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Cross-Modality Temporal Processing Deficits in Developmental Phonological Dyslexics

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Neuroanatomical evidence suggests that poor readers may have abnormal lateral (LGN) and medial (MGN) geniculate nuclei responsible for temporal processing in visual and auditory domains respectively (Livingstone & Galaburda, 1993). Although behavioral evidence does support this neuroanatomical evidence in that poor readers have performed poorly on visual and auditory tasks thought to require the utilization of the LGN and MGN, respectively, appropriate examination of the coexistence of these behavioral abnormalities in the same population of poor readers has yet to take place. The present study examined correlations between visual and auditory temporal processing scores of all readers (collapsed groups), good readers, and poor readers who were isolated into phonological and surface dyslexic subtypes. The same subjects and data from Cestnick and Coltheart (1999) and Cestnick and Jerger (2000) were used to run the analyses. Results demonstrated a multitude of correlations between these tasks for the phonological dyslexic group only. It is contended that cross-modality temporal processing deficits may exist in poor nonlexical (phonological dyslexics) as opposed to poor lexical (surface dyslexics) readers. It is conceivable that phonological dyslexics may also have deficiencies within the LGN and MGN, or perhaps within systems related to these nuclei. The precise cause of these processing patterns and correlations is still unknown.

Some researchers have claimed that poor readers may have temporal processing deficits across modalities. Evidence for this claim lies in several lines of research demonstrating poor readers' low performance on a variety of temporally presented visual stimuli [e.g., visual motion detection, flicker contrast sensitivity, or tasks requiring the mimicking of various visual stimuli (light flashes or abstract shapes)] or auditory stimuli [e.g., tone or consonant–vowel pair tasks or tasks requiring the mimicking of various auditory stimuli (clicks, tones, or speech stimuli)] where they were instructed to demonstrate detection, discrimination, or temporal order of temporally presented stimuli. Although poor readers have demonstrated abnormal performance on tasks said to measure temporal processing of visual and auditory stimuli, and neuroanatomical evidence suggests dyslexics have abnormal lateral and medial geniculate nuclei thought to be responsible for this processing in respective visual and auditory domains (Livingstone & Galaburda, 1993), claims of cross-modality temporal processing deficits in dyslexics are premature for a variety of reasons. Most studies have not examined temporal processing within the same subjects across both visual and auditory modalities, have not acknowledged or compared heterogeneous populations of poor readers on these tasks, and have neither isolated nor eliminated

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confounds of sequential versus nonsequential recall or confounds of more rapid versus slow presentations within temporal tasks, to name a few (controls for these factors are essential, e.g., although temporal order and rapid presentation confounds interact, they are also independent; Cestnick & Jerger, 2000).

Given that studies have not isolated such variables, it is difficult to know what tests may encompass the precise processing deficits observed in many poor readers. Despite this, however, many tests which poor readers have struggled with have shared a temporal processing component and consensus exists among researchers that tests of visual motion perception and contrast sensitivity in the visual domain (thought to evoke the magnocellular system in particular), and tests which temporally present brief nonspeech stimuli (e.g., tones) in the auditory domain, are difficult for many poor readers and may be evoking similar neurological processes in their respective domains.

Several recent studies have demonstrated that not all poor readers have difficulty on these tasks of temporal processing. Cestnick and Coltheart (1999), for example, demonstrated that poor nonlexical readers have difficulty with visual motion detection, whereas poor lexical readers do not. Similarly, Spinelli et al. (1997) also demonstrated that poor lexical readers performed normally on a visual test of contrast sensitivity. In the case of temporal auditory processing, it has also been demonstrated that poor nonlexical readers perform differently than poor lexical readers on tasks with temporal tone presentations, and collapsed (good and poor readers) analyses has also revealed a strong relationship between nonword reading and rapid auditory temporal processing (within a same–different mode of recall) as well as between the degree of nonword reading relative to irregular word reading and performance and auditory temporal tasks (Cestnick & Jerger, 2000).

In order to make the claim that poor readers have cross-modality rapid temporal processing deficits, we must acknowledge the type of poor reader, whether the task involves recalling temporal order or simply detecting or discriminating stimuli (or ‘‘gaps’’ between stimuli) presented in succession, and what effects evolve from varying interstimulus intervals, as these confounds lead to different relationships with nonlexical/lexical reading.

Using the same subjects and data from Cestnick and Coltheart (1999) and Cestnick and Jerger (2000), who underwent the Ternus test of visual motion detection and Tallal’s tone Repetition Tests respectively, the present study examines cross-modal temporal processing of phonological and surface dyslexics by examining correlations between their performance on these tasks.

METHODS

Previous Studies

Subjects in Both Studies (Cestnick & Coltheart, 1999; Cestnick & Jerger, 2000)

The Castles Word/Nonword Test 1994 (Coltheart & Leahy, 1997) was used to determine good, poor, phonological, and surface dyslexic groups. Phonological and surface dyslexics were determined by first subtracting each good reader’s raw nonword score from their raw irregular word score (irregular words − nonwords) to come up with normal difference scores and then ensuring that poor readers fell above the highest positive or below the lowest negative score to denote phonological and surface dyslexics respectively. This strict criterion led to 10 phonological and 3 surface dyslexics of 40 poor readers. The diagnostic criterion was slightly relaxed whenever necessary to confirm findings with larger sample sizes.

Ternus Test of Visual Motion Detection (Cestnick & Coltheart 1999)

Three horizontally aligned equidistant squares were briefly presented (frame 1) and then re-presented moved to the right by one imaginary equidistant square and flashed on the screen again (frame 2). Several alternating presentations of frame 1 and frame 2 were given. When the interstimulus interval between the presentation of frame 1 and 2 is approximately 50 ms or more, the three squares appear to move backward and forward as a group. If, however, the interstimulus interval from frame 1 to 2 is less than 50 ms, the three squares do not appear to move to the right and left as a group; instead, the first square appears to disappear from position one and reappear in a fourth position (after the third square). The former illusion can be referred to as apparent group movement and the latter as apparent element movement.

These group and element movement illusions are considered to evoke magno and parvo routes respectively (Breitmeyer & Ritter, 1986a, 1986b; Braddick, 1980; Petersik & Pantle, 1989). Breitmeyer and Ritter, (1986a, 1986b) argue, for example, that during the successive presentations of the Ternus display images of the second and third squares persist from frame 1 to frame 2 when the ISI is short enough. The integration of the persisting image from frame 1 with the contents of frame 2 leads to the perception that the second and third squares are stationary. That rules out the group movement percept and hence element movement is seen. As ISIs increase, the visible persistence of frame 1 is progressively less likely to be present at the onset of frame 2, and so the group movement percept is progressively less likely to be ruled out.

From this standpoint, element movement depends on the parvo system, since that system maintains the persisting images of central squares, which rules out the group movement percept. Group movement depends on the magno system, since that system is responsible for terminating visible persistence via inhibition of the parvo system. Even if we do not wish to accept visible persistence theory as true and prefer alternative explanations of behavioral patterns such as temporal presedence (Burr, Morrone, & Ross, 1994; Burr, Holt, Johnstone, & Ross 1982) or roles of attention in such processing (Cestnick & Coltheart 1999; Steinman, Steinman, & Garzia, 1998), the Ternus task is a fine model from which to examine such phenomenon. This task evokes different visual illusions as a result of changes in temporal presentations of visual stimuli and, as such, is an appropriate means of measuring visual perception within an alternating temporal framework.

In Cestnick and Coltheart (1999), poor nonlexical readers (phonological dyslexics) showed abnormal performance while poor lexical readers (surface dyslexics) showed normal performance on this task compared to good readers.

Tone Repetition Test (Cestnick & Jerger, 2000)

The Repetition Test was devised by Tallal (1980) and was used to measure possible rapid auditory temporal processing skills thought to underlie language/reading difficulties. The idea was that difficulty with processing rapid temporal auditory stimuli could lead to poor speech perception due to similar rapid formant transitions in speech, which could subsequently lead to poor reading as a result of inappropriate phoneme applications to graphemes (nonlexical reading). To test for difficulty processing rapid temporal auditory stimuli, participants listened to two tones (100 and 305 Hz with stimulus presentations of 75 ms at 70 db SPL) via earphones and moved a lever left or right to discriminate between the tones or detect orders of presentation of the tones. Interstimulus intervals between tone presentations were varied in order to pick up on possible auditory temporal processing difficulties. Five subtests made up the test: Association, two Sequencing tasks (Fast and Slow), and two Same–Different tasks (Fast and Slow).

Results of this test performance, outlined in Cestnick and Jerger (2000), demonstrated poor nonlexical readers had poor performance on both sequencing and same–different tasks, with particular difficulty on rapid presentation tasks, whereas poor lexical readers had poor performance on the rapidly presented tone sequencing task only. These findings suggested the potential existence of generally poor temporal processing skills in phonological dyslexics in particular. Later work (Cestnick & Jerger, 2000b) further linked this processing to speech perception.

Present Study

Data from the above studies were used for the present one.

In Cestnick and Coltheart (1999), each child's raw scores for the ''three moving'' choice at each of 12 interstimulus intervals (intervals between the presentations of frame 1 and 2) were converted to *z* scores and linear regressions were run with these scores at each ISI to get three scores per subject: r^2, slope, and intercept. These fixed scores afforded the opportunity to examine relationships between nonword/irregular word reading and visual temporal processing and are used here again in the present study for correlational analysis with the auditory tone tasks.

Similarly, data from Cestnick and Jerger (2000) was used in the present study. Raw scores of 24 for each of the five tone subtests were used in correlational analysis with the three Ternus measures.

Correlational analyses between these visual and auditory tests of rapid processing were run for both good and poor reader groups, meaning the isolated dyslexic subtype groups in particular (phonological and surface dyslexics).

RESULTS

Tallal's Repetition Test and Ternus Visual Motion Detection Correlations

If the Ternus and Repetition tests do successfully isolate those with poor temporal processing skills, which are in some way related to poor nonlexical reading skills, neither good readers nor surface dyslexics (poor lexical readers) should show relationships between these visual and auditory tasks given their normal performance on these tasks and lack of relationship between these and their reading skills (Cestnick & Coltheart, 1999; Cestnick & Jerger, 2000; Spinelli et al., 1997). This was the case; using all five of the auditory tone subtests and all three visual motion detection measures, no correlations existed for good readers, and surface dyslexics showed one negative correlation between Slow Sequencing (tones) and Ternus, $r^2 = -.9968(3)$, $p = .051$. This demonstrated the relationship between their normal motion detection performance and abnormal Fast (tone) Sequencing, which disappeared when *n* was raised ($n = 7$). The higher surface dyslexic *n* led to a significant correlation between Fast Same–Different (tones) and Ternus intercept, $r^2 = .780(7)$, $p = .039$) scores [this significance remained at $n = 9$, $r^2 = .688(9)$, $p = .041$], demonstrating that their normal or precocious rapid auditory temporal perception (within the same–different mode of recall) was highly correlated with their normal visual motion detection skills.[1]

[1] It is interesting to note that not only did Cestnick and Coltheart (1999) demonstrate a clear relationship between good nonword reading and normal Ternus performance, and Cestnick and Jerger (2000) demonstrate a similar relationship between good nonword reading and Fast Same–Different auditory performance, but we also see a strong relationship between good Fast Same–Different auditory performance and normal Ternus performance. Both good readers and surface dyslexics (normal nonword relative to irregular word reading) did fine on both Fast Same–Different auditory and Ternus tasks; however, phonological dyslexics (poor nonword relative to irregular word reading) performed poorly on both of these tasks. These findings further suggest that the greater the nonword reading relative to irregular word reading, the greater the performance on temporal tasks.

If there is a shared underlying cause of poor temporal processing across visual and auditory domains that the correlational analyses successfully measures, phonological dyslexics, who demonstrated deviant performance on both visual and auditory temporal processing tasks and relationships between these and poor nonlexical reading, should be more likely to show correlations between these scores.

Results demonstrated that performance on every one of the phonological dyslexics' tone subtests was highly correlated with their Ternus visual motion r^2 scores, and some of their tone subtests were also correlated with their Ternus intercept and slope measures: Tallal's Fast Sequencing and Ternus $r^2 = .829(7)$, $p = .012$; Tallal's Slow Sequencing and Ternus $r^2 = .939(7)$, $p = .001$, and Ternus intercept $r^2 = .884(7)$, $p = .008$, and Ternus slope, $r^2 = .878(7)$, $p = .009$; Tallal's Slow Same–Different and Ternus $r^2 = .739(7)$, $p = .058$; Tallal's Fast Same–Different and Ternus $r^2 = .802(7)$, $p = .030$. These correlations exemplify their general and similar poor performance on both visual motion and tone perception tasks (Fig. 1). As expected, scores from the Association control condition (a task demonstrating an understanding of the direction to move a lever to make choices about what tones were heard) were not correlated with the Ternus scores (phonological dyslexics did not differ from good readers on the Association task). This further suggests that relationships between the temporal tasks are likely not a reflection of similar task-mastery effects (e.g., general learning), as subjects did not differ in their mastering of the tasks, but did differ in their overall performance on these tasks as well as in the relationships between these.

It is interesting that poor nonlexical readers' auditory and visual processing scores are related, but poor lexical readers' are not. This is particularly interesting in lieu of previous analyses which demonstrated that these dyslexic groups do not differ on memory or learning factors as well as previous ANCOVA and partial correlational analyses which further supported that memory and learning subtest performance was unrelated to performance on the temporal tasks (Cestnick & Jerger, 2000).

These analyses suggest that the group differences in auditory and visual temporal

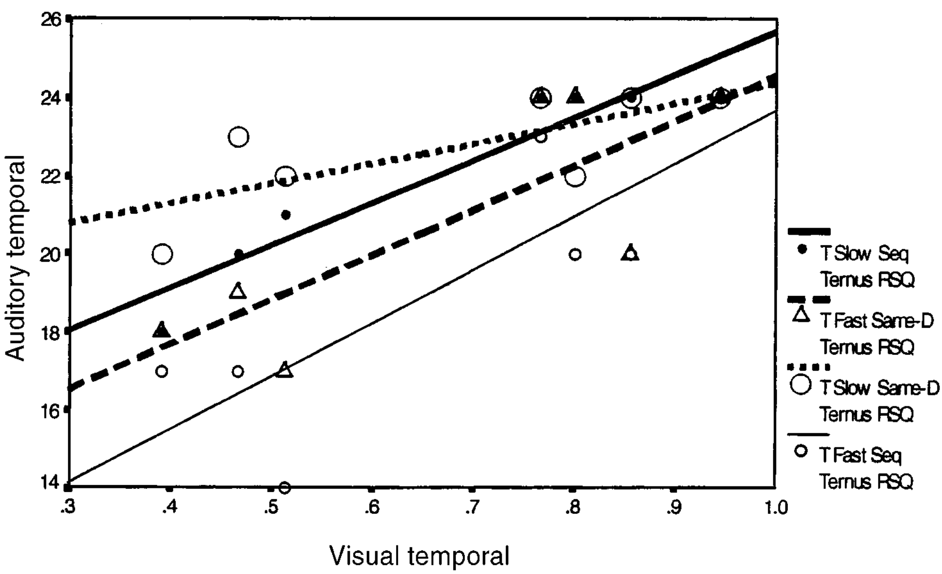

FIG. 1. Phonological dyslexics Ternus r^2 and Tallal subtest correlations (note: slope and intercept correlations not plotted here). T denotes Tallal's Repetition subtests; Slow seq = slow sequencing; Fast Same-D = fast same different; Slow Same-D = slow same different; Fast seq = fast sequencing; RSQ = r^2.

processing associations observed here are likely not a result of the phonological dyslexics simply not understanding or mastering the task requirements as well as the surface dyslexics.

In addition, because phonological dyslexics' performance on the auditory temporal tasks were correlated with their visual motion perception performance irrespective of mode of recall or rapid versus slow presentations, a shared property across all tone tasks is likely associated with their visual motion perception, which might include any of the following (not an exhaustive list): frequency, amplitude, or gap (ISI) perception or confounds associated with the brevity of stimuli.

DISCUSSION

What Could Cause the Correlations between Poor Temporal Processing Deficits Across Modalities?

Neurologically speaking, simultaneous deficits to magnocellular paths in both visual and auditory systems could mimic the behavioral cross-modality temporal processing difficulties observed in phonological dyslexics in particular. Livingstone and Galaburda's (1993) study demonstrating LGN and MGN damage in particular within their dyslexics (postmortem) calls for the consideration of this damage potentially existing within phonological dyslexics who tend to have cross-modality temporal processing difficulties. As discussed in Cestnick and Coltheart (1999), if large magno cells of visual and auditory systems are likely susceptible to similar insults, it follows that simultaneous deficits to these could create cross-modality temporal processing deficits. Of course, it is noted that deficits to other or additional areas to LGN and MGN areas in visual and auditory paths can also mimic poor temporal processing patterns observed in phonological dyslexics in particular (e.g., optic or cochlear nerve damage can lead to poor visual motion detection and poor speech perception respectively and/or higher cortical areas involved in attention may play a role in these patterns; see Cestnick, 2000).

Given that we are still in early evolutionary stages of understanding precisely how cells and/or systems process transient stimuli (particularly within the auditory system), it is difficult to design appropriate tests to match underlying neuroanatomical counterparts as well as to determine what facets of temporal processing tests may be contributing to abnormal performance observed in poor readers. Because of this, it is also difficult to validate presumptions that the visual and auditory temporal tasks examined herein may be stimulating the LGN and MGN areas specifically or other areas/systems, for that matter. Phonological dyslexics' behavioral patterns on these tasks may coexist for presently unidentified reasons.

Because, poor readers (subtypes not isolated) have shown abnormal performance on low tone frequency detection/discrimination tasks (McAnally & Stein, 1997; Witton et al., 1998), it could be the case that poor readers (poor nonlexical readers in particular) have abnormal low tone frequency perception and, hence, poor performance across tone tasks (Cestnick & Jerger, 2000). Poor frequency and/or amplitude detection or discrimination would adversely affect the phase locked (temporal) cells with roles in the perception of temporal presentations and possibly temporal order or same–different perception of these tones. How we interpret the cause of temporal perception problems is dependent on how we define temporal processing and at present it is not clear how we should do this.

As our understanding of the precise nature of these deficits in dyslexics evolves, we can begin to abandon the all-encompassing term ''temporal processing'' and replace it with reference to complex stimuli (e.g., combined effects from FM/AM, ISI, and stimuli duration properties within particular recall frameworks) and the physiological/anatomical/neurological functions involved in the perception of these. An easy place to start is within the acknowledgment, isolation, and examination of heterogeneous poor reader groups (or collapsed analyses using lexical versus nonlexical reading for quantitative analyses) on tasks thought to evoke various facets of auditory/visual systems. This is necessary to help understand which stimuli properties and their neurological counterparts are involved in tasks of temporal perception as well as how these may be related to different reading processes.

Given that phonological dyslexics demonstrated poor performance on cross-modality tasks sharing temporal properties, and these poor performance patterns were correlated with one another (which is not the case for good readers or surface dyslexics), it is sensible to consider possible shared causes of their cross-modality performance. It is also sensible to examine if and how these cross-modality performance patterns may or may not be related to poor nonword reading.

Note: Cestnick & Jerger (2000b) examines relationships between data presented there and speech perception.

REFERENCES

Breitmeyer, B. G., & Ritter, A. (1986a). The role of visual pattern persistence in bistable stroboscopic motion. *Vision Research,* **26,** 1801–1806.

Breitmeyer, B. G., & Ritter, A. (1986b). Visual persistence and the effect of eccentric viewing, element size and frame duration on bistable stroboscopic motion percepts. *Perception and Psychophysics,* **39,** 275–280.

Burr, D. C., Morrone, M. C., & Ross J. (1994). Selective suppression of the magnocellular visual pathway during saccadic eye movements. *Nature,* **371,** 511–513.

Burr, D. C., Holt, J., Johnstone, J. R., & Ross, J. (1982). Selective suppression of the motion sensitivity during saccades. *Journal of Physiology,* **333,** 1–15.

Cestnick, L., & Coltheart, M. (1999). The relationship between language and visual processing in developmental dyslexia. *Cognition,* **71**(3), 231–255.

Cestnick L. (2000). Neuroanatomy, attention, magnocellular function and dyslexia: bringing it together. Unpublished manuscript.

Cestnick, L., & Jerger, J. (2000a). Auditory temporal processing and lexical/nonlexical reading in developmental dyslexia. *Journal of the American Academy of Audiology,* **11,** 501–513.

Cestnick L., & Jerger J. (2000b). Auditory temporal processing, speech perception and lexical/nonlexical reading. Unpublished manuscript.

Coltheart, M., & Leahy, J. (1997). Assessment of lexical and nonlexical reading abilities in children: Some normative data. *Australian Journal of Psychology,* **48,** 136–140.

Ladavas, E., Umilta, C., & Mapelli, D. (1997). Lexical and semantic processing in the absence of word reading: Evidence from neglect dyslexia. *Neuropsychologia,* **5**(8), 1075–1085.

Livingstone, M. S., Rosen, G. D., Drislane, F. W., Galaburda, A. M., (1993). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Sciences of the USA,* **88**(18), 7943–7947.

Petersik, A., & Pantle, T. (1989). The two-process distinction in apparent movement. *Psychological Bulletin,* **106,** 107–127.

Reynolds, C., & Bigler, E. (1994). *Test of Memory and Learning* (TOMAL). Austin, TX: ProEd.

Steinman, B. A., Steniman, S. B., & Garzia, R. P. (1996). Reading with an M Neuron: How a defective magnocellular pathway interferes with normal reading. In R. P. Garzia (Ed.), *Vision and reading*. St. Louis, MO: Mosby-Year Book.