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Divided-Attention and Directed-Attention Listening Modes in Children with Dichotic Deficits: An Event-Related Potential Study

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Abstract

Dichotic listening (DL) procedures are commonly employed in the evaluation of auditory processing in children. Review of the various clinical tests reveals considerable diversity in both the signals employed and their mode of administration. The extent to which other non auditory-specific factors influence the test outcome is often difficult to determine. Individual differences in memory, attention, facility with test stimuli, and report strategy are always of potential concern in the interpretation of results.

In the present study, we examined behavioral and electrophysiological (ERP) responses for 20 children during two DL tasks. Two groups of children were evaluated. One group was comprised of children who showed substantial ear differences on clinical measures of DL; the other group showed no such deficits and served as age-matched controls. In one of the DL tasks, participants monitored dichotic stimuli using the divided-attention (unfocused) mode. In the other DL task, a directed-attention (focused) mode was employed. Both tasks involved simple "same-different" judgments for real words presented in a basic reference-probe paradigm. We purposefully sought an easy DL task in order to minimize the number of extra-auditory factors influencing their performance. For control purposes, a diotic procedure involving the same stimuli was also included.

Results showed that the amplitude of the elicited late-positive component (LPC) was smaller and prolonged in latency for the group of poor listeners as compared to the control group. This finding occurred only when dichotic stimuli were presented in the divided-attention mode. When participants directed their attention to a single side, or when listening in a diotic mode, the LPC for both groups was more similar. Group differences in the N400 component were apparent for both listening tasks. Results are discussed in relation to an inability of some children to inhibit processing of unattended auditory information. Implications for the clinical administration of dichotic listening tests are also discussed.

Key Words: Auditory event-related potentials, auditory processing disorder, auditory tests, children, dichotic, directed attention, divided attention

Abbreviations: APD = auditory processing disorder; CHAPS = Children's Auditory Performance Scale; CV = consonant vowel; DL = dichotic listening; EEG = encephalographic activity; ERP = event-related potential; LED = left-ear disadvantage; LPC = late-positive component; REA = right-ear advantage; SSW = Staggered Spondee Word test

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Sumario

Los procedimientos de Audición Dicótica (DL) son comúnmente empleados en la evaluación del procesamiento auditivo en niños. La revisión de varias pruebas clínicas revela una diversidad considerable tanto en las señales empleadas como en su modo de administración. En qué grado otros factores no específicos de la audición influyen en los resultados de las pruebas es a menudo difícil de determinar. Las diferencias individuales en memoria, atención, facilidad con los estímulos de la prueba y la estrategia de reporte, tienen siempre influencia potencial en la interpretación de los resultados.

En el presente estudio, examinamos respuestas conductuales y electrofisiológicas (ERP) en 20 niños con dos tareas de DL. Se evaluaron dos grupos de niños. Un grupo estaba constituido por niños que mostraban diferencias sustanciales entre los oídos en las mediciones clínicas de la DL; el otro grupo no mostró tal déficit y sirvieron como controles pareados por edad. En una de las tareas de DL, los participantes monitorearon estímulos dicóticos utilizando el modo de atención dividida (no concentrada). En la otra tarea de DL, se empleó un modo de atención dirigida (concentrada). Ambas tareas involucraron juicios simples de "igual-diferente" para palabras reales presentadas en un paradigma de sondeo de diferencia básica. A propósito, buscamos una tarea de DL fácil, para minimizar el número de factores extra-auditivos que influían en el desempeño. Para propósitos de control, se incluyó también un procedimiento diótico que utilizara los mismos estímulos.

Los resultados muestran que la amplitud del componente positivo tardío (LPC) generado era más pequeña y más prolongada en latencia para el grupo de oyentes pobres comparado con el grupo control. Este hallazgo tuvo lugar sólo cuando se presentaron estímulos dicóticos en el modo de atención dividida. Cuando los participantes dirigieron su atención a un sólo lado, o cuando escucharon en un modo diótico, el LPC para ambos grupos fue similar. Las diferencias de grupo en el componente N400 fueron aparentes para ambas tareas de audición. Se discuten los resultados en relación con la incapacidad de algunos niños de inhibir el procesamiento de información auditiva a la que no se le está prestando atención. Se discuten las implicaciones para la administración clínicas de pruebas de audición dicótica.

Palabras Clave: Potenciales auditivos relacionados con el evento, trastornos de procesamiento auditivo, pruebas auditivas, niños, dicótico, dirigido, atención dirigida, atención dividida

Abreviaturas: APD = Trastorno de procesamiento auditivo; CHAPS = Escala Infantil de Desempeño Auditivo; CV = consonante-vocal; DL = audición dicótica; EEG = actividad encefalográfica; ERP = potencial relacionado con el evento; LED = desventaja del oído izquierdo; LPC = componente positivo tardío; REA = ventaja del oído derecho; SSW = Prueba de Palabras Espondaicas Escalonadas

The degree and direction of interaural asymmetry on dichotic listening (DL) tests, or, in some cases, the lack thereof, has received considerable interest in research examining a wide spectrum of clinical disorders, ranging from dyslexia and attention-deficit disorder to schizophrenia and epilepsy. In the particular case of children suspected of having an auditory processing disorder (APD), there is cause to suggest that discrepancies between the right- and left-ear performance scores, generally in the form of a left-ear deficit (LED), may be one sign characterizing the disorder (Morton and Siegel, 1991; Lamm and Epstein, 1994; Moncrieff and Musiek, 2002; Moncrieff et al, 2004). Studies using auditory event-related potentials (ERPs) to explore interaural asymmetry in these children have obtained similar results (Jerger et al, 2002; Moncrieff et al, 2004). Given the profile of the test outcome and what is known about the maturation and role of the corpus callosum in mediating interhemispheric communication, it has been hypothesized that the LED may arise from a disruption in the interhemispheric transfer of auditory information (Musiek et al, 1984; Jerger et al, 1986; Musiek et al, 1988).

While abnormal interaural asymmetry may be indicative of APD (Keith, 1984; Bellis, 1996; Chermak and Musiek, 1999; Jerger et al, 2002; Moncrieff et al, 2004), there are both theoretical and methodological issues that complicate a more auditory-specific interpretation of test results. Of these, none has received more focus in the literature than the influence of spatial attention on interaural asymmetry. Much of the early dichotic research employed a divided-attention or "unfocused" listening mode; listeners repeated back everything heard in both ears and were free to choose how they deployed attention (for review of DL procedures, see Bryden, 1988). Subsequent studies using more directed-attention or "focused" procedures have revealed that the ear differences obtained in the divided-attention mode were susceptible to the influence of spatial attentional factors (Bryden et al, 1983; Mondor and Bryden, 1991; Asbjornsen and Hugdahl, 1995; Voyer and Flight, 2001). Studies utilizing functional brain imaging techniques such as PET (positron emission tomography) and fMRI (functional magnetic resonance imaging) have further revealed that the degree of activation even in primary auditory cortex is affected by the manipulation of attentional resources (O'Leary et al, 1996; Jäncke et al, 1999; Hugdahl et al, 2000).

Though focused-attention procedures were introduced to bring volitional shifts in attention under experimental control, such instructions in children may generate an order or priming effect that alters the magnitude of interaural asymmetry (Hiscock and Chipeur, 1993). Instructions to report only the information presented to the right ear may bias responses in favor of that ear, even when attention is directed to the left side on subsequent trials. This may be of greater concern when the test structure incorporates relatively few directed-right and directed-left listening conditions. The most effective method to capture and maintain attention to the directed side, whether it be through verbal instructions or the unilateral presentation of a tonal precue, can also influence the size of interaural asymmetry (Voyer and Flight, 2001).

In summary, while dichotic procedures have proven sensitive to the identification of centrally based auditory deficits, complete "control" for non auditory-specific factors, such as attention, on test results has proven difficult. Regardless of which DL tests are used, there is concern that extra-auditory factors, such as facility with stimulus materials, attention, or memory, may influence test performance. Indeed, the extent to which deficits on clinical DL tests are attributable to auditory and/or other factors still remains one of the more daunting challenges facing clinicians who evaluate children for APD.

Perhaps part of the problem arises from the considerable diversity observed among clinical DL tests in the stimuli employed and mode of administration. While review of the more commonly used tests exceeds the scope of this paper (for review of dichotic paradigms, see Jerger and Martin, 2006), it is only to be expected that children can show considerable variability in the amount of interaural asymmetry on different DL tests (Moncrieff and Musiek, 2002). This, in itself, complicates a more direct comparison or "cross-check" of the results obtained on screening-based procedures, like the SCAN test (Keith, 2000), with those obtained on more "diagnostic" DL tests, such as the Staggered Spondee Word test (SSW: Katz et al, 1963), Dichotic CV Test (Berlin et al, 1973), Pediatric Speech Intelligibility Test (Jerger, 1987), and Dichotic Digits Test (Musiek, 1983).

The goal of this study was to examine the effects of listening mode (i.e., divided and directed attention) on DL performance in a group of children suspected of having APD. We also attempted to minimize a number of extra-auditory factors known to influence behavioral performance (e.g., facility with stimulus materials, memory, order of report, etc.). While such an approach reduces those components that make auditory processing in the real environment interesting, it nonetheless might help uncover a common factor influencing DL test results in children. Behaviorally, such an approach is difficult. Responses on a simple DL test would likely reach ceiling levels and preclude any meaningful processing differences that potentially exist between different subject groups. Electrophysiological procedures, on the other hand, are well suited to examine the timing of information processing in spite of: (1) a lack of an overt verbal response and (2) similarity between groups in behavioral performances. Since electrophysiological measures have proven beneficial to our understanding of other auditory disorders, it is reasonable to ask whether such an approach might provide insight on the nature of DL deficits.

The auditory event-related potential (ERP) consists of a series of characteristic positive and negative voltage fluctuations or "components" in electroencephalographic activity (EEG) in response to an auditory stimulus (Picton, 1992). Earlier appearing components (e.g., N1) are associated primarily with sensory or exogenous aspects of a stimulus encoding while the later components (e.g., P3) reflect subsequent endogenous or cognitive aspects in stimulus evaluation. Depending upon task demands and stimulus parameters, both the early and late components may be present in the ERP waveform.

Of the more endogenous ERP components, research examining the brain mechanisms underlying different aspects of language processing has revealed at least two main components that are sensitive to experimental variations in linguistic content. The first component, a negative going potential that reaches maximal amplitude approximately 200–600 msec post-onset of an auditory or visual stimulus, is typically referred to as the "N400" (Kutas and Hillyard, 1984). The second component, characterized by a positive deflection in the waveform around 600–1000 msec, is often referred to as the "P600" (Osterhout and Holcomb, 1992), the "late positive shift" (Hagoort et al, 1993), or, simply, "a late positive component (LPC)."

The N400 potential appears as an increase in ERP amplitude (i.e., negativity) to semantically incongruous words presented either in word pairs or sentences and is often interpreted to reflect involvement of those brain mechanisms underlying semantic processing (see review by Kutas and Federmeier, 2001). Studies examining N400 scalp topography have shown that it reaches, at least in adults, peak amplitude over the midline electrodes positioned over the parietal (PZ) and centroparietal (CPZ) areas. The neural generators underlying this component are uncertain, but important contributions from the medial temporal lobe have been suggested (McCarthy et al, 1995). While most accounts link the N400 to various aspects of semantic processing, the amplitude and latency of the N400 can be modulated by a host of experimental and subject factors, including semantic priming effects (Holcomb and Neville, 1990), the context in which linguistic decisions are made (Bentin, 1989), allocation of attentional resources (Bentin et al, 1995), and age (Federmeier et al, 2003).

Appreciably fewer studies have examined the N400 in children. Holcomb et al (1992) examined N400 amplitude and latency to semantically anomalous sentences in children and young adults 5 to 26 years of age. Results showed that N400 amplitude and latency decreased with advancing age. In addition, the scalp topography of the N400 was found to be distributed more anteriorally than that often observed in adults, possibly implicating a second distinct component unique to children that overlaps the N400 (Holcomb et al, 1992). Whether this second component reflects maturational changes in attentional capture (Holcomb et al, 1985) is uncertain. A recent study by Atchley et al (2006) extends earlier research (Hahne and Friederici, 1999; Friederici and Hahne, 2001) characterizing the N400 in children, with the most salient features being decrease in N400 amplitude and latency with advancing age and wide distribution in N400 scalp topography for younger listeners.

The later P600/LPC component appears as a positive shift in the ERP waveform, with maximum positivity over centroparietal areas, and is typically observed in response to violations in grammatical number agreement and/or other syntactic anomalies (Osterhout and Holcomb, 1992; Münte et al, 1997; Atchley et al, 2006). Despite being elicited in similar experimental paradigms that yield the N400, the LPC is somewhat more controversial in its neurophysiological interpretation. Some have hypothesized that the LPC indexes those mental operations involved in the reanalysis of linguistic stimuli upon detection of morpho-syntactic anomalies (Osterhout et al, 1994; Friederici et al, 1996). Therefore, the LPC may be sensitive to distinct aspects in linguistic processing (Ousterhout and Holcomb, 1995; Osterhout and Nicol, 1999). Juottonen et al (1996) describe the LPC as a reflection of further evaluation in stimulus meaning and ability to integrate verbal information into the construct of semantic memory. Others associate the LPC with more general cognitive aspects in information processing, such as context updating and working memory (see Coulson et al, 1998a, 1998b). Thus, the LPC may be an extension of those mental operations that underlie stimulus categorization abilities, similar to those believed to produce the P3 component. To some extent, the interpretation of the LPC often reflects the experimental paradigm in which it is evoked. We associate the LPC as a psychophysiological manifestation of timeliness in those cognitive or late selection processes (e.g., context and memory updating) involved in, for example, the categorization of rare and frequent stimulus events.

In this study, we report N400 and LPC data obtained from children during dichotic listening (DL). Two groups were tested: One group was comprised of children who showed a substantial left-ear deficit on clinical measures of DL; the other group showed no such deficits and served as age-matched controls. The experimental DL tasks required listeners to make simple "same-different" judgments to familiar words. To examine the influence of spatial attention on the N400 and LPC, both divided-attention and directed-attention listening modes were administered. A third control condition involving diotic listening using the same stimuli was also included. We examined the hypothesis that an inability to allocate appropriate attentional resources may underlie some of the DL deficits observed in children evaluated for APD.

METHODS

Subjects and Recruitment

Twenty children between the ages of 8 years, 11 months and 13 years, 8 months participated in the study. Half of the participants were referred to our laboratory for evaluation in light of their poor performances on clinical measures of dichotic listening (DL), such as the SCAN, SSW, or Dichotic Digits Test. These children, hereinafter referred to as the "dichotic deficits" group (DD group), were recruited to participate in the study via brochures locally distributed to audiologists and speech-language pathologists. Overall, each child in the DD group was described by parental report as having academic difficulties. Particular areas of concern were auditory attention, following multistep instructions, reading, and delays in age-appropriate expressive language skills. A second group, comprised of children who showed no history of listening and academic problems, based on a detailed parent questionnaire, served as control participants. None of the control participants had any prior experience with the behavioral and electrophysiological procedures employed in the study. Informed consent was obtained from all participants in accordance with the University of Texas at Dallas's guidelines. Table 1 summarizes the age and gender distribution of the participants in each group.

All participants were right-handed by standard questionnaire (Annett, 1970) and learned English as their first language. All participants had pure-tone hearing thresholds on both ears of 20 dB HL or better at octave intervals over the frequency range 500 to 8000 Hz. Interaural threshold differences at each test frequency never exceeded 10 dB. Tympanograms and acoustic reflexes, screened at 1000 Hz with ipsilateral stimulation, were normal on each ear for all participants. None of the participants had any known neurological deficit or were taking medications that could influence the recording of electroencephalographic activity (EEG).

Listening ability for each participant was assessed using the Children's Auditory Performance Scale (CHAPS; Smoski et al,

Table 1. Age and Gender Distribution of the Participants in the Control and Dichotic Deficit Groups

	Mean Age (SD)	Gender
Control Group (N = 10)	11 years, 0 months (1.48)	7 males, 3 females
Dichotic Deficits Group (N = 10)	10 years, 7 months (1.35)	8 males, 2 females

Note: Standard deviations are indicated in parentheses.

Table 2. Summary of the Children's Auditory Performance Scale (CHAPS) for the Control and DD Groups

	Listening Condition						
	Noise	Quiet	Ideal	Multiple Inputs	Auditory Memory Sequencing	Auditory Attention Span	Total
Control group	.029	.414	.467	.400	.412	.263	.308
DD group	**-2.086**	**-1.371**	-.633	-.800	**-2.137**	-.900	**-1.467**

Note: Items qualifying as "at risk" (i.e., ≤-1.0) are in bold type for emphasis.

1998). Table 2 summarizes average parental ratings for each group across the different listening conditions implemented on the CHAPS. Overall, parental ratings for the DD group were in the "at-risk" range for learning difficulties (≤-1.0). From Table 2, at-risk ratings were indicated for listening abilities in noisy and quiet environments, and for auditory memory sequencing. The total average condition score was -1.47. For control participants, the total average range condition score was in the pass range (.31). Ratings across the different listening conditions for this group were also within the pass range.

General Procedures

Participants were tested over two sessions to reduce fatigue. Care was taken to ensure that each study session was conducted approximately at the same time of day. The second session was completed on the next day for 14 of the participants. The remaining participants completed the second session within a two week period. Each session lasted approximately two hours. In the first session, following routine audiometric and middle-ear assessment procedures, the Competing Words and Competing Sentences subtests of the SCAN-C were administered to each participant. The Competing Words subtest is a dichotic listening (DL) task that involves divided attention with precued direction. Listeners are asked to report both words heard but in a preferential order. On the first half of trials, listeners first report the word presented to the right ear followed by the word presented to the left ear. On the second half of trials, the words presented to the left ear are repeated first. The Competing Sentences subtest is a dichotic task that involves directed attention. On the first half of trials, listeners attend and report only the sentence presented to the right ear. On the second half of trials, listeners monitor and report the sentence presented to the left ear. SCAN stimuli were presented through standard audiometric headphones at a comfortable listening level (50 dB HL). The SCAN subtests, which are screening procedures, were selected as clinical measures of DL because (1) inspection of the diagnostic reports furnished to our laboratory revealed that children in the DD group showed, overall, particular difficulties on these subtests; (2) the SCAN test is widely used by audiologists for screening for APD; and (3) there has been overall consistency of the SCAN test in producing interaural asymmetry in children (Moncrieff and Musiek, 2002). Most importantly, since the results on the SCAN subtests formed the basis of group classification used in this study, we felt it appropriate to corroborate past diagnostic reports and re-administer the SCAN subtests to all participants. Scoring of each SCAN subtest was performed in accordance with the supplied manual for the SCAN.

Upon completion of the SCAN subtests, participants were fitted with an elastic cap containing multiple electrodes used in the recording of auditory ERPs. Following cap placement, participants underwent one of two dichotic listening tasks incorporating either a divided-attention or directed-attention listening mode. Half of the participants completed the divided-attention task on the first session; half at the beginning of the second session. Finally, a diotic control task, incorporating the same stimuli used in the dichotic tasks, was presented at the end of the second session. Positioning the control task at the end of the experiment was purposefully sought in order to evaluate whether differences between groups on the dichotic tasks (if any) were related to fatigue and/or the selection of linguistic stimuli (i.e., stimulus effect).

Experimental Tasks

Participants were comfortably seated in a medical examining chair within a sound-treated room. Auditory stimuli were presented via three loudspeakers positioned at ear level around the participant. Two of the loudspeakers were positioned 1.5 meters on either side of the participant's head. The third loudspeaker was positioned 2.2 meters directly in front of the participant. Presentation intensity for auditory stimuli delivered from the three loudspeakers was presented at a comfortable listening level, approximately 58 dB SPL-A, as determined by a sound level meter positioned at the location of the participant's head during testing.

In each of the three experimental tasks, participants were asked to listen to familiar monosyllabic words. To facilitate similar word onsets and offsets in dichotic stimuli, 48

Table 3. Linguistic Stimuli Used in the Experimental Tasks

Linguistic Stimuli (N = 48)			
Bait	Keep	Gap	Pick
Beak	Kick	Gate	Pig
Bed	Kid	Get	Pipe
Beg	Kite	Gig	Put
Bike	Dad	Goat	Tack
Book	Date	Good	Take
Boot	Deep	Got	Toad
Bought	Dip	Guide	Took
Cake	Dock	Pack	Top
Cap	Dog	Pad	Tub
Coat	Duck	Paid	Tug
Cook	Dug	Peg	Type

consonant-vowel-consonant words (CVCs) incorporating plosives in the initial and final word position were used (see Table 3). Speech stimuli were recorded in an audiometric sound-treated room by an adult male, monolingual speaker of English. Speech was sampled at a rate of 22,050 Hz with 16-bit amplitude resolution using the Cool Edit Pro software (Syntrillium Software Corp). Overall intensities of the words were equated based on their average root mean square amplitudes. Word durations were digitally equated (if necessary) using a selective resampling algorithm on the steady state portion of the vowel. We ensured, however, that no degradation in the percept of the consonants or vowels in such cases occurred. The average word duration was 500 msec, and ranged from 478 msec to 530 msec. Overall presentation level of linguistic stimuli was determined using speech noise calibrated to the average intensity of the words when presented in the soundfield.

Our purpose was to evaluate DL performance with experimental procedures that minimized the involvement of nonauditory factors on performance, such as memory (e.g., order of report) and facility with linguistic materials. To this end, a listening task requiring only simple categorical “same” or “different” judgments was employed. For all listening tasks, auditory stimuli were presented in a basic reference-probe paradigm; participants were asked to judge whether an initial reference stimulus (e.g., a single word) was repeated in a subsequent probe stimulus. Probe stimuli consisted of either a single word (diotic condition) or dichotic word pair (dichotic conditions). A “same” judgment, therefore, occurred when the reference word was repeated again in the probe stimulus. A “different” judgment occurred when the reference word was not repeated. Participants indicated their response following each trial by manually pressing one of two buttons, labeled “yes” and “no” and vertically positioned in front of them. Participants were instructed to press “yes” for same judgments and “no” for different judgments. During the diotic task, for example, the participant would press “yes” if the reference and probe word were the same (i.e., a physical match) or “no” if the words were different. For the dichotic tasks, the participant would press “yes” if the reference word was repeated as one of the two words in the dichotic probe. In this case, the physical match could occur either on their left side (same-left) or right side (same-right). If the reference word was different from both words in the dichotic probe, the participant would respond “no.” Figure 1 shows an example of a “same” judgment for each of the experimental tasks (further described hereinafter). Instructions were verbally given to each participant prior to each listening task along with a brief practice session to ensure that they understood the directions.

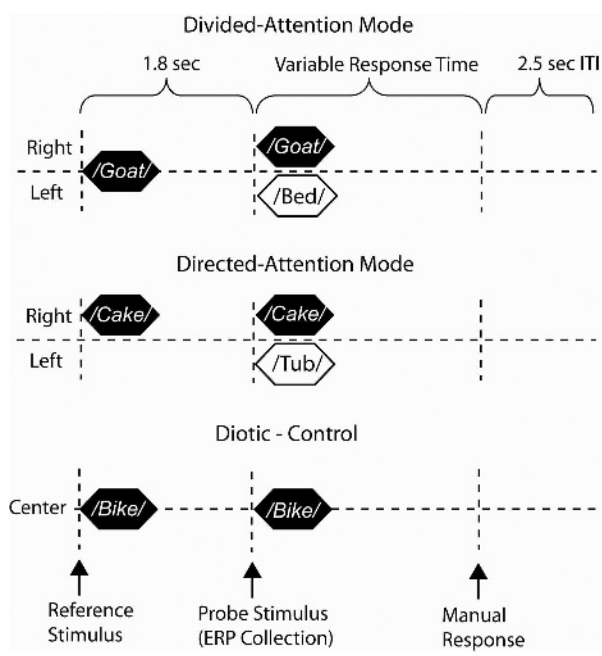

Figure 1. Schematic of a single trial presented in each of the three listening tasks. For the two dichotic tasks, only a same-right judgment is shown.

Stimulus onset asynchrony between the reference and probe was held constant at 1.8 seconds. The participant's manual response triggered the next trial, following a 2.5 second delay. Each dichotic task required overall about 40 minutes to complete (~3 minutes per listening block) including generous rest breaks between listening blocks. The diotic task required approximately 20 minutes to complete.

Dichotic with Divided Attention

In this task, participants were asked to monitor dichotic stimuli (i.e., probe stimuli) using a divided-attention listening mode. Participants were instructed to attend to both words constituting the dichotic pair for the occurrence of the preceding reference word. The reference word was presented diotically (i.e., from the right and left loudspeakers) to achieve a percept along the midline. A total of 192 trials were presented over six listening blocks (32 trials each). Half of the trials (96 trials) incorporated "same" judgments; the other half of the trials incorporated "different" judgments. Of the total number of "same" trials, half (48 trials) incorporated "same-left" judgments; the other half constituted "same-right" judgments. Since a divided-attention mode was employed during this task, separation of "different" judgments as a function of side (i.e., "different-right" and "different-left") was not possible. The number of trials was selected on the basis of the minimum number of trials needed to adequately assess the electrophysiological response from participants to each stimulus event. Trials corresponding to each event type were pseudorandomly presented within each listening block, with the exception that no more than two of the same stimulus events occurred consecutively.

Dichotic with Directed Attention

In this task, participants were asked to monitor dichotic probe stimuli in a directed-attention (focused) mode. Participants were instructed to attend only to the words presented on a predetermined side (right or left) and ignore the competing words presented contralaterally. To reinforce spatial attention to the directed side, the reference word preceding each dichotic stimulus was presented from the loudspeaker on the *same side* to which the participant was asked to focus. A total of 192 trials were presented over six listening blocks (32 trials each), with participants receiving either attend-left or attend-right instructions on half the blocks. The side to be attended was alternated over the duration of the task, and the side to be attended first was counterbalanced across participants. As in the divided-attention task, half of the trials in this condition (96) involved "same" judgments; half involved "different" judgments. Of the total number of "same" trials, half (48) incorporated "same-left" judgments; half incorporated "same-right" judgments. The word in the dichotic probe constituting a "same" judgment was always presented to the attended side. In contrast to the divided-attention task, "different" judgments corresponding to side of occurrence (e.g., "different-right" and "different-left") were possible. Each event type was pseudorandomly presented within each listening block.

Diotic Control Condition

In the final listening task, participants were asked to monitor the same words but from a spatially neutral position. That is, both the reference and probe stimulus consisted of single words presented from a loudspeaker facing the participant. Although stimuli were presented from a single loudspeaker, we refer to this condition as "diotic" since both ears receive the same stimulus via the soundfield. Again, participants were asked to decide whether the reference and probe words were the "same" or "different." A total of 96 trials were presented over three listening blocks (32 trials each). Half of the trials involved "same" judgments (48 trials); half involved "different" judgments. Each event type was pseudorandomly presented within each listening block.

Electrophysiological Procedures

ERPs were collected using the Neuroscan electrophysiologic data acquisition system (Acquire, Compumedics). Continuous EEG activity was recorded from 30 silver-silver chloride electrodes mounted in an elastic cap (Neuroscan) affixed to the scalp according to a modification of the International 10-20 system. Electrode impedances were always less than 5 kohms. Eye movements and eye blinks were monitored via electrodes placed above and at the outer canthus of the left eye. EEG channels were referenced to linked mastoid electrodes with a forehead electrode as ground. Ongoing EEG activity was sampled at 500 Hz, amplified, analog filtered from 0.10 to 70 Hz, digitized, and stored for off-line analysis.

Offline, EEG recordings were visually inspected. Movement and irregular ocular artifacts (nonblinks) were omitted from further analysis. Systematic eye movements (blinks) were spatially filtered from the continuous EEG recording by performing a spatial singular value decomposition (spatial PCA) on the average eye blink of each individual participant (Ille et al, 2002). Following removal of ocular and other recording artifacts, individual epochs, ranging from a 200 msec prestimulus interval to 1600 msec postonset of probe stimuli, were derived. Accepted epochs were separately averaged according to stimulus type. Successfully averaged ERP waveforms were then linearly detrended, baseline corrected relative to the prestimulus interval, and digitally low-pass filtered at 20 Hz (-48 dB/octave). A minimum of 25 acceptable epochs constituted an individual ERP waveform; the average number of accepted epochs was approximately 40 epochs. Thus, we determined that approximately 16% of the ERP data across the different stimulus events was artifact-rejected for each group of participants.

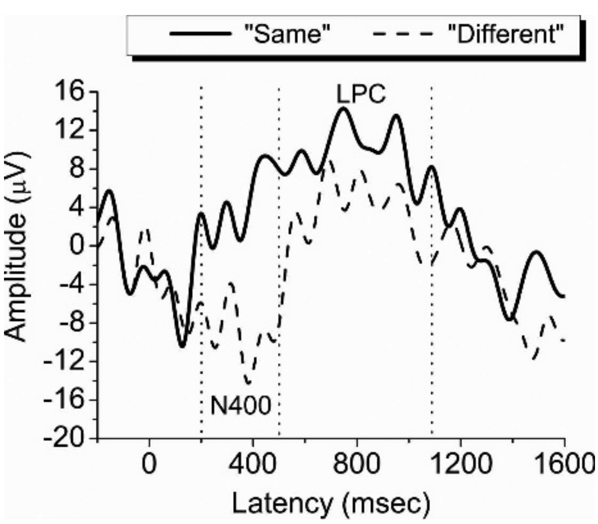

Figure 2. ERP waveform morphology. Data were taken from a nine-year-old boy in the DD group during the diotic condition. The ERP waveforms represent "same" and "different" judgments. The recordings are from a midline electrode in the parietal region (PZ). Both the N400 and LPC components can be identified.

Description of ERP Waveforms

In the present paper, we focus on the later endogenous waveform components as an index of timeliness in cognitive processing during DL. In this regard, we expected the resultant ERP waveform morphology to show two distinct, but overlapping, components reflecting two task-specific processes: (1) a processing negativity (N400) in the 200 to 500 msec region indexing semantic analysis of closeness of fit (Kutas and Hillyard, 1984) between the reference and probe stimulus, and (2) a subsequent late-positive component (LPC) in the 500 to 1100 msec region reflecting further cognitive aspects of stimulus evaluation and response categorization. Based on previous dichotic studies (Jerger et al, 2000, 2002; Martin et al, 2006), we anticipated that these components, particularly the LPC component, would be maximally distributed over the parietal recording electrodes. As an illustrative example, Figure 2 shows two ERP waveforms from a nine-year-old boy in the DD group during the diotic listening condition. Data were taken from a single parietal electrode (PZ) and represent a "same" and "different" judgment. From the figure, both types of judgments evoked a robust LPC component over the 500–1100 msec region. In the case of "different" judgments, however, a processing negativity (i.e., N400) was observed over the 200–500 msec region relative to that observed for the "same" judgments.

Analysis of ERP Waveforms

To examine the nature of interaural asymmetry in ERP responses, as opposed to interhemispheric asymmetry, we restrict our analyses to a single midline electrode positioned over the parietal region (PZ).

Rationale for the selection of this particular electrode was based on the topography of the LPC maximum response. Figure 3 shows the grand-averaged topographic maps for the LPC component in response to "same" and "different" judgments obtained during the diotic condition for both groups of listeners. In all cases, the maximum LPC response occurs over the midline in the parietal region.

The LPC and N400 components of each individual waveform were quantified via measurement of mean amplitudes and peak latencies. For the N400 component, mean amplitudes were taken over the 200 to 500 msec latency interval; for the LPC component, mean amplitudes were taken over the 500 to 1100 msec latency interval. Mean amplitudes rather than peak amplitudes were selected as more objective measures of the amplitude of the N400 and LPC components that often show a maximum response that extends over several hundred milliseconds. Peak latencies were obtained by an automated peak detection algorithm confirmed by visual inspection. For each dichotic task, mean amplitudes and peak latencies for the N400 and LPC were analyzed separately in a repeated measures analysis of variance (ANOVA) design with listener group affiliation serving as the between-subjects factor and type of judgment (same or different) and side of presentation (right or left) serving as within-subjects factors. For the diotic task, type of judgment served as the single within-subjects factor. Due to relatively small sample sizes, nonparametric statistical procedures were also employed to confirm significant group differences observed with ANOVA. Mann-Whitney U-tests were used for between-group analyses (Siegel, 1956). Statistical significance was evaluated at the 0.05 alpha error level.

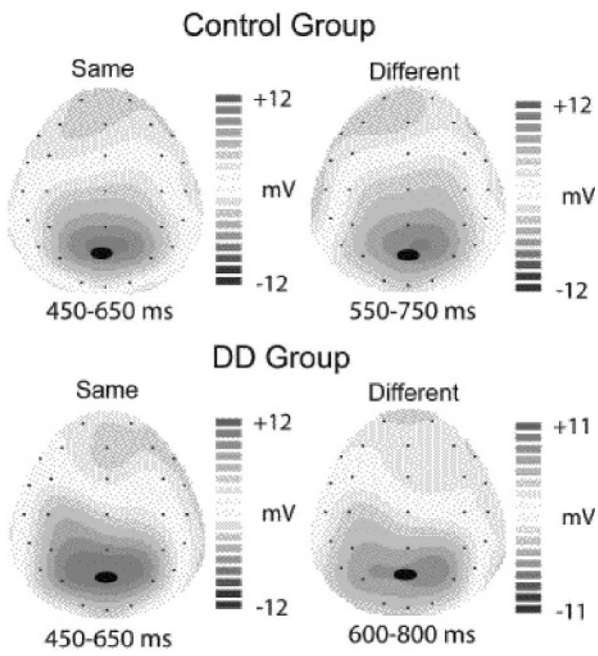

Figure 3. Grand-averaged topographic maps of the LPC component obtained during the diotic condition for both groups of listeners. In all cases, the LPC response is maximal across the parietal electrode array. Differences in the time scales used to generate each topographic map reflect inherent latency differences in the two types of judgments (i.e., "same" or "different") made by participants. Amplitude was adjusted to reflect the maximal LPC response in each condition. Location of the PZ electrode is indicated with a black circle.

RESULTS

Clinical Measures of Dichotic Listening

Figure 4 shows the results of the Competing Words and Competing Sentences subtests of the SCAN for both groups. On the Competing Words subtest, listeners in the control group showed minimal ear differences in their responses to the dichotic stimuli, irrespective of the word to be repeated first. For this group, only a slight left-ear disadvantage (approximately two words) was obtained when the words presented to the right ear were repeated first. This interaural asymmetry disappeared when the words presented to the left ear were repeated first. For the group of children suspected of having dichotic listening deficits (DD group), a different pattern emerged. This group showed a substantial left-ear deficit that remained approximately the same magnitude irrespective of the side that attention was initially focused. When the word to be repeated first was in the right ear, the average left-ear deficit was approximately seven words. For the left-ear first condition, the average left-ear disadvantage was approximately six words. On the Competing Sentences subtest, a similar pattern in results was observed. The DD group showed a substantial left-ear deficit (average of seven items) whereas the control group exhibited little ear difference.

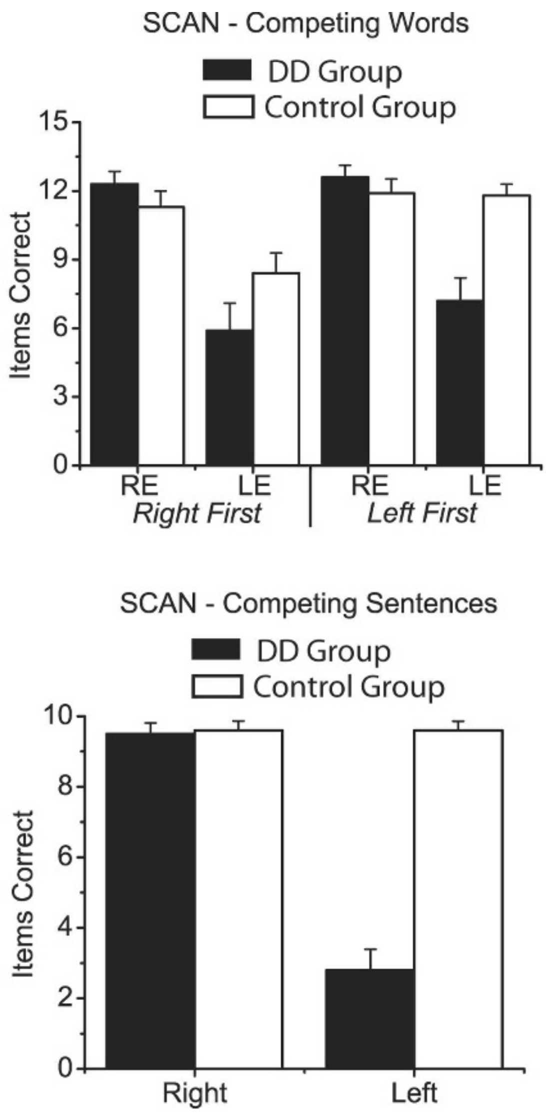

Figure 4. Results for the SCAN Competing Words and Competing Sentences subtests for both groups. Error bars indicate SEM.

Based on the recruitment procedures used in this study, differences in behavioral performance between the two participant groups on the SCAN subtests were only to be expected. Nevertheless, we felt it appropriate to statistically confirm group differences on the SCAN using ANOVA. For both subtests, participant group served as a between-subjects factor. For the Competing Words subtest, the initial side to which attention was focused (i.e., report right first, report left first) served as a within-participants factor. For the Competing Sentences subtest, the within-subjects factor was the side to which attention was focused (i.e., report right, report left). As expected, a significant group x ear interaction was found on both SCAN subtests (Competing Words: $F_{(1,18)} = 15.64$, $p < 0.001$; Competing Sentences: $F_{(1,18)} = 51.92$, $p < 0.0001$). For both subtests, the interaction effect occurred as a result of the poor performances by the listeners in the DD group to stimuli presented from the left side. Clinically, each of the listeners in the DD group would be identified as having "borderline" to "disordered" dichotic listening function, based on either an overall low performance score on one of the two subtests (i.e., percentile rank less than 9%) and/or large ear differences exceeding 15% of the normed sample for the Competing Words subtest.

Experimental Findings

Response Accuracy

Table 4 shows the average accuracies for both groups of listeners on the three

Table 4. Average Response Accuracies (in percent) for Both Groups to Each Stimulus Event on the Three Experimental Listening Tasks.

		Accuracy (in %)	
Task	Stimulus Event	Control Group	DD Group
Divided Attention	Same-Right	96.32 (.98)	92.05 (1.58)
	Same-Left	94.26 (.60)	83.97 (2.65)
	Different (both)	98.53 (.45)	96.73 (.71)
Directed Attention	Same-Right	97.09 (1.32)	94.37 (1.56)
	Same-Left	96.67 (1.36)	95.42 (1.58)
	Different-Right	97.92 (.62)	96.04 (1.57)
	Different-Left	98.75 (.56)	97.92 (.62)
Diotic - Control	Same	99.58 (.28)	98.13 (.66)
	Different	99.58 (.28)	98.54 (.70)
Overall Performance:		97.63	94.80

Note: SEM values are shown in parentheses.

experimental listening tasks. Overall, average accuracies were excellent for both groups. The average accuracy for the control group across all test conditions was 97%, 94% for the DD group. For the divided-attention task, both groups were overall more accurate to “same-right” judgments as compared to “same-left” judgments, $F_{(1,18)} = 16.628$, $p = 0.0007$. The DD group also showed a slight decrease in response accuracy (83%) to “same-left” responses on the divided-attention task as compared to the control group, $F_{(1,18)} = 5.834$, $p = 0.027$. Thus, the LED observed for the DD group on the SCAN subtests was also observed on the experimental DL task incorporating divided attention. Group differences in response accuracy to left-sided or right-sided stimulus events on the directed-attention procedure as well as the diotic control task failed to reach statistical significance.

Electrophysiological Results

Figure 5 shows grand-averaged ERP waveforms for both groups of listeners across the three listening tasks. Several findings are evident from the waveforms obtained during the divided-attention task (left panels). First, irrespective of which side (left or right) constituted a “same” judgment (top-left panel), overall larger LPC amplitudes were observed for the control group as compared to the DD group. Second, in the same figure, LPC peak latencies were earlier for the control group (~600–800 msec) as compared to those obtained for the DD Group (~800–1000 msec). Third, N400 amplitudes to “same” judgments were overall larger for the DD group as compared to control participants. Finally, for both groups, LPC amplitudes to “same-right” judgments were slightly larger than those observed for “same-left” judgments.

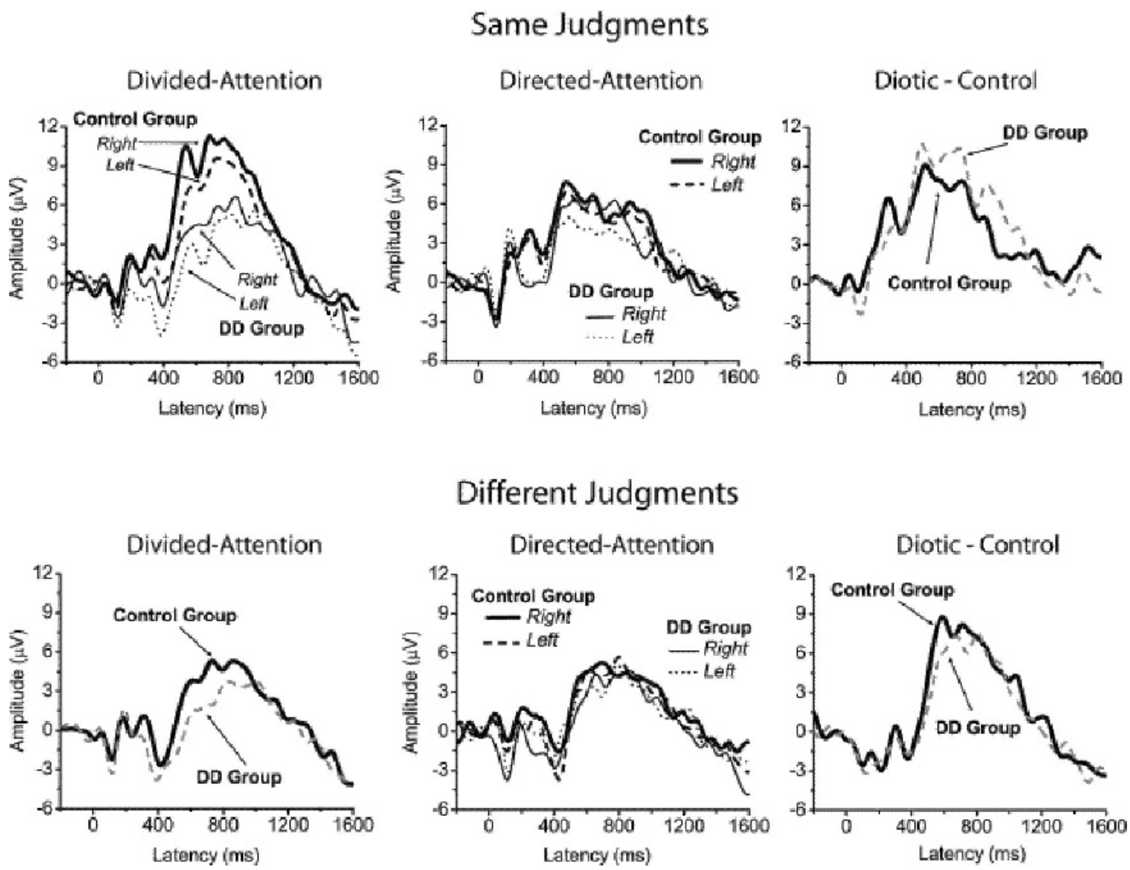

Figure 5. Grand-averaged ERP waveforms for both groups of listeners on the three listening tasks. Data are taken from electrode PZ.

Grand-averaged ERP waveforms on the divided-attention task corresponding to "different" judgments (bottom-left panel) were more similar between the two groups. Since a side-specific "different" judgment was not possible, only a single ERP waveform is shown for each group. In contrast to "same" judgments, "different" judgments for the two groups are characterized by a robust N400 component consistent with a semantic incongruity between the reference and probe stimuli. LPC amplitudes to "different" judgments were slightly larger for the control group as compared to the DD group.

The ERP waveforms obtained on the directed-attention task (middle panels) were more similar between the groups. As expected, "different" judgments evoked a more robust N400 component as compared to "same" judgments (i.e., a semantic incongruity effect). A slight decrease in LPC amplitude for "same-left" judgments was observed for the DD group as compared to the control group. However, compared to the group differences observed for the LPC on the divided-attention task, LPC amplitudes and latencies were overall more similar between the groups when participants were asked to focus their attention to one side. A robust N400, similar to that expected for "different" judgments, was also observed in "same" judgments for the DD group.

Grand-averaged ERP waveforms obtained during the control task are shown in the right panels of Figure 5. Overall, for both "same" and "different" judgments, LPC and N400 amplitudes and latencies were similar for each group. Again, responses to "different" judgments evoked a larger and more robust N400 component than "same" judgments.

Figure 6 summarizes the mean LPC amplitude and peak latency data for the two groups on each listening task. For the divided-attention condition (left panels), control listeners showed larger mean LPC amplitudes to "same" judgments than those

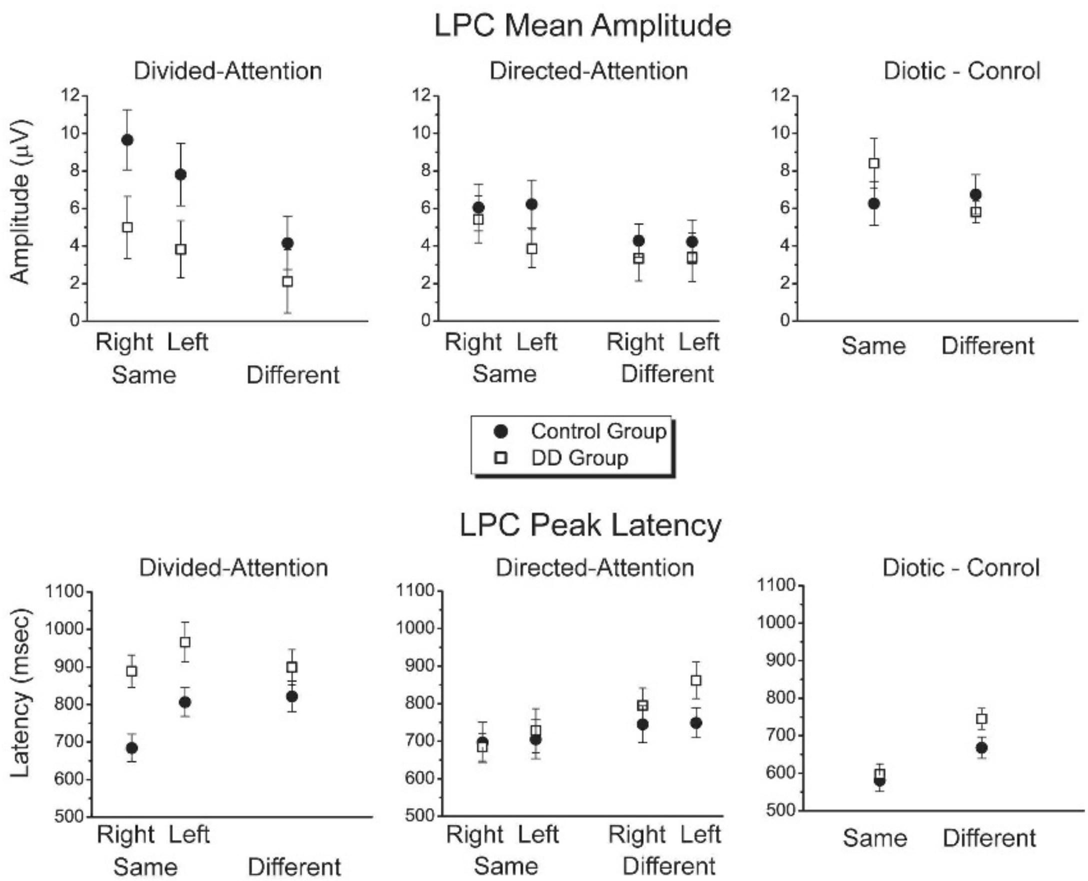

Figure 6. Summary of the LPC mean amplitude and peak latency data for both groups on the three listening tasks. Data are taken from electrode PZ.

obtained for the DD group, $F_{(1,18)} = 4.688$, $p = 0.044$. Control listeners showed earlier LPC peak latencies to "same" judgments as compared to those obtained for the DD group, $F_{(1,18)} = 12.020$, $p = 0.003$. While LPC amplitudes tended to be larger for "same-right" as compared to "same-left" judgments (see top-left panel in Figure 5), the amount of interaural asymmetry in either group failed to reach statistical significance. Both groups showed earlier LPC responses to right-sided "same" judgments as compared to left-sided "same" judgments, $F_{(1,18)} = 10.215$, $p = 0.001$. Mann-Whitney U tests also confirmed group differences on the divided-attention task with regard to LPC mean amplitude ($p = 0.012$) and peak latency ($p = 0.009$) to "same" judgments. Group differences in LPC measures for "different" judgments failed to reach statistical significance via either unpaired *t*-tests or Mann-Whitney U tests.

Analyses of mean LPC amplitude and of peak latency on the directed-attention condition (middle panels) revealed only main effects of type of judgment (same or different). Mean LPC amplitudes were larger for "same" judgments as compared to "different" judgments, $F_{(1,18)} = 7.984$, $p = 0.011$. Mean LPC peak latencies were earlier for "same" judgments as compared to "different" judgments, $F_{(1,18)} = 16.824$, $p < 0.001$. When each type of judgment was analyzed separately, no significant main effects or group interactions for mean LPC amplitude and peak latency were obtained for this listening condition.

For the diotic control condition (right panels), mean LPC amplitudes to "same" judgments were slightly larger for the DD group than for the control group, but neither a main effect of group or judgment type or their interaction was significant. Both groups showed earlier LPC peak latencies to "same" judgments as compared to "different" judgments on the control listening task, $F_{(1,18)} = 22.163$, $p < 0.001$. Overall, on both the directed-attention and diotic tasks, LPC measures were similar for the two groups of listeners.

Figure 7 summarizes N400 mean

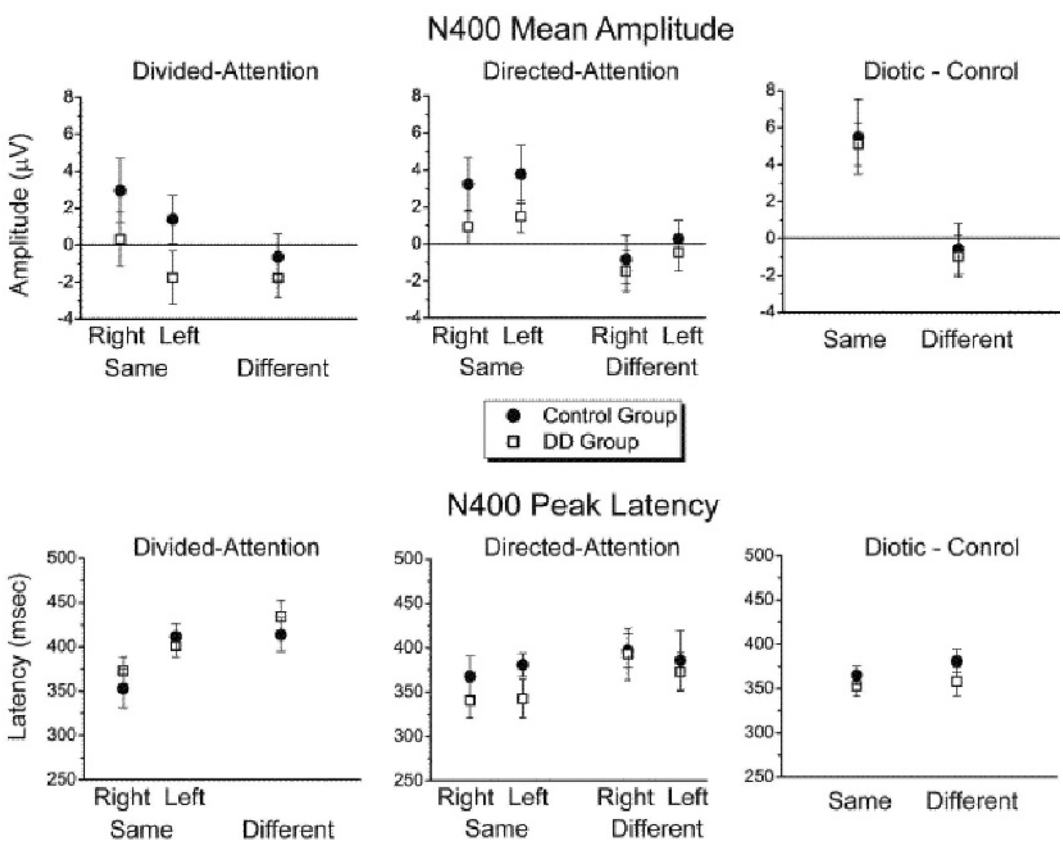

Figure 7. Summary of the N400 mean amplitude and peak latency data for both groups on the three listening tasks. Data are taken from electrode PZ.

amplitudes and peak latencies for both groups on each listening task. For the divided-attention condition (left panels), the DD group showed larger N400 amplitudes to "same" judgments as compared to those observed for the control group. While N400 mean amplitudes corresponding to "same" judgments were not statistically different between the two groups, an analysis of peak N400 amplitudes did, in fact, reveal that N400 amplitudes were larger overall for the DD group, $F_{(1,18)} = 6.062$, $p = 0.024$. This group difference in N400 amplitude to "same" judgments on the divided-attention task was also confirmed by a Mann-Whitney U test ($p = 0.005$). N400 mean amplitudes for the two groups were larger overall for left-sided "same" judgments as compared to right-sided "same" judgments, $F_{(1,18)} = 6.110$, $p = 0.024$. For "different" judgments on the divided-attention task, N400 amplitudes were similar between groups. While N400 peak latencies were earlier to right-sided "same" judgments as compared to left-sided "same" judgments, $F_{(1,18)} = 11.884$, $p = 0.003$, no statistical difference between the two groups was obtained for N400 peak latency.

An analysis of N400 mean amplitudes for the directed-attention condition (top-middle panel) revealed a main effect of type of judgment (same or different), $F_{(1,18)} = 19.703$, $p < 0.001$. While the listeners in the DD group tended to show larger N400 mean amplitudes to "same" judgments as compared to control listeners (see waveforms in Figure 5), this trend did not reach statistical significance when analyzed via standard parametric procedures (ANOVA, $p = 0.169$). When the same data were analyzed via the Mann-Whitney U test, N400 amplitudes to "same" judgments did in fact differ between groups ($p = 0.025$). While the two statistical procedures yielded different outcomes for N400 amplitude, results of the Mann-Whitney U test appear more consistent with the magnitude of the group difference observed in the ERP waveforms for "same" judgments on the directed-attention task. For "different" judgments, N400 mean amplitudes were similar for each group. No additional main effects or group interactions for N400 latency were obtained.

For the diotic control condition (right panels), "different" judgments, again, produced a robust N400 component as compared to "same" judgments (N400 mean amplitude: $F_{(1,18)} = 22.442$, $p < 0.001$). No additional main effects or group interactions for N400 mean amplitudes or peak latencies were observed on this task.

Summary of Results for Experimental Tasks

The main results of the study can be summarized as follows:

1. Overall behavioral accuracy in all three experimental tasks was excellent for the control and DD groups (97% and 94%, respectively). Poorer performance (83%) by the DD group for "same-left" judgments was found only on the divided-attention task.
2. On the diotic control task, ERP waveforms were similar for the two groups; no significant differences were found for either the LPC or N400 components. Thus, on a spatially "neutral" task, the groups were similar.
3. On the dichotic task incorporating divided-attention, robust group differences in the ERP waveforms were found. Control listeners showed larger LPC mean amplitudes to "same" judgments as compared to the DD group. LPC peak latencies to "same" judgments were also earlier for the control group.
4. Both groups showed larger LPC amplitudes for right-sided "same" judgments as compared to left-sided "same" judgments, particularly on the divided-attention task. This is consistent with the well known right-ear advantage in DL. The magnitude of interaural asymmetry in ERP responses, however, did not differ between the groups.
5. When listeners were asked to direct attention to a specific side (i.e., directed attention), LPC mean amplitudes and peak latencies were more similar between groups.
6. Larger N400 amplitudes to "same" judgments were found on both dichotic tasks for the DD group as compared to that observed for control listeners.

DISCUSSION

Interaural Asymmetry

While computation of a listener's total composite score on a DL test can be diagnostically useful, it is the degree and direction of interaural asymmetry that has historically been of most interest for assessment of the integrity of the binaural auditory system. In this study, we selected a group of children (DD group) who demonstrated prior difficulty on clinical tests of DL. On the SCAN, these children showed substantial interaural asymmetry in the form of left-ear deficit (LED). Experimentally, a similar behavioral profile was found for the same listeners, but only on the DL task involving divided attention. When the same listeners focused attention to one side, the degree of interaural asymmetry in behavioral accuracy altogether disappeared. It would appear that, for this group of children, the behaviorally observed LED stemmed primarily from those processing demands unique to the divided-attention mode.

Electrophysiologically, the direction of interaural asymmetry in ERP responses was consistent with the expected right-ear advantage (REA) in DL. On the divided-attention task, for example, the two groups of listeners showed larger LPC amplitudes to right-sided "same" judgments as compared to left-sided "same" judgments. Interestingly, the degree of interaural asymmetry in ERP measures remained similar between the two groups on all experimental tasks. It is important, however, to bear in mind that the experimental DL procedures employed here were considerably less demanding than those typically encountered by audiological patients. For example, the Competing Words subtest of the SCAN is a divided-attention task that requires listeners to repeat, in a preferential order, both of the words heard. Those factors known to influence children's responses on basic speech understanding measures, such as word familiarity, frequency of usage, age of acquisition, and their phonemic similarity to other frequently encountered words, apply equally to this procedure. For the experimental DL procedures, on the other hand, listeners were given opportunity to hear and review the test items prior to the listening tasks. This minimized the effects of facility with test materials. The utility of a simple "same-different" paradigm required only a single manual response, minimizing the demands on memory and report strategy. It was expected, therefore, that listeners would compare favorably with regard to behavioral accuracy on the experimental DL tasks.

We do not mean to imply that the SCAN subtests were ineffective at identifying children, at least to a first screening approximation, who show signs of auditory processing weaknesses. Results clearly show that some children evaluated for APD do experience pronounced difficulty on these tests. Rather, our concern is to what extent do extra-auditory factors, irrespective of the clinical test employed, potentially influence the outcome of results? Both the behavioral and electrophysiological results on the experimental tasks suggest that the degree of interaural asymmetry observed in DL may be minimized to a greater extent when demands on memory, report strategy, and facility with linguistic materials are reduced.

Mode of Dichotic Administration

Consistent with the behavioral results, group differences were most apparent in the electrophysiological recordings obtained during the DL task with divided attention. As shown in Figures 5 and 6, control participants showed larger LPC amplitudes and shorter LPC latencies to "same" judgments as compared to the DD group. Although the magnitude of interaural asymmetry in the ERP waveforms did not differentiate the two groups, an overall reduction in LPC amplitude and delay in LPC peak latency for the DD group suggests that these listeners may have particular difficulty processing dichotic stimuli in the divided-attention mode.

What is the basis for this processing disadvantage in the DD group? Given the cognitive demands unique to the divided-attention mode, the most parsimonious explanation is that some children may show difficulty in dividing attention between spatially separate sound sources. The source of the processing delay, as evidenced in the LPC to "same" judgments, could result from two temporally overlapping processes: (1) awareness of the phonemic and/or semantic congruity between the reference word and one of the words in the dichotic probe (i.e., a "same" judgment), and (2) suppression of the phonemic and semantic information inherent to competing words. It follows that if the listener can appropriately divide attention to both auditory channels, recognition of the "same" stimulus (i.e., the repeated reference word), irrespective of the side of occurrence, can readily be made and the competing word becomes of little consequence. If the listener is unable to allocate attentional resources effectively, both words must be analyzed, either phonemically or semantically, to a greater extent. This comes, however, at the expense of slower speed in processing.

If the processing delay to "same" judgments on the divided-attention task results from prolonged semantic analysis of dichotic stimuli, group differences in the N400 should also be apparent. Inspection of the N400 amplitudes to "same" judgments on this task is consistent with this idea (Figure 5). The DD group showed larger N400 amplitudes to "same" judgments as compared to control listeners. Moreover, N400 amplitudes for the DD group to "same" judgments are similar to those observed for their "different" judgments. Thus, for the DD group, larger N400 amplitudes to "same" judgments may reflect semantic intrusion of the competing word, which, in itself, corresponds to a pure "different" judgment.

In summary, robust differences in ERP responses between the two groups were found on the divided-attention task. From the standpoint of audiological applications, however, we can identify some potential extra-auditory factors unique to this mode of dichotic administration (e.g., memory, speed of processing, attention) that complicate the assessment of more auditory-specific factors on results. We have previously argued that administration of dichotic listening tests using both divided- and directed-attention modes can provide insight into the relative contributions of cognitive and auditory-specific factors influencing interaural asymmetry (Jerger and Martin, 2006). If there is truly an auditory-specific deficit contributing to poor dichotic performance on a divided-attention task, it should be apparent under any mode of administration. To this end, we turn our focus to the ERP results obtained on the directed-attention task.

The ERPs obtained during the directed-attention task were, overall, more similar between groups. Similarities in LPC amplitude and latency on this task would suggest that the DD group benefited from instruction to focus attention to one auditory channel rather than both. An unexpected finding, however, was the persistent group difference (via Mann-Whitney U test) in N400 amplitude to "same" judgments on this task. Again, the DD group showed larger N400 amplitudes as compared to control listeners (Figure 5). It is possible that the semantic analysis of the competing word, even though nominally unattended, influenced the extent to which information on the attended side is processed. Since the physical match between the reference stimulus and the word (in the dichotic pair) constituting a "same" judgment always occurred on the attended side, it is difficult to ascertain to what extent listeners in the DD group may have "monitored" information in the unattended channel. Future studies are underway in our laboratory to explore this possibility. In any event, the directed-attention procedure proved to minimize the group differences observed for the LPC on the divided-attention task.

Taken together, we interpret the pattern of ERP results obtained for the DD group on both DL tasks as consistent with a processing disadvantage primarily in the cognitive domain. This conclusion does not, however, negate the possibility that auditory-structural factors are involved. Indeed, the auditory-structural basis for interaural asymmetry in DL has been well documented over the years. Results of this study nonetheless suggest that the magnitude of interaural asymmetry, particularly when assessed with divided-attention procedures, may emphasize additional mechanisms unique to attention.

It could be argued that the group differences observed on the divided-attention task resulted from a more generalized slowing in speed of mental processing. If this were the case, we might also expect to see group differences on a more simple (nondichotic) task. Results on the diotic control procedure, which incorporated the same stimuli used in the dichotic tasks, were not consistent with this view. LPC and N400 measures on this task were similar between each group. It would appear, therefore, the processing deficit observed for the DD group is unique to the dichotic mode.

Finally, group differences in N400 amplitude were observed on both dichotic tasks. Traditionally, the N400 has been shown to be a sensitive index in the depth of semantic analysis for both auditory and visual stimuli. Following this line of reasoning, group differences in N400 amplitude could be interpreted as evidence for qualitative differences in the semantic analysis of the linguistic stimuli used in this study. However, given the similarities between groups in the N400 on the diotic task, it is difficult to argue that this result stemmed from a more global semantic deficit per se. Rather, we relate the larger N400 amplitudes for the DD group to an additional processing negativity, which may reflect an increase in the cognitive effort necessary to allocate attentional resources appropriately during DL. ERP studies focusing on attention in children have reported a similar attentional component that may overlap the time course of the N400 (Courchesne, 1978; Holcomb et al, 1985).

Clinical Implications

Results show that the mode of DL test administration is an important factor to consider when interpreting test results. In this study, group differences in ERP measures were most robust on the dichotic task involving divided attention. This could be interpreted as evidence for the exclusive use of divided-attention procedures for clinical assessment of APD in children. We, however, suggest the opposite. The extent to which interaural asymmetry on this listening mode is attributable to attentional factors and/or auditory factors is difficult to sort out. Rather, the utility of directed-attention procedures, ones that incorporate the same or similar test materials as those presented using divided attention, may be helpful in separating both bottom-up and top-down processing biases underlying interaural asymmetry in DL.

What accounts for the difference between behavioral performances on divided-attention versus directed-attention dichotic procedures? Traditionally, the rationale for using directed-attention procedures was to minimize (control) the cognitive demand imposed by the task and, in turn, allow for a more direct assessment of the auditory-structural component underlying interaural (and hemispheric) processing biases. Accordingly, increases in the magnitude of interaural asymmetry on divided-attention procedures, as compared to that observed on directed-attention tasks, would reflect involvement of more cognitive (attentional) factors. It is becoming increasingly clear, however, that the mechanisms underlying the directed-attention paradigm may differ in many respects from those found with divided attention. Hugdahl (2003) suggests that despite identical instructions to the listener, the directed-left and directed-right tasks tap different mental processes. In particular, a persistent REA on the directed-left task indicates impairments in executive function over the more dominant, stimulus-driven effect characterizing the processing of right-sided inputs. Of course, maturational delay or impairment of the corpus callosum could produce a similar behavioral profile. Whatever the mechanisms may be, we feel that the combined use of divided- and directed-attention procedures may play a useful role in uncovering the nature of DL deficits in some children. Unfortunately, to our knowledge, no standardized test procedure that incorporates both listening modes is commercially available to audiologists.

Concern about the influence of attention and other extra-auditory factors on DL test results is not new. In fact, certain procedures, for example, dichotic fusion tests (Repp, 1976; Wexler and Halwes, 1983), have been proposed over the years to minimize the influence of volitional shifts in attention on DL performance. More recently, Shinn et al (2004) compared behavioral performances in young adults on a dichotic rhyme (fusion) test (DRT) with the dichotic CV (consonant-vowel) test. They administered each test under both divided-attention and directed-attention modes. Results indicated that the magnitude of interaural asymmetry across tests was more stable using the DRT as compared to the dichotic CV test. Because the dichotic "fusion" effect is believed to arise from lower centers in the central auditory pathway (e.g., brainstem), it may be less contaminated by attentional mechanisms. The authors conclude that the DRT procedure may be of value to audiologists in the separation of more global processing biases, such as attention, from more auditory-specific factors. Future research is needed with the procedure to investigate potential response biases in the stimuli used on the DRT and its robustness in the evaluation of children.

Clearly, the effects of attention and other extra-auditory factors on behavioral performance are difficult to disentangle. While interaural asymmetry on DL tests remains an important index in the evaluation of the binaural auditory system, the results of this study suggest that extra-auditory factors, such as attentional capacity, should be carefully considered. Given the likely comorbidity of APD and other developmental disorders, techniques that aim to separate extra-auditory factors on test results are needed.

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