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Auditory pattern recognition and brief tone discrimination of children with reading disorders

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Abstract

Auditory pattern recognition skills in children with reading disorders were investigated using perceptual tests involving discrimination of frequency and duration tonal patterns. A behavioral test battery involving recognition of the pattern of presentation of tone triads was used in which individual components differed in either frequency or duration. A test involving measurement of difference limens for long and short duration tones was also administered. In comparison to controls, children with reading disorders exhibited significantly higher error rates in discrimination of duration and frequency patterns, as well as larger brief tone frequency difference limens. These results suggest that difficulties in the recognition and processing of auditory patterns may co-occur with decoding deficits in children with reading disorders.

Learning outcomes: (1) As a result of this activity, the participant will be able to identify a relationship between reading and temporal processing. (2) As a result of this activity, the reader will be able to discuss the difference between sight–word decoding and phonological decoding. (3) As

Abbreviations: DL, frequency difference limen; ISI, interstimulus interval; PPVT-III, *Peabody Picture Vocabulary Test*—third edition; SPL, speech perception level; WISC-III, Weschler Intelligence Test for Children, third edition; WRMTR, *Woodcock Reading Mastery Test—Revised*

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a result of this activity, the reader will be able to explain a relationship between reading skills and the identification of auditory patterns.

1. Introduction

Reports of the processing of auditory temporal information and its relationship to the development of reading and reading disorders are widespread in the research literature. Previous investigations have revealed that deficits in auditory temporal processing are often found in samples of children and adults who have reading disorders (Cestnick & Jerger, 2000; Farmer & Klein, 1995; Heath, Hogben, & Clark, 1999; Protopapas, Ahissar, & Merzenich, 1997; Tallal, 1980; Walker, Shinn, Cranford, Givens, & Holbert, 2002; Witton et al., 1998). Many investigators have studied the relationship of various phonemic and phonological skills to the development of reading abilities and have concluded that these skills are crucial for reading acquisition at an early age (Catts, Fey, Tomblin, & Zhang, 2002; Torgesen, Wagner, & Rashotte, 1994). However, the relationship of underlying auditory perceptual or temporal deficits to reading development, specifically word recognition, remains controversial. These studies have been inconclusive in their findings, which attempt to explain the association between underlying auditory processing efficiency and word recognition abilities. Other studies have not consistently found that individuals with reading disorders exhibit co-morbid auditory processing deficits. Perhaps part of this uncertainty is due to the use of different theoretical models in the frameworks of their experimental designs, which results in varied participant selection criteria for reading abilities and auditory and/or visual experimental tasks.

Many studies have examined the relationship of temporal processing (visual and auditory) deficits to reading disorders as a function of a word recognition deficit profile (Bretherton & Holmes, 2003; Cestnick, 2001; Cestnick & Jerger, 2000) or decoding skills in general (Walker et al., 2002). Specifically, these researchers have investigated whether phonological decoding skills (i.e. nonsense word reading) or sight–word recognition skills are more related to underlying auditory perceptual abilities. The majority of these studies have found that auditory temporal processing skills are associated more with phonological decoding, and that children with primary word recognition deficits in phonological decoding appear to exhibit more auditory temporal processing deficits. Another recent study, however, found that sight–word decoding abilities might be associated with auditory temporal processing skills as well. In an adult study, Walker et al. (2002) found a positive relationship between sight–word recognition (visual/lexical decoding) and auditory temporal processing, which was not found for phonological decoding. In a recent investigation, Cestnick and Jerger (2000) examined various auditory temporal processing skills including association, sequencing, rapid perception, and same–different tasks in two groups of children with different types of reading disorders: poor lexical readers (sight–word recognition) and poor nonlexical readers (phonologically impaired). In Cestnick and Jerger's study, Tallal's early auditory temporal processing protocol (Tallal, 1980) was replicated with these reading subgroups. Results of the study revealed that the poor lexical readers exhibited difficulties in sequential recall of rapidly presented tones, while the poor nonlexical readers exhibited global difficulties in recall of tones regardless of presentation speed or recall mode. In addition, a positive association of nonlexical reading and abilities on tasks involving fast ‘‘same–different’’ and fast ‘‘sequencing’’ was found. Lexical reading was particularly associated with auditory sequencing abilities. The authors concluded that because the two different reading groups did not differ on basic memory and learning tasks, but differed on auditory temporal processing tasks, specific auditory temporal processing abnormalities may exist in children with reading disorders. In addition, the authors interpreted their results to suggest that an auditory temporal processing deficit might underlie deficient nonword reading (Cestnick & Jerger, 2000).

It has been suggested that auditory temporal processing problems may underlie poor development of phonemic awareness abilities, or the ability to process, discriminate, and manipulate sound units, which would result in reading deficits. To address this relationship, Bretherton and Holmes (2003) measured temporal processing skills in a series of tone, speech, and visual-order tasks in a group of children with developmental reading deficiencies. These auditory tasks were then compared to skills in phonemic awareness. No relationships were found among reading and phonemic awareness and tone-order perceptual efficiency. The authors concluded that deficits in auditory temporal processing might not cause deficits in phonemic processing or reading decoding skills.

In another study, the relationship of auditory temporal processing and reading disorders was investigated in children with and without oral language delay (Heath et al., 1999). Temporal auditory order judgment tasks and phonological decoding skills were investigated in three groups of children. The group with both oral language and reading disorders exhibited the most difficulty in completing the temporal order judgment task, which suggested the presence of auditory temporal processing deficits. The group with both reading and language deficits was found to exhibit the greatest deficit in phonological decoding skills, although the group with only reading disorders exhibited significant deficits in nonword reading (phonological decoding) when compared to normal readers. The authors suggested that their findings indicate that temporal processing deficits may not be the unitary cause of reading and phonological deficits in children (Heath et al.).

In a meta-analysis, Bailey and Snowling (2002) describe previous studies that have investigated the broad range of auditory temporal processing tasks in reading disordered groups of children and adults, which include temporal ordering of rapid signals, frequency difference limens of varying tones, detection of frequency and amplitude tonal differences, binaural processing, and backward masking. It appears that not all children with language and/or reading deficits exhibit problems in auditory temporal processing skills. It would appear that more consistency is needed in experimental group identification, criterion, and parameters, which in turn would allow for more homogeneity within groups. This is needed to more fully understand the relationship between the development of auditory temporal processing in children with normal and disordered reading abilities.

Walker et al. (2002) examined auditory recognition and brief tone discrimination skills of adults with reading disorders. In this earlier adult study, a series of auditory temporal processing tasks were used which required the pattern recognition of tone triads in which individual components differed in either frequency or duration. An additional test involving measurement of frequency difference limens for long and short duration tones was also administered. Results revealed that the adults with reading disorders were significantly less efficient in recognition of duration patterns when compared with the normal adult readers. No group difference was found for the frequency pattern task. For the frequency difference limens, both groups were found to have larger frequency difference limens with the shorter tones (20 and 50 ms) when compared to the longer tones (200 ms). Significant correlations were found between word recognition decoding (sight–word reading) and duration pattern processing which was interpreted as suggesting a relationship between reading abilities and temporal pattern perception in adults.

Although controversial, the relationship between auditory temporal processing abilities and reading decoding skills has been explored in numerous studies involving both children and adults with reading disorders. Temporal auditory processing deficits have been suggested as being causal or co-morbid in these clinical populations. In addition, co-morbid conditions, such language-disorders and general learning disabilities, may alter interpretations of temporal auditory investigations and the effects on reading development and efficiency. It is evident that the literature has yet to provide a conclusive statement as to the relationship, either causal or associated, between underlying auditory skills and types of reading disorders.

The present study examined reading and auditory processing abilities in children with normal and disordered reading skills. Specifically, the present study investigated the relationship between reading skills (phonological and lexical) and abilities in the recognition of frequency and duration patterns, and in the perception of frequencies of short and long tone pulses (a brief tone paradigm). Relationships between auditory temporal processing tasks, word recognition skills involving sight–word decoding and phonological decoding, and intelligence were also explored in this study.

2. Method

2.1. Participants

A total of 18 children participated in the experimental study including 9 children with reading disorders ($M = 10.67$, S.D. 1.42) and 9 age-matched controls ($M = 10.75$, S.D. 1.72). Prior to the first data collection session, all participants exhibited audiometric air-conducted thresholds of 20 dB HL (ANSI, 1996) or better for the frequencies of 250–8000 Hz, at both ears, as well as normal middle ear pressure and compliance. All children had English as their primary language, with negative histories of neurological disorders, head trauma or surgery, active otologic disease, dizziness, tinnitus, or attention deficit disorder/attention deficit hyperactivity disorder. To control for cerebral dominance each participant was right-handed, based on a handedness questionnaire (Annett, 1970), None of the study participants (experimental or control group) were previously diagnosed with an attention deficit hyperactivity disorder.

In order to document the presence of a reading disorder primary deficits in decoding or single written word recognition were identified based on the results of the *Woodcock Reading Mastery Test—Revised*, WRMT-R (Woodcock, 1987). To be included in the experimental group participants had to exhibit below average standard scores ≤ 84 on the

Word Identification and/or the Word Attack subtests. To be included in the control and normal reading group, participants had to exhibit average standard scores $\geq$90 on the Word Identification and/or the Word Attack subtests. See Table 1 for mean standard scores and standard deviations for each group for the WRMTR. Examination of the WRMT-R test scores (see Table 1) reveals that each of the reading disordered participants exhibited reading scores well below the cutoff score to be identified as reading disordered. In addition, each of the control participants exhibited reading scores well above the criterion score to qualify as having normal reading skills. *t*-Tests revealed significant differences of

Table 1
Individual reading and language scores by group standard scores for *Woodcock Reading Mastery Test—Revised*

Participant	Word Identification	Word Attack
Control		
C1	102	117
C2	99	97
C3	109	113
C4	100	102
C5	102	114
C6	121	107
C7	124	126
C8	102	108
C9	109	102
Mean (S.D.)	107.6 (9.2)	109.6 (8.9)
Reading disordered		
RD1	60	36
RD2	75	65
RD3	83	75
RD4	52	86
RD5	42	67
RD6	76	67
RD7	81	92
RD8	79	83
RD9	65	75
Mean (S.D.)	68.11 (14.2)	71.78 (16.3)
	Control	Reading disordered
Language scores for *Peabody Picture Vocabulary Test* III		
1	119	92
2	110	90
3	105	99
4	115	102
5	105	90
6	124	110
7	124	96
8	105	131
9	125	99
Mean (S.D.)	114.0 (8.7)	101.1 (12.9)

reading ability between the groups for both Word Identification decoding ($t = -6.093$, $p = .000$) and Word Attack ($t = -6.962$, $p = .000$).

To control for general verbal ability, participants in both groups had to demonstrate an average receptive lexicon as demonstrated by standard scores ≥ 90 ($M = 100 \pm 15$) on the *Peabody Picture Vocabulary Test* III (PPVT-III) (Dunn & Dunn, 1997). See Table 1 for mean group standard scores and standard deviations for each group for the PPVT-III. To control for general cognitive ability, all participants were required to have average nonverbal intelligence of ≥ 90, as measured by the Weschler Intelligence Scales for Children—Weschler Intelligence Test for Children, third edition (WISC-III) (Weschler, 1991), or the *Test of Nonverbal Intelligence*—TONI-3 (Brown, Sherbenou, & Johnson, 1997). For the reading disordered group, the mean nonverbal intelligence score was 97.67 (S.D. 10.67) and for the control group, the mean nonverbal intelligence score was 112.22 (S.D. 11.7). In order to determine if group differences existed on cognitive measures, a *t*-test was conducted which revealed significant group means differences ($p = .022$). Due to this finding, IQ was used as a covariate for all statistical procedures.

2.2. Frequency and Duration Pattern tests

The Frequency Pattern test was administered according to the protocol of Musiek and Pinheiro (1987). The Duration Pattern test was administered according to the procedure of Museik, Baran, and Pinheiro (1990). The Dartmouth–Hitchcock—Department of Veterans Affairs compact disk (CD) recording of frequency and duration patterns was utilized for the stimulus presentation. For the frequency patterns, the low frequency tones were 880 Hz, while the high frequency tones were 1122 Hz. The tone pulses were 150 ms in duration (10 ms rise/fall time) with a 1000 ms interstimulus interval (ISI). The duration patterns, consisting of 1000-Hz tones, were either short or long in duration. The duration for the short and long tones was 250 and 500 ms, respectively, with an ISI of 300 ms. The tones were generated digitally and shaped with a cosine-squared function. After a brief training session, each participant was presented with 30 frequency and then 30 duration patterns to each ear separately. Patterns consisted of tone triads consisting of two similar stimuli and one deviant stimulus, such as ‘‘low–high–low’’ for frequency or ‘‘long–short–long’’ for duration. The tones were presented at 50 dB HL. The participant’s task was to verbally indicate the pattern sequence. No feedback as to accuracy of responses was provided. Scores were recorded as percent correct.

2.3. Brief tone frequency difference limen tests

2.3.1. Stimuli and instrumentation

The standard stimuli consisted of digitally generated 1000-Hz tone pulses, with linear rise/fall times of 5 ms (0–100% of full amplitude) and steady-state (plateau) durations of 190, 40, and 10 ms. The tones were presented at 60 dB peak speech perception level (SPL) monaurally. The stimuli were generated utilizing a Pentium-based microcomputer with a 16-bit Data Translation DT2823 data acquisition card serving as the analog signal input/output interface. All signals were generated at a 20-kHz sampling rate. After conversion to analog form, the tones were amplified by a Nicolet Aurora audiometer and presented to the participant through acoustically matched insert earphones (Etymotic Model ER-3A).

2.3.2. Psychophysical test procedure

Each participant was seated in a sound-treated audiometric test booth in front of a color computer monitor. The experimenter was seated next to the participant and held the computer keyboard to record the listener's response and to initiate successive trials. The test protocol consisted of a two-alternative, two-interval, forced-choice paradigm developed by Hall and Wood (1984). In each trial, a monitor display was presented that consisted of a 300-ms warning light, followed by two 600-ms observation intervals marked by the occurrence of two different colored square graphics (''red'' followed by ''green''). The two intervals were separated by a 600-ms pause. Standard and comparison stimuli were presented in each interval. The standard and comparison tones were of the same duration, and the comparison tones occurred 200 ms after the offset of the standard tones. In one interval (randomly determined), the two tones were of equal frequency; in the other interval, the comparison tone was higher in frequency. The participant was required to indicate verbally which interval contained the ''different'' tones. The experimenter then entered the participant's response at the computer keyboard. Feedback was provided by briefly presenting the appropriate red or green square graphic on the participant's monitor. Our rationale for having the tester in the test room with the child was that, in our experience (Cranford, Thompson, Hoyer, & Faires, 1996), young children are more focused on the discrimination task if only required to provide a verbal responses and not press any response key.

An adaptive procedure (Levitt, 1971) was used in which the frequency difference between the standard and comparison tones was increased following an incorrect response, but decreased only following two consecutive correct responses. This procedure estimates the 70.7% performance level. Each step involved a doubling or halving of the frequency difference value for the next trial. In the present study, a run was terminated after 13 reversals, and the frequency difference limen (DL) was taken as the average of the last 9 reversals. The absolute DL value at each reversal point, rather than the logarithm of these values, was used to compute these averages. In each test, the initial starting frequency difference for the 200-ms duration tones was 100 Hz. For tones of 50- and 20-ms duration, the starting frequency differences were 150 and 200 Hz, respectively.

Before testing, all participants received a training session. The first stage of training consisted of presenting a series of trials involving 200-ms tones with a frequency difference of 300 Hz. After the participant accurately responded to five consecutive trials with these longer tones, they were further trained until they exhibited five consecutive correct responses to trials containing 50-ms tones with a frequency difference of 300 Hz and then to trials with 20-ms tones and a frequency difference of 1000 Hz. The second phase of training required the participant to discriminate progressively smaller frequency differences with 200-ms tones. Using an initial frequency difference of 100 Hz and a frequency change factor of 2.0, this procedure followed the psychophysical procedure described above until eight reversals were obtained. Following training, the formal testing was given. Each of the three tone durations was tested once at each ear, and the order of the six subtests was determined using Latin square logic. The total testing time, including training, for each participant averaged 60 min. A brief rest break was presented at the session midpoint.

3. Results

3.1. Frequency and Duration Pattern tests

The raw data (percent correct scores) for both frequency and duration patterns were converted using an arcsine transformation. Following this arcsine transformation, two separate repeated measure analysis of covariance (ANCOVA) procedures were completed, with nonverbal IQ as the covariate, with ear as the within subject factor, and group as the between subject factor. The mean test scores (percent correct) and standard deviations are summarized in Table 2 for both groups for both the frequency and duration patterns. With the Frequency Pattern test, a significant group effect was found [$F(1,15) = 9.003$, $p = .009$]. The children with reading disorders performed significantly lower than the normal reading peers in the detection of frequency patterns. A significant main effect was not found for ear or for IQ (nonverbal intelligence). The interaction between group and ear was not significant for the Frequency Pattern test. For the Duration Pattern test, a significant main effect of group was found [$F(1,15) = 12.87$, $p = .003$]. The children with reading disorders performed significantly poorer than the normal reading

Table 2
Individual and mean percent accuracy (standard deviation) of frequency and duration pattern scores

Participant	Pattern			
	Frequency		Duration	
	Right[a]	Left[a]	Right[a]	Left[a]
Control participants				
C1	100	100	100	72
C2	100	100	100	60
C3	100	100	100	100
C4	100	92	100	92
C5	96	100	88	100
C6	80	88	84	82
C7	76	68	80	100
C8	100	100	88	100
C9	100	100	92	96
Mean (S.D.)	94.6 (9.6)	94.2 (10.8)	92.4 (7.8)	90.9 (13.2)
Reading disordered participants				
RD1	24	36	44	32
RD2	80	80	84	76
RD3	66	44	48	48
RD4	100	100	72	64
RD5	76	76	40	36
RD6	56	60	52	64
RD7	36	44	28	36
RD8	76	64	64	72
RD9	80	80	84	84
Mean (S.D.)	66.0 (23.7)	64.9 (21.1)	57.3 (19.8)	56.9 (19.3)

[a] Ear.

peers in detecting duration patterns. For the Duration Pattern test, a significant main effect was not found for ear or for IQ. The interaction of group and ear was not found to be significant for the Duration Pattern test, nor was the interaction of IQ and ear.

3.2. Brief tone frequency difference tests

Fig. 1 shows the brief tone data for both groups following the ranked transformations. A three-way mixed model ANCOVA was then used to investigate the transformed DLs as a function of group, ear, and tone duration, with IQ as the covariate. A significant main effect of group was found [$F(1,15) = 7.210$, $p = .017$] revealing that the reading disordered group exhibited larger DLs when compared to their normal reading peers. A significant main effect of tone duration was found [$F(2,15) = 6.783$, $p = .004$]. Tukey HSD post hoc tests revealed that the 20 ms duration test was significantly different from the 200 ms duration test ($p < .05$). The 50-ms duration test was not found to be significantly different from the 20 ms duration test or from the 200 ms duration test. The main effect of ear was not found to be significant. The two-way interactions of tone duration and group, ear and tone duration were not found to be significant. In addition, none of the three-way interactions were found to be significant.

3.3. Correlational analysis

A series of nonparametric correlation tests (Spearman rank correlation coefficient) were performed to investigate the relationship between participants' performance on the experimental tasks (frequency and duration tests, brief tone tests), measures of reading

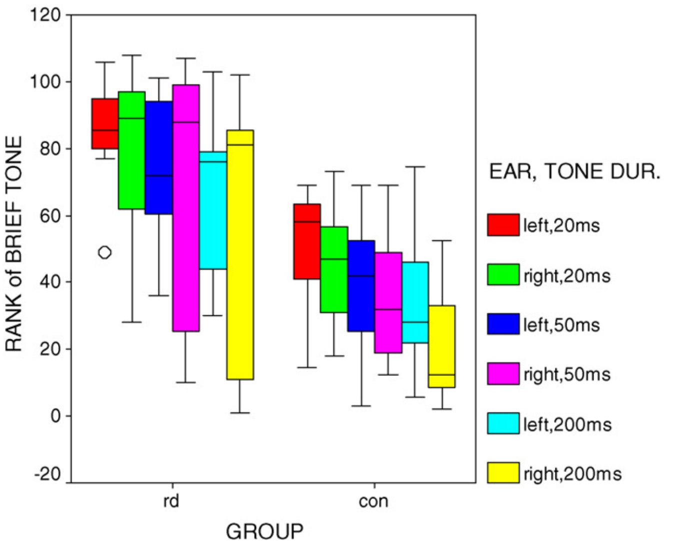

Fig. 1. Distribution of transformed DLs for the brief tone tests in both the reading disordered and the control groups (rd: reading disordered group; con: control group).

ability (standard scores from the *Woodcock Reading Mastery Test—Revised*), and intelligence (nonverbal scores from the TONI-3 or the Performance IQ score of the WISC-III). Ear effects were not found on any of the temporal processing tasks; therefore, correlational analyses were completed by examining the relationship of general temporal processing tasks to reading and intelligence.

For the control group, the only significant correlation was between the brief tone 20 ms task and Duration Pattern test ($r_s = -.68$, $p < .01$). This indicated that as accuracy increased on the Duration Pattern test, the FDL for the brief tone 20 ms task improved. None of the other correlations were significant for this group.

For the reading disordered group, a significant positive correlation was found for the Frequency Pattern and Duration Pattern tests ($r_s = .76$, $p < .05$) indicating that as performance improved on the recognition of frequency patterns, performance also improved for the recognition of duration patterns. In the brief tone tests, significant positive correlations were found for the 20 and 50 ms ($r_s = .77$, $p < .05$), the 20 and 200 ms ($r_s = .75$, $p < .05$), and for the 50 and 200 ms comparisons ($r_s = .95$, $p < .01$). These correlations reveal that for the reading disordered participants, the performance on the one of the tests was strongly associated with performance on another brief tone task. In addition, a significant positive correlation was found between Word Attack and IQ ($r_s = .94$, $p < .01$). This indicates that for the reading disordered participants, the ability to phonologically decode nonsense words was strongly associated with nonverbal intelligence.

4. Discussion

Results of the present study revealed significant differences in the accuracy of auditory temporal processing between children with reading disorders and normal reading peers. The children with reading disorders were found to be significantly more deficient in their ability to recognize patterns of tonal stimuli that differed in both frequency and temporal duration, when compared to normal reading peers. This finding is similar to other studies that have found that both children and adults with reading disorders exhibit deficits in perceptual auditory temporal processing, especially for nonspeech stimuli (Cestnick & Jerger, 2000; Heath et al., 1999; Walker et al., 2002).

In the present study, children with reading disorders demonstrated specific problems in the detection of frequency patterns. In comparison to their normal reading peers, the children with reading disorders exhibited a higher error rate in temporally processing both frequency (frequency) and duration patterns. This pattern has not been found for adults with reading disorders with similar auditory temporal processing tasks. Walker et al. (2002) found that adults with reading disorders exhibited deficits in the recognition of duration patterns but not frequency patterns.

Results also revealed that the reading disordered children exhibited severe deficits on another form of temporal processing test involving the discrimination of small frequency differences in short duration tonal signals. Deficits in the brief tone discrimination were not found in the earlier study involving adults with reading disorders (Walker et al., 2002). This brief tone test has been shown to be sensitive to neuropathologies associated with normal aging (Cranford & Stream, 1991), temporal lobe dysfunction (Cranford, Stream, Rye, & Slade, 1982), and in early chronic otitis media (Cranford et al., 1996).

The performances of the present reading disordered children tended to be poorer and also more inconsistent, in contrast to the earlier tested reading disordered adults (Walker et al., 2002) on all of the nonspeech temporal processing measures. The fact that the reading disordered children's performance was poorer in the brief tone discrimination task, when comparing the results to adults in the previous study (Walker et al.) at all three tone durations, suggests a more global impairment of frequency discrimination in general, independent of tone duration. This would suggest that the auditory system of the children with reading disorders, in contrast to age matched cohorts or adults with reading disorders, may be more immature or underdeveloped. However, these same results would be expected if the reading disordered children had more general cognitive problems related to short-term memory, motivation, and attention. Clearly, more studies are needed that attempt to separate underlying sensory versus cognitive bases for the disordered reading problem(s). Electrophysiological measures or some of the newer neural imaging techniques (e.g., functional MRI) might provide such information.

Structural versus functional bases for reading disorders have been provided by recent investigations involving event-related potentials and functional imaging (Heim et al., 2000; Heim, Freeman, Eulitz, & Elbert, 2001; Lachman, Berti, Kujala, & Schroger, 2005; Temple et al., 2001). Heim et al. (2000) reported a study of right-handed children with dyslexia and a matched control group. They applied high temporal resolution magnetoencephalography (MEG) to investigate the functional aspects of the left-hemisphere auditory cortex. The authors noted a difference between the two groups with regards to the location of the M210 generators. They speculate that this atypical source of generation in the children with dyslexia could be either structural or functional in nature. Heim et al. concluded that additional study is needed to investigate whether this difference in activity is solely in the left-hemisphere or is also paralleled in the right-hemisphere.

Temple et al. (2001) applied fMRI imaging in the investigation of both the auditory and visual sensory systems to children with dyslexia and normal reading children. The fMRI findings illuminated a lack of temporal–parietal cortical activity during letter rhyming tasks in the dyslexic children. The children with dyslexia exhibited poor performance on phonological tasks, which correlated to their poor reading abilities. In addition, these children did not exhibit the left temporal–parietal activation as seen in the normal reading group. As this study suggests, children with reading disorders exhibit difference of cortical activation when engaged in behavior and activities associated with reading, including auditory and phonological tasks.

The relationship between the auditory temporal processing abilities and specific decoding skills (phonological and lexical) was also investigated in this study. In the present study, the children in the reading disordered group exhibited relatively poorer sight–word recognition decoding when compared to phonological decoding skills, but overall possessed below average decoding skills for both sight–word and phonological decoding skills. In this study, no significant associations were found for any of the experimental auditory temporal processing tasks and the two specific word recognition skills in the areas of phonological decoding and sight–word recognition. In the adult study (Walker et al., 2002), a significant relationship was found for sight–word recognition skills and duration pattern processing, but only for the reading disordered group. This finding does not support previous studies that have shown that deficits in auditory temporal processing appear to be related more to phonological decoding tasks (Cestnick, 2001; Cestnick & Jerger, 2000; Witton et al., 1998) or to individuals with primary deficits in phonological decoding skills.

Auditory temporal processing deficits, as measured by a variety of different psychophysical techniques (e.g., stimulus rate discrimination, temporal gap detection, and temporal order judgment), have been found to co-occur in individuals who have developmental reading and language disorders (Farmer & Klein, 1995; Heath et al., 1999; McAnally & Stein, 1996; Witton et al., 1998). Temporal processing deficits have been suggested as a causal link to the lack of decoding development in children with reading disorders (Farmer & Klein, 1995; Tallal, Miller, & Fitch, 1993), especially in the development of phonologically based decoding skills, which requires auditory or phonemic analysis skills. The continued existence of deficits in temporal processing of duration patterns into adulthood (Walker et al., 2002), but not in frequency patterns suggests that frequency related processing difficulties may be alleviated with age (maturation). However, the similar profile of deficits in duration patterns in both children and adults with reading disorders supports the presence of developmental reading disorders in adulthood. Deficits in processing temporal auditory information, in both adults and children with reading disorders, may be related to a less mature auditory system (Thompson, Cranford, & Hoyer, 1999).

The need for additional study in auditory temporal processing and connections to reading development and disorders is evident. Continued research is needed to investigate the relationship of anatomical/physiological factors to differing temporal tasks as well as the investigation of the role that multimodality perception contributes toward language and literacy.

Appendix A. Continuing education

1. Tallal (1980) observed that differences between reading disordered and normal readers existed when the _____ of the auditory stimuli was increased.
   a. frequency
   b. rate
   c. intensity
   d. harmonic
2. It is known that reading skills can be predicted from early _____ and _____ abilities.
   a. hearing, speech
   b. IQ, hearing
   c. IQ, speech
   d. phonemic awareness, phonological awareness
3. A relevant discussion in the current literature is whether _____ or _____ deficits are the key to understanding the relationship between reading disorders and auditory temporal processing.
   a. hearing, speech
   b. speech-specific, auditory-specific

c. hearing, intelligence
d. vision, hearing

4. This study indicated that recognition and processing of _____ may co-occur with decoding deficits in children with reading disorders.
a. tonal stimuli
b. auditory pitch
c. auditory patterns
d. visual flicker

5. Cestnick and Jerger (2000) observed that children with poor lexical and nonlexical reading profiles have overall weak _____ abilities.
a. visual fusion
b. auditory temporal
c. hearing
d. rhyming
e. verbal

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