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Effects of general processing capacity and sustained selective attention on temporal processing performance of children with specific language impairment

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ABSTRACT
This study investigated the potential influences of general processing capacity and sustained selective attention on the temporal processing of a group of children with specific language impairment (SLI) and a group of age-matched (CA) controls. Children completed a sustained selective auditory attention task and two speech processing tasks, the Speech Identification Task, representing a cognitively more complex task, and a standard speech discrimination task, representing a cognitively less complex task. The speech stimuli included two-formant, 40-ms transition [ba] and [da] consonant–vowel (CV) syllables and the nonstop CV syllable [sa]. We hypothesized, in accordance with Tallal's temporal processing deficit view, that if SLI children have a fundamental deficit in temporal processing, they should demonstrate poor performance on both speech processing tasks relative to CA children. By contrast, if the temporal processing problem of SLI children relates to a limitation in general processing capacity, the SLI children should show better performance on the discrimination task compared to the identification task. Alternatively, if poor sustained selective attention mediates SLI children's poor temporal processing, the SLI children should show poor performance on an independent measure of auditory attention, which in turn should account for a portion of the variance in any observed group differences in temporal processing. Results showed no group difference in sustained selective auditory attention. On the identification task, group, stimulus-type, and interaction effects emerged. SLI children performed more poorly than CA children, and stop CV syllables were identified less frequently than the nonstop CV syllable. On the discrimination task, there were no main effects or interactions for accuracy (A′ score). For the reaction time analysis, only a stimulus-type effect was found, with children responding faster to the /sa/ syllable. Results were interpreted to suggest that these SLI children did not evidence a basic temporal processing deficit. Rather, the SLI children's poor identification task performance was interpreted to reflect an interaction between these children's more limited general processing capacity and the nature of the task.

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Children with specific language impairment (SLI) are thought by some to suffer from a basic temporal processing deficit (e.g., Tallal & Stark, 1981; Tallal, Stark, & Mellitis, 1985a, 1985b). This view has been most strongly advocated by Tallal and her colleagues (Tallal et al., 1985a, 1985b; Merzenich et al., 1996). These authors argued that the language impairment of SLI children is secondary to such a processing deficit. However, these children's poor performance on various temporal processing tasks was interpreted by other investigators to reflect a limitation in general processing capacity (Leonard, McGregor, & Allen, 1992), an attention problem (Helzer, Champlin, & Gillam, 1996), or slower task learning (Stark & Heinz, 1996; Tomblin & Quinn, 1983). The present study addressed two of these possibilities, limited general processing capacity and poor auditory attention, by comparing the performance of SLI children and a group of age control children on two temporal processing tasks (varying in processing demands) and a measure of sustained selective attention.

The notion that SLI children suffer from a temporal processing deficit has occupied a cornerstone position in the child language disorders literature for many years (Tallal et al. 1985a, 1985b, 1996; Tallal & Piercy, 1975; Tallal & Stark, 1981). According to Tallal, SLI children have particular trouble processing rapidly presented information, linguistic or nonlinguistic, and that this difficulty directly hinders their language processing and subsequent language learning. With respect to impaired speech processing, this view derives from findings reported by Tallal and colleagues showing that, relative to age peers, SLI children have greater difficulty processing (i.e., identifying, discriminating, remembering, sequencing) speech containing rapid consonant–vowel/vowel–consonant formant transitions. When these brief-duration segments are lengthened, however, SLI children and their age mates demonstrate comparable performance. The general conclusion advanced by Tallal and associates is that it is the brevity of the information, not the character of the formant transition per se, that gives rise to impaired speech perception in these children (e.g., Tallal & Piercy, 1975). Moreover, performance on temporal processing tasks has been shown to reliably discriminate SLI children from non-SLI children (Tallal et al., 1985b). The conclusion that SLI children exhibit deficient temporal processing has been based on these children's performance on the Repetition Method (e.g., Stark & Tallal, 1988). This method includes various tasks such as the identification task and the serial memory task. On the identification task, for example, children are taught to associate one response button for one consonant–vowel (CV) syllable (e.g., /ba/) and a second response button for another CV syllable (e.g., /da/). After such training, children are then presented one of the syllables and asked to press the proper button, thereby demonstrating their ability to identify the appropriate stimulus. In the serial memory task, children are presented with a series of the same kinds of CV syllables and asked to press the response buttons in the order in which the syllables were delivered.

Other experimental studies, however, have reported mixed results regarding the temporal processing abilities of SLI children. Wright et al. (1997) compared the temporal processing of 8-year-old SLI children and a group of age-matched controls on a set of forward, backward, and simultaneous masking tasks. Children were asked to respond when they detected a brief tone that occurred before,

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during, or after a masking noise. Wright et al. found that, relative to control children, SLI children required significantly higher thresholds (i.e., index of temporal resolution/processing) in the backward masking task and had a strong tendency to require higher thresholds in the forward masking task. Wright et al. interpreted these findings as evidence of a temporal processing deficit in SLI children. That is, these findings imply that the temporal window used to sample auditory stimuli is larger in SLI children, thus possibly leading to their failure to differentiate stimuli when the distinguishing acoustic feature is very brief. Helzer et al. (1996) reported that their SLI children obtained similar thresholds to age controls on a forward masking task (although they required a greater number of trials to reach criterion) but yielded significantly higher thresholds in a backward masking task. By contrast, Bishop and colleagues (Bishop, Carlyon, Deeks, & Bishop, 1999) showed that their group of SLI children was no worse than their age peers to perform on a variety of nonlinguistic auditory processing tasks, including masking tasks. Likewise, Nittrouer (1999) reported no such difficulties on the part of her children with reading disorder compared to a control group processing a variety of synthesized brief-duration speech stimuli.

Although the evidence for temporal processing problems in SLI children is mixed and somewhat controversial, their "causal" significance to the condition SLI is highly controversial (e.g., Johnston, 1992; Leonard et al., 1992; Rees, 1981; Tomblin & Quinn, 1983). For instance, although SLI children may have difficulty distinguishing such contrasts as /da/ and /ba/, they rarely substitute one sound for the other in their spontaneous speech (Leonard, 1998). In addition, even young normally developing children (under 4.5 years) do not perform well on the simplest speech processing tasks used by Tallal and associates. Other researchers have argued that the perceptual deficits of SLI children may be as much a result as a cause of their language impairment (Johnston, 1992), whereas others suggest that these children are simply slower at learning such tasks (Tomblin & Quinn, 1983; Stark & Heinz, 1996). Other researchers have suggested that these children have difficulty managing the information processing demands inherent in various perception tasks (Leonard et al., 1992; Sussman, 1993). Finally, some investigators (Mody, Studdert-Kennedy, & Brady, 1997; Studdert-Kennedy & Mody, 1994) have argued that the poorer temporal processing of children with reading or language problems reflects a speech-specific deficit, and not a general auditory temporal processing problem. They argue that these children show perceptual confusion between phonetically similar syllables rather than difficulty perceiving the temporal properties of speech.

As mentioned earlier, Leonard et al. (1992) suggested that the poorer perceptual processing performances of SLI children may reflect a limitation in general processing capacity rather than a speech perception deficit, per se. The notion that SLI children have more limited processing capacity than their age peers has been invoked by a number of investigators to help explain a wide range of language problems exhibited by these children (e.g., Bishop, 1992; Gathercole & Baddeley, 1990; Johnston & Smith, 1989; Montgomery, 1995b, 2000). Processing capacity has been conceptualized in different ways by different investigators (e.g., size of working memory, processing speed, computational energy, efficiency and power of processing schemes). In models of processing

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capacity that regard capacity from a functional point of view (e.g., Kail & Bisanz, 1982; Kail & Salthouse, 1994), it represents the amount of work performed within a given unit of time, where speed and the efficiency and power of processing routines or schemes are of essence. By contrast, models regarding capacity from a structural perspective view capacity as a function of the amount of work space (e.g., working memory) available to perform complex mental tasks requiring the storage and processing of information (Just & Carpenter, 1992). Both views assume, however, that when task demands exceed available processing capacity, some kind of storage or processing trade-off results. In Tallal's identification task (and her serial memory task), for instance, there is an initial stimulus exposure period in which the child listens to a number of trials of two different CV syllables. The purpose of the trials is to teach the child to associate one of the syllables to a certain colored dot on a response board and the other stimulus with another colored dot. After this training period, the child is then presented with one of the two syllables and asked to identify which one he or she heard by pointing to the appropriate dot. Thus, successful task performance would appear to require the coordination of a number of information processing abilities. These abilities presumably include such things as associating a different colored dot with a specific syllable, attending to an input stimulus (e.g., /ba/, /da/), comparing an input syllable with a stored template, identifying which stimulus was heard, deciding which dot to point to, and then making a motor response. Leonard and colleagues (1992) have proposed that SLI children's ability to identify two speech stimuli that are perceptually close to one another may be compromised by the cognitive complexity of such a task.

A similar argument was made by Sussman (1993), who found that the speech perception abilities of children with language impairment (LI) were comparable to age peers when the complexity of the task was minimized. Using an identification task and a discrimination task, Sussman (1993) examined whether LI children were as sensitive as age controls in detecting subtle changes in the formant structure of CV syllables. On the discrimination task (requiring a same–different judgment), the groups performed comparably. By contrast, on an identification task (requiring identification of one of two similar-sounding CVs), the LI children showed greater variability in accuracy than the age controls. Sussman argued that this poorer performance of the LI children was related to a delayed phonetic categorization ability, not to deficient perceptual processing. Sussman thus cautioned that what some researchers might argue as evidence of a speech perception deficit by LI children may instead be their difficulty in managing the demands of the task.

Paradigms such as forward, backward, and simultaneous masking, although undoubtedly sensitive to basic aspects of temporal processing (Buss, Hall, Grose, & Dev, 1999; Zwicker & Schorn, 1982), are also influenced by central factors, as indicated by relatively large variance and learning effects, even in adult listeners (Buss et al., 1999). This is particularly the case in backward masking (Buss et al., 1999). Hartley, Wright, Hogan, and Moore (2000) reported significant developmental improvement in temporal resolution abilities in normally developing children between the ages of 6 and 10 years of age using a backward masking task. Thus, masking tasks may not be the best choice to use when

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assessing the temporal processing abilities of SLI children, many of whom are known for their inefficient learning across a variety of tasks and task domains (e.g., Kiernan & Snow, 1999; Stark & Heinz, 1996; Tomblin & Quinn, 1983). Thus, it is possible that the poorer backward masking performance (and other poorer perceptual performances) of the SLI children reported by both Helzer et al. (1996) and Wright et al. (1997) may reflect slow learning (Stark & Heinz, 1996; Tomblin & Quinn, 1983) rather than poor temporal processing. Alternatively, because such tasks require significant vigilance, some kind of attentional problem may underlie the poor masking performance of some SLI children. Helzer et al. (1996), in fact, suggested this possibility when explaining the poorer temporal processing of their SLI children. Although only anecdotal, other researchers have suggested that SLI children evidence poor attentional functioning, especially in the area of sustained selective attention (Powell & Bishop, 1992; Stark & Montgomery, 1995). In short, then, the poorer temporal processing exhibited by SLI children may not reflect a basic speech processing deficit, but rather a limitation in general processing capacity, poor attentional functioning, and/or inefficient task learning.

Accordingly, the present study was designed to examine the issue of whether the temporal processing performance of SLI children might be related to a limitation in general processing capacity and/or sustained selective auditory attention. We assessed children's temporal processing using two tasks, Tallal's Identification Task (Stark & Tallal, 1988), presumably representing a more complex processing task, and a traditional discrimination task, presumably representing a simpler task. General processing capacity was inferred based on an analysis of each of the speech processing tasks (described later). Sustained selective auditory attention was assessed using an auditory continuous performance task.

METHOD

Participants

Twelve children with SLI between the ages of 6 and 10 years (M = 8;4) and 12 typically developing children (M = 8;4) matched for age (CA) participated in this study. Each group included 7 girls and 5 boys. Each SLI–CA subject pair was matched by gender and age ±3 months. There was no significant group difference in age, $t(22) = .09$, $p > .05$. Consistent with other researchers (e.g., Elliot & Hammer, 1988; Elliot, Hammer, & Scholl, 1989; Leonard et al., 1992), this study included only CA children. We did not include a younger, language-matched control group because the youngest SLI children in our study were 6 years of age. This would have meant including normally developing children potentially as young as 4.5 years. Because it has been shown that typically developing children of this age tend not to perform well on the speech perception tasks of the sort used in this study (Tallal, 1976), particularly the identification task, we elected not to include a younger group of children.

Each child demonstrated normal-range intelligence (85–125) as measured by performance on the Test of Nonverbal Intelligence–2 (TONI-2; Brown, Sherbenou, & Johnsen, 1990). Children also passed a hearing screening via audiometric

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Table 1. *Chronological age* (*years:months*)*; PPVT-R standard score; Receptive Language Score* (*RLS*) *and Expressive Language Score* (*ELS*) *on the CELF-R; Test of Reception of Grammar* (*TROG*) *standard score; and Test of Nonverbal Intelligence IQ score for the SLI and CA children*

			CELF-R			
Group	Age	PPVT	RLS	ELS	TROG	IQ
SLI	8:4	88	75	68	79	99
M						
SD	1.4	4.3	4.5	6.0	4.9	7.5
Range	6:4–10:5	70–110	63–80	59–76	66–83	88–112
CA	8:4	115	113	107	114	110
M						
SD	1.5	11.9	9.5	9.6	7.4	8.6
Range	6:5–10:5	92–134	101–128	95–126	100–122	95–123

puretone screening at 15 dB HL bilaterally (ANSI, 1992), had normal or corrected vision, and presented no oral motor or structural abnormalities that affected movements of the articulators. All of the children also passed an articulation screening, as determined by a score at or above the 67th percentile on the Goldman–Fristoe Test of Articulation–Revised (Goldman & Fristoe, 1986). All of the children were free of psychological or psychiatric disturbance (as indicated by parent report) and were taking no medication for any reason.

The SLI children performed more than 1 *SD* below the mean on at least two subtests in each of the receptive and expressive portions of the Clinical Evaluation of Language Fundamentals–Revised (CELF-R; Semel, Wiig, & Secord, 1987). They also attained a total receptive language score and a total expressive language score that were at least −1 *SD* on the CELF-R and on the Test of Reception of Grammar (Bishop, 1989). The children's receptive lexical knowledge was also assessed using the Peabody Picture Vocabulary Test–Revised (PPVT-R, Dunn & Dunn, 1981). However, no criterion for entrance into the study was set for this measure. Eight of the 12 SLI children had received previous diagnosis of language impairment. The CA children scored at or above −1 *SD* on the same language measures, and none had a history of receiving speech–language services. Table 1 displays summary data for each group on the language and cognitive measures.

Temporal processing tasks

Speech stimuli. The acoustic stimuli for both speech processing tasks included the two-formant /ba/ and /da/ CV syllables and the syllable /sa/. The /ba/ and /da/ syllables were the same stimuli used in our previous studies (e.g., Montgomery, in press; Montgomery & Leonard, 1998) and were selected for this study because this contrast contained the brief-duration features that have con-

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sistently distinguished SLI and CA children. The /sa/ syllable was included because it represented a "longer duration" stimulus, the fricative portion being the targeted/contrasted longer duration acoustic element. Thus, this stimulus was quite different, phonetically and perceptually, from the stop syllables. As such, its inclusion allowed us to test the prediction (described more fully later) that poor performance on the identification task by the SLI children is related to difficulty managing the information processing demands of the task. Specifically, when faced with having to identify perceptually similar sounding syllables (e.g., /ba/ and /da/) in a timely fashion, the SLI children should show poor performance.

The stop stimuli were created on a cascade software synthesizer (Klatt, 1980), implemented on a PDP 11/23 laboratory computer, and transferred to a CompuAdd 386 PC computer. Stimuli were synthesized at a 10-kHz sampling rate and had the following characteristics: (a) the total syllable duration was 250 ms and the fundamental frequency was 115 Hz for the first 200 ms and then fell linearly to 75 Hz over the last 50 ms; (b) the amplitude was 70 dB for the first 200 ms and then fell to 45 dB over the last 50 ms; (c) the consonant portion of the syllable lasted for 10 ms, the CV formant transition lasted for 40 ms, and the steady-state vowel portion lasted for 200 ms; and (d) each syllable contained two formants.

As there was no synthesized version of the /sa/ stimulus, this stimulus was a naturally produced syllable produced by a male speaker and edited (using ASYST interactive software) on the PC lab computer. The editing procedures yielded a 250-ms length stimulus that included an initial 100-ms fricative segment followed by a 150 ms steady-state vowel. Thus total syllable duration was identical (i.e., 250 ms) for all three syllables.

Identification task. This task was a slightly modified version of the identification task used by Tallal and Stark (1981). We used this task because it has been used frequently in the Tallal studies and hence presumably represented, for our purposes, a more cognitively demanding temporal processing task. In the original task only two response choices were available, but in our task there were three. The purpose of the task is to assess the child's ability to identify different CV syllables by pointing to a certain colored dot. The stimuli for the present task were presented on a high-quality audiotape. The child and examiner sat at a table, with a response card in front of the child that contained three different colored dots. The first part of the task was to train the child to associate each syllable with a different colored dot. The examiner first demonstrated touching the yellow dot (top left of page) each time the /ba/ syllable was heard. The child then listened to 12 exposure trials of /ba/, pointing to the yellow dot on each trial. This procedure was repeated for the /da/ syllable (pointing to blue dot on top right of page) and the /sa/ syllable (pointing to white dot centered at bottom of page). The examiner did not label the sounds or repeat them. The child was neither encouraged nor discouraged if he or she attempted to label the stimuli or mimicked the sounds. For the second part of the task, the child heard 18 trials of the three syllables presented in random order and practiced pointing to the correct dot for each syllable. The experimenter provided feedback on the first six trials. The child was required to perform at or above 75% correct to advance on to the experimental portion of the task. The child was provided with

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one repetition of the training phases if needed. The experimental portion consisted of 48 trials with equal numbers of each syllable presented in random order. The child was given no specific feedback but was encouraged to do his or her best. The child was encouraged to respond as accurately as possible; speed of responding was not encouraged.

From an information-processing point of view, it is reasonable to assume that the processing demands of this task might include such things as (a) attending to the auditory and visual stimuli during training and testing, (b) creating and storing an auditory template of each syllable, (c) learning to associate each syllable with a certain dot, (d) deciding which input syllable was heard by comparing it to a stored template, and (e) deciding which dot to point to and then making a motor response. Thus, to correctly identify a syllable requires the ability to assign it a specific response (i.e., associating it with a certain dot and pointing to that dot). We might further assume that these mental operations need to be completed in a relatively timely fashion, before the input syllable fades from short-term memory. Relative to the demands of the discrimination task (described later), we believe that the collection of mental operations inherent in this task should pose special difficulty for the SLI children.

Discrimination task. A standard speech discrimination task was used to test the hypothesis that presenting a task that is cognitively less demanding might benefit the temporal processing performance of children with SLI. This task assessed both the accuracy and speed of discriminating perceptually similar sounding and dissimilar sounding pairs of CV syllables. The stimuli were delivered (10 and 4.5 kHz filtered) via the CompuAdd computer. The experimental trials consisted of 90 syllable pairs: 60 same-syllable pairs/trials (40 stop CV pairs, 20 nonstop CV pairs) and 30 different-syllable pairs/trials. Same and different trials were randomly presented. For each CV pair, a 500-ms interstimulus interval (ISI) separated CV1 and CV2. The child sat in the test booth in front of a response button, while the examiner sat in an adjoining room delivering the stimuli to the child at a comfortable listening level. The task consisted of four parts. The child first was exposed to the three different "sounds" (the examiner never labeled the stimuli); each CV was presented 10 times in isolation. Next, the examiner told the child that he or she would hear two of the sounds one right after another and then must decide whether the two sounds were the same or different. If they were the same, the child was to press the button as quickly as possible; if the two sounds were different, he or she was not to press the button. The examiner demonstrated the task for six trials. Third, the child was presented 18 practice trials and trained to respond as quickly as possible only on the "same" trials. The child was strongly encouraged to wait until both sounds were heard before responding or withholding a response. Thus, both response accuracy and speed were stressed. Direct feedback was given for the first six trials. The children were required to achieve 75% correct on this training phase before going on to the experiment proper. They were permitted one repetition of each of the training phases if this 75% criterion was not initially met. Last, the children were presented with three sets of 30 experimental trials. Again, the child was encouraged to respond with both accuracy and speed only on the "same"

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trials. The external clock was gated on at the onset of CV1 and was stopped as soon as the child made a response. For the "same" trials, responses made before the offset of CV2 were defined as a false alarm. Failures to respond were defined as misses. A valid reaction time (RT) was defined as the difference between the onset of CV1 and when the child appropriately responded (i.e., after CV2 offset). The RT was automatically calculated by and stored on the computer (using a custom written program).

We reasoned that the information-processing requirements of this task collectively were less complex than those of the identification task. This task presumably entailed such processes as (a) attending to the CV stimulus pairs, (b) storing the CV stimuli momentarily in short-term memory, (c) judging whether two syllables were the same or different (i.e., stimulus identification thus is not necessary), (d) deciding whether to respond or withhold a response, and (e) making a speeded response (if appropriate).

Auditory detection RT task

Because the speech discrimination task included RT as a dependent variable, an auditory detection RT task was included as a measure of auditory reception and motor response, independent of the demands for speech processing. This task also provided children with practice and familiarity with performing a timed task. The stimuli consisted of two pure tones, a 500-Hz 500-ms duration tone and a 2000-Hz 1-s duration tone. The first tone served as a warning tone for the second tone. The ISI between the tones varied randomly among 1.5, 2.0, 2.5, and 3.0 s. The child sat in the test booth at a table with the response button in front of him or her and was instructed to listen for two "beeps," a low one followed by a high one, and to press the response button as soon as he or she heard the high beep. Both response accuracy and speed were encouraged. Several practice trials preceded the 32 test trials. The external clock was gated on at the onset of tone 1 and stopped as soon as the child made a response. Responses made before the offset of tone 2 were defined as false alarms. Failures to respond were defined as misses. The child's RT was automatically captured by, and stored on, the computer. RT was calculated as the difference between the onset of CV1 and the time when the child appropriately responded.

Sustained selective attention task

We chose to examine sustained selective attention because (a) it has been suggested that children with SLI have difficulty sustaining their selective attention, (b) sustained selective attention is a dimension of attention that can be most reliably assessed without confound from other dimensions of attention (Mirsky, Anthony, Duncan, Alhearn, & Kellam, 1991), and (c) both speech processing tasks presumably required some degree of sustained selective attention on the part of the children. We used the Auditory Continuous Performance Test (ACPT, Keith, 1994) to measure this ability. The task was administered according to standard administration procedures. In this task, the child listened to an 11-min audiotape, consisting of a list of 600 monosyllabic words read by a male speaker

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at a rate of approximately 2 words/s. The child was instructed to listen for the target word *dog* and to raise or tap a finger whenever he or she heard the target. The target word never appeared twice in a row. The sustained attention aspect of the task related to the child having to maintain attention over time. The selectivity aspect of the task related to the child having to make a response to a specific stimulus while disregarding all nontarget items. The examiner sat next to the child in the test suite and recorded all responses, including correct responses, false positives, and misses. During the task the examiner did not speak to the child or encourage him or her to pay attention or stay focused. However, before the task began the examiner encouraged the child to stay focused throughout the task. Practice trials preceded the experimental trials to familiarize the child with the speaker's voice and the target word and to ensure that he or she understood the task.

Counterbalancing of tasks

Two counterbalanced orders of the experimental tasks were created. The only constraint within this scheme was that the auditory detection RT task always immediately preceded the discrimination task, because the former task served to familiarize the children with the response demands of the latter. Equal numbers of subjects in each group received one of the two orders. All the auditory stimuli were presented to the children under headphones at a comfortable listening level.

Predictions

If the temporal processing deficit view advocated by Tallal and associates is correct, we might hypothesize that the SLI children, relative to the CA children, should perform poorly on both speech processing tasks. Irrespective of task demands, the SLI children should have difficulty processing the brief-duration, /ba/ and /da/ syllables, but not the /sa/ syllable. By contrast, in accordance with a limited processing capacity view, we would predict that, relative to the CA children, the SLI children should perform more poorly on the identification task but comparably on the discrimination task. Relative to the discrimination task, it might be hypothesized that the processing demands of the identification task should exceed the general processing capacity of the SLI children, thus resulting in poor performance. Specifically, the SLI children should have difficulty identifying the /ba/ and /da/ syllables because of an inability to identify these stimuli in a timely fashion (due to perceptual confusion); they should show no trouble identifying the longer duration, /sa/ item. Finally, if poor attentional control adversely affects the temporal processing of SLI children we should see (a) the SLI children perform poorly on the ACPT and (b) a significant portion of the variance of any group differences in speech processing accounted for by performance on the ACPT.

Data analysis

For the ACPT, the primary dependent variable was number of hits to the target *dog*. For the identification task, the dependent variable was the percentage of CV items correctly identified. For the discrimination task, two dependent vari-

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Table 2. *Performance by the SLI and CA children on each experimental task*

	SLI			CA		
	M	*SD*	Range	*M*	*SD*	Range
ACPT	112	5.5	101–118	114	9.3	89–120
No. hits						
No. false alarms	1.3	1.9	0–6	0.67	1.23	0–4
Identification task	81	12.8	63–100	94	6.8	81–100
Correct stops (%)						
Correct nonstops (%)	98	4.7	88–100	100	0.0	0.0
Discrimination task	90	11.8	65–100	93	6.4	78–100
Accuracy (A′)						
Stops						
Nonstops	93	9.7	75–100	97	3.1	92–100
RT (ms)	1,018	143.4	797–1,234	1,064	145.3	812–1,325
Stops						
Nonstops	878	153.3	715–1,267	932	138.4	735–1,226
Auditory RT task	521	132.8	360–875	439	118.7	221–602
RT (ms)						

ables were analyzed: accuracy (i.e., percentage of hits for "same" trials) and RT for all same trials correctly responded to. For the accuracy analysis, the data were converted to an A′ score (described later). Reaction time also was the dependent variable in the auditory detection RT task. Finally, although the groups differed in nonverbal IQ, IQ was not used as a covariate in the following analyses because preliminary correlational analyses showed that it was not significantly correlated with any task performance in either group. In other words, the linear and parallel slopes assumption was not violated; therefore, a standard repeated measures analysis of variance (ANOVA) was appropriate.

RESULTS

Sustained selective attention: ACPT task

The number of possible hits on the ACPT was 120. Children with SLI had a mean number of correct hits of 112 and the CA children had a mean of 114. The mean number of false alarms (where the child raised his or her finger on any nontarget word) for SLI children was 1.33 and 0.67 for the CA children. The SLI children and the CA children yielded similar hit rates, $t(22) = .–59$, $p > .05$, and false alarm rates, $t(22) = 1.03$, $p > .05$. Table 2 displays group means and standard deviations for all dependent variables for each experimental task.

Identification task

A total of 48 syllables was presented: 16 /ba/, 16 /da/, and 16 /sa/ syllables. To compare performance between the stop syllables (32 total) and the nonstop syl-

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lable (16 total), the number of correct identifications was converted to percentage correct. The SLI children obtained a mean of 81% for the stop syllables and 98% for the /sa/ syllable. The CA children obtained a mean of 93% for the stop syllables and 100% for the /sa/ syllable. A group (SLI, CA) × Syllable Type (stop, nonstop) repeated measures ANOVA revealed significant effects of group, $F(1) = 11.38$, $p < .01$, and the SLI children performed worse than the CA children; and syllable type, $F(1) = 27.76$, $p < .01$, and lower scores were obtained for stop syllables. The Group × Syllable Type interaction was also significant, $F(1) = 6.07$, $p < .05$. Follow-up between-group t tests indicated that the SLI and CA children performed comparably on the /sa/ syllable, $t(22) = -1.43$, $p > .05$, but on the stop syllables, the SLI children performed worse than the CA children, $t(22) = -3.07$, $p < .01$. A follow-up within-group ANOVA for SLI children revealed a significant effect for syllable type, $F(1) = 18.68$, $p < .01$, with poorer performance on the stop syllables. A similar within-group ANOVA for the CA children also revealed a significant syllable type effect, $F(1) = 9.85$, $p < .01$, with poorer performance for stop syllables. The significant Group × Syllable Type interaction and significant syllable type effect for the CA group was due to the fact these children performed without error on the /sa/ syllable, thereby producing a ceiling effect. Thus, although both groups had greater difficulty identifying stop syllables compared with the nonstop syllable, this discrepancy was much greater for the SLI children.

Auditory detection RT task

Prior to data analysis, each subject's RT data set was examined for outlier responses. Outliers were defined as any data point falling at or greater than ±2 *SD* from each subject's mean RT (Fazio, 1990) and were eliminated from each subject's data set. Less than 2% of responses were outliers for each group. No group differences emerged with respect to number of outliers, $t(22) = 1.25$, $p > .05$. A mean RT was calculated for each subject. All false alarms, failures to respond, and outliers were replaced by the subject's mean RT to yield a complete data set for each child. A mean hit rate of 95% and a false alarm rate of 2.92% were obtained for the SLI children. These children also obtained a mean RT of 521.67 ms. The CA children obtained a hit rate of 96% and a false alarm rate of 0.83%. They obtained a mean RT of 439.33 ms. Independent group t tests were computed to determine whether there were group differences in accuracy and RT. Results showed there were no significant differences in hit rate, $t(22) = -.51$, $p > .05$, or false alarm rate, $t(22) = 1.35$, $p > .05$. The groups also did not differ in RT, $t(22) = 1.60$, $p = 0.12$. As there was no group difference in mean RT, there was no need to use subjects' mean RT as a covariate in the analysis of the discrimination RT data.

Discrimination task

Analysis of accuracy data. In this task, children made a forced-choice alternative response wherein they either pressed the button, for "same" trials, or withheld a response, for "different" trials. As such, this response format may have

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resulted in a potential confounding bias for determining accuracy. This format may have invited children to respond in a pro-social way, responding "yes" or "similar" on all trials (Bishop, 1992). To correct for this potential bias, the accuracy data for each child were converted into an A′ score (i.e., an adjusted sensitivity score). An A′ score is a ratio of the proportion of correct hits to the proportion of false alarms. An A′ of 1.00 indicates perfect sensitivity, whereby a subject correctly responds to all of the "same" trials and makes no false alarms. An A′ of 0.50 indicates chance performance. For the SLI children, the mean A′ was 90 for the stop syllable pairs and 93 for the /sa/ syllable pairs. For the CA children, the mean A′ was 93 for the stop syllable pairs and 97 for the /sa/ syllable pairs. A Group (SLI, CA) × Syllable Type (stop, nonstop) repeated measures ANOVA revealed no effects for group, $F(1) = 2.18$, $p > .05$, or syllable type, $F(1) = 2.58$, $p > .05$, nor a significant Group × Syllable Type interaction, $F(1) = .10$, $p > .05$.

Analysis of RT data. Prior to analysis of the RT data, each subjects' data set was examined for all outlier responses, which were defined as any RT falling to greater than or equal to ±2 *SD* from that subject's mean RT (Fazio, 1990). Less than 2% of responses were outliers for each group, and no group differences emerged with respect to number of outlier responses, $t(22) = 1.03$, $p > .05$. There was no significant difference between the groups on false alarms, $t(46) = -1.10$, $p > .05$. A mean RT was calculated for each subject. Within each subject's data set, all no responses, false alarms, and outliers were replaced with his or her mean RT to yield a complete data set. The SLI children yielded a mean RT of 1018 ms for the stop syllable pairs and a mean RT of 878 ms for the /sa/ syllable pairs. The CA children obtained a mean RT of 1064 ms for stop syllable pairs and a mean RT of 932 ms for /sa/ syllable pairs. A Group (SLI, CA) × Syllable Type (stop–stop, nonstop–nonstop) repeated measures ANOVA revealed a significant effect for syllable type, $F(1) = 10.41$, $p < .01$, with stop syllable pairs yielding longer RTs. However, there was no significant group effect, $F(1) = 1.43$, $p > .05$, nor a significant Group × Syllable Pair interaction, $F(1) = .01$, $p > .05$.

DISCUSSION

The aim of the present study was to test whether the temporal processing problem characteristic of many SLI children reflects a fundamental deficit in temporal processing (e.g., Tallal & Piercy, 1975; Tallal et al., 1985a, 1985b), a limitation in general processing capacity (Leonard et al., 1992), and/or a problem with sustained selective attention (e.g., Helzer et al., 1996). To answer this question, a group of SLI children and a group of age control children completed two speech processing tasks: an identification task (Tallal & Stark, 1981), representing a more cognitively demanding task, and a standard discrimination task, representing a less cognitively demanding task. The children also completed a sustained selective auditory attention task.

The present results offer no support for the claim that these SLI children possess a basic deficit in temporal processing. As we hypothesized, if SLI chil-

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dren suffer from a temporal processing impairment, they should have performed poorly on both the identification and discrimination tasks, compared to the CA children. Irrespective of task demands, the SLI children should have had difficulty processing the stop CV syllables. However, this clearly was not the case. Whereas the SLI children, relative to the CA children, indeed performed more poorly on the identification task, the groups showed comparable performance on the discrimination task, in terms of both accuracy and speed of response. The fact that the SLI and CA children performed comparably on the discrimination task thus implies that the SLI children indeed had the ability to process the temporal cues associated with the stop CV syllables. To successfully perform on this task, children presumably (and minimally) needed to store both CV syllables momentarily, judge whether the two were the same, and then make a speedy response in the event they were the same. The SLI children thus could not have solved this task if they had processed inferior temporal processing abilities (or if the overall information processing demands of the task had exceeded their general processing capacity). We are then left with two possible explanations that do not involve inferior temporal processing for why the SLI children performed poorly on the Identification Task. One possibility is that the SLI children were less able to sustain their selective auditory attention (e.g., Powell & Bishop, 1992; Stark & Montgomery, 1995), thereby hindering their ability to perform on an attention-demanding task of the sort used here. Our results offer no support for this hypothesis either. Recall that both the SLI and CA children performed well on the ACPT. In fact, no group difference emerged. These results thus strongly suggest that the variable of sustained selective attention cannot explain the SLI children's poor identification task performance.

The other possibility is that SLI children's temporal processing (as measured by the identification task) is constrained by a more limited general processing capacity (Leonard et al., 1992). On this view, it is the interaction of task complexity and the brevity of the speech stimuli (and hence perceptual confusability) that pose the problem for SLI children. In combination such task factors exceed the processing capacity of SLI children. The present results appear to offer clear support for this hypothesis. Viewed in this way, the response pattern of the SLI children can be explained. Recall that the SLI children performed especially poorly on the brief-duration, stop CV items. However, for the /sa/ syllable (characterized as a longer duration stimulus), the groups performed similarly. Such a response pattern indicates that it was only when the SLI children had to process the brief-duration, perceptually confusing CV stimuli (e.g., Sussman, 1993) that their processing capacity was apparently exceeded. The overall pattern of results from this study fits well with the findings of Sussman (1993), who also reported that children with language impairment, relative to CA children, performed worse on a similar identification task but comparably on a discrimination task.

What might be the locus of the SLI children's presumed problem in managing the demands of the identification task? We might assume that the task entailed such processes as (a) attending to the auditory and visual stimuli during training and testing, (b) creating and storing an auditory template of each syllable, (c)

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learning to associate each syllable with a certain dot, (d) deciding which input syllable was heard by comparing it to a stored template, and (e) deciding which dot to point to and then making a motor response. In addition, the ability to correctly identify an input syllable presumably depends on the listener completing the identification process in a relatively timely fashion, before the input syllable fades from short-term memory (STM). While only speculative, we might assume that the SLI children's problem was not related primarily to difficulty learning to associate a specific dot with a certain syllable. If this were the case, the SLI children should have showed less accuracy even for the /sa/ syllable. Perhaps the most likely possibility relates to the various STM demands of the task. Several investigators have proposed that SLI children suffer from a deficit in phonological short-term working memory (e.g., Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990; Montgomery, 1995a). According to Baddeley (1986), working memory is a multicomponent, resource-limited system comprising a controlling "central executive" that is subdivided into two distinct "slave" systems, the articulatory loop system and the visuospatial scratch pad. The central executive is thought to regulate information flow within working memory, the retrieval of information from other memory systems, and the processing and storage of information. The articulatory loop is assumed to comprise a capacity-limited phonological STM store and an articulatory control process (i.e., subvocal rehearsal) that acts to refresh and maintain speech material in the store for a brief period. Functionally, the articulatory loop (i.e., phonological working memory) is thought to be responsible for the temporary storage of verbal information (particularly unfamiliar sound patterns) while other cognitive tasks are performed.

Some investigators (Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990; Montgomery, 1995a) have suggested that SLI children have less phonological STM capacity than their age mates. However, it does not seem likely that diminished capacity was the culprit here, especially given that only a single CV item had to be retained for comparison with a stored CV template. Children with SLI are known to be able to store and repeat novel phonological input for considerably longer than was the case with the CV items used in the present study (Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990; Montgomery, 1995a). Perhaps these children's difficulty may be found in one or more of the other operations of phonological working memory. The SLI children may have had difficulty establishing a phonological representation (Gathercole & Baddeley, 1990) of each CV syllable when initially creating a CV template and/or when listening to the CV stimuli during the experiment proper. However, poor phonological encoding does not seem to be a likely possibility, either. If it were, the SLI children also should have had difficulty identifying the /sa/ syllable, not just the stop syllables. In addition, the SLI children should have performed poorly on the discrimination task, in which they had to encode both syllables to immediately compare them for their phonetic similarity. Perhaps the SLI children were less efficient at rehearsing the input syllable once it was encoded. This possibility seems equally unlikely. Numerous findings have shown that SLI children of this age range tend to use verbal rehearsal (Kail & Leonard, 1986) and show comparable rehearsal-speech rates to their age peers

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(Gathercole & Baddeley, 1990; Montgomery, 1995a; Stark & Montgomery, 1995). Thus, the most likely trouble spot for the SLI children may be related to more rapidly fading phonological representations (e.g., Gathercole & Baddeley, 1990; Gillam, Cowan, & Marler, 1998). Recall that this task did not require timed response; rather, accuracy was strongly encouraged. However, those children who identified the input stimulus and made a response in a relatively timely fashion, before the input faded from phonological STM, should enjoy greater success than those who did not. It might be argued, then, that the SLI children took longer to identify and respond to the brief-duration syllables because of their phonetic similarity/perceptual confusability (e.g., Mody et al., 1997). By contrast, the phonetically distinct /sa/ syllable was more easy to identify before it faded from phonological STM.

Two final comments are in order. First, the SLI children's poor identification task performance may have been due to diminished efficiency in learning the task (e.g., Kiernan & Snow, 1999; Stark & Heinz, 1996; Tomblin & Quinn, 1983). Slower task learning and limited processing capacity, however, are not necessarily mutually exclusive possibilities. Given sufficient practice, the combination of mental operations that the SLI children needed to use to successfully complete this novel task might be performed with greater efficiency and automaticity. Second, our two stop syllables were synthetic, whereas the nonstop syllable was a naturally produced, edited item. It might be argued that any observed syllable effects could have been confounded by the fact that any naturally produced CV item should be more phonetically and perceptually distinct than any synthetically created CV item, given the greater acoustic redundancy inherent in natural speech. This was exactly our intent. The inclusion of /sa/ thus permitted us to assess whether SLI children's apparent temporal processing problem reflects a true temporal processing limitation or is the consequence of the interaction of the nature of the stimuli and task demands. Without its inclusion, our efforts to address this interaction would have fallen short.

In conclusion, the results of this study appear to offer clear and supporting evidence for the suggestion that the temporal processing difficulties exhibited by SLI children do not necessarily reflect a fundamental deficit in temporal processing (Leonard et al., 1992; Sussman, 1993). Rather, SLI children's poorer temporal processing appears to be highly dependent on the nature of the task. As the cognitive demands of speech processing tasks increase, SLI children's ability to demonstrate their temporal processing abilities is compromised. The results of this study provide us with an important reminder about the very nature of SLI. Because SLI children tend to show a variety of processing limitations, researchers and clinicians alike must take care to consider how the information processing abilities of these children interact with the demands of the task we are asking them to perform (Lahey & Bloom, 1994).

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