow) may indicate the location where the stimulus will be presented (a push cue) from a location spatially removed from that of the forthcoming stimulus. Yantis and Jonides (1990) showed that pull cues usually automatically capture attention, whereas push cues must be consciously processed before attention is oriented. Thus, verbal cues such as those that have been used in prior forced-attention dichotic studies may be similar to push cues that must be voluntarily acted on and interpreted by the participant before attention is deployed to the appropriate location. In the Mondor and Bryden study, attention was manipulated by presentation of a pre-exposural tone cue to the to-be-attended ear. The time period between the onset of the cue and the onset of the dichotic trial (Stimulus Onset Asynchrony) (SOA) was varied so as to control the time available to orient attention. Sizeable REAs were apparent at the shortest SOA (150 ms) but were attenuated at longer intervals (450, 750, and 1050 ms SOA). In addition, Mondor and Bryden found that performance improved with SOA for the left ear but not for the right ear. These effects were interpreted as evidence of an attention bias to the right ear in the typical DL experiment.

Obrzut et al. (1993) employed an identical paradigm to that used by Mondor and Bryden (1991). It was predicted that for normal control children, the magnitude of the REA would be reduced as the time available to orient attention increased. Children with LD were also expected to show a change in the magnitude of the REA with varying SOAs, but that the rate of that change would be deviant from controls. For the control children, the results confirmed that the REA for verbal discrimination obtained in standard DL experiments is quite dependent on attention processes. There was a tendency by both groups to more often report the item from the unattended right ear than from the unattended left ear, which indicated an attention bias toward the right ear. In addition, a subgroup of mixed control children and children with LD had difficulty performing the dichotic task at above-chance levels because they were unable to effectively orient attention to the cue. It was also shown that REAs obtained beyond 750-ms SOA (i.e., 1250 and 2000-ms SOA) were not substantially attenuated from that obtained at 450 to 500-ms SOA (Obrzut, Horgesheimer, & Boliek, 1999) for children (*M* age = 8 years 7 months). By assessing shorter and longer SOAs, it was demonstrated that young control children were unable to maintain attention to the left side of space (i.e., LE) for more than a brief period of time. Perhaps their inability to effectively orient attention is related either to an underlying atypically organized functional (or structural) system or to a lack of motivation. However, it has been found that children with early hearing problems (otitis media with effusion) compared to age-matched controls who had no history of otitis media or hearing problems, were also not able to modulate the ear advantage during directed attention tasks (Asbjornsen et al., 2000). This latter finding is similar to that found for some groups of children with LD as previously noted. Alternatively, LD may increase the risk for otitis media.

Although Obrzut et al. concluded that the data from their 1993 study support the hypothesis that auditory perceptual asymmetries in children are the result of the interaction of hemispheric capability and attention factors (see Obrzut, Boliek, & Bryden, 1997), it was not decisively shown that the tone cue was more effective than verbal cuing for orienting attention in children with LD. Further, it remains unclear whether inadequate attention systems are a symptom of atypical cerebral organization, or a function of weak hemispheric specialization (see Obrzut, 1995). However, some clarification with regard to attention systems was provided by Hiscock, Inch, and Kinsbourne (1999), who demonstrated that the selective attention instruction influences late (response selection) processes rather than early (stimulus identification or encoding) processes. Given this finding, one might conclude that it is rather "frontal, executive functions" (response selection is frequently attributed to the anterior cingulate cortex and adjacent medial frontal regions) than pure attention factors (orientation towards a source of information, usually attributed to regions of the parietal cortex) that might explain the deficits in these children. In addition, studies employing electrophysiological and neuroimaging techniques have found lateralized disturbances in various brain regions in children with LD (see Duffy, Denkla, Bartels, & Sandini, 1980; Hynd, Semrud-Clikeman, & Lyytinen, 1991; Mattson, Sheer, & Fletcher, 1992; Mazzotta & Gallai, 1992; Morris, Obrzut, & Coulthard-Morris, 1989).

The inconsistency of studies reporting substantial effects of attention on ear asymmetries in children with or without LD may also be due to a developmental difference in the ability to use verbal or spatial (tone) cues to select stimuli for recall. Along this line, Obrzut, Boliek, and Asbjornsen (2006), for example, administered 60 trials of a monaural tone cue task, 60 trials of a binaural verbal cue task, and 60 trials of a monaural verbal cue task to direct attention to either the left or right ear before the presentation of CV syllable pairs in a DL task. The sample included 30 right-handed children (15 control, and 15 with LD) with a mean age of 10.8 years. Whereas all 3 cue conditions were effective in orienting attention for control subjects, larger shifts were apparent under both binaural and monaural verbal instructional cue conditions. In contrast, subjects with LD showed larger shifts of attention under the tonal cue condition. Fig. 1 shows the Task *x* Group interaction based on mean percentage accuracy of dichotic ear scores combined.

Theoretically, these findings are consistent with the notion that children with LD experience weaker left hemisphere language processing skills, in contrast to their more developed right hemisphere nonverbal, spatial skills.

2.4. Are there differences in DL performance with various subtypes of LD?

Further efforts were extended to explore the theoretical and clinical implications of research using the DL technique. For example, in the past, researchers tended to view learning disabled populations as homogeneous entities (Benton, 1975). However, the effort to identify subtypes of LD has been quite successful (e.g., Boder, 1973; Fisk & Rourke, 1979; Satz & Morris, 1981). Most of these researchers have obtained data to demonstrate at least two types of disabled readers: those with auditory-linguistic problems and those with visuospatial problems. Perhaps not all poor readers would show weak lateralization but only those who manifest certain deficiencies in expressive or receptive language (Bryden, 1982). Some support for this hypothesis was found by Obrzut (1979), who employed the DL task with Boder's (1973) subtypes of Dysphonetic, Dyseidetic, and Alexic readers. These groups differ in their approach to reading and spelling tasks. The Dysphonetics appear to have deficits in phonetic skills while Dyseidetics can decipher words phonetically but have problems perceiving whole words and remembering nonphonetic sight words. The Alexic reader is one who can neither remember sight words nor can use phonetic skills in word analysis. His results indicated that Dysphonetic readers (those with auditory-linguistic deficits) *and* visuospatial deficits) showed poorer auditory lateralization and greater deficits in attention than did Dyseidetic readers (those with only visuospatial deficits). This suggests that while children who

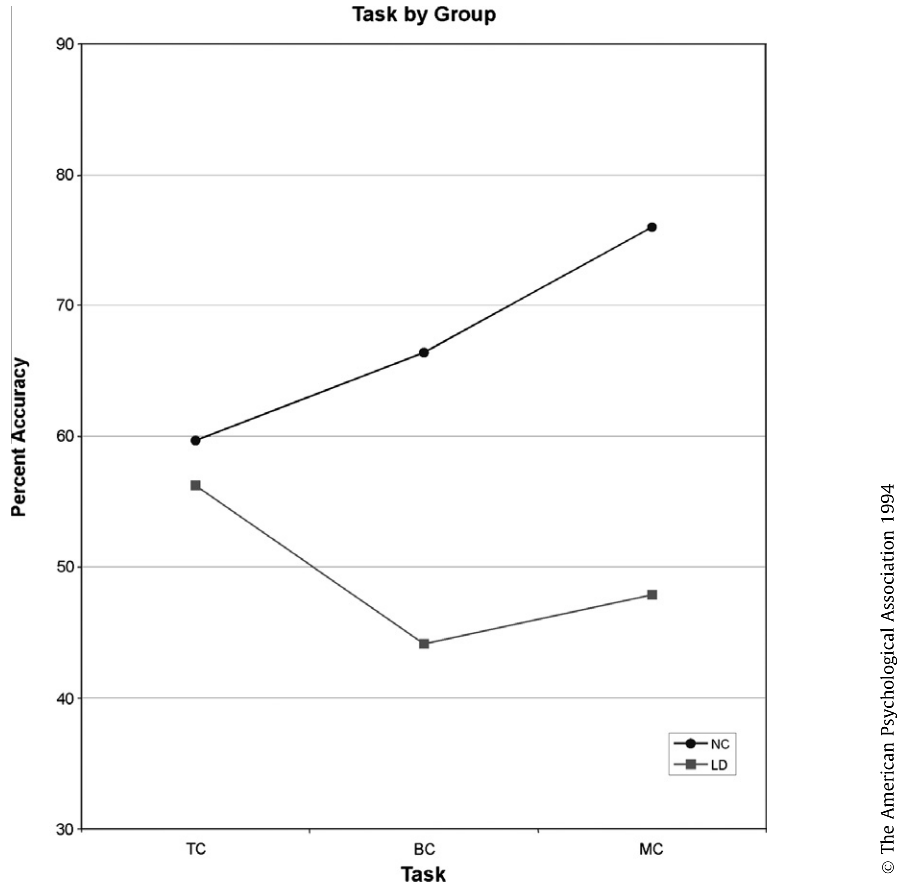

Fig. 1. The task x group interaction based on mean percentage accuracy of dichotic ear scores combined.

experience LD as a group show attention deficits, perhaps there are significant differences within the population itself.

Studies with these two groups of children were also conducted employing other experimental constructs to investigate their potential effect on functional asymmetries. In one such study, the effects of hemispace and directed attention were examined with normal children and those with LD to determine the extent of how these two attentional strategies influence perceptual laterality as reflected by the DL REA (Boliek, Obrzut, & Shaw, 1988). Another study used cued DL to investigate differences in language lateralization among right-handed (control), left-handed, bilingual, and children with LD and found that attention factors play a larger role in unilateral processing for some anomalous groups of children (i.e. left-handers and those with LD) while not affecting others (i.e. controls and bilinguals) (Obrzut, Conrad, Bryden, & Boliek, 1988).

Still other DL studies have provided further support to the attention shifting hypothesis with children who experience LD. These studies attempted to measure the relationship between DL performance on measures of intelligence, mathematics and reading achievement (Hynd, Obrzut, & Obrzut, 1981), on the Tactile Performance Test and the Category Test from the Halstead-Reitan Neuropsychological Test Battery (Obrzut et al., 1983), on simultaneous and successive processing tasks from the Kaufman Assessment

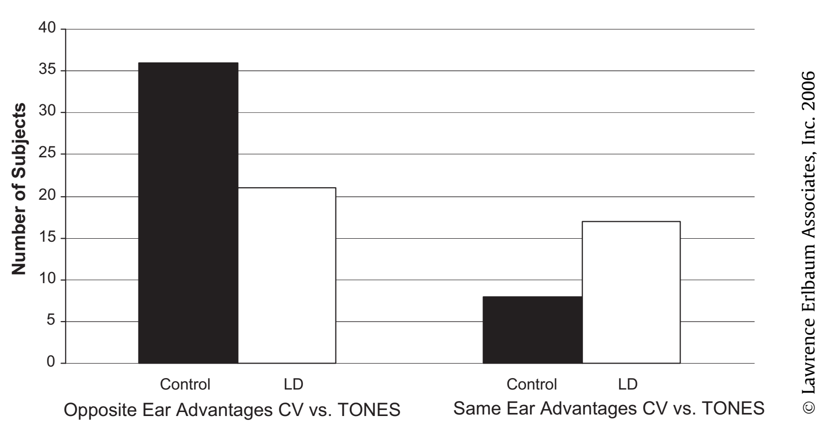

Fig. 2. Number of control and learning-disabled subjects who changed ear advantages with reports of consonant–vowel (CV) versus tonal stimuli, compared with the number of subjects who maintained the same ear advantage.

Battery for Children (K-ABC) (Obrzut et al., 1985), and memory as a function of distinctive encoding, hemisphere processing and selective attention (Swanson & Obrzut, 1985).

2.5. Are there differences in left- and right-hemisphere processing between normal children and children who experience LD?

While trends in information processing and attention mechanisms have been identified and validated, the majority of studies have been directed at understanding verbal processing in normal children and children who experience LD. In contrast, research in the perception of nonverbal stimuli (dichotically presented pitch and tonal stimuli) with child populations has been virtually nonexistent. Thus, Obrzut, Conrad, and Boliek (1989) assessed the interactions of handedness and attention on verbal *and* nonverbal processing tasks for both left- and right-handed good readers from those children who experience LD. The findings provided support to the hypothesis that attention factors have a greater influence on auditory processing of verbal than nonverbal stimuli for various groups of children and also suggest reversed or bilateralized processing abilities for language in strongly left-handed children with sinistral relatives. Along this same line of work, age and sex differences in left- and right-hemisphere processing also were assessed to answer the question of whether left- and right-hemisphere functions are lateralized in the same direction and degree in age-related normal control children compared to children who experience LD (Obrzut, Boliek, Bryden, & Nicholson, 1994). Findings indicated neither age nor sex differences in response accuracy or lateralized processing of CV stimuli were evident for control children. Borderline significance ($p < .06$) was obtained for tonal stimuli. In contrast, CV stimuli elicited a bilateral response in younger children with LD, and tonal stimuli elicited a bilateral response in all children with LD. Furthermore, control children were oppositely lateralized for verbal and nonverbal stimuli, whereas subjects with LD exhibited a general processing bias to the same hemisphere. Fig. 2 shows these results for both groups of children.

The data do not fully support the developmental invariance hypothesis and may even suggest a bilateral processing deficiency in children who experience LD.

Whereas the DL procedure has been used with adults and children to assess the functions of the cerebral hemispheres separately, few studies with adults have employed comparable tasks to assess both hemispheres in the same individuals (Bryden & MacRae, 1989; Bulman-Fleming & Bryden, 1994), and no studies with normally achieving children and/or children diagnosed with LD have employed comparable tasks to assess concurrent left- and right-hemisphere processing. Most attempts with adults to demonstrate a dissociation on left- and right-hemisphere function in the same individuals have either used separate verbal and nonverbal instructions or have required multiple responses to the same stimulus pairing, thus making it possible that the results are affected by order of report, priming, and strategy effects (Bryden & Bulman-Fleming, 1993). Therefore, Obrzut, Bryden, Lange, and Bulman-Fleming (2001) used a signal-detection paradigm with normally achieving children and children diagnosed with LD to assess both left- and right-hemisphere functions simultaneously when two-syllable words differing only in the initial stop consonant (bower, dower, power, tower) and spoken in different emotional tones (happy, angry, sad, neutral) were paired dichotically. Results indicated that although both control children and children with LD demonstrated an overall REA for word stimuli and an LEA for emotional stimuli, and that emotional stimuli were easier to process than word stimuli, children with LD were less accurate in processing both types of stimuli than their control counterparts. 'Complementary specialization' as assessed through distribution of laterality effects, was found to be greater for control children than for children with LD. This finding is consistent with previous results obtained by Obrzut et al. (1994) without the use of a concurrent processing paradigm, which showed that children with LD are more likely to exhibit a general processing bias to the same hemisphere. In general, although children with LD experience weaker left hemisphere language processing skills, in contrast to their presumed more developed right hemisphere, nonverbal spatial skills, it is fairly well established that these children exhibit a bilateral processing deficiency that results in their LD.

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