Backward and Simultaneous Masking Measured in Children With Language-Learning Impairments Who Received Intervention With Fast ForWord or Laureate Learning Systems Software

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The developers of a computer-assisted language intervention program called Fast ForWord (FFW) have claimed that their software changes temporal processing abilities as a result of specialized modifications to the acoustic and temporal properties of the speech signal within the program. This pilot study compared changes in auditory temporal processing in children who received FFW training and in children who received training with computer-assisted language intervention programs that were not designed to improve auditory perceptual skills. Four boys with Language-Learning Impairments (LLI) and 3 boys with typical language participated. Two of the boys with LLI received the FFW program, and the other 2 received a bundle of computer-assisted instruction (CAI) programs published by Laureate Language Systems (LLS). The FFW and LLS programs were presented on the same schedule.

To assess temporal processing, signal thresholds in backward and simultaneous masking conditions were evaluated just before, during, and immediately after language training. The boys with typically developing language received no training. Children with typical language produced signal thresholds in the backward masking condition that were markedly lower than those in the simultaneous masking condition. This disparity is indicative of normal temporal processing. Conversely, 3 of 4 children with LLI failed to demonstrate a simultaneous-backward difference during baseline. The lack of a difference implies that temporal processing was not normal in these children. The fourth child with LLI had signal thresholds that paralleled those of the children with normal language development. This child also had the mildest form of LLI.

Of the 3 children whose temporal processing was abnormal, 2 boys showed decreased signal thresholds in the backward masking condition. However, the improvement was sudden, occurring relatively early in the training sequence, and observed with both treatment programs. The third child with abnormal temporal processing failed to show a change in backward masking at any time during treatment. Over the course of the experiment, signal thresholds for *all* listeners decreased by similar amounts in both backward and simultaneous masking. Taken together, these results do not support the presence of a program-specific improvement in temporal processing. In addition to the temporal processing deficits revealed by backward masking, group differences in response patterns implicate auditory memory involvement or differences in maintaining attention.

Key Words: auditory processing, language-learning impairment, auditory memory, auditory training, temporal masking

Children with LLI often present auditory processing deficits (Worster-Drought & Allen, 1929). In fact, numerous attempts have been made to identify these deficits as the primary cause of LLI (Eisenson, 1972; Elliott & Hammer, 1993; Stark & Tallal, 1988; Tallal et al., 1996; Tallal, Miller, & Fitch, 1993; Tallal & Piercy, 1973; Tallal, Stark, Kallman, & Mellits, 1981). A consistent interpretation has been that children with LLI perform significantly worse than age-matched peers with typically developing language on tasks requiring discrimination of brief sounds (Elliott & Hammer, 1993; Elliott, Hammer, & Scholl, 1989; Tallal, 1990).

A recent study of temporal masking has extended these earlier findings. Temporal masking refers to the position in time of a target sound (the signal) relative to that of a nontarget sound (the masker). The basic conditions of temporal masking are backward masking (the signal precedes the masker), simultaneous masking (the signal and masker occur together), and forward masking (the signal follows the masker). People with temporal processing problems often have difficulty distinguishing the signal from the masker when they are presented very close together in time. They can compensate for this weakness when the signal is presented at a suitably intense level. Therefore, elevated signal thresholds in backward and forward masking conditions are thought to reflect difficulties with temporal processing. For example, Wright et al. (1997) reported that children with LLI had significantly higher (poorer) signal thresholds than their age-matched peers, but only in the backward masking condition. Their thresholds in simultaneous and forward masking were similar to those of unimpaired controls, indicating that children with LLI did not have a temporal processing deficit in a general sense. Even so, finding that backward masking differentiates children with LLI suggests that some of these children may have a specific form of an auditory temporal processing deficit.

Various strategies have been developed to treat language disorders. Computer-based training programs have emerged recently and are receiving considerable attention. One such program is called Fast ForWord (FFW; Scientific Learning Corporation [SLC], 1998). As noted in the introductory article (Friel-Patti, Frome Loeb, & Gillam, 2001, this issue), FFW is designed to train temporal processing, speech perception, and language comprehension skills. The developers of FFW incorporated acoustically modified speech into their program with the idea that these modifications would facilitate retraining the brain to process temporal aspects of speech more effectively (Merzenich et al., 1996; Merzenich et al., 1999; Tallal et al., 1996). The primary hypothesis was that if children's LLIs resulted from a generalized temporal processing deficit, improving temporal processing skills would result in improved language skills

Laureate Learning Systems publishes computer intervention programs for children and adults with special language-learning needs. One important difference between the LLS programs and FFW is that the LLS software does not contain modified speech. Therefore, it was not specifically designed to improve auditory processing.

The present investigation was part of a pilot project designed to compare the language outcomes of children who received LLS and FFW treatment (Gillam, Crofford, Gale, & Hoffman, 2001, this issue). Our primary goal was to investigate changes in the auditory processing abilities of children who received the two computer-based language programs. If the modified component of FFW led to improvement in temporal processing abilities of children with LLI, then we would expect children who received FFW training to demonstrate improved backward masking thresholds after training. Further, because the LLS programs do not contain modified speech and were not designed to improve temporal processing, children with LLI who received LLS training should not demonstrate changes on these same measures. Data from 4 children with LLI are reported: 2 received FFW training and 2 received a subset of LLS programs delivered on the FFW schedule.

In addition, this preliminary study was designed to replicate the finding by Wright et al. (1997) that children with LLI had poorer thresholds in backward masking conditions than children with normally developing language. Three children with normally developing language served as a no-treatment control group. These children were tested on the same schedule as the children with LLI, but they received no formal language training during the study.

Method

Participants

Seven boys, between the ages of 6;10 and 9;3 (years; months), participated in the study (Table 1). Four of the participants had LLI and had been previously diagnosed as language-learning impaired by licensed speech-language pathologists. Three of the boys with LLI, 2 of whom were monozygotic (identical) twins, participated in the study reported by Gillam, Crofford, Gale, & Hoffman (2001, this issue). One child in the Gillam et al. study could not be included in this investigation because of scheduling conflicts. He was replaced by FFW 1, who had been referred for FFW treatment by a neuropsychologist whose

TABLE 1. Participant comparisons for boys with LLI who received Fast ForWord (FFW 1, FFW 2) and Laureate Learning System (LLS 1, LLS 2) training and boys with normally developing language (NDL 1, NDL 2, NDL 3).

	FFW 1	FFW 2	LLS 1	LLS 2	NDL 1	NDL 2	NDL 3
Chronological age	7;0	6;11	7;5	6;11	6;10	9;3	7;2
OWLS Listening Comprehension Scale—Standard Scores	94	76	82	70			
OWLS Oral Expression Scale—Standard Scores	111	70	70	72			
OWLS Composite Scores	102	71	74	69			
TONI Composite Scores	99	11	83	102			

Note. OWLS = Oral and Written Language Scales; TONI = Test of Nonverbal Intelligence–2 (Brown, Sherbenou, & Johnson, 1997).

testing revealed auditory processing and memory problems that interfered with learning in classroom situations. This child attended a school for children with communication disorders, and his parents and teachers were concerned that his difficulties with auditory processing were interfering with classroom communication and literacy abilities. FFW 1 did not score below normal limits on the Listening Comprehension and Oral Expression scales of the Oral and Written Language Scales (OWLS; Carrow-Woolfolk, 1995), but his profile was not dissimilar from that of some participants in the FFW field trial (Tallal & Merzenich, 1997).

Three boys with typically developing language were recruited by parent and teacher report of grade-appropriate expressive and receptive language performance. One of the boys with normally developing language was approximately 2 years older than the other 6 participants. Buss, Hall, Grose, and Dev (1999) found that children between the ages of 5 and 11 years did not differ on simultaneous and backward masking measures. Since the no-treatment control group was included to evaluate potential changes in auditory temporal processing without treatment, the age difference for one control child was not expected to be a confounding factor.

All children passed a hearing screening in both ears at the time of testing (level = 20 dB HL; frequencies = 500–4000 Hz in octave intervals). According to parental report, none of the children had physical, motor, or emotional impairments or had been treated for otitis media for a year before participating in this study.

Stimuli and Listening Conditions

The signal was a brief 1 kHz tone with an overall duration of 20 ms as measured from onset to offset at the zero voltage point. The signal envelope was shaped with a gating function (cosine-squared) that produced rise and fall times of 10 ms with no plateau. The starting phase of the signal was fixed at 0°.

The masker was a narrow-band noise that extended from 0.6 to 1.4 kHz. Beyond the two cutoff frequencies, the masker level decreased at the rate of –96 dB/octave. The overall duration of the masker was 300 ms, and its envelope was shaped with a gating function that included 10-ms rise/falls. The pressure spectrum level of the masker was about 42 dB/Hz (overall level = 71 dB SPL).

All stimuli were generated digitally via a high-speed array processor (TDT, AP2). The signal was created in the time domain using a sampling frequency of 50 kHz. The masker was initially synthesized in the frequency domain using an 8192-point buffer. This buffer was then converted to the time domain via inverse Fourier transformation. The signal and masker were played through separate channels of a digital-to-analog converter (TDT, DD1). The signal and masker were low-pass filtered to prevent aliasing (Stewart filters, VBF34 [cutoff frequency = 5.0 kHz]). The signal was routed to a programmable attenuator (TDT, PA4) and then to one input of an adder (TDT, SM3) while the masker was connected to a second input of the adder. The signal and masker were added together, the output was routed to a headphone buffer (TDT, HB5), and the stimuli were delivered to a single earphone (Etymotic, ER-3A insert type).

There were three listening conditions. The masker and signal were presented together in two conditions (backward or simultaneous masking), whereas the signal was presented by itself (quiet) in the third condition. In backward masking, the signal preceded the masker, so these stimuli did not overlap in time. Specifically, the negatively sloped offset of the signal envelope (ending at a zero voltage point) was coincident with the positively sloped onset of the masker envelope (beginning with a zero voltage point), creating a triangular perceptual window that we will refer to as a “pause.” In simultaneous masking, the onset of both the signal and the masker were synchronous; therefore, these stimuli overlapped in time. In the signal-in-quiet condition, the masker channel was unplugged so that only the signal was presented.

Treatment Conditions

The four boys with LLI participated in a 4-week language intervention program. Two children received training with FFW, and 2 received training with a bundle of seven programs published by LLS. The computer-based language programs are described in detail in Friel-Patti, Frome Loeb, and Gillam (2001, this issue) and Gillam, Crofford, Gale, and Hoffman (2001, this issue). As noted by Gillam et al., one important difference between the two computer intervention programs is that FFW used modified speech as auditory stimuli in each of the seven exercises. None of the programs in the LLS bundle employed modified speech stimuli.

Each boy, accompanied by a parent, came to the University of Texas (UT) Speech and Hearing Center 5 days per week. The daily session consisted of five exercises, each lasting for a minimum of 15 minutes and a maximum of 20 minutes. During that time, the boy worked on the computer-based training program under the supervision of a speech-language pathologist.

We set a mastery criterion of 90% completion on five of seven exercises in both the FFW and LLS conditions. None of the children in either treatment condition reached this criterion after 20 days of training. The 2 children who received FFW both had the least success on the Circus Sequence exercise, which was specifically designed to improve temporal processing. The 2 children who received the bundle of LLS programs differed with respect to the exercises that were problematic for them. One child (LLS 1) reached less than 50% completion on two programs that were designed to improve auditory memory (Following Directions and Concentrate). The other child (LLS 2) reached criterion on those programs but struggled with a program that focused on verb tenses (*swim*, *swam*, *swum*) and a program that focused on vocabulary and categorization skills (Twenty Categories). Nonetheless, following the treatment period, 3 of the 4 children made significant gains on the OWLS as demonstrated by posttest scores that were higher than the 95% confidence interval of the pretest scores. One child

(FFW 1) did not present significant gains on the OWLS.

Children in the no treatment condition came to the UT Speech and Hearing Center for a baseline session and four weekly visits. The no-treatment control children attended regular education classes during the study.

Procedure

The dependent variable was the listener's threshold. To estimate each child's signal threshold in the three listening conditions (signal in quiet, simultaneous masking, and backward masking), a three-interval three-alternative forced-choice paradigm (3I3AFC) was used. This procedure estimated the signal level required to produce 69.1% correct response (Levitt, 1971).

A series of listening trials (known as a run) was administered. On each trial the signal was randomly presented in one of three observation intervals. The observation intervals were 350 ms in duration and were separated by 500 ms. Following the third interval, the listener indicated which interval contained the signal. The intensity of the next signal was automatically adjusted based on the listener's response. The signal became more intense by 2 dB after each incorrect response and less intense by the same amount after three consecutive correct responses. The sequence then repeated with the presentation of another trial. Over the course of a run, the signal level decreased and increased numerous times. A reversal occurred when the signal level changed direction (i.e., from decreasing to increasing intensity or vice versa). The signal level at each reversal was automatically recorded, and the participant's threshold was estimated by calculating the arithmetic mean of the last 10 reversals in a run.

The testing procedure consisted of five signal threshold estimates. The first was called "baseline" and included the hearing screening, language testing, and the initial measures on each of the three listening conditions. Signal thresholds elicited during baseline were the mean of three listening trials. Two of the boys (one from each training program) completed baseline testing in a single session. The other two boys required two sessions, which were conducted on consecutive days.

The first probe occurred about 10 days after baseline; subsequent probes took place at weekly intervals thereafter. These sessions were brief (about 10 minutes long) because only one run for each condition of backward and simultaneous masking was completed. Probe 4 occurred approximately 5 weeks after baseline. This period corresponded to the length of treatment received by the children with LLI. Probe 4 was identical to baseline except that only one run was completed per condition.

During testing, the listener sat in front of a computer console that was located in a quiet room. (The ambient noise level in the room was less than 47 dB SPL as measured with a sound-level meter that was equipped with an octave-band filter [center frequency = 1.0 kHz].) Three colorful pictures, one corresponding to each of the listening intervals, were positioned on the computer screen. The examiner explained there would be three intervals. The child should listen carefully during each one, trying to find the sound that was *different*. After listening, he should indicate his choice by clicking the mouse pointer on the appropriate picture. Children received immediate feedback. A colorful picture appeared on the screen after correct responses, and a black and white picture appeared after incorrect responses.

Following the verbal instructions, the experimenter provided a sample signal via a small loudspeaker. The level of the signal was increased, as necessary, until the listener responded correctly. The listener was then given the opportunity to perform several (5–7) practice trials on his own. When the experimenter was convinced that the child understood the task, the earphone was positioned and several more practice trials were completed. The training run was then terminated and a test run was begun.

This sequence (training followed by testing) was used for each of the three listening conditions. The condition order was counterbalanced across listeners to control for order effects. During testing, the experimenter sat behind the listener and did not provide any assistance. An experimental run ended after 10 reversals or after 60 trials, whichever occurred first. Invoking the 60-trials rule usually meant the signal level was too high initially. In these rare cases, the level was decreased and the run was repeated. Listeners received verbal encouragement and a tangible reward upon successful completion of each run. Rest breaks were taken as needed. All listening was done monaurally with the right ear.

Results

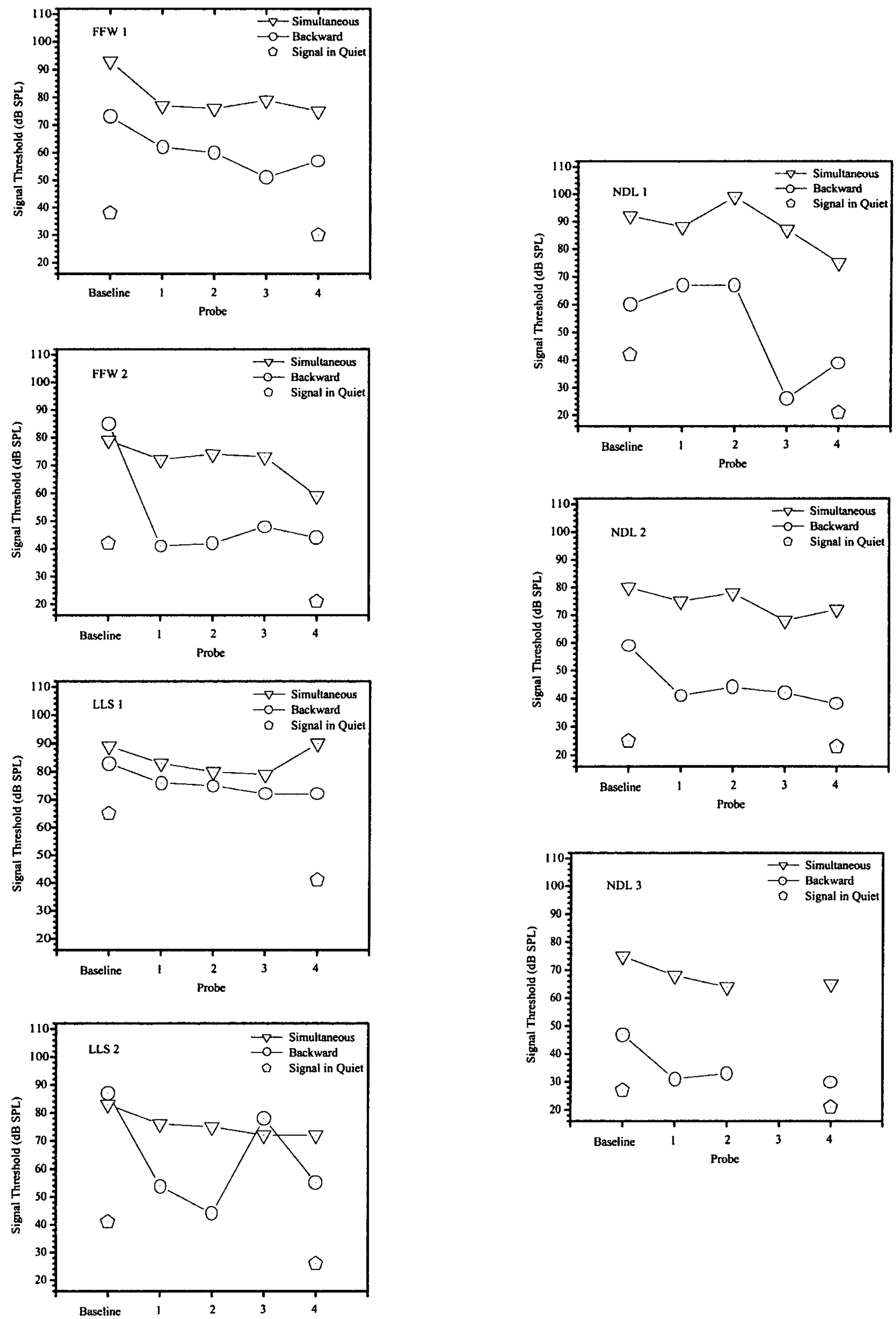
Quiet Thresholds

Signal threshold for each listener was measured in quiet (i.e., the masker was not present). This step was undertaken for two reasons. First, we wanted to confirm that the psychophysical task was not too difficult. In fact, all 7 listeners were able to perform the task using the training technique described in the Method section. Second, we wanted to establish that the hearing threshold for the test signal was within normal limits. During baseline testing, signal thresholds for 6 out of 7 listeners fell within the normal range, given the brief duration of the signal.[1] The signal threshold for 1 of the children with LLI remained elevated even after reinstruction. It should be noted that this child had passed a hearing screening at 20 dB HL earlier in the session; therefore, it is unlikely that the elevated threshold was due to the presence of pathology.

Signal threshold was measured in quiet at the beginning and again at the end of the experiment. This provided an opportunity to observe practice effects. In this context, a "practice effect" is defined as the decrease in signal threshold over time. The results are plotted in Figure 1, where each graph depicts the thresholds for an individual

[1] The upper limit of normal hearing for the brief, 1-kHz signal was extrapolated from the reference equivalent sound pressure level for a 1-s tone delivered via an insert-type earphone (ANSI S3.6, 1996). The extrapolation assumes an effective duration of 10 ms, perfect integration of power over time, and a 20-dB upper limit for normal hearing.

FIGURE 1. Signal threshold measured in the quiet (pentagons), simultaneous masking (triangles), and backward masking (circles) conditions during baseline and probe sessions. Graphs in the left column are from individual listeners with language-learning impairment who received language training. Listeners FFW 1 and FFW 2 participated in the Fast ForWord program; listeners LLS 1 and LLS 2 participated in programs from Laureate Learning Systems. Graphs in the right column are from individual listeners with typical language; they did not receive any language training.



participant. The graphs in the left column are for the listeners who received treatment, and the graphs in the right column are for those who did not. In the left column, the top two graphs show the results for the 2 boys who received FFW training; the bottom two graphs depict the results for the 2 boys who received training with the LLS.

The seven graphs reveal that, during the final probe, all participants produced signal thresholds in quiet (pentagons) that were lower than those measured during baseline. The average decrease in signal threshold per participant was about 13 dB. Because quiet thresholds were not measured during the treatment phase, it is impossible to determine the specific time course of the practice effect.

Masked Thresholds

In Figure 1, signal thresholds in simultaneous and backward masking are plotted by session for individual listeners. Within each graph, the triangles and circles indicate signal thresholds for simultaneous and backward masking, respectively. Signal thresholds measured during the baseline are based on the average of three threshold estimates. Signal thresholds obtained in the probe sessions are based on a single estimate.

The 3 listeners with normally developing language (NDL1, NDL2, NDL3) show similar patterns, and their results are considered together. The graphs in the right column of Figure 1 reveal that signal thresholds in simultaneous masking are higher than thresholds in backward masking. Additionally, the trend is for signal thresholds in both simultaneous and backward masking to decrease over time.

Because there is no obvious pattern for the listeners with LLI, their results are examined separately. Participant FFW 1 (left column, top graph) received the FFW treatment. His signal thresholds in both simultaneous and backward masking were essentially the same as those measured for the normal listeners. Specifically, signal thresholds in simultaneous masking were about 25 dB higher than those obtained in backward masking, and they decreased over time. This listener was the least impaired of the children with LLI, and his masking data closely paralleled those of the children with normally developing language.

Participant FFW 2 (left column, second graph from top) also participated in the FFW program. His thresholds during baseline were consistent with the general pattern of masking reported by Wright et al. (1997) for children with LLI. Namely, signal thresholds in backward masking were elevated so that they matched those in simultaneous masking (i.e., there was no difference between simultaneous and backward masking). In fact, during baseline testing, FFW 2's signal threshold in backward masking was slightly higher than his threshold in simultaneous masking. This pattern was never observed in children with normally developing language. Once treatment was initiated, the signal threshold in backward masking decreased precipitously, and the familiar difference between signal thresholds in simultaneous and backward masking emerged. Following the sudden decrease, signal thresholds in backward masking did not change appreciably over time, whereas signal thresholds in simultaneous masking decreased gradually.

Participant LLS 1 (left column, second graph from bottom) received training with the Laureate programs. The signal threshold in backward masking was lower than that in simultaneous masking, but the difference (6 dB) is much smaller than that typically seen in children with normally developing language. The trend was for signal thresholds in both simultaneous and backward masking to decrease at the same rate, so the small difference between simultaneous and backward masking was maintained across sessions.

Participant LLS 2 (left column, bottom graph) also received treatment with the LLS programs. During baseline, there was essentially no difference between signal thresholds measured in simultaneous and backward masking. This pattern was consistent with the results of Wright et al. (1997) for children with LLI. Like FFW 2, this listener experienced a marked decrease in signal threshold in backward masking immediately after treatment began. With the exception of Probe 3, the separation of simultaneous and backward masking curves seen in most normally developing children and adults persisted over time.

Correct Responses by Observation Interval

To investigate the possibility that factors other than temporal processing influenced these children's performance, the rate (in percent) of correct response for the three observation intervals was examined for each experimental condition. Table 2 shows the mean percent correct for 3 boys with LLI versus the 3 boys with normally

TABLE 2. Mean percent correct responses (and standard deviations) across observation intervals for three experimental conditions.

	Observation Interval					
	LLI			NDL		
Experimental Condition	1	2	3	1	2	3
Signal in quiet	83 (10)	81 (11)	85 (10)	86 (10)	90 (2)	89 (5)
Simultaneous Masking	65 (9)	77 (6)	80 (5)	85 (2)	80 (7)	85 (2)
Backward Masking	63 (6)	82 (6)	85 (5)	83 (10)	86 (5)	87 (5)

developing language (data for the seventh participant are not available).

In the signal-in-quiet condition, both participant groups had similar mean correct responses across the three observation intervals. In simultaneous masking, the NDL group maintained a high percentage of correct responses (80%–85%) across the three observation intervals. However, the LLI group responded correctly less often (65%) when the signal occurred in Interval 1 than they did when the signal occurred in Interval 2 (77%) or Interval 3 (80%). This pattern persisted in the backward masking, where the difference in percent correct between Intervals 1 and 2 was approximately 20 points, a large effect size of 1.2. The NDL group maintained equivalent accuracy in backward masking across the three observation intervals. Thus, it is likely that attention and memory factors contributed to the backward masking results.

Discussion

Auditory Temporal Processing and LLI

In adults with normal hearing, signal thresholds typically are higher in simultaneous masking than in backward masking (e.g., Duifhuis, 1973; Elliott, 1962). This suggests that listeners are able to take advantage of the brief temporal separation (triangular pauses) that occurs between the signal and masker in backward masking. Listeners who resolve the separation between signal and masker effectively earn better (lower) thresholds in backward masking than in simultaneous masking, where there is no separation. Therefore, one estimate of auditory temporal processing is based on the difference between thresholds measured in simultaneous versus backward masking, where a large difference is indicative of good temporal processing.

In the present study, children with normal language development obtained signal thresholds in simultaneous masking that were higher than those found in backward masking. Our results agree with those reported by Wright et al. (1997), who made similar measurements in children with normal language development. Additionally, we found that the difference between signal thresholds in simultaneous and backward masking was approximately 30 dB for the children with normal language development. This value agrees with the average difference typically found in adults when using comparable signals and maskers (e.g., Elliott, 1971). Therefore, the temporal processing ability (at least as we have defined it) of children with normal language development was considered to be adult-like. Notice also that improvements in threshold levels over time are roughly equivalent for all three listening conditions, suggesting learning effects over time. We will return to this topic later in the discussion.

Although the pattern is less clear in children with LLI, certain trends are apparent. During baseline testing, 3 of 4 children failed to show the characteristic difference between simultaneous and backward masking seen in normally developing children and adults. These children had normal signal thresholds in simultaneous masking, but their thresholds in backward masking were higher than normal, resulting in very little gap between the simultaneous and backward masking thresholds at the beginning of our study. Wright et al. (1997) reported similar findings for children with LLI.

It must be pointed out that Bishop et al. (1999) and Thibodeau, Friel-Patti, and Britt (2001, this issue) did not find a difference between language-impaired and control groups on a backward masking task. The reasons for the discrepancy are unclear. Bishop et al. used a masker level that was 10 dB lower than ours. Because the amount of backward masking is directly related to masker level (Elliott, 1971), it is possible that the level used by Bishop et al. was not intense enough to allow sufficient backward masking. Additionally, their participants were somewhat older than ours. Buss et al. (1999) reported a trend toward improved thresholds on backward masking in older children, but the amount of improvement did not reach statistically significant levels.

Although the experimental runs and stimuli were identical to those used in the Thibodeau et al. study, there were procedural differences in data collection and the language measures that were used. In our study, the group-averaged standard scores on the OWLS Listening Comprehension and Oral Expressive scales were both 81. In the Thibodeau et al. study (2001, this issue), two children received a version of the Test of Oral Language Development–Primary (TOLD-P:3 or TOLD-P:2). They received Listening Quotient standard scores of 109 and 91 and Speaking Quotient standard scores of 93 and 79. Three other children in the Thibodeau et al. study received the OWLS. These children's mean Listening Comprehension and Oral Expressive scale standard scores were 89 and 83, respectively. These results suggest that the children in our study were more language-impaired than those in the Thibodeau et al. study. Elliott and Hammer (1993) found that children with language-learning problems performed more poorly on auditory discrimination tasks than children with normally developing language. There was a predictive relationship between auditory discrimination and the degree of language competency in the children who participated in their study. The population of children with LLI is heterogeneous, and subgroups may exist that can be classified according to severity. Given this scenario, equivocal results between our study and the Thibodeau et. al. study could be the result of sampling differences.

The elevated thresholds in backward masking suggest that 3 of the children with LLI were unable to resolve the triangular interval between the signal and masker before they began treatment. A fourth child in the language impaired group (FFW 1) performed normally on a standard language test (see Table 1). If the simultaneous-backward difference reflects auditory temporal processing and if temporal processing ability relates to language competence, one would expect to find a relatively large simultaneous-backward difference for FFW 1, given that his language abilities were well within the normal range. FFW 1's results conform to this expectation. This child had been referred for the FFW program by a local neuropsychologist because of difficulties on memory testing and auditory processing screening. Given his performance on our psychoacoustic testing, he may not have had temporal auditory processing difficulties, or the simultaneous-backward difference may not have been sufficiently sensitive to detect subtle forms of auditory processing and memory impairments.

One boy (LLS 1) showed little change in the simultaneous-backward difference during treatment except on the final probe, where the magnitude of the difference increased. It is worth noting that the increase in the difference resulted from a change in simultaneous masking rather than backward masking. This participant received LLS training. It is clear that the treatment failed to effect a marked change in auditory temporal acuity. However, this child's Oral Expression scale and Composite scores on the OWLS improved by approximately 1 standard deviation, and his mean length of utterance (a general measure of language development) improved from a mean of 4.78 before treatment to a mean of 5.44 after treatment, an individual effect size of .99. In this case, improvements in language ability did not appear to be accompanied by improvements on our psychoacoustic task.

Two of the boys with LLI (FFW 2 and LLS 2), who happened to be identical twins, had improved (lower) thresholds in backward masking during treatment. These children also had very similar improvements on the OWLS and MLU. The critical question, of course, is whether the language-training program produced the impressive decrease in backward masking thresholds, which then produced the changes in language ability. At least three lines of evidence argue against a compelling treatment effect. One reason is that the improvement was rather abrupt. Sudden decreases in signal threshold have been reported in the psychophysical literature (e.g., Leek & Watson, 1984; Neff & Dethlefs, 1995). Such changes usually occur in the absence of any instruction from the experimenter. The participant, after listening to many presentations of the signal, spontaneously learns which cue permits maximum detectability.

Another argument against a treatment effect is that the improvement occurred very soon after training began. The children participated in six or seven intervention sessions before the administration of the first probe after baseline. It is possible that 1 week of training is all that was required to produce an improvement in backward masking. However, neither of these children had progressed very far on the computerized language intervention programs after the first week of training.

Finally, the decrease in backward masking was independent of the type of treatment the boys received. One child received FFW training, and the other received training with a bundle of programs published by LLS. Since FFW was designed to improve temporal processing skills, whereas the LLS bundle was designed to improve memory, vocabulary, and syntax, it is unlikely that both programs would effect a change in backward masking at essentially identical points in the training sequence. Although signal thresholds in backward masking decreased for FFW 2 and LLS 2, an easily perceived unequivocal relationship (allowing no misunderstanding) between this improvement and the computer-based training was not observed.

Practice and Task Effects

There was one pattern in the results that persisted across participant groups, listening conditions, and treatment programs. Specifically, signal threshold tended to decrease (improve) across the test sessions. We usually refer to such improvements as "practice effects" when they are present universally and continue over time. Presumably, practice effects result from increased familiarity with the listening task. It is important to look for practice effects so that the efficacy of a treatment is not overestimated.

A review of signal threshold change across sessions shows that the *type* of improvement is a distinguishing factor between the two groups. The three children with normally developing language had their lowest thresholds at the time of the final probe; the children with LLI did not. Even when excluding the data from FFW 1, the other children with LLI demonstrated more threshold variability across sessions than the children with normally developing language. The fourth and fifth probes did not typically represent their best thresholds. Bishop et al. (1999) reported a similar pattern of deteriorating thresholds with continued training in children with LLI, whereas children with normally developing language showed a more stabilized learning curve. Such performance patterns in children with LLI imply the possibility that some aspect of the task (e.g., auditory memory or attentional load) independent of temporal auditory processing may be critical.

Psychoacoustic tasks may make nonauditory demands on listeners that can overshadow masking effects under experimental investigation (Bishop et al., 1999; Hirsh & Watson, 1996). Bishop et al. (1999) demonstrated the importance of understanding such performance effects. They used two methods of threshold estimation: a two-interval, two-alternative, forced-choice paradigm (2I2AFC) and a three-interval, two-alternative, forced-choice paradigm (3I2AFC). A significant effect of test method was reported. Both groups of children had better (lower) thresholds with the 3I2AFC procedure. Bishop et al. attributed this difference to an increased processing load with the 2I2AFC. According to their argument, the 2I2AFC task requires the acoustic characteristics of each experimental interval to be encoded before the listener can make a correct identification. In the 3I2AFC task employed by Bishop et al., the masker occurred in all three intervals, but appeared with the signal in only the second or third interval. The child determined the presence or absence of the signal using a simpler discrimination of acoustic difference. That is different from the 2I2AFC task, which requires the child to fully process the acoustic differences of each stimulus across the two experimental intervals.

Bishop et al.'s results suggest that task complexity influences the estimation of threshold in *acoustic processing* tasks independent of masking ability. In the case of

Bishop et al., there was no effect of group, so the relationship between the two groups of children remained unchanged. However, if the impaired backward masking performance of the LLI group in the Wright et al. (1997) study was a function of task complexity rather than impaired or inefficient temporal auditory processing, it is conceivable that the two psychoacoustic tasks used by Bishop et al. may not have been demanding enough to reveal higher order impairments (e.g., auditory memory or attention load) that often accompany auditory perceptual impairments.

Computer-Based Language Programs and Backward Masking

The children with LLI in this study received one of two language intervention programs. One program (FFW) indirectly addressed language deficits by training auditory temporal discrimination. The developers of the FFW program assert that extensive, repetitive training with their modified speech stimuli results in substantial improvements in auditory temporal processing, approximating the performance of children with normally developing language (Merzenich et al., 1999). The other intervention (a bundle of seven programs published by LLS) treated LLI through memory, vocabulary, syntax, and narrative tasks. All the children in this study, including the boys with normally developing language, who did not receive any language intervention, demonstrated improved signal thresholds on *all* conditions. Three of the 4 children with LLI showed improved thresholds at the time of the final probe (the threshold of Participant LLS 1 remained unchanged). In addition, the improved backward masking thresholds of the 2 children participating in FFW remained higher (worse) than those of children in the control group, and the difference between the FFW and NDL groups remained relatively unchanged. The findings that signal threshold improvements occurred across all stimulus conditions suggest that increased familiarity with the psychophysical task, rather than exposure to computer-based instruction, was responsible for the changes. Our results indicate that improvement occurred in backward masking with computer-assisted language treatment, regardless of the presence or absence of modified speech. Additionally, improved thresholds in backward masking in children with LLI did not approximate those of the children with normally developing language, although many of the FFW exercises were specifically designed to enhance temporal processing.

Task Complexity

In the 3I3AFC paradigm used in this study, the signal occurred with equal probability in either of the three observation intervals. As discussed above, this arrangement carries a greater memory load than the Bishop et al. (1999) 3I2AFC task, where the signal occurred only in the final two intervals. In our study, when the signal occurred in Interval 1, the participant was required to hold the acoustic signal in memory during Intervals 2 and 3 (1000 ms) and then during the decision/response period. Informal observation of participant behaviors showed that, with decreasing signal intensity (increasing task difficulty), all participants seemed to take longer to choose the interval that contained the signal. Consequently, with decreasing signal intensity, there could be a significant increase in the response time between signal presentation and participant identification of signal interval.

We also included a signal-in-quiet condition with the brief duration signal. This condition was not present in either the Bishop et al. (1999) or Wright et al. (1997) study. It is possible to view the three experimental conditions as being graduated in terms of task difficulty. The signal-in-quiet condition was not a masking task. It was simply a detection of the signal, within our 3I3AFC procedure. A comparison of the percent correct responses across the three observation intervals revealed that both groups of children were equally proficient in detecting the presence of the signal regardless of the interval where it occurred. This condition failed to differentiate the children either by signal intensity or interval order.

Compared to listening in quiet, detecting a signal in the presence of a masker may be more challenging. The child must listen for the signal when there is competing acoustic information from the masker. We have already mentioned that both LLI and NDL groups had similar signal thresholds, and both groups demonstrated training effects for simultaneous masking. However, review of the percent correct responses for the three observation intervals reveals a somewhat different pattern for the two groups of children. Recall that children with LLI were less likely to detect the signal in the simultaneous masking condition if it occurred in the first interval. The backward masking task had the added demand of two signals (as in the simultaneous masking condition), but it also increased the overall processing load with the addition of the signal's temporal component (Buss et al., 1999). The same pattern was observed in the data for backward masking.

Our finding of decreased accuracy coupled with the failure of the simultaneous masking condition to distinguish the two groups provides further support for the argument that increased cognitive demand, independent of auditory processing, may have been a factor. Such a difficulty with either creation or retention of complex signals (e.g., representation of complex codes) has been previously hypothesized in children with LLI. Gillam, Cowan, and Marler (1998) hypothesized that, in these children, extra mental processing and increased processing time lead to decay of the mental representation of the stimulus. This decay would not necessarily result in the absence of signal processing. Rather, it would create an incomplete or "fuzzy" representation of the signal. Under these conditions, performance on tasks like backward masking could appear to reflect auditory processing deficits, when in fact it was processing capacity limitations that were actually being measured.

It is important to note that, even with training, the backward masking thresholds of children with LLI did not approach those of the children with NDL. Therefore, a true difference in auditory processing abilities between the two groups cannot be ruled out. We argue, however, that this difference cannot be attributed solely to a temporal processing deficit. Our results suggest that children with LLI may also have difficulty retaining the stimulus in memory.[2]

Limitations

This was a preliminary study with a small sample size that limited us to descriptive analyses. We do not assume that these results generalize to all children with LLI. We believe our results need to be corroborated before they can be considered compelling.[3] Two children, LLS 2 and FFW 2, received delayed treatment. Our results would be more informative if we had been able to administer the psychoacoustic testing during their delayed baseline period and their treatment period. Unfortunately, scheduling constraints limited our testing to one baseline immediately before treatment and their treatment period.

Summary

Using a 3I3AFC procedure, we replicated the Wright et al. (1997) finding that backward masking differentiated children with LLI from their age-matched peers before treatment. We continued weekly testing during treatment with two computer-assisted language intervention programs and found that neither FFW nor a bundle of seven programs from LLS resulted in significant improvement in backward masking behaviors. Children with LLI did not respond correctly as often in masked conditions (both simultaneous and backward) when the signal occurred in the first interval of a three-interval listening task. This suggests that auditory memory or attention factors contributed to their higher (poorer) signal threshold levels. In conclusion, our results indicate that, when performing multiple tasks of graduated complexity, children with LLI may show difficulties with complex information processing that are not restricted to the auditory domain.

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[2] After examining the data presented in this study, one colleague commented that the lack of a warning signal might have been a factor in the interval correct response pattern. This would suggest an attention impairment, rather than impaired encoding of acoustic information. If that were true, the pattern of decreased signal identification in observation interval one should have been present for the LLI group in the signal in signal-in-quiet condition.

[3] It should be noted that, in a follow-up study with a larger sample size and with children whose degree of language impairment was comparable to that of FFW 2 and LLS 2, the absence of a backward masking "advantage" was replicated. In addition, analyses of auditory-evoked potentials were consistent with auditory memory deficits in children with language impairments (Marler, Champlin, & Gillam, 2001).

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