Learning Disabilities: A Contemporary Journal 1(1), 27-36, 2003

Auditory Perceptual Impairments and Learning Disabilities: Theoretical and Empirical Considerations

Gary A. Troia[1]
University of Washington

A proximal cause of reading disabilities is a deficit in phonological processing. A consequence of this deficit is inferior performance in one or more cognitive operations that use phonological information, including phonological awareness, lexical retrieval, and verbal memory. Some assert that these phonological processing difficulties are the direct result of impaired auditory perceptual skills. This paper examines the theoretical and empirical grounds for this hypothesis. First, evidence in support of perceptual deficits as a root cause of poor reading achievement and specific language impairments is presented, followed by opposing evidence. Finally, research that has examined the efficacy of interventions based on the auditory perceptual deficit hypothesis is reviewed.

In the United States, nearly 2.9 million school-age children and youth are identified as having a learning disability, representing approximately 50% of the total number of children served in special education programs (U.S. Department of Education, 2001). A majority of these children have chronic reading problems that place them at risk for academic failure, school withdrawal, and a diminished quality of life. Over the past three decades, an overwhelmingly vast and diverse base of empirical research has provided convincing evidence that a proximal cause of reading disabilities (RD) is a deficit in phonological processing (e.g., Lyon, 1995; Share & Stanovich, 1995; Stanovich, 1988; Stanovich & Siegel, 1994; Troia, in press). A consequence of this deficit is inferior performance, regardless of IQ, in one or more cognitive operations that use phonological information, including phonological awareness (e.g., Blachman, 1991; Metsala, 1999; Stanovich, 1986, 1991; Vellutino & Scanlon, 1987; Wagner & Torgesen, 1987), naming (e.g., Badian, 1993; Felton & Wood, 1989; Wolf & Bowers, 1999), and verbal memory (e.g., Rapala & Brady, 1990; Torgesen, Wagner, & Rashotte, 1994). But what causes this core phonological processing deficit? Some researchers assert phonological processing difficulties seen in children with RD and children with language disorders are the direct result of impaired auditory perceptual skills (e.g., Tallal, Merzenich, Miller, & Jenkins, 1998; Tallal, Miller, & Fitch, 1993; Wright, Bowen, & Zecker, 2000; Wright, Lombardino, King, Puranik, Leonard, & Merzencih, 1997). The purpose of this paper is to examine the theoretical and empirical grounds for this hypothesis (see Kuhl, 1991, 1999; Nittrouer, 2002 for reviews of critical constructs in speech and non-speech perceptual research).

The Case For Auditory Perceptual Impairments as a Root Cause of RD

Early research investigating auditory perceptual difficulties focused on children with specific language impairments (SLI) who, as a group, appear to exhibit greater difficulty in speech perception than their non-disabled peers of the same age. Specifically, children with SLI display more errors when asked to identify, discriminate, and serially order speech stimuli that rely on temporally cued information, such as brief formant transitions that cue place of articulation and rapidly occurring voice onset times that cue consonant voicing features (Elliott, 1986; Elliott & Hammer, 1988; Elliott, Hammer, & Scholl, 1989; Leonard, McGregor, & Allen, 1992; Tallal & Piercy, 1974, 1975). Tallal and Piercy (1974), for example, found that children with SLI performed more poorly than their typically developing peers on discrimination and temporal order judgment tasks using pairs of synthesized consonant-vowel (CV) syllables in which the formant transitions of the stop consonants were 43 ms in duration (the total duration of each syllable was 250 ms) and the syllables were separated by an interstimulus interval (ISI) of 95 ms or less. In contrast, the children with SLI performed just as well as the control participants on these tasks when pairs of synthesized steady-state vowels of the same total duration were used as stimuli regardless of the ISI between the syllables. In a subsequent experiment using similar procedures with the same group of children, Tallal and Piercy (1975) presented two vowel-vowel syllables (/ew/ and /aew/) in which the first steady-state vowel of the syllable had a duration of 43 ms and two CV syllables (/ba/ and /da/) in which the formant transitions were lengthened to 95 ms. The performance of the children with SLI on the discrimination and serial ordering tasks, compared with that of the children without disabilities, was diminished for the vowel-vowel stimuli but not for the CV stimuli at shorter ISIs. These findings led the researchers to conclude that the duration of the acoustic cue (and not the formant transition itself) was critical to accurate perception.

Deficits in processing the temporal aspects of acoustic signals among children with SLI do not appear to be confined to speech; these children also perform more poorly than their age-matched peers without language disorders on discrimination and serial ordering tasks when pairs of complex non-verbal tones (tones composed of multiple frequencies similar to those found in the spectra of speech sounds) that differ only in fundamental frequency are presented with a combination of brief ISIs and short tone durations (Tallal & Piercy, 1973a, 1973b). Deficits in perceiving rapidly changing acoustic information in speech and non-speech stimuli also have been found in some children with RD (De Weirdt, 1988; Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Hurford & Sanders, 1990; Reed, 1989;

[1] Correspondence concerning this article should be addressed to Gary A. Troia, Area of Special Education, University of Washington, 102 Miller Hall, Box 353600, Seattle, WA 98195. E-mail: gtroia@u.washington.edu

Tallal, 1980; Thibodeau & Sussman, 1979; Werker & Tees, 1987), particularly those who have poor pseudoword reading skills arising from phonological processing difficulties (Adlard & Hazan, 1998; Tallal, 1980; Tallal & Stark, 1981). For example, Reed (1989) presented complex non-verbal tones of 75 ms duration, vowels (/e/ and /ae/) of 250 ms duration, and CV syllables (/ba/ and /da/) of 250 ms duration, separated by an ISI of 400, 300, 150, 50, or 10 ms, to good and poor readers. Although the performance of the good readers on discrimination and temporal order judgment tasks was not substantially affected by decreasing ISIs, the performance of the poor readers was affected. In other words, their accuracy decreased significantly with shorter ISIs for non-verbal tones (recall that these were of shorter duration than the other stimuli) and CV syllables (with brief formant transitions), but not steady-state vowels. Reed then identified the poor readers who performed worst on the perceptual tasks and compared them with their matched controls on a vowel serial ordering task in which white noise was introduced. The increased difficulty of this task negatively affected the performance of both groups equally. Because the children with RD did not experience comparatively greater difficulty with processing the steady-state auditory cues in vowels under demanding conditions, a deficit in processing brief acoustic information appeared to be at the heart of the weaker performance of children with reading problems.

Not only do children with SLI and RD have perceptual difficulties with rapidly presented auditory stimuli that contain transient information, they also display more discrimination errors when presented with rapidly occurring visual patterns (e.g., flashes) than their normal peers (e.g., Eden, Stein, Wood, & Wood, 1995; Lovegrove, 1993; Rose, Feldman, Jankowski, & Futterweit, 1999; Tallal, Stark, Kallman, & Mellits, 1981) and they are less adept at perceiving and producing sequential motor movements, especially ones that occur rapidly (Tallal, Stark, & Mellits, 1985; Wolf, 1991; Wolff, Cohen, & Drake, 1984). In conjunction with research findings from psychoacoustic studies like those described above, these results imply that many children with language and learning disabilities have a perceptual disorder that may be related to pansensory deficits in temporal processing (for a review of this body of work, see Farmer & Klein, 1995; Klein & Farmer, 1995; Tallal et al., 1993). The auditory temporal processing deficit described by Tallal, Merzenich, and their colleagues to be at the core of at least some developmental disabilities, including RD (Tallal, 1984, 1990; Tallal, Merzenich, Miller, & Jenkins, 1998; Tallal et al., 1993; Tallal, Miller, Jenkins, & Merzenich, 1997), is but one aspect of this fundamental disorder. Such a disorder may emerge as early as the first year of life, possibly serving as a biological marker of SLI (Benasich & Tallal, 1996), and continue to manifest itself throughout the life span as differences in perceptual behavior, linguistic competence, neurophysiological functioning, and brain morphology (e.g., Galaburda, Corsiglia, Rosen, & Sherman, 1987; Galaburda & Livingstone, 1993; Galaburda, Menard, & Rosen, 1994; Merzenich & Jenkins, 1995; Merzenich, Schreiner, Jenkins, & Wang, 1993; Nagarajan et al., 1999; Tallal et al., 1993).

This evidence does not produce a "smoking gun" though; a functional relationship between auditory perceptual difficulties and phonological processing deficits must be demonstrated as well. At this time, such a relationship has not been established, but correlational evidence suggests that both auditory perceptual deficits and phonological processing deficiencies are present in at least some children with RD. Specifically, speech perception contributes unique variance in phonological awareness performance and early reading achievement (Chiappe, Chiappe, & Siegel, 2001; Manis, McBride-Chang, Seidenberg, Keating, Doi, & Petersen, 1997; Metsala, 1997; McBride-Chang, 1995; Nittrouer, 1999; Scarborough, 1998), but only a subset of poor readers who exhibit phonological awareness impairments also exhibit difficulties with speech perception (Manis et al., 1997). This subset probably consists of a large proportion of children with SLI; delayed morphological development is a prominent characteristic of SLI and problems in speech perception have been found to hinder the acquisition of grammatical markers (Elliott & Hammer, 1988; Joanisse, Manis, Keating, & Seidenberg, 2000; Joanisse & Seidenberg, 1998; Leonard et al., 1992; Stark & Heinz, 1996). Moreover, children with SLI are more likely than not to have reading problems (Catts, Fey, Zhang, & Tomblin, 1999; McCardle, Scarborough, & Catts, 2001). Many studies of acoustical perceptual deficits in children with RD may, in fact, include a large number of participants with SLI rather than with pure RD, which could produce an overestimate of the presence of speech (and nonspeech) perception weaknesses in the RD population.

McBride-Chang and her colleagues (McBride-Chang, 1996; McBride-Chang, Wagner, & Chang, 1997) believe that speech perception influences reading indirectly through its relationship with phonological awareness. For example, McBride-Chang et al. (1997) determined that performance on a speech discrimination task (the words *bath* and *path* were presented on a continuum of voice onset time, which is the acoustic property that differentiates these words) by kindergartners was correlated with performance on phonemic awareness tasks administered at the same time and 15 months later. Children with the highest kindergarten speech discrimination scores eventually became the strongest readers in first grade, but when the variance explained by IQ, verbal memory, phonological awareness, and letter knowledge was statistically removed, speech perception did not make an independent contribution to growth in word recognition. However, speech discrimination did make an independent contribution to growth in phonological awareness, as did IQ and memory (also see McBride-Chang, 1995).

The Case Against Auditory Perceptual Impairments as a Root Cause of RD

Although studies that support the existence of a general temporal processing disorder in at least some children with SLI and RD are persuasive, they have not gone unchallenged. Perhaps the most notable critics, Studdert-Kennedy and his colleagues (Studdert-Kennedy, Liberman, Brady, Fowler, Mody, & Shankweiler, 1995; Studdert-Kennedy & Mody, 1995; Mody, Studdert-Kennedy, & Brady, 1997) contend that findings from the most influential studies (Reed, 1989; Tallal, 1980; Tallal & Piercy, 1973a, 1973b) are flawed both conceptually and methodologically for three reasons. First, they take issue with use of the term "temporal processing" because it has been applied rather indiscriminately to different phenomena. For example, temporal processing has been used to describe perception of temporal aspects of the acoustic signal, including formant transition duration, voice onset time, and fricative-vowel gap time, perception of acoustic events that are sequentially ordered, and perception of brief acoustic events. Studdert-Kennedy and colleagues insist that there is a differentiation between rate of processing and processing of rate. In the former case, rapid perception of brief acoustic events is implied; in the latter, perception of the temporal characteristics (e.g., rapid changes in formant frequencies or voicing) of the stimuli is implied. In the studies conducted by Tallal and her colleagues, this differentiation is not clearly made, although it appears that rate of processing is of concern (see Tallal, 1980).

Second, Studdert-Kennedy and others reason that independent deficits are likely responsible for the perceptual difficulties children with SLI and RD display on non-verbal and verbal auditory discrimination tasks, problems with the latter arising from a linguistic deficit rather than a general auditory perceptual disorder. Specifically, children with language impairments and reading problems perform poorly on perceptual tasks involving speech stimuli because they are less capable of forming phonological representations for the stimuli (also see Sussman, 1993). A phonological processing disorder could result in poor discrimination of phonemes that differ in only one articulatory feature (i.e., place of articulation, manner of articulation, or voicing), as do /b/ and /d/ in the CV syllables used in much of Tallal's work.

Third, they argue that appropriate non-speech control stimuli have not been used in much of the research in speech discrimination; consequently, difficulty with rapidly presented brief tones may relate to a different underlying deficit. Tones presented to children with SLI in Tallal and Piercy's (1974, 1975) studies did not share the same brief and rapidly changing onset frequencies as the CV syllables that were presented; if a temporal processing disorder was the root cause for the children's perceptual difficulties, then such non-verbal stimuli should elicit the same pattern of diminished performance. Mody et al. (1997) set out to examine this hypothesis in a sample of skilled and less skilled second-grade readers. In their study described below, the less skilled readers read at grade level and exhibited temporal order judgment difficulties whereas the skilled readers read above grade level and did not display serial order judgment problems.

Mody et al. (1997) created two complex non-verbal tones of 250 ms duration with a 35 ms transition to serve as non-speech control stimuli for synthetic CV syllables that differed on one articulatory feature (/ba/ and /da/). The two tones were composed of sine waves with durations and frequency trajectories identical to those of the center frequencies of the second and third formants of (/ba/ and /da/), respectively. Thus, tone discrimination depended on perceiving brief transitions in formant frequencies, but not on creating phonological representations. They also assessed the children's ability to discriminate between other pairs of CV syllables that differed on all three articulatory features: /ba/-/sa/ and /da/-/fa/. They found that less skilled readers did not differ significantly from skilled readers at any ISI (ranging from 10 ms to 100 ms) on tone discrimination (actually, the skilled readers performed more poorly than the less skilled readers at the shortest ISI). However, the less skilled readers did make significantly more discrimination errors when presented with /ba/ and /da/ at shorter ISIs. The skilled and less skilled readers performed comparably when discriminating between the two other CV syllable contrast pairs. The researchers concluded that trouble with discriminating between CV syllables could not be caused by a general deficit in processing rapid acoustic information because such a deficit also would have affected the less skilled readers' ability to discriminate between non-verbal tones that were acoustically similar to their corresponding CV syllables. Moreover, because the children who performed poorly on the /ba/-/da/ discrimination task did not exhibit similar deficiencies in discriminating less phonetically similar CV syllables, Mody et al. propose that it is phonetic similarity between phonemes that creates perceptual difficulties for some children. Support of this last point was provided in a study by Stark and Heinz (1996), who found that children with SLI had difficulty identifying steady-state vowels of both long and short duration that were phonetically similar (/e/ and /ae/), but not vowels that were more contrastive.

Other empirical evidence suggests that the existence of an auditory temporal processing deficit in children (and adults) with disabilities should not be accepted at face value (e.g., Bishop, Carlyon, Deeks, & Bishop, 1999; Brady, Shankweiler, & Mann, 1983; Chiappe, Stringer, Siegel, & Stanovich, 2002; Helzer, Champlin, & Gillam, 1996; Marshall, Snowling, & Bailey, 2001; Nittrouer, 1999; Sussman, 1993). First, children with SLI and reading problems perform poorly on discrimination tasks in which aspects of the acoustic signal other than duration or speed are manipulated, which indicates that temporal processing alone cannot explain these children's auditory perceptual deficits. For example, De Weirdt (1988) found that poor readers were disadvantaged in comparison to good readers on a pure-tone discrimination task in which the frequency of the tones was manipulated rather than formant transition duration or ISI. In this study, tones were presented at a constant duration of 130 ms and an ISI of one second.

Second, replication of Tallal's (Tallal, 1980; Tallal & Piercy, 1973a, 1973b) findings has been difficult to achieve (e.g., Norrelgen, Lacerda, & Forssberg, 2002). When pairs of complex non-verbal tones differing in fundamental frequency were presented at 40, 75, and 250 ms duration with ISIs of 10, 50, 100, and 400 ms to a large sample of children with and without learning difficulties, Waber et al. (2001) found no interaction between disability status and either stimulus duration or ISI. The children referred for learning problems consistently performed worse than their non-referred peers and the magnitude of this difference remained constant across ISIs and tone durations. Thus, impaired perception associated with briefer and faster stimuli, reported in Tallal's work, was not found among this group of children with academic weaknesses. In fact, Stark and Tallal (1988) reported a group of children with SLI who exhibited discrimination errors for CV syllables with formant transitions lasting 40 ms and 80 ms, which conflicted with their prior findings. However, in this experiment, only two formant frequencies were used to synthesize the stimuli rather than five. This raises the possibility that children with disabilities require more acoustic information or greater redundancy in that information to be able to successfully perform discrimination tasks. Godfrey et al. (1981) reported that their children with and without RD had more trouble discriminating /da/-/ga/ pairs than /ba/-/da/ pairs because the former differ only in their third formant whereas the latter differ in both their second and third formants. Once again, the amount of acoustic information present appeared to affect children's relative discriminative abilities; when differences were cued by less information, discrimination became more difficult (also see Adlard & Hazan, 1998). This presumption is consistent with the position taken by Studdert-Kennedy (Studdert-Kennedy et al., 1995; Studdert-Kennedy & Mody, 1995; Mody et al., 1997).

Finally, researchers have paid little attention to the role of attentional capacity in temporal processing and how attention influences performance on psychoacoustic tasks. Breier, Fletcher, Foorman, Klaas, and Gray (2003) examined this issue in a large-scale study with 150 children between the ages of seven and 14 years who were identified as having either RD (but not SLI), RD plus attention deficit disorder with hyperactivity (ADHD), ADHD, or normal development. Two findings stood out: (a) children with ADHD exhibited a reduction in performance across perceptual tasks and (b) the RD groups exhibited higher detection thresholds for tone onset time asynchrony but not tone gaps, which implies that these children may have been more sensitive to backward masking effects (these occur when a second signal is delivered in close temporal proximity to the first signal and would be expected to elevate thresholds). Such findings challenge the existence of a pervasive deficit in auditory temporal processing among children with RD and suggest that attention is an important variable to consider.

Interventions Based on Auditory Perceptual Research

The controversy surrounding the temporal processing disorder that is presumed to be the root cause, in at least some cases, for phonological processing difficulties and linguistic impairments in children with RD and SLI has yet to be resolved. Nevertheless, interventions based on this presumption have been developed and tested (see Table 1 for descriptions of these studies). For example, Hurford and Sanders (1990) were able to significantly improve speech discrimination among second- and fourth-grade children with RD. The intervention was relatively brief; children participated in the training activities for 30-45 minutes per day for three or four days. One group of children received the experimental treatment in which their discrimination skills were progressively refined for decreasing ISIs, first using pairs of steady-state vowels, then CV syllables with liquid and nasal consonants (which are continuant sounds much like vowels), and finally CV syllables with initial stop consonants. Another group completed the same activities, but the stimuli consisted of simple pure tones. Following training, the children in the experimental treatment group performed significantly better than those in the control group on a measure of speech discrimination that used untrained consonant sounds in the test stimuli. Moreover, their post-treatment speech discrimination performance was similar to that of a group of children without reading problems. Hurford (1990) replicated this study with a group of second- and third-grade poor readers who also exhibited weak phonemic awareness on a sound deletion task. Although children in the control group showed little improvement in phonemic awareness at the end of the study, those who were taught to discriminate pairs of syllables at faster presentation rates demonstrated significant improvement.

Habib, Espresser, Rey, Giraud, Braus, & Gres (1999) used acoustically modified speech in a rhyme detection task with 10- to 12-year-old French-speaking children with RD to improve their phonological awareness. The formant transitions were differentially amplified and the entire speech signal was slowed by a constant factor with a gradual reduction in degree of modification over the treatment period. The six children who completed the activities for one hour per day, five days per week, for five consecutive weeks with acoustically modified speech showed significantly greater improvement in phonological awareness than six children who completed the same activities with unmodified speech, who did not display any significant improvement. These results were observed again after one month had elapsed. In contrast, McAnally, Hansen, Cornelissen, and Stein (1997) found that neither compression nor expansion of syllable duration (the manipulation was uniform across the syllable rather than isolated to the formant transition) or consonant formant frequencies significantly improved the discrimination of CVC syllables (all consonants were stops) in white noise over baseline performance (discrimination without acoustic modifications) of 15 adolescents with RD and 15 adolescents with average reading skills.

A computer-assisted instructional program called Fast ForWord Language™ (FFW), based on the premise that intensive training in auditory perceptual and spoken language comprehension skills can improve the communicative competence and academic success of at-risk children and those identified with disabilities, has been the subject of several recent studies. FFW uses seven interactive game-like exercises to provide practice in non-verbal and verbal sound discrimination, vocabulary recognition, and language comprehension. Children between the ages of four and 14 complete the exercises for 60 to 80 minutes each day during the first week of training and for 100 minutes each day thereafter until they complete the program, usually within four to eight weeks. Most importantly, according to the developers, the acoustic waveforms presented in the exercises are prolonged using an algorithm that retains their spectral content and, in some cases, their transitional elements are amplified. As children progress through the exercises, signal duration and intensity are gradually normalized. These signal modifications are made to address the presumed auditory perceptual difficulties of at least some children with SLI and RD.

Preliminary clinical studies conducted by the developers of the FFW software yielded promising results (see Merzenich et al., 1996; Tallal et al., 1996). In one study, seven children with language disorders and reading difficulties between the ages of five and nine participated in activities that incorporated the acoustic modifications described above with gradual normalization for three hours per day, five days per week, for four weeks. The children played prototypes of the FFW game-like exercises called "Circus Sequence" and "Phoneme

Identification" and were provided individual instruction on eight other language processing tasks. In addition, they listened to acoustically modified pre-recorded stories at home for one to two hours each day. Five of the seven participants' performance on the prototype exercises improved substantially over the treatment period, but performance on the other eight exercises was not reported. As a group, their performance on norm-referenced tests of speech discrimination and language comprehension improved significantly. Moreover, changes in presumed temporal processing (evaluated by performance on a non-verbal auditory sequential perception task) were highly correlated with posttest performance in language comprehension.

In a second study, 22 children with language and reading impairments between five and 10 years of age were matched for age, nonverbal intelligence, and receptive language skills. They were assigned to an experimental treatment condition in which the activities incorporated acoustically modified signals or to a comparison treatment condition in which the same activities were presented with unmodified acoustic waveforms (e.g., natural speech). The activities used in both conditions included revised versions of the "Circus Sequence" and "Phoneme Identification" games and two additional FFW game prototypes, "Old McDonald's Flying Farm" and "Phonic Match." Additional individual language instruction and homework were provided to both groups. Children in both treatment groups showed significant improvements in speech discrimination, memory, and receptive language skills after four weeks of daily training (improvements in exercise performance were evident for most, but not all of the children), but those who completed the activities using acoustically modified signals demonstrated significantly greater gains (about two years growth), which were maintained six weeks later. In addition, children in the experimental treatment condition displayed significant gains in non-verbal auditory sequential perception, whereas those in the comparison treatment condition did not.

Although these findings are encouraging, they do not demonstrate the efficacy of FFW. First, the children in the Tallal et al. (1996) and Merzenich et al. (1996) studies were provided with individual language intervention and homework assignments in addition to the computer exercises, which makes it impossible to attribute the treatment results solely to the FFW exercises (Gillam, 1999). Moreover, only a few of the FFW exercises were included in these studies, so the FFW program *per se* was not evaluated. Second, intervention time in these preliminary studies approximated 300 minutes per day, three times the 100 minutes per day required of FFW participants (Gillam, 1999). Third, because the intervention was multifaceted, it is difficult to isolate the components of the treatment regimen (e.g., discrete learning trials, massed practice, immediate feedback and reinforcement, instruction in multiple language skills, progress monitoring and responsive adaptation, signal lengthening and amplification) most closely associated with observed improvements in auditory perceptual skills and language performance (Gillam, 1999; Studdert-Kennedy et al., 1995; Veale, 1999). Fourth, some of the outcome measures were similar to the FFW exercises, possibly biasing the results in favor of positive treatment effects (Veale, 1999).

The results of subsequent large-scale field trials of the entire FFW program have been released to the public but have not been published in peer-reviewed outlets (the findings are summarized in Veale, 1999 and on the Scientific Learning Corporation web site at www.scilearn.com). In the first field trial, over 500 children with language comprehension deficits between four and 14 years of age received FFW training from 63 specially trained clinicians at 35 sites (primarily clinics and private practices) in the United States and Canada. The children varied in their diagnoses and severity of disability, but according to Tallal et al. (1997), approximately 90% of the participants achieved a gain of about one standard deviation on one or more norm-referenced tests of auditory perception and discrimination and oral language development. In a separate school pilot study, 452 at-risk students in grades K through three in 19 public schools in 9 school districts across the country participated in a stratified randomized group experiment. The majority (67%) of children who received FFW training over a period of about 40 school days demonstrated significantly greater progress (an average of 1.8 years growth) in language comprehension and phonological awareness in comparison to their peers who did not receive training. Gillam (1999) noted five major flaws in the field trials: (a) gains may have been overestimated because the tests used to document progress were very similar to some of the training exercises; (b) regression to the mean was not accounted for by using confidence intervals, thus, at least in the national field trial without a control group, differences between pretest and posttest scores simply may have been due to measurement error (also see Studdert-Kennedy et al., 1995); (c) inadequate participant selection criteria were established; (d) there was no control of Rosenthal effects (examiners also delivered the intervention, which may have biased their administration and scoring of the outcome measures); and (e) there was a reliance on norm-referenced tests, which are not necessarily good indicators of children's ability to use language in authentic social and academic contexts.

Until recently, there was limited opportunity for independent replication and extension of these findings in experimental investigations; the developers of FFW were understandably reluctant to release the software to other researchers before related patents and licenses had been granted. Hook, Macaruso, and Jones (2001) conducted the first published independent experimental evaluation of FFW. Eleven children with RD between the ages of seven and 12 years participated in the FFW intervention for approximately two months while 9 other children with RD, matched for age, IQ, phonemic awareness ability, and reading level, participated in a comparison treatment in which the children completed activities from the Orton-Gillingham (OG) multisensory phonics training program. Another 11 poor readers, matched on the same criteria, served as a longitudinal no-contact control group. The students in the FFW group and the OG group made significant but equivalent gains in phonological awareness, but neither group demonstrated significant gains in word recognition, and the OG group achieved higher posttest scores in decoding than the FFW group. These results were obtained despite the fact that the FFW group received over double the amount of intervention time (56 hours) as that received by the OG group (25 hours). Although both the FFW group and the no-contact control group showed gains in phonemic awareness and all aspects of reading (word recognition, decoding, and comprehension) over a two-year period following the intervention, those gains were similar between groups. Children who participated in a FFW displayed immediate gains in oral language production, but not oral language comprehension, serial naming rate, or working memory; the gains in oral language were not maintained two years later. Finally, the completion rate of the FFW activities was not related to treatment outcomes. These findings cast doubt on the efficacy of FFW for improving the language-related skills of children with reading disabilities and, perhaps more importantly, suggest that a simpler, less intensive, and more cost effective treatment yielded similar (and in the case of decoding skills, better) outcomes. However, the results must be interpreted cautiously because of the small and circumscribed sample selected for the study.

Troia and Whitney (in press) conducted another independent experimental evaluation of the efficacy of FFW for a group of elementary-age children referred for poor achievement. Twenty-five students between the ages of six and 12 participated in the FFW program for about two months while 12 other children, matched for grade, IQ, and special education eligibility, served as a no-contact control group. The children in the FFW group outperformed their peers in verbal expression and, when the weakest students in both groups were compared, in syllable and sound blending and reduction of problem behavior ratings. Thus, FFW had a substantial, albeit limited impact on children's oral language skills, academic performance, and social behaviors. Interestingly, Troia and Whitney did not find an aptitude-treatment interaction for their sample, possibly because the students performed well within the average range on most of the dependent measures before beginning the FFW program. The results from this study must be considered in the context of three serious design limitations. First, the sample of elementary school students was not representative of the population of children with disabilities for which FFW is intended. Second, participants were not randomly assigned to treatment conditions and attempts to match students were not completely successful. Third, a sizable number of students in the study never advanced to training levels at which the synthesized speech approximated normal rate and amplification characteristics and, consequently, they may not have been able to achieve demonstrable improvements in oral and written language.

In a separate study with migrant Spanish-speaking students in grades one through six, Troia (submitted) found that, except on a measure of sight word recognition where children in a FFW treatment group achieved a significantly greater gain than those in a no-contact control group, pretest to posttest changes in test scores for English language proficiency, oral language competence, phonological awareness, decoding and reading comprehension, and classroom behavior were equivalent for the two groups. However, when students who were least fluent in spoken English in each group were compared, the children in the treatment group demonstrated superior gains in expressive language, sight word recognition, and pseudoword decoding. Once again, FFW seemed to have a substantial but limited impact on the oral language skills and reading performance of children in the study. In this study, random assignment was used for a majority of the participants, but successful exercise completion with diminished acoustic modification was only a little more than 60%.

The studies conducted by Troia and his colleagues suggest that FFW benefits children with the weakest oral language abilities the most, a finding not in conflict with other research in which children with RD received speech discrimination training using acoustic signal modifications that affected the temporal envelope of the stimuli (cf. Habib et al., 1999; Hurford, 1990; Hurford & Sanders, 1990; McAnally et al., 1997). In both of his studies, though, a comparison was made between a FFW treatment group and a group that did not receive any special auditory perceptual training or additional language comprehension instruction (a limitation shared with some of the studies conducted by the program developers), so Hawthorne effects could not be ruled out. In the study conducted by Hook and her colleagues (2001), the effects of FFW were no greater than those obtained with a more traditional intervention program that involved no manipulation of the acoustic parameters of training stimuli. Finally, little is known about the "active ingredients" of FFW because a number of instructional variables (e.g., multiple language remediation exercises, variations in program length, intensity, and completion for individual students, and separate acoustical modifications) are confounded. As such, evidence supporting the effectiveness of FFW, a program based on the premise that some children with disabilities exhibit auditory temporal processing deficits, does not necessarily validate the existence of such problems. In all, the intervention research in this area is inconclusive and perhaps a bit premature; we need a better grasp of the nature of temporal processing and its relationships with cognitive and linguistic skills required for literacy achievement.

Gary Troia, Ph.D., *is assistant professor in the College of Education at the University of Washington. He specializes in literacy assessment and instruction for at-risk learners and children with high-incidence disabilities. His current research focuses on writing strategy instruction for elementary and middle school students and the development of a comprehensive metaphonological skills curriculum for preschoolers with oral language impairments.*

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Table 1 Intervention Studies for Children Using Acoustically Modified Speech.

	Habib et al. (1999)	Hook et al. (2001)	Hurford (1990)
Participants			
Experimental Comparison	Six 10-12-year-olds with RD None	Eleven 7-12-year-olds with RD Nine 7-12-year-olds with RD	Eighteen 2nd and 3rd graders with RD None
Control	Six 10-12-year-olds with RD All children were French-speaking Groups were matched for pretest phonological awareness, "educational," and "cognitive" levels	Eleven 7-12-year-olds with RD Groups were matched for age, IQ, word reading, and phonological awareness using WISC-III, WRMT-R, and the LAC	Eighteen 2nd and 3rd graders with RD Groups were matched for age, reading ability, and phoneme deletion in real and pseudowords
Acoustic Modification	Transitions within words amplified Rate of presentation slowed by constant factor for stimulus (up to 2) Gradual normalization over period	Transitions within words amplified Transitions within words slowed Gradual normalization over period	ISIs were progressively shortened from 400 to 10 ms (criterion was set at 8 consecutive correct at 10 ms/>24 correct at ISIs<80ms
Treatment Exercises	Rhyme oddity identification using real and pseudowords for both groups	Experimental group received FFW Comparison group received OG phonics	Phoneme discrimination for vowels and CV syllables for both groups
Treatment Period	5 weeks	Approximately two months	3-4 days
Treatment Intensity	5 hours/week	8.3 hours/week for experimental group 5 hours/week for comparison group	30-45 minutes/day
Outcome Measures	Same as treatment exercise but novel Stimuli (experimenter developed)	LAC (phonological awareness) WRMT-R (word identification, word attack, and passage comprehension) TWS-3 (spelling) TOLD/TOAL (spoken language comprehension and production) RAN/RAS (rapid naming) WJ-R Numbers Reversed (working memory)	Phoneme deletion in real and pseudowords (experimenter developed)
Findings	Experimental group made significant gains while the control group did not Gains were maintained one month later Gains approached performance levels of normal readers	OG group improved more than FFW group in word attack Neither group made significant gains in word identification FFW and OG made similar gains on LAC FFW and control group made similar immediate and long-term (2 years) gains on LAC, all reading measures, and spelling The FFW group made greater immediate gains in spoken language and rapid naming, but these were not maintained Neither group made significant long-term gains in spoken language or working memory	Experimental group made significantly greater gains than control group regardless of grade Third graders with RD who received training performed similarly to a group of normal readers, but second graders with RD who received training still displayed inferior performance in comparison with second graders without RD

	Hurford & Sanders. (1990)	Troia (submitted)	Troia & Whitney (in press)
Participants			
Experimental	Thirteen 2nd graders and 4 4th graders with RD	Ninety-nine 1st-6th graders	Twenty-five 1st-6th graders in Title 1 or Learning Assistance Program
Comparison	Eleven 2nd graders and 4 4th graders with RD	None	None
Control	Thirteen 2nd graders and 14 4th graders without RD Groups were matched for age, reading level, and pretest visual and CV practice discrimination trials	Ninety-two 1st-6th graders All children were native Spanish speakers in migrant education Groups were matched for grade, IQ, and English language proficiency or were randomly assigned	twelve 1st-6th graders in Title 1 or Learning Assistance Program Groups matched for grade, IQ, and special education eligibility
Acoustic Modification	ISIs were progressively shortened from 400 to 10 ms for vowel, CV syllable, and tone pairs	Transitions within words amplified Transitions within words slowed Gradual normalization over period	Transitions within words amplified Transitions within words slowed Gradual normalization over period
Treatment Exercises	For the experimental group, phoneme discrimination for vowels, CV syllables with liquids and nasals, and CV syllables with stop plosives, in that order For the comparison treatment group, tone pairs were used	Experimental group received FFW	Experimental group received FFW
Treatment Period	3-4 days	Approximately 8 weeks	Approximately 10 weeks
Treatment Intensity	30-45 minutes/day	Approximately 8.3 hours/week	Approximately 8.3 hours/week
Outcome Measures	CV syllable discriminationusing near and far transfer items (experimenter developed)	LAS/WMLS (English proficiency) OWLS (spoken language comprehension and production) WJ-R Sound Blending/LAC/ experimental rhyme production and phoneme segmentation tasks (phonological awareness) WJ-R (word identification and word attack) SSRS (social skills and behavior)	OWLS (spoken language comprehension and production) CTOPP (phonological awareness, rapid naming, and working memory) WJ-R (word identification and word attack) SSRS (social skills and behavior)
Findings	Experimental group made significantly greater gains than comparison group regardless of grade Comparison group performed similarly at pretest and posttest Children with RD in experimental group performed like average readers Experimental group's performance similar on near and far transfer items	Experimental group made significantly larger gains in word identification than control group Children in the lowest quartile who received FFW made greater gains on most measures than those in the highest quartile Children least fluent in English in the experimental group made significantly greater gains in word identification, word attack, and spoken language than children least fluent in English in the control group	Experimental group made significantly greater gains in spoken language production than control group Children in the lowest quartile of the experimental group made significantly greater gains in phonological awareness (blending) and reduction of problem behaviors than children in the lowest quartile of the control group