Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Phonetics 31 (2003) 509–527

Journal of Phonetics

www.elsevier.com/locate/phonetics

Auditory processing in dyslexia and specific language impairment: is there a deficit? What is its nature? Does it explain anything?

Stuart Rosen*

Department of Phonetics & Linguistics, University College London, 4 Stephenson Way, London NW1 2HE, UK

Received 6 December 2002; received in revised form 23 June 2003; accepted 2 July 2003

Abstract

There is much controversy about the extent to which auditory processing deficits are important in the genesis of language disorders, particularly specific language impairment (SLI) and dyslexia (or specific reading disability—SRD). A review of the available literature reveals that some but not all auditory skills are impaired, on average, in groups of SLI/SRD listeners. Typically only a minority of SLI/SRD listeners exhibit any auditory deficits, and there is little or no relationship between the severity of the auditory and language deficits in SLI/SRD groups. Control groups sometimes exhibit stronger relationships of this type. It is not yet clear why some auditory skills but not others differentiate the two groups, but the claim that the deficit is specific to rapid temporal processing is almost certainly wrong. Nor is the deficit specific to speech sounds. Nonverbal intelligence must be accounted for in any exploration of the relationship between auditory and language/literacy skills. No clear relationships between nonspeech and speech deficits have yet been demonstrated. Thus auditory deficits appear not to be causally related to language disorders, but only occur in association with them.

Keywords: Dyslexia; Specific language impairment (SLI); Auditory processing

1. Introduction

There is a long history and much controversy about the extent to which auditory processing deficits are important factors in the genesis of a variety of language disorders. Our focus here will be on the two most common developmental language disorders, specific language impairment (SLI) and

---

*Tel.: +44-20-7679-7404; fax: +44-20-7383-0752.

E-mail address: stuart@phon.ucl.ac.uk (S. Rosen).

doi:10.1016/S0095-4470(03)00046-9

dyslexia (or specific reading disability—SRD). Apart from the fact that both these disorders concern deficits in some part of the language system, they also share the property of being *specific* deficits, occurring in the context of other cognitive abilities that are more or less normal.

Dyslexia or *SRD* is often defined as a deficit in reading and spelling despite adequate intelligence and access to conventional instruction. *SLI*, on the other hand, is typically diagnosed by late-developing and impaired language abilities alongside more-or-less normal cognitive abilities, and the absence of any frank neurological signs or peripheral hearing impairment (Bishop, 1997). SLI, which has also been known as *developmental a- or dys-phasi*a, is much less well known to the scientific community, not to mention the public at large. Some of its characteristics (at least as expressed in one child with a fairly 'pure' version of SLI) can be appreciated in the description of AZ (van der Lely, Rosen, & McClelland, 1998).

AZ, now in his 20s, was late to develop language, using only 3 words at age 5—*Mummy*, *Daddy*, *Gangan* (for Grandma). When tested as a teenager, he made errors in plural forms (*two mens, two foot*s) and verb tense (*My dad go to work; This is what they ated*). In an elicitation task, he had a great deal of difficulty in using embedded phrases (*Which cat Mrs White stroked? What did Mrs Brown dropped*?). All these occur in the presence of what appear to be normal pragmatic abilities, and a nonverbal IQ in the region of 120–130.

2. What causes SLI and SRD?

Although there are a wide variety of theories which attempt to account for these disorders, two general approaches have received the most attention. The first posits that both SLI and SRD arise from deficits in systems that are specifically linguistic (also known as the *domain-specific* view). Dyslexia, in this view, arises from deficits in phonological memory and processing, which is to say, processes specific to speech sounds (Snowling, 1998). Similarly, SLI is claimed to result from deficits in neural systems processing grammar, and more specifically syntax (van der Lely et al., 1998).

On the other hand, many claim that deficits in underlying nonlinguistic sensory mechanisms are the core deficit in these disorders. Difficulties in visual processing have often been implicated, but only with reference to dyslexia (see Ramus, 2003, for a more complete review of the evidence of various sensori-motor deficits in dyslexia). Far stronger claims have been made for the role of impaired *auditory* processing in the genesis of SLI and dyslexia, especially as concerns the perception of rapidly changing or transient sounds. Note that the auditory deficit implied here is *not* one that can be found in the functioning of the auditory periphery but would more properly be referred to as a *central* auditory processing disorder (CAPD), typically occurring in the presence of a more or less normal audiogram.

Of course, the linguistic and sensory deficits are not necessarily exclusive. Auditory and visual processing deficits may be linked, as expressed most elegantly in the form of the magno-cellular hypothesis (Stein, 2001). More importantly, the auditory processing theories make explicit claims that phonological deficits arise from the auditory deficits, which in turn lead to the language disorder. Insofar as literacy requires explicit meta-phonological awareness related to the auditory structure of speech, it is easy to see how an impaired phonological system could lead to dyslexia. For SLI, grammatical difficulties have frequently been tied to imperfect perception of the relevant (and often auditorily indistinct) morphological inflections (e.g., past tense markers in regular English verbs). It has also been hypothesized that limitations in (verbal) working memory, arising from a phonological coding deficit, can impede the learning of various grammatical structures (see Joanisse & Seidenberg, 1998, for an exposition of these views). Why impaired auditory processing should lead to SLI in some cases and dyslexia in others is not yet clear at all.

In any case, our discussion will focus on the empirical evidence relevant to theories which posit deficiencies in auditory processing as the core deficit in SLI and dyslexia. We will attempt to answer questions such as: What, if any, auditory processing deficits are associated with SLI/SRD? How specific, and how consistent are they? What distinguishes auditory skills which are impaired from those which are unimpaired? Are there relationships between impaired speech and impaired nonspeech deficits? And perhaps most importantly, does the auditory deficit *explain* SLI/SRD? Before doing this, however, it will be illuminating to review the history of ideas in this area.

3. Auditory processing deficits as causes of SLI/SRD: a short history

Perhaps the first claim that a language deficit could arise from a CAPD was made in the context of an acquired language disorder. Efron (1963) assessed the ability of both aphasic and nonaphasic adults (all with brain injuries, mostly stroke) to perform a temporal order judgement (TOJ) task, using 10-ms bursts of pulses which varied greatly in fundamental frequency. The aphasic listeners performed considerably more poorly on this task, leading Efron (p. 418) to conclude that "…we should not look upon the aphasias as unique disorders of *language* but rather as an inevitable consequence of a primary defect in temporal analysis."

This idea, that a specifically *temporal* aspect of central auditory processing could underlie a language disorder, was taken up and applied to SLI and dyslexia, most notably in a series of papers by Tallal and her colleagues. Much use was made of a modified version of TOJ, known as the repetition task. First, two distinct sounds are presented in isolation, and the listener learns to respond to them differentially (typically by pressing one of two buttons). Then the sounds are presented in pairs, at various inter-stimulus intervals (ISIs), and the listener responds with two button presses to identify the order of the two stimuli presented. Unlike standard TOJ, the two sounds can be identical in the repetition task. This also leads to the possibility of running the task as a same/different judgement, yet using the identical stimuli.

This task was first used in a study of children with SLI by Tallal and Piercy (1973). They showed that SLI children did poorly for short ISIs, whether the task was run as a same/different judgement or repetition task. At long ISIs, all children performed at or near ceiling. A similar study in dyslexics also found deficits specific to stimuli with short ISIs, but only in 8 of 20 children (Tallal, 1980). Tallal and Piercy (1974) then went on to use speech sounds, finding that SLI children had great difficulty discriminating /bɑ/ from /dɑ/, stimuli which were distinguished only by changes in rapid formant-frequency transitions (over the course of ≈40 ms). From these findings came the claim that the auditory deficit was specific to processing rapidly changing, or brief, auditory inputs. Corroborating evidence for this view came from the report that speech stimuli with lengthened transitions were much better discriminated (Tallal & Piercy, 1975). From this association of auditory deficits with language disorders sprang the claim that the auditory problem *caused* the language problem.

Although research on this theme continued through the 1970s and 1980s, there was a sudden growth of interest in the 1990s, for at least three reasons. First, there was an increased awareness of the high incidence of these impairments coupled to an emphasis on academic performance in children (perhaps 5–10% of children have SLI or SRD, with much overlap of the groups—Bishop, 1997; McArthur, Hogben, Edwards, Heath, & Mengler, 2000).

Second, was the development and application of a computer-run rehabilitation program which claimed remarkable results in ameliorating SLI primarily through improving auditory processing (Merzenich et al., 1996; Tallal et al., 1996). Following on from early work by Hurford and Sanders (1990) in speech training of dyslexic children, Fast ForWord (as the program is known) has three essential features: (1) training with nonspeech, e.g., using the repetition task but with frequency-modulated sinusoids; (2) training with synthesized minimal pairs of words, e.g., *coat* vs. *goat*, and; (3) the use of an 'enhancement' algorithm claimed to make natural speech more intelligible for these children through a process of lengthening and envelope manipulation.

Finally was the demonstration of a dramatic auditory deficit in SLI children using a more-or-less standard psychoacoustic task—backward masking. Wright et al. (1997) investigated the degree of masking obtained for a variety of temporal and spectral relationships between a noise masker and a short probe tone. Most strikingly, although the SLI children had more or less normal thresholds for simultaneous masking (when the probe is temporally in the middle of the masker) and forward masking (when the probe follows the masker), they were dramatically impaired in backward masking (when the probe precedes the masker). There was no overlap between the performance of the two groups, with a greater than 40 dB difference in median thresholds.

4. Taking account of the current situation

With our history lesson over, we go on to consider at least some of the main questions about the relationship between auditory processing and language disorders.

4.1. Are any auditory processing deficits associated with SLI/SRD?

To this question, the answer is a resounding 'yes.' There have been dozens of studies which have reported group differences between controls and people with SLI and/or SRD, both adults and children, on a variety of auditory tasks. Some have already been mentioned, but Fig. 1 shows some more recent results. The left-hand side of Fig. 1a shows the minimally detectable depth of frequency modulation (FM) at 2 Hz impressed on a 500 Hz carrier for a group of dyslexic adults and controls (Witton et al., 1998). Note that, at least on average, the dyslexic listeners require a greater degree of modulation. Similarly, the left-most boxes in Fig. 1b display the thresholds obtained by dyslexic and control teenagers in a backward masking task more or less identical to the one used by Wright et al. (1997). Note that the average threshold for the dyslexic teenagers is considerably higher than that obtained by the controls. Group deficits have also been noted for the detection of amplitude modulation (Menell, McAnally, & Stein, 1999), in phonemic categorization (Adlard & Hazan, 1998), in a beat detection task involving the labeling of sinusoids

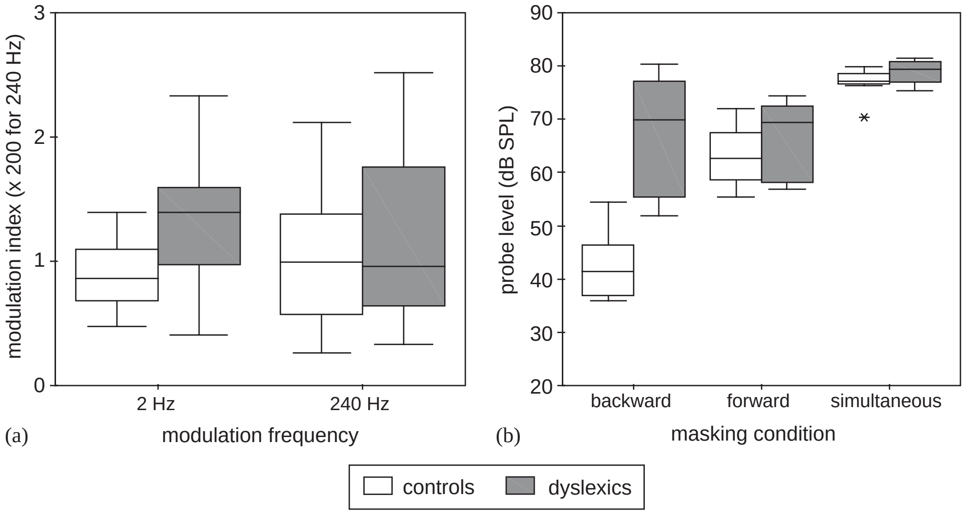

Fig. 1. (a) Left panel: Boxplots of the minimal degree of frequency modulation (FM) necessary to discriminate a modulated sound from a steady-state sound, for dyslexic and control adults (Witton et al., 1998). The box indicates the inter-quartile range of values obtained, with the median indicated by the solid horizontal line. The whiskers show the range of measurements. (b) Right panel: Boxplots of the masked thresholds in backward, forward and simultaneous masking obtained from dyslexic and control teenagers (Rosen & Manganari, 2001). The asterisk indicates an outlying point more than 3 box lengths from the lower edge of the box.

varying in rise time (Goswami et al., 2002), and in the discrimination of speech sounds (Reed, 1989; Kraus et al., 1996), among others.

4.2. Are all auditory skills impaired in SLI/SRD groups?

This question too has a resounding answer—'no.' There is little doubt that auditory tasks differ in the extent to which they are affected by the presence of SLI/SRD in the test population, although it is far from clear what aspects of the tasks are responsible for this difference. The right-hand side of Fig. 1a shows that dyslexic adults are not impaired in the detection of FM for a 240 Hz modulator, even though they are impaired at 2 Hz. Similarly, Fig. 1b shows normal performance in simultaneous and forward masking for dyslexic teenagers in the presence of quite impaired performance in backward masking. Such findings are extremely comforting, of course, lending credence to the notion that there is a deficit that is genuinely auditory. Were performance on all tasks impaired, it would be more tempting to ascribe impaired performance to impaired general mechanisms, for example, in attention. Insofar as a deficit can be demonstrated for stimuli varying in some crucial acoustic feature, and not in others, using the same task, the demonstrated deficit is not readily accounted for by task demands (in memory, for example). Note though, that there is still the possibility that performance in some auditory tasks requires a greater cognitive load than others. Therefore, poor performance in one task in the presence of adequate performance on another in a similar test configuration may not be a sufficient control. It has, for example, long been clear that backward masking depends more heavily on 'central' auditory processing than do forward or simultaneous masking (Elliott, 1962, 1971; Pastore, Harris, &

Goldstein, 1980; Puleo & Pastore, 1980; also see Hartley & Moore, 2002 for a contrary view). If backward masking demanded more attentional resources, say, it could be that the poor performance in this task simply reflected this greater cognitive demand. The possibility of such interactions has hardly been mentioned in the literature, never mind adequately addressed.

4.3. Are other cognitive abilities associated with auditory processing?

Given that SLI/SRD groups are impaired, on average, relative to control groups, it is essential to ensure that this difference does not arise from some other cognitive difference between the groups, apart from the language disorder. As it turns out, there is a long-standing literature on the robust relationship between simple sensory processing tasks and other cognitive skills (Deary, Head, & Egan, 1989; Raz, Moberg, & Millman, 1990; Deary, 1995). The task that has seen the most intensive investigation is known as the *auditory inspection time* (AIT) task, on the basis of an analogy with the initial visual version of the task. There are many similarities between this and the 'classic' repetition task. Again two harmonic complexes differing in fundamental frequency are presented sequentially, but here an explicit TOJ is required. Instead of varying the ISI of the trial pair, the durations of both stimuli in the pair are varied, and there is a following masking sound. Performance in this task has been linked to IQ generally, without much real difference between verbal and nonverbal scales. Therefore it may be that relationships between auditory and linguistic skills are mediated through the influence of general intelligence on both.

For a recent illuminating example, consider in Fig. 2 a re-analysis of part of the wide-ranging study of Ahissar, Protopapas, Reid, and Merzenich (2000). Performance for controls in frequency discrimination under backward masking (FR-BM) accounts for 37% of the variance in nonword reading. However, a measure of nonverbal IQ accounts for 45% of the variance in nonword

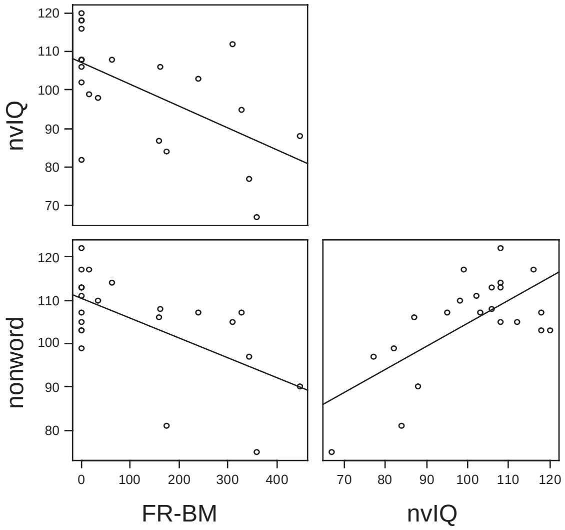

Fig. 2. Shared variance among adult control listeners in a measure of nonword reading, nonverbal IQ and a simple psychoacoustic task (FR-BM: frequency discrimination under backward masking). This task may also be considered a TOJ task, with two 20-ms tones (900 and 1100 Hz) followed by a noise masker at an adaptively varied ISI. Shorter threshold ISIs indicate better performance. Data from Ahissar et al. (2000).

reading, and 35% of the variance in FR-BM. Therefore, once nonverbal IQ is taken into account, the psychoacoustic task only accounts for a non-significant 6% of the variance. Of course, not every psychoacoustic skill has its predictive value reduced to such an extent. A similar re-analysis of simple frequency discrimination and a version of the repetition task (two-tone identification) reveals that about 25% of the variance in nonword reading can be accounted for by either task, after accounting for the influence of nonverbal IQ (itself responsible for over 40% of the variance in each case).[1]

It is therefore essential to consider the contribution of other cognitive abilities to auditory performance, a fact that has only recently become widely recognized. As a result, many published studies (even recent ones) do not routinely assess cognitive abilities apart from those language skills which are the focus of study. A model of good practice is provided by Talcott et al. (2000) who investigated the relationship between reading and detection of FM in a group of unselected children with a wide range of abilities. They found that thresholds for detection of FM at 2 Hz remained a strong predictor for phonological skills (including nonword reading) even after the influence of nonverbal IQ was factored out. (Note that nonverbal IQ accounted for 18% of the variance in the FM task.)

Of greater controversy is the extent to which verbal (as opposed to nonverbal) skills should be partialled out of the relationship between auditory and language skills (e.g., Witton, Stein, Stoodley, Rosner, & Talcott, 2002). The problem here, though, is that the verbal skills partialled out (e.g., digit span) may be just as much a core feature of SLI/SRD as impaired language/literacy, thus underestimating the contribution of auditory skills. Digit span has sometimes been seen as an index of the kind of sensory memory necessary for a typical psychoacoustic task, but it also plausible that these are distinct memory skills. Likely to be fruitful is further investigation into individual variability in the component skills that make up auditory performance apart from sensory acuity.

4.4. What proportion of SLI/SRD listeners has auditory impairments?

Although the earliest work, reporting only group means, gave the impression that auditory deficits were more or less uniform in the SLI/SRD group (Tallal & Piercy, 1973), later studies often noted that a significant proportion of SLI/SRD listeners performed normally, even in the presence of an overall group difference (Tallal, 1980; Reed, 1989). Recently, this finding has become a focus of attention, the argument being that if impaired auditory processing is *the* cause of SLI/SRD, it should be manifest in all people with the disorder. It is clear (at least for the more intensively studied dyslexics) that this is not the case. A recent review of 10 studies estimated the

---

[1] In each case, one outlier is excised from the data. If all the subjects are included in the analyses, the predictive value of the psychoacoustic tasks decreases markedly, accounting only for about 14% of the variance. Note that there are a number of difficulties in interpreting the study of Ahissar et al. (2000) unambiguously. First, only a subset of listeners was assessed for nonverbal IQ. Second, there is a pervasive problem of outliers, as is apparent in their Fig. 2. For example, 51% of the variance in nonword reading for controls is accounted for by a simple test of frequency discrimination. This correlation, however, depends upon a small number of listeners. If 5 of the 38 listeners are taken out of the analysis (on the basis of extreme values of Cook's distance, a statistic that assesses the influence of each case on the estimated regression coefficients—Cook & Weisberg, 1999) the variance accounted for falls to a non-significant 4%.

incidence of auditory deficits to be about 40% (Ramus, 2003). Thus the majority of dyslexics exhibit *no* auditory problems.

The situation in SLI is much less clear, primarily because of the paucity of studies, but the incidence of auditory deficits in the SLI population could well be higher. For example, in recent studies of teenagers with a relatively pure form of SLI, 5 of 15 were within normal limits for a number of nonspeech auditory tasks (Rosen, van der Lely, Adlard, & Manganari, 2000; van der Lely, Rosen, & Adlard, submitted). Stronger evidence for the idea that auditory problems are more common in SLI than dyslexia comes from a couple of studies which found auditory deficits to be restricted to those dyslexics with accompanying oral language deficits. Joanisse, Manis, Keating, and Seidenberg (2000) assessed speech categorization abilities using two speech continua, and only found deficits in a group with comorbid language impairment. In fact, a careful look at their Fig. 3 indicates that the entire relationship between language and speech perceptual abilities appears to arise from 2 listeners (from a population of 9 dyslexics with language impairment out of a total dyslexic population of 48 children). Heath, Hogben, and Clark (1999) too only found deficits on a version of the nonspeech repetition task in dyslexic children with concomitant oral language deficits.

But these studies should not be taken to indicate that poor auditory processing is only found in dyslexics with frank oral language deficits, even if it appears that auditory deficits will be more prevalent in such cases. A recent study of dyslexic university students with language abilities equal to their controls, still found auditory deficits in a significant proportion (Ramus et al., 2002).

In short, it seems unlikely that even a majority of people with SLI/SRD will prove to have any auditory deficit at all. This appears to be a problem for theories that posit such deficits as the *core* deficit in SLI/SRD, although it might be argued that such a deficit existed for a crucial period in language development and then resolved. Such a possibility certainly seems plausible, although it is then difficult to see how rehabilitation schemes which aim to ameliorate the auditory deficit by training with nonspeech sounds can be justified (Merzenich et al., 1996). It may also be that an auditory deficit is a factor only for some proportion of people with SLI/SRD, but there is little or no evidence that, as might be expected, the SLI/SRD associated with an auditory deficit is any different in kind from that found in association with unimpaired audition.

4.5. Does the auditory deficit correlate with language ability within, as well as across, groups?

If auditory deficits are the prime cause of SLI/SRD, we should expect strong correlations between measures of auditory processing and language skills, not only across the entire population, but within groups of controls and those affected by SLI/SRD as well. In fact, it appears that these relationships are much more robust within control, than within dyslexic groups (Ahissar et al., 2000), although the explanation for this varies. Ahissar et al. (2000), for example, propose that at least some of those with reading difficulties make special efforts to improve their reading, which thus leads to better reading than would be predicted by auditory performance. But there is no empirical evidence to support or refute this suggestion.

Another possibility is that auditory skill, although correlated with reading ability in controls, and different on the group level, is of little import for reading ability for dyslexics. The data of Witton et al. (1998) provide an interesting example for re-analysis in light of this idea, using techniques that are standard in linear regression (but particularly well described in Chapter 12 of Cook & Weisberg, 1999).

In Witton et al.'s study, performance by dyslexic and control adults in detecting FM at 2 Hz was used to predict a measure of nonword reading, expected to be most related to phonological skills. As Fig. 3a shows, there is a moderately strong correlation between these two measures over the two groups of listeners, accounting for 31% of the variance. Inspection of the scatter plot, however, shows that nearly all of the control data falls below the regression line with most of the dyslexic data above it. Also, the variability around the regression line appears to be much greater for the dyslexic group.

This is perhaps clearer to see if we examine the model residuals, the difference between what is predicted and observed for nonword performance by a particular listener based on his/her FM detection ability. Fig. 3b shows these residuals as a function of performance in the FM task. Data that satisfies the assumptions of a linear regression model lead to residual plots with no pattern. Here, patterns are clearly visible for the residuals of the two listener groups, in that both seem to show a downward trend. This means that the nature of the regression appears to be different in the control and dyslexic groups, and lumping them together can be misleading. It is therefore natural to construct a statistical model that allows for the regression lines to be different for the two groups. In effect, two distinct regression lines, one for each of the groups, are fit to the data (Fig. 4a).

Clearly these two independent regression lines, accounting now for 55% of the variance, provide a much better description of the data than a single regression line ($p<0.001$). The residual plot is much improved as well (Fig. 4b), with no trends apparent within the groups. Interestingly, the two regression lines appear to have approximately the same slope, and in fact there is no statistical evidence that the slopes are different ($p > 0.8$). A model with parallel lines still accounts for nearly 55% of the variance.

In fact, once listener group is used as a predictor (accounting for 51% of the variance), performance on the FM task only accounts for a statistically insignificant 4% more. Even this

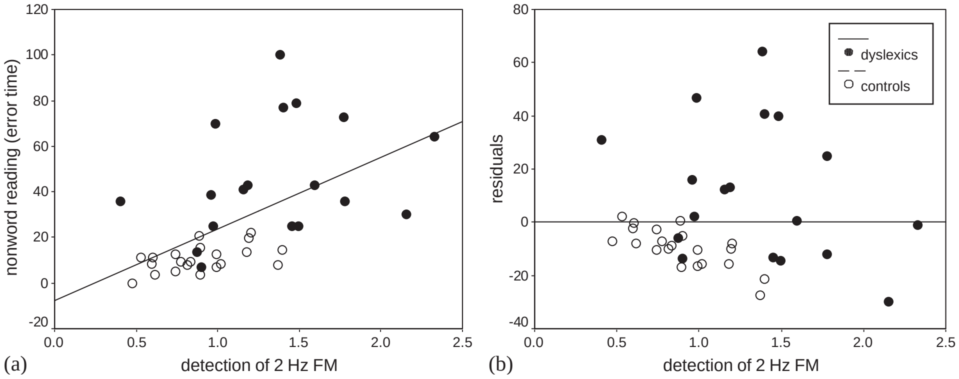

Fig. 3. (a) Left panel: An omnibus measure of nonword reading combining both accuracy and time as a function of performance in an FM detection task at 2 Hz for dyslexic and control adults (Witton et al., 1998). Higher values on each scale indicate worse performance, and the regression line drawn is the best fit by least squares. (b) Right panel: Residuals arising from the regression shown in the left hand panel as a function of FM detection ability for the two listener groups.

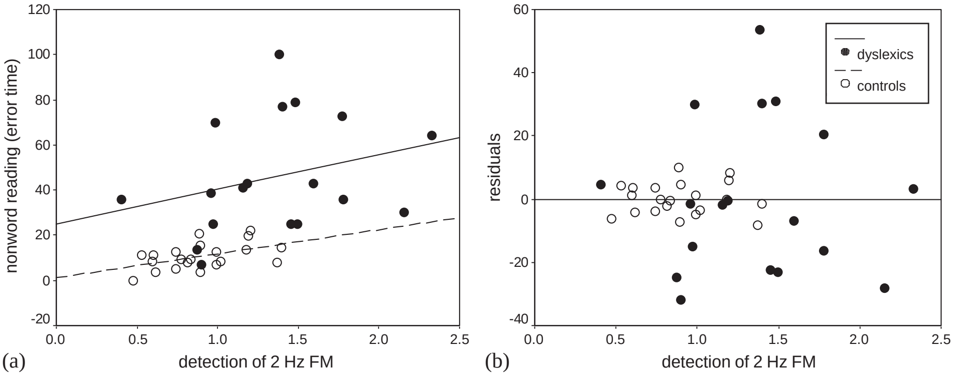

Fig. 4. (a) Left panel: Data as in Fig. 3. Here the two regression lines are least-square fits independently drawn for the two listener groups. (b) Right panel: Residuals arising from the regression shown in the left hand panel as a function of FM detection ability for the two listener groups.

somewhat overstates the case. As the variability of the dyslexics in nonword reading is so much greater than that of the controls (readily apparent in Fig. 4b), it is not strictly viable to include both groups in the same regression model (linear regression models assume constant variability around the predicted mean, just as all cells in an ANOVA should have the same variance—the so-called *homoscedasticity* assumption). When the two groups are treated separately, there is no longer a statistically significant relationship between nonword reading and FM detection for the dyslexic group (accounting for only 8% of the variance), whereas for the controls, a significant 24% of the variance is still accounted for. (Taking account of nonverbal intelligence, unfortunately not assessed in this study, could weaken the predictive value of FM detection). Thus auditory performance appears to have little explanatory power in relation to other factors. In other words, once you know someone is dyslexic, knowledge about auditory skills is irrelevant for predicting nonword reading.

Similar analyses reveal the same pattern of results for the beat detection task (related to the perception of amplitude envelope) employed by Goswami et al. (2002). Consider for example the utility of this skill for predicting performance in nonword reading (Fig. 5). Drawing a regression line through all the data accounts for a highly significant 20% of the variance. Again, however, there is strong statistical evidence for three separate regression lines (one for each group, $p < 0.002$), but no evidence that the slopes are different ($p > 0.25$). The difference in the intercepts for different groups accounts for a further 16% of the variance. But if the group difference is taken into account first, this explains 33% of the variance with the auditory task accounting for an insignificant 3% more. In fact, there is only weak statistical evidence that the slopes of the three regression lines are not zero ($p = 0.075$). As in the Witton et al. data described above, only the age-matched controls, but not the dyslexics (nor the reading-level-matched controls), maintain the significant correlation between nonword reading and beat detection if treated as independent groups. Note that this result is in the face of a highly significant difference between the level of performance in the auditory task between the dyslexic and age-matched control groups. A similar analysis of the relationship between beat detection and spelling ability leads to similar conclusions.

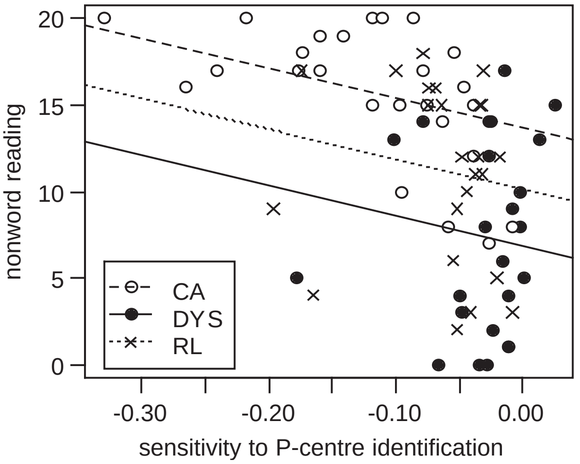

Fig. 5. The relationship in children between accuracy in nonword reading and performance in a task involving the detection of rhythmic beats cued by differences in the rise time of amplitude envelopes (DYS: dyslexics; CA: age-matched controls; RL: reading-level-matched controls). Performance in the auditory task is indexed by the slope of the psychometric function, with more negative slopes indicating better performance. Data from Goswami et al. (2002).

van der Lely et al. (submitted) too have examined the relationship between language measures and auditory performance in three discrimination tasks but in a group of SLI teenagers, and a number of age- and language-matched control groups. Again, on the group level, the SLI teenagers exhibited poorer performance than the age-matched controls, but there were no correlations between any language measure and any auditory one within the SLI group. Interestingly, for the normally developing children (and with appropriate age corrections), a measure of grammar correlated with none of the auditory tasks, whereas a measure of vocabulary did. This is perhaps not too surprising, inasmuch as vocabulary development is understood to depend on a whole host of linguistic and nonlinguistic cognitive abilities, whereas grammar is presumed to be more ‘domain-specific.’ But certainly no support for the idea that auditory processing is crucial for language development can be found here.

Clearly, a central issue in all these analyses is the extent to which people with SLI/SRD and their controls should be treated as a single group, or distinct ones. In a study like that of Talcott et al. (2000), where participants were recruited without regard to their reading abilities, it seems natural to treat them as a single population, even though, presumably, some dyslexics will form part of the group. (But inferences from such studies may not in fact be applicable to dyslexics.) In more typical studies, where participants are selected on the basis of reading ability (or some other trait), it seems wise to entertain the possibility of different relationships among measured attributes, and thus to perform both types of analysis. It may well turn out that the entire group behaves in a uniform manner. Or, as seen above, there may be important differences between the groups that need to be taken account of explicitly.

The drawback of analyzing disparate groups of subjects as a single group is that any trait associated differentially with the groups (but not necessarily causally related to the main attribute of interest), will lead to significant correlations. On the other hand, if some trait is causally related to the attribute of interest, the correlations will show up both in group and individual analyses.

An interesting case is provided by White et al. (submitted) where phonological skills are shown to be predictive of literacy both within and across groups of dyslexics and controls.

To summarize, there appears to be reasonably good evidence that auditory processing skills can predict literacy performance to some extent in groups of normal readers (but for evidence to the contrary, see Watson & Kidd, 2002; Watson et al., 2003), but not in groups of dyslexics. For more general language measures, no relationship has yet been reported for a measure of grammar and auditory performance. (Note though one report of an association between an auditory deficit at school entrance and poor reading comprehension $2\frac{1}{2}$ years later, but not poor phonological skills—Share, Jorm, MacLean, & Matthews, 2002).

It seems highly unlikely, a priori, that the role of auditory processing in determining language/literacy would be qualitatively different in control and SLI/SRD groups. It may simply be that the degree of variability in language/literacy measures in SLI/SRD populations is typically so much greater than that found in control groups, that the contribution of auditory skills is swamped by other factors. Similarly, it may be that there is a basic skill not yet taken account of which is responsible for better performance in both psychoacoustic and reading tasks (for example, something to do with attention). Again, the greater overall variability within the dyslexics could preclude the observation of the correlation induced by this common factor. In either case, improving auditory skills in SLI/SRD groups would be expected to have a negligible effect on language/literacy skills.

4.6. *Which auditory skills have been found effective in distinguishing SLI/SRD groups from controls in more than one or two studies?*

Relatively few tasks have, in fact, been investigated in more than a very small number of studies. Generally speaking, there appear to be more extensive data concerning nonspeech tasks, although a reasonable number of studies have found simple segmental speech discrimination tasks to differentiate control from SLI/SRD groups (Reed, 1989; Kraus et al., 1996; Adlard & Hazan, 1998; Joanisse et al., 2000; van der Lely et al., submitted) although there are exceptions (Ramus et al., 2002; White et al., submitted for publication). Strikingly, the repetition task has proved to be one of the most robust of all tasks, distinguishing SLI/SRD populations from controls in many studies. Detection of FM at 2 Hz, too, has seen success in more than one laboratory (Witton et al., 1998; Ramus et al., 2002) although two recent studies of LI and dyslexic children found no group difference on this task (Bishop, Carlyon, Deeks, & Bishop, 1999; White et al., submitted for publication).

Backward masking, which at first appeared to be a most promising task has been, perhaps, the most disappointing. Although robust group differences have been reported for dyslexic (Rosen & Manganari, 2001) and SLI teenagers (Rosen et al., 2000), the group differences are nowhere near the magnitude reported by Wright et al. (1997). Worse still, there are a number of reports that backward masking fails to distinguish SLI/SRD groups at all, sometimes even when other auditory tasks do (Bishop et al., 1999; Ahissar et al., 2000). In a recent study (Cohen, Vanniasegaram, & Rosen, 2002), backward masking did not distinguish controls from children referred to an ENT clinic for 'listening problems,' even when a simple word discrimination task and a same/different variant of the 'classic' task of Tallal and Piercy (1973) did.

Part of the failure to replicate Wright et al. (1997) appears to arise not from differences in the performance of the SLI/SRD groups, but rather from the extremely low thresholds from the control group of 8-year olds in backward masking. Although there is a strong developmental improvement in backward masked thresholds (Buss, Hall, Grose, & Dev, 1999; Rosen et al., 2000), Wright et al.'s control children appear to be performing at levels more appropriate for teenagers and adults. As suggested first by Bishop et al. (1999), it is possible that these children, at least partly recruited within the university community, were not drawn from the more general population represented by the SLI children (although they were matched in nonverbal IQ to the SLI group). Also, performance in backward masking is very variable, and it may simply be that Wright et al. happened to get better performers than other groups did. If the performance of 8-year olds in Rosen et al. (2000) is instead compared to Wright et al.'s (1997) SLI children, there is considerably more overlap in performance between control and SLI children, although still with a significant difference (decreasing the effect size statistic from a value of 3.6 to a still substantial 1.4).

A number of factors may affect whether SLI/SRD groups exhibit a deficit in backward masking compared to a control group in any particular study. Studies vary greatly in the diagnostic criteria for group selection, and the degree of impairment in SLI/SRD participants. The relative deficit may vary strongly with the age of the listeners. We have already seen that there may be selection biases for listeners, especially control listeners, and there is also of course the role of chance, especially when groups are small. Importantly, variable results between studies are much easier to understand if the true difference between SLI and normally developing children is smaller than that initially reported by Wright et al. (1997).

4.7. What distinguishes auditory skills which are impaired from those which are unimpaired?

Given that there is at least reasonable evidence that some auditory tasks distinguish SLI/SRD groups from controls, and some do not, it is natural to ask what it is that is different about the tasks. Presumably, a good answer to this question would lend great insight into the nature of the auditory deficit, and its possible effects on speech perception.

4.7.1. Is it rapid auditory processing?

This question too can be answered unambiguously—absolutely not! Although Tallal and her colleagues have been consistent proponents of the view that the auditory deficit evidenced by SLI/SRD populations has to do with 'rapid auditory processing,' this position is no longer viable.

Firstly, four studies show that deficits in the 'classical' nonspeech repetition task evidenced by dyslexics are not restricted to short ISIs, as long as performance at long ISIs is not at ceiling (Reed, 1989; Nittrouer, 1999; Marshall, Snowling, & Bailey, 2001; Waber et al., 2001). The original claim of Tallal and Piercy (1973) that the deficit is restricted to short ISIs can neither be refuted nor affirmed because all the listeners were performing at near-perfect levels for long ISIs. More strikingly, in a recent study in which the repetition task was applied to children entering school, it was only on a test involving *long* ISIs that those later identified as SRD performed more poorly than those reading normally (Share et al., 2002).

Secondly, many 'slow' or static tasks are problematic for dyslexics. The detection of amplitude modulation is uniformly worse across modulation rates (10–320 Hz) for adult dyslexics, not being confined to rapid rates (Menell et al., 1999). Although it might be argued that even 10 Hz modulations involve a 'rapid' acoustic feature, such a claim cannot be made for the impaired detection of FM by dyslexic adults at 2 Hz already mentioned (Witton et al., 1998). Also, a recent study concerning the processing of amplitude modulations shows deficits in dyslexic children extending to acoustic features varying over 100 ms or more (Goswami et al., 2002).

Thirdly, there are many 'rapid' tasks for which performance is not impaired, even in the presence of other nonspeech auditory deficits. We have already seen that dyslexic and SLI listeners can evidence normal performance for detection of short tones following a masker (*forward masking*) even when detection of short tones preceding a masker (*backward masking*) is impaired. Clearly, the temporal-resolving abilities of a listener are equally stressed in both these situations, so the distinction between the two configurations must lie elsewhere.

Strikingly, and contrary to the claims of Farmer and Klein (1995), even gap detection, the auditory task meant to assess temporal resolving power most directly, does not distinguish dyslexic listeners from controls (McAnally & Stein, 1996; Schulte-Korne, Deimel, Bartling, & Remschmidt, 1998; Ahissar et al., 2000).

There have also been two recent studies of adult dyslexics in which a wide variety of auditory tasks were used (Amitay, Ahissar, & Nelken, 2002; Ramus et al., 2002). Although there were clear group differences in some tasks and not others, there was no sense in which the affected tasks could be classified as involving 'rapid' processing and the unaffected tasks 'slow'.

The evidence is not confined to nonspeech sounds. Poor readers can show impaired use of long-lasting spectral differences, yet be more influenced in their perception by rapid formant transitions than good readers (Nittrouer, 1999). Adlard and Hazan (1998) showed no general deficit for dyslexics in perceiving formant transitions in synthetic speech, and the speech-perceptual deficits they did demonstrate (in a subgroup of dyslexic children) were not restricted to contrasts signalled by highly dynamic acoustic cues.

Finally, there is little evidence that slowing speech improves discrimination of speech sounds, nor speech intelligibility. Bradlow et al. (1999) lengthened the formant transitions in synthetic /dɑ/-/ɡɑ/ stimuli but this had no effect on the behavioral discriminability of the sounds, neither for control children nor those with language-learning problems (in contrast to what was reported by Tallal & Piercy, 1975). Stollman, Kapteyn, and Sleeswijk (1994) lengthened natural speech and found no effect on intelligibility in language-impaired, hearing-impaired and control children, nor in normal adults.

4.7.2. Is it speech vs. nonspeech?

In a sense, this question simply replicates the central theoretical question in the area—that of domain specificity vs. domain generality. To what extent is any auditory deficit found in SLI/SRD specific to speech sounds? As we shall see, this factor may play some role, but seems unlikely to be crucial.

A strong impetus to exploring this question in a sophisticated way was the study of Mody, Studdert-Kennedy, and Brady (1997). They found that a group of poor-reading children who were also poor at discriminating a synthetic /bɑ/-/dɑ/ contrast showed no deficit with a nonspeech analogue of this contrast incorporating similar critical distinguishing acoustic features (sine-wave speech). In the same vein, Serniclaes, Sprenger-Charolles, Carré, and Demonet (2001) found no evidence of a general deficit in dyslexic children for discriminating sine-wave speech stimuli. In fact, they argued that the deficits seen in phonemic categorization by dyslexics are likely to arise from *better than normal* discrimination of within-category differences. Further studies using a different nonspeech analogue found the discrimination deficit to be weaker (or nonexistent) for isolated second-formant transitions than for speech sounds in dyslexics (Rosen & Manganari, 2001) and SLI children (van der Lely et al., submitted). Therefore, the perceptual deficit cannot only be a difficulty with formant transitions. Either, there is a specific linguistic/phonological component to the deficit (as argued by Mody et al. and Serniclaes et al.) or there may be an important effect of acoustic complexity (the speech sounds in some of the studies are acoustically considerably more complex than the nonspeech analogues). From either point of view, this makes the claimed success of training with simplified stimuli, as used in Fast ForWord, difficult to understand.

In short, there is as yet no unambiguous evidence that the auditory deficit is restricted to speech sounds. In fact, in a recent study of dyslexic university students in which a wide variety of speech and nonspeech tests were applied, none of the speech tests distinguished the dyslexics from the controls statistically, although a number of nonspeech tasks did (Ramus et al., 2002).

4.8. Can any demonstrated nonspeech deficit be shown to explain a related speech deficit?

As we have seen in the last section, a demonstrated deficit for speech sounds cannot as yet be linked clearly to a related nonspeech deficit. Now we reverse the direction of the question. Given any particular nonspeech deficit, can we show a speech perceptual deficit that flows from that?

It is perhaps surprising that although the auditory deficit hypothesis posits a clear link between impaired nonspeech processing abilities and difficulties with speech sounds, none has yet been demonstrated. The nature of the theorizing has been vague, with general problems in 'rapid' auditory processing claiming to be expressed as difficulties in perceiving speech contrasts conveyed by rapid acoustic changes, but little more specific than this.

The work on backward masking by Wright et al. (1997) seemed to point to more promising theoretical avenues. If it was the case that later arriving sounds could perceptually interfere with recently arriving earlier ones, it was easy to see why performance in the repetition task would only be impaired for short ISIs. It also led naturally to the explanation of why discriminating a /bɑ/-/dɑ/ contrast would be difficult, insofar as the following vowel would be expected to exert backward masking on the initial distinctive formant transitions.

Unfortunately, this interesting hypothesis does not stand up to investigation. Rosen and Manganari (2001), as discussed above, showed a deficit in backward masking for dyslexic teenagers, with normal performance for forward masking. They went on to investigate in the same listeners the discrimination and identification of synthetic /bɑ/-/dɑ/ sounds (which should be subject to backward masking) and synthetic /ɑb/-/ɑd/ sounds (which should be subject to forward masking from the vowel to the distinctive formant transitions). Yet the asymmetry in the degree of backward and forward masking was not mirrored in any asymmetry in discriminating or identifying /bɑ/-/dɑ/ as compared to /ɑb/-/ɑd/.

This is not, of course, to say that no such relationship could be found. But it is striking that nearly 30 years of research has not produced a single example of a clear relationship between a speech and nonspeech deficit.

4.9. Does the auditory deficit explain SLI/SRD?

This, of course, is the most important question of all, and one which is likely to be the subject of debate for many years to come. Auditory deficits certainly are more common in SLI/SRD groups than in controls, but far from universal. As Bishop et al. (1999) has pointed out, an auditory deficit is neither necessary nor sufficient to cause SLI/SRD. There are many people with dyslexia and SLI who appear to have completely normal auditory processing; on the other hand, there are auditory deficits in people with normal language and literacy skills. Furthermore, the severity of the auditory deficit does not appear to predict the severity of the language/literacy deficit. These findings may seem somewhat paradoxical, but a look again at Figs. 4 and 5 perhaps clarifies the situation. Typically, there is a great deal of overlap between SLI/SRD and control groups in their performance on the auditory task. If we consider people with similar auditory performance, we can see that there is still a great difference in their performance on some language-based task. This (and the flat regression lines relating language to auditory skill, especially in the SLI/SRD groups) is at the heart of what appears to be the uselessness of the auditory measure as a gauge of the language/literacy deficit. A number of studies have addressed this issue in particular, by comparing the language/literacy skills of those in the SLI/SRD group who perform particularly well on auditory tasks, and those who perform more poorly. Generally speaking, no differences in language/literacy have been found (Marshall et al., 2001; Share et al., 2002; van der Lely et al., submitted) although it has been argued that auditory skills can place an upper limit on phonological skills (Ramus et al., 2002).

Thus auditory deficits appear not to be causally related to language disorders, but only occur in association with them. Although the higher incidence of auditory processing problems in people with language disorders needs explaining, it seems likely that a better understanding of SLI and SRD will arise by considering the specifically linguistic nature of the deficits.

Acknowledgements

Thanks to Caroline Witton and Merav Ahissar for providing the original data from their studies. I would also like to thank my collaborators in this area for many fruitful discussions: Heather van der Lely, Franck Ramus, Usha Goswami, Mazal Cohen, Iyngaran Vanniasegaram, Alan Adlard, Eva Manganari & Sarah White. Most of all, my sincerest appreciation to Sarah Hawkins for advice and suggestions above and beyond the normal call of an editor's duty.

References

Adlard, A., & Hazan, V. (1998). Speech perception abilities in children with specific reading difficulties (dyslexia). *Quarterly Journal of Experimental Psychology*, *51A*, 153–177.

Ahissar, M., Protopapas, A., Reid, M., & Merzenich, M. M. (2000). Auditory processing parallels reading abilities in adults. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 6832–6837.

Amitay, S., Ahissar, M., & Nelken, I. (2002). Auditory processing deficits in reading disabled adults. *Journal of the Association for Research in Otolaryngology*, *3*, 302–320.

Bishop, D. V. M. (1997). *Uncommon understanding: Development and disorders of language comprehension in children*. Hove, UK: Psychology Press.

Bishop, D. V. M., Carlyon, R. P., Deeks, J. M., & Bishop, S. J. (1999). Auditory temporal processing impairment: Neither necessary nor sufficient for causing language impairment in children. *Journal of Speech Language and Hearing Research*, *42*, 1295–1310.

Bradlow, A. R., Kraus, N., Nicol, T. G., McGee, T. J., Cunningham, J., & Zecker, S. G. (1999). Effects of lengthened formant transition duration on discrimination and neural representation of synthetic CV syllables by normal and learning-disabled children. *Journal of the Acoustical Society of America*, *106*, 2086–2096.

Buss, E., Hall, J. W., Grose, J. H., & Dev, M. B. (1999). Development of adult-like performance in backward, simultaneous, and forward masking. *Journal of Speech Language and Hearing Research*, *42*, 844–849.

Cohen, M., Vanniasegaram, I., & Rosen, S. (2002). Central auditory function in normal hearing school children. *Audiologia Newsletter*, *7*, 26 (abstract).

Cook, R. D., & Weisberg, S. (1999). *Applied regression including computing and graphics*. New York: Wiley.

Deary, I. J. (1995). Auditory inspection time and intelligence—what is the direction of causation? *Developmental Psychology*, *31*, 237–250.

Deary, I. J., Head, B., & Egan, V. (1989). Auditory inspection time, intelligence and pitch discrimination. *Intelligence*, *13*, 135–147.

Efron, R. (1963). Temporal perception, aphasia and déjá vu. *Brain*, *86*, 403–424.

Elliott, L. L. (1962). Backward masking: Monotic and dichotic conditions. *Journal of the Acoustical Society of America*, *34*, 1108–1115.

Elliott, L. L. (1971). Backward and forward masking. *Audiology*, *10*, 65–76.

Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin and Review*, *2*, 460–493.

Goswami, U., Thomson, J., Richardson, U., Stainthorp, R., Hughes, D., Rosen, S., & Scott, S. K. (2002). Amplitude envelope onsets and developmental dyslexia: A new hypothesis. *Proceedings of the National Academy of Sciences of the United States of America*, *99*, 10911–10916.

Hartley, D. E. H., & Moore, D. R. (2002). Auditory processing efficiency deficits in children with developmental language impairments. *Journal of the Acoustical Society of America*, *112*, 2962–2966.

Heath, S. M., Hogben, J. H., & Clark, C. D. (1999). Auditory temporal processing in disabled readers with and without oral language delay. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *40*, 637–647.

Hurford, D. P., & Sanders, R. E. (1990). Assessment and remediation of a phonemic discrimination deficit in reading disabled 2nd and 4th graders. *Journal of Experimental Child Psychology*, *50*, 396–415.

Joanisse, M. F., Manis, F. R., Keating, P., & Seidenberg, M. S. (2000). Language deficits in dyslexic children: Speech perception, phonology, and morphology. *Journal of Experimental Child Psychology*, *77*, 30–60.

Joanisse, M. F., & Seidenberg, M. S. (1998). Specific language impairment: A deficit in grammar or processing? *Trends in Cognitive Sciences*, *2*, 240–247.

Kraus, N., McGee, T. J., Carrell, T. D., Zecker, S. G., Nicol, T. G., & Koch, D. B. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Science*, *273*, 971–973.

Marshall, C. M., Snowling, M. J., & Bailey, P. J. (2001). Rapid auditory processing and phonological ability in normal readers and readers with dyslexia. *Journal of Speech Language and Hearing Research*, *44*, 925–940.

McAnally, K. I., & Stein, J. F. (1996). Auditory temporal coding in dyslexia. *Proceedings of the Royal Society of London Series B-Biological Sciences*, *263*, 961–965.

McArthur, G. M., Hogben, J. H., Edwards, V. T., Heath, S. M., & Mengler, E. D. (2000). On the "specifics" of specific reading disability and specific language impairment. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *41*, 869–874.

Menell, P., McAnally, K. I., & Stein, J. F. (1999). Psychophysical sensitivity and physiological response to amplitude modulation in adult dyslexic listeners. *Journal of Speech Language and Hearing Research*, *42*, 797–803.

Merzenich, M. M., Jenkins, W. M., Johnston, P., Schreiner, C., Miller, S. L., & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training. *Science*, *271*, 77–81.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology*, *64*, 199–231.

Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems? *Journal of Speech Language and Hearing Research*, *42*, 925–942.

Pastore, R. E., Harris, L. B., & Goldstein, L. (1980). Auditory forward and backward masking interaction. *Perception & Psychophysics*, *28*, 547–549.

Puleo, J. S., & Pastore, R. E. (1980). Contralateral cueing effects in backward masking. *Journal of the Acoustical Society of America*, *67*, 947–951.

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology*, *13*, 212–218.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2002). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain*, *126*, 841–865.

Raz, N., Moberg, P. J., & Millman, D. (1990). Effects of age and age-related differences in auditory information-processing on fluid and crystallized intelligence. *Personality and Individual Differences*, *11*, 1147–1152.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental Child Psychology*, *48*, 270–292.

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and nonspeech auditory processing in children with dyslexia? *Journal of Speech Language and Hearing Research*, *44*, 720–736.

Rosen, S., van der Lely, H., Adlard, A., & Manganari, E. (2000). Backward masking in children with and without language disorders. *British Journal of Audiology*, *34*, 124 (abstract).

Schulte-Korne, G., Deimel, W., Bartling, J., & Remschmidt, H. (1998). Role of auditory temporal processing for reading and spelling disability. *Perceptual and Motor Skills*, *86*, 1043–1047.

Serniclaes, W., Sprenger-Charolles, L., Carré, R., & Demonet, J. F. (2001). Perceptual discrimination of speech sounds in developmental dyslexia. *Journal of Speech Language and Hearing Research*, *44*, 384–399.

Share, D. L., Jorm, A. F., MacLean, R., & Matthews, R. (2002). Temporal processing and reading disability. *Reading and Writing: An Interdisciplinary Journal*, *15*, 151–178.

Snowling, M. (1998). Dyslexia as a phonological deficit: Evidence and implications. *Child Psychology & Psychiatry Review*, *3*, 4–11.

Stein, J. (2001). The magnocellular theory of developmental dyslexia. *Dyslexia*, *7*, 12–36.

Stollman, M. H. P., Kapteyn, T. S., & Sleeswijk, B. W. (1994). Effect of time-scale modification of speech on the speech recognition threshold in noise for hearing-impaired and language-impaired children. *Scandinavian Audiology*, *23*, 39–46.

Talcott, J. B., Witton, C., McLean, M. F., Hansen, P. C., Rees, A., Green, G. G. R., & Stein, J. F. (2000). Dynamic sensory sensitivity and children's word decoding skills. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 2952–2957.

Tallal, P. (1980). Auditory temporal perception, phonics and reading disabilities in children. *Brain and Language*, *9*, 182–198.

Tallal, P., Miller, S. L., Bedi, G., Byma, G., Wang, X. Q., Nagarajan, S. S., Schreiner, C., Jenkins, W. M., & Merzenich, M. M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science*, *271*, 81–84.

Tallal, P., & Piercy, M. (1973). Defects of nonverbal auditory perception in children with developmental aphasia. *Nature*, *241*, 468–469.

Tallal, P., & Piercy, M. (1974). Developmental aphasia: Rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia*, *12*, 83–94.

Tallal, P., & Piercy, M. (1975). Developmental aphasia: The perception of brief vowels and extended stop consonants. *Neuropsychologia*, *13*, 69–74.

van der Lely, H. K. J., Rosen, S., & Adlard, A. (submitted). Grammatical language impairment and the specificity of cognitive domains: Relations between auditory and language abilities.

van der Lely, H. K. J., Rosen, S., & McClelland, A. (1998). Evidence for a grammar-specific deficit in children. *Current Biology*, *8*, 1253–1258.

Waber, D. P., Weiler, M. D., Wolff, P. H., Bellinger, D., Marcus, D. J., Ariel, R., Forbes, P., & Wypij, D. (2001). Processing of rapid auditory stimuli in school-age children referred for evaluation of learning disorders. *Child Development*, *72*, 37–49.

Watson, C. S., & Kidd, G. R. (2002). On the lack of association between basic auditory abilities, speech processing and other cognitive skills. *Seminars in Hearing*, *23*, 85–95.

Watson, C. S., Kidd, G. R., Horner, D. G., Connell, P. J., Lowther, A., Eddins, D. A., Krueger, G., Goss, D. A., Rainey, B. B., Gospel, M. D., & Watson, B. U. (2003). Sensory, cognitive, and linguistic factors in the early academic performance of elementary school children: The Benton-IU project. *Journal of Learning Disabilities*, *36*, 165–197.

White, S., Milne, E., Rosen, S., Hansen, P. S. J., Frith, U., & Ramus, F. (submitted for publication). Sensorimotor processing in dyslexia: A multiple case study of dyslexic children.

Witton, C., Stein, J. F., Stoodley, C. J., Rosner, B. S., & Talcott, J. B. (2002). Separate influences of acoustic AM and FM sensitivity on the phonological decoding skills of impaired and normal readers. *Journal of Cognitive Neuroscience*, *14*, 866–874.

Witton, C., Talcott, J. B., Hansen, P. C., Richardson, A. J., Griffiths, T. D., Rees, A., Stein, J. F., & Green, G. G. R. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. *Current Biology*, *8*, 791–797.

Wright, B. A., Lombardino, L. J., King, W. M., Puranik, C. S., Leonard, C. M., & Merzenich, M. M. (1997). Deficits in auditory temporal and spectral resolution in language-impaired children. *Nature*, *387*, 176–178.