Research Article

Phonological Priming With Nonwords in Children With and Without Specific Language Impairment

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Purpose: The cross-modal picture–word interference task is used to examine contextual effects on spoken-word production. Previous work has documented lexical–phonological interference in children with specific language impairment (SLI) when a related distractor (e.g., *bell*) occurs prior to a picture to be named (e.g., a bed). In the current study, the authors examined whether interference also arises with nonwords as distractors.

Method: In Study 1, children with SLI ($N = 20$; ages 7;1 [years;months] to 11;0) and age-matched controls named pictures accompanied by (a) phonologically related nonwords, (b) unrelated nonwords, or (c) the word *go* (baseline). Stimulus asynchrony (SA) varied across blocks with distractors occurring prior to (–300 ms, –100 ms) or after (+100 ms, +300 ms) the pictures. In Study 2, a cross-sectional sample

of children ($N = 48$, 5;3 to 10;9) and adults ($N = 16$) performed the same task.

Results: Child and adult control participants showed phonological priming (not interference) at early and late SAs, whereas children with SLI showed priming only at late SAs. Effect sizes correlated with language skills (Clinical Evaluation of Language Fundamentals–Fourth Edition scores; Semel, Wiig, & Secord, 2003). In the cross-sectional sample, anticipatory priming at SA –300 varied with age, with larger effects in older children.

Conclusions: Children with SLI utilize phonological information when it is available just in time for word production but fail to anticipate upcoming stimuli. Poor anticipatory processing may adversely affect language fluency in children with SLI.

Specific language impairment (SLI) is associated with deficits in lexical and phonological processing (Schwartz, 2009). Children with SLI are slower to acquire words than their peers with typical language development (TLD; Nash & Donaldson, 2005; Oetting, Rice, & Swank, 1995). They often experience difficulties in phonologically encoding the word forms of newly introduced vocabulary (Alt & Suddarth, 2012; Maillart, Schelstraete, & Hupet, 2004) and in accessing the words they already know (e.g., Dockrell, Messer, George, & Wilson, 1998; Faust, Dimitrovsky, & Davidi, 1997; German 1984; Lahey & Edwards, 1996; Rice, Buhr, & Nemeth, 1990). Their difficulties in word learning and word finding are thought to stem from reduced phonological short-term memory capacity

(Gathercole & Baddeley, 1990; Gupta & MacWhinney, 1997) in combination with poor implicit learning of temporally patterned information, such as auditory sequences of phonemes or syllables (Evans, Saffran, & Robe-Torres, 2009; Ullman & Pierpont, 2005).

Phonological short-term memory (also referred to as *the phonological loop*, cf. Baddeley, Gathercole, & Papagno, 1998) is a buffer that supports the temporary storage and encoding of sequentially organized phonological representations. Its capacity is often assessed using nonword repetition tasks in which children are asked to repeat back a series of nonsense words of varying lengths (Gathercole, Willis, Baddeley, & Emslie, 1994). Nonword repetition skills correlate positively with vocabulary size in children, with poor nonword repetition recognized as a behavioral marker of SLI (Bishop, North, & Donlan, 1996; Conti-Ramsden, Botting, & Faragher, 2001; Dollaghan & Campbell, 1998; Metsala, 1999). The procedural deficit hypothesis (Ullman & Pierpont, 2005) views the limited capacity of phonological short-term memory in children with SLI as stemming from underlying deficits in implicit procedural learning of sequential patterns (also referred to as *statistical learning*, cf. Saffran, Aslin, & Newport, 1996). This hypothesis is

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supported by findings linking sequence-learning skills in children with assessments of their language abilities (e.g., Tomblin, Mainela-Arnold, & Zhang, 2007; see Lum, Conti-Ramsden, Morgan, & Ullman, 2014, for a meta-analysis).

Competition and Priming in Lexical Access

Models of lexical access propose that multiple words compete for retrieval until one has reached sufficient strength for a decision to be made in favor of its selection (Dell, 1986; Levelt, Roelofs, & Meyer, 1999; Magnuson, Dixon, Tanenhaus & Aslin, 2007; Marslen-Wilson, 1987). Studies of spoken-word recognition in children and adolescents with SLI (e.g., Mainela-Arnold, Evans, & Coady, 2008; McMurray, Samelson, Lee, & Tomblin, 2010) report greater lexical-phonological competition between words sharing onsets (i.e., members of the same phonological cohort) in comparison to TLD controls. Mainela-Arnold and Evans (2014) have more recently linked lexical-phonological competition in children with and without SLI to individual differences in implicit learning of auditory sequences (assessed using the statistical learning task of Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). Using a gating procedure in which children listened to increasingly longer segments of a spoken word that they attempted to identify on the basis of partial information, implicit statistical learning predicted the numbers of intrusions (incorrect responses) beyond the gate at which the spoken word was first correctly identified. Thus, not only did children with SLI experience greater competition between phonologically related words than their TLD peers, but the extent of competition was tied to the efficiency of auditory sequence learning.

The process of lexical competition is strongly driven by contextual cues, with words previously spoken, heard, or read determining how efficiently a target word may be accessed (D. E. Meyer & Schvaneveldt, 1971). Manipulating contextual cues that vary in their relationship to a target allows researchers to evaluate the efficiency of lexical access in children with and without SLI. Priming experiments have gained popularity as a method for exploring how cues held temporarily in phonological short-term memory affect lexical access. Velez and Schwartz (2010) examined phonological, semantic, and repetition priming in school-age children with SLI, using a running list paradigm in which children made animacy judgments about spoken words. In contrast to their TLD peers, children with SLI failed to show either semantic or phonological priming effects but demonstrated robust repetition priming. Gray, Reiser, and Brinkley (2012) also failed to find evidence of phonological priming in preschool-age children with SLI, using a cued shadowing paradigm in which participants heard pairs of words and had to repeat the second word. Taken together, these studies suggest that children with SLI fail to benefit from phonological cues occurring prior to their targets.

In incremental models of speech production (e.g., Dell, 1986; Roelofs, 1997), word forms are encoded sequentially with the phonological segments of a target word assembled in a phonological output buffer prior to its articulation.

Due to weak phonological representations, children with SLI may utilize incremental processing strategies to a lesser extent than their TLD peers. This hypothesis can be tested using the cross-modal picture-word interference (PWI) task by manipulating the timing of a phonological cue (an auditory distractor) in relation to its target (a picture to be named) and comparing the time course of the cue's effect on lexical access in children with and without SLI. On the basis of PWI studies with adults (A. S. Meyer & Schriefers, 1991; Schriefers, Meyer, & Levelt, 1990) as well as children (Brooks & MacWhinney, 2000), a phonologically related distractor is expected to yield its maximal effect when presented shortly after the target picture—that is, at stimulus asynchronies (SAs) ranging from +100 ms to +150 ms. At this interval, the phonological information provided by the distractor is available just as the phonological segments of the target are being assembled in the phonological output buffer.

Seiger-Gardner and Brooks (2008) used the cross-modal PWI task to examine effects of phonologically related words on lexical access in 7- to 11-year-olds with and without SLI. Overall, children with SLI required more time and made more errors in naming pictures than age-matched controls. When the picture occurred 150 ms after the distractor (late SA condition +150), both groups named pictures paired with onset-related distractors (e.g., *bed* paired with a picture of a bell) faster than pictures paired with unrelated distractors (e.g., *sock* paired with a picture of a bell). The timing of this effect matched the predictions of incremental speech production models (Dell, 1986; Roelofs, 1997). Thus, children with and without SLI appeared to show intact priming of information in the phonological output buffer in which phonological segments are held as they are sequenced for spoken-word production. However, when the distractor terminated 150 ms prior to the picture to be named (early SA condition -150), children with SLI, but not controls, showed a phonological interference effect, with slower naming of pictures paired with onset-related versus unrelated distractors (see also Seiger-Gardner & Schwartz, 2008). This phonological interference effect bears resemblance to the lexical-phonological interference effect observed in children and adolescents with SLI in studies of spoken-word recognition (Mainela-Arnold et al., 2008; McMurray et al., 2010). Thus, children with SLI experience heightened lexical-phonological competition among words in the same phonological cohort in lexical access across spoken-word production and recognition tasks.

More critically, the presence of a phonological priming effect at SA +150 in children with SLI—that is, with the target occurring prior to the auditory distractor—contrasts with the lack of phonological priming observed in studies in which the phonological cue occurred prior to its target (Gray et al., 2012; Velez & Schwartz, 2010). Although the tasks used across studies differ along multiple dimensions (e.g., picture naming vs. semantic judgments vs. cued shadowing), the conflicting results suggest that the timing of the phonological cue in relation to its target might be a critical factor influencing whether children with SLI benefit from the presence of the cue.

Aims and Hypotheses of the Current Study

The current study was conducted to further explore the time course of phonological processing in lexical access in children with and without SLI. To eliminate possibly complex lexical interactions between distractor–target pairs with overlapping sound patterns (e.g., *bell* and *bed*), we used nonwords (e.g., *besb*) rather than words (e.g., *bed*) as auditory distractors in the PWI task. The use of nonword distractors was expected to eliminate lexical competition between the distractor and its target and thus allow us to contrast effects of early versus late phonological distractors in children with and without SLI—that is, nonword distractors would not be viewed as plausible responses in the PWI task as they were not the names of pictures in the response set. To compute phonological priming effects, we compared response times (RTs) and error rates for pictures paired with related versus unrelated nonwords with the prediction that presentation of a phonologically related nonword would facilitate retrieval of the phonological segments needed to name the target picture. With the onset of the distractor following the picture (late SA conditions +100 and +300), we expected groups to perform similarly, as observed in Seiger-Gardner and Brooks (2008). However, with the distractor occurring prior to the picture (early SA conditions –300 and –100), we expected groups to diverge as would be consistent with reports of a lack of a phonological priming effect in SLI in studies in which the phonological cue occurred prior to its target (e.g., Gray et al., 2012; Velez & Schwartz, 2010).

To summarize, the current cross-modal PWI study used nonword distractors and varied the interval between the presentation of the auditory distractor and the target picture. Children with and without SLI at varying age ranges were tested with the following hypotheses:

1. Children with SLI would show evidence of incremental processing by demonstrating a pattern of phonological priming (faster responses in naming a picture paired with a phonologically related vs. unrelated nonword) at late SA conditions that is indistinguishable from TLD peers—that is, we expected children with and without SLI to utilize phonological information when it was available just in time for speech production, with the distractor yielding its peak effect when occurring 100 ms after the picture to be named.
2. Children with SLI would fail to show anticipatory phonological priming when the auditory distractor occurred prior to its target, suggesting a failure to use the phonological cue to predict the upcoming stimulus.

Study 1

Method

Participants

Forty children (24 boys, 16 girls, ages 7;0 [years;months] to 11;0; $M = 8;6$, $SD = 1;1$) were recruited from child subject pools at Lehman College and the College of Staten Island,

City University of New York. Children with SLI (14 boys, six girls) ranged in age from 7;1 to 11;0 ($M = 8;7$), and TLD controls (10 boys, 10 girls) ranged in age from 7;0 to 11;0 ($M = 8;5$). All children were drawn from households in which American English was the primary language as verified through a language background questionnaire. Children were administered the Test of Nonverbal Intelligence–Third Edition (TONI-III; Brown, Sherbenou, & Johnson, 1997), the Peabody Picture Vocabulary Test–Fourth Edition (PPVT-4; Dunn & Dunn, 2007), and the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003). Children in the SLI group had a diagnosis of a language impairment by a speech-language pathologist, were enrolled in speech and language therapy, and/or had a composite score of 81 or lower (corresponding to 1.3 SD below M) on the CELF-4.

Table 1 summarizes assessment test results and t tests comparing SLI and TLD groups; children in the SLI group scored significantly below controls on all standardized measures. Children with SLI scored lower on language assessments in comparison to the nonverbal assessment: CELF versus TONI, $t(19) = -10.98$, $p < .001$; PPVT versus TONI, $t(19) = -3.93$, $p < .001$. Furthermore, their comprehensive language assessment scores were lower than their vocabulary scores: CELF versus PPVT, $t(19) = -8.97$, $p < .001$, which suggests larger deficits in grammar relative to vocabulary. In contrast, for children with TLD, standardized scores were similar across assessment tests: all values of $t(19) < 1.1$. The observed pattern of lower verbal than nonverbal scores in the SLI group but not the TLD group is consistent with the SLI profile. Likewise, the 9-point difference in TONI scores between groups is consistent with a recent meta-analysis reporting that children with SLI score 0.69 SD units below their TLD peers on measures of nonverbal cognition (Gallinat & Spaulding, 2014).

Materials and Design

Target pictures were 64 black and white line drawings of common objects from a standardized set (Cycowicz, Friedman, Rothstein, & Snodgrass, 1997), with an additional four pictures serving as practice items. For each target, we created a phonologically related nonword distractor, which shared the onset consonant(s) and vowel with the name of the picture. These nonwords and the word *go* were recorded by a female native speaker of English (average duration = 510 ms, $SD = 69$ ms).

Across trials, each target picture was paired with three distractors: (a) a phonologically related nonword that sounded like the name of the target (e.g., *truv* paired with a picture of a truck); (b) an unrelated nonword that was related to the name of a different picture in the response set and unrelated to the target (e.g., *besb* paired with a picture of a truck); and (c) the word *go* (baseline), which was used to remind participants to name the pictures as fast as they could. The 64 target pictures were arranged into four lists of 48 trials: To counterbalance the 64 pictures across three distractor conditions and four SA conditions, we assigned 16 pictures to each distractor condition per list,

Table 1. Mean standardized scores and range for language and nonverbal intelligence assessments with *t* test results comparing groups.

Group	Age	CELF			PPVT	TONI
		Receptive	Expressive	Total		
SLI	8;7 (1;2) 7;1 to 11;0	76.5 (11.6) 51–92	71.3 (9.9) 49–89	72.2 (10.3) 48–85	86.9 (8.7) 69–101	97.6 (11.9) 78–121
TLD	8;5 (1;2) 7;0 to 11;0	104.3 (8.3) 83–117	111.5 (9.1) 98–134	110.1 (9.0) 97–130	109.2 (12.8) 95–148	106.2 (16.0) 83–142
<i>t</i> test	.39	–8.4**	–13.4**	–12.4**	–6.4**	–2.1*

Note. *n* = 20 in each group. Standard deviations in parentheses.

p* < .05. *p* < .001.

see Appendix. Thus, each list presented only 48 of the 64 pictures in the response set.

Distractors were presented through headphones at each of four SA conditions: –300 ms, –100 ms, +100 ms, +300 ms. Assignment of lists to SA conditions was counterbalanced across participants, with a different list used at each SA. In the early distractor conditions (–300 ms, –100 ms), the offset of the distractor preceded the onset of the picture by either 300 or 100 ms, whereas in the late distractor conditions (+100, +300), the onset of the picture preceded the onset of the distractor by 100 ms or 300 ms.

Apparatus

The experiment was run on a Dell personal computer using E-Prime 1.1 software (Schneider, Eschman, & Zuccolotto, 2002) and utilized a voice key connected to a button box timer. The voice key was used to detect the participant's response, which triggered the program to advance to the next trial. All responses were recorded using a digital CD recorder. A light detector was attached to the monitor, which generated a pure tone on a separate track of the audio recording (inaudible to participants) each time a picture appeared on the screen (i.e., the background shifted from black to white). This pure tone allowed us to calculate RTs directly from the audio recording by directly measuring the time from the onset of the trial to the initiation of the participant's response (using Sound Forge 7.0 software). This procedure minimized loss of trials due to voice key insensitivity (i.e., failing to pick up the onset of the child's response).

Procedure

Participants took part in two sessions conducted in a language development laboratory. One session was devoted entirely to assessment tests and the other to the PWI task and completion of any remaining assessments.

Children first completed a practice block to familiarize themselves with the 68 pictures to be named. Pictures were presented one at a time on the computer screen, and children were asked to name them in turn. During the practice block only, children were prompted with the correct response whenever they used a nontarget word (e.g., *T-shirt* to refer to a button-down *shirt*) or an article (e.g., *the* truck, *a* cat). After the practice block, the PWI task was introduced:

Children were instructed to put on their headphones and to ignore the words while focusing on naming the pictures as quickly as possible. In each trial, the target picture remained on the computer screen until the child responded or for a maximum of 4 s. Trials were advanced using a voice key—that is, a microphone positioned on a stand in front of the child. The child's voice activated the voice key, which triggered the offset of the picture and the initiation of the subsequent trial after a delay (intertrial interval) of 2 s.

PWI trials were blocked by SA condition, with the order of blocks counterbalanced across participants. Each block comprised 50 trials divided into two sub-blocks of 25 trials each. The first trial paired one of the practice pictures with the distractor *go*. The remaining 24 trials presented half of the targets from one of the lists, with eight targets per distractor condition (phonologically related, unrelated, baseline). The order of the two sub-blocks within each block and the order of the trials within each sub-block were randomized. Children were allowed a short break (e.g., to drink water) after each sub-block of 25 trials. A research assistant, seated behind the child, provided encouragement and reminders to name the pictures as quickly and accurately as possible.

Data Analysis

Statistical analyses were conducted on error rates and RTs. Proportions of errors were arcsine transformed as recommended by Cohen (1967). As a result of the skewed distribution of RTs,¹ we used median RTs (ms) for each condition as the dependent variable. Trials involving a naming error, speech disfluency, or failure to respond within 4 s were counted as errors and excluded from RT analyses. Lost trials were not counted as errors and were removed from analyses. Lost trials occurred when ambient noise or breathing triggered the voice key prematurely, which advanced the program to the next trial without allowing the child time to respond. Lost trials comprised 0.4% of all trials.

As preliminary analyses, we evaluated group differences in error rates and RTs in picture naming at baseline. The main analyses focused on early and late priming effects

¹Supplementary analyses indicated that the degree of skew in RTs did not vary significantly across SLI and TLD groups.

in each group. We conducted planned comparisons of phonologically related and unrelated distractor conditions at each SA using arcsine-transformed error proportions and median RTs as dependent variables. For each analysis of variance (ANOVA), effect sizes for main and interaction effects are reported as partial eta squared. For each planned comparison, effect sizes were calculated by dividing the F statistic with the sum of the F statistic and the residual degrees of freedom and applying a square root to that value, which yields an r value that can be interpreted accordingly (Field, 2009).

Throughout the results, we use the term *facilitation* to describe a decrease in latency compared to baseline and the term *inhibition* to describe an increase in latency compared to baseline. We use the term *priming* to refer to the overall technique as well as the difference between the related and unrelated distractor conditions irrespective of their relationship to baseline.

Results

Errors

Table 2 displays the mean percentages of errors for children with SLI and TLD as a function of distractor type and SA condition. First, we compared error rates for the baseline condition, using a mixed-design ANOVA with group (SLI, TLD) as a between-subjects variable, and SA condition (−300, −100, +100, +300) as a within-subjects variable. This analysis yielded a main effect of group, $F(1, 38) = 8.53$, $p = .006$, $\eta_p^2 = .18$, with higher error rates for children with SLI ($M = 10.9\%$) than TLD controls ($M = 6.6\%$) at baseline. No other effects approached significance.

To examine the effects of the nonword distractors on error rates, we conducted a mixed-design ANOVA with group as a between-subjects variable and distractor type (phonologically related, unrelated) and SA condition (−300, −100, +100, +300) as within-subjects variables. Children with SLI produced more errors ($M = 10.5\%$) than TLD controls ($M = 6.1\%$), $F(1, 38) = 15.10$, $p < .001$, $MSE = .274$, $\eta_p^2 = .28$. Overall, children made fewer errors when the picture was paired with a phonologically

related nonword ($M = 5.8\%$) than when it was paired with an unrelated nonword ($M = 10.8\%$), $F(1, 38) = 33.13$, $p < .001$, $MSE = .128$, $\eta_p^2 = .47$. In addition to these main effects, there was a two-way interaction of distractor type and SA, $F(3, 114) = 3.38$, $p = .021$, $MSE = .072$, $\eta_p^2 = .08$, with larger differences in error rates for related versus unrelated distractor types at the late SAs (+100, +300), in which the picture was presented first and both the picture and distractor were processed simultaneously. No other effects were significant.

For children with SLI, the effect of distractor type on error rates (i.e., fewer errors in naming pictures paired with phonologically related nonwords) was evident at the late SA conditions: +100: $F(1, 57) = 8.90$, $p = .004$, $MSE = .066$, $r = .37$; +300: $F(1, 57) = 14.58$, $p < .001$, $MSE = .066$, $r = .45$, but did not approach significance at early SAs: −300: $F(1, 57) = 1.83$, $p = .18$, $MSE = .066$, $r = .18$; −100: $F(1, 57) = 1.45$, $p = .23$, $MSE = .066$, $r = .16$. TLD controls produced significantly fewer errors in naming pictures paired with phonologically related nonwords at the earliest SA −300, $F(1, 57) = 6.93$, $p = .011$, $MSE = .079$, $r = .33$, and at both late SAs: +100: $F(1, 57) = 25.59$, $p < .001$, $MSE = .079$, $r = .56$; +300: $F(1, 57) = 10.20$, $p = .002$, $MSE = .079$, $r = .39$. The effect at SA −100 was not significant, $F(1, 57) = 1.62$, $p = .20$, $MSE = .079$, $r = .17$.

Errors were coded qualitatively as nontarget, disfluency, or no response. Nontarget responses comprised all lexical errors, most of which were the names of other pictures in the set and/or were semantically related to the target (e.g., *barn* for *house*). Disfluencies were speech errors, such as repeating the word onset or saying *um* before the target response. No response comprised trials for which the child failed to name the picture within 4 s. Both groups showed similar distributions of error types, with 48% nontarget, 35% disfluency, and 17% no response in the SLI group and 49% nontarget, 38% disfluency, and 13% no response in the TLD group.

RTs

Table 2 displays mean RTs for each distractor and SA condition; note that these group means are averages of

Table 2. Median (SD) reaction times (ms) and error rates (%) for SLI and TLD groups ($n = 20$ in each) as a function of stimulus asynchrony and distractor type.

Group	Distractor	Early stimulus asynchrony				Late stimulus asynchrony			
		−300		−100		+100		+300	
		Median (SD)	Error rate, % (SD)	Median (SD)	Error rate, % (SD)	Median (SD)	Error rate, % (SD)	Median (SD)	Error rate, % (SD)
SLI	Related	800 (172)	8.5 (7.5)	875 (248)	10.0 (9.6)	984 (311)	6.7 (6.0)	870 (360)	8.1 (7.6)
	Unrelated	850 (206)	10.4 (6.9)	895 (224)	12.2 (9.6)	1141 (330)	12.6 (10.1)	958 (442)	15.8 (7.7)
	Baseline	810 (156)	9.1 (8.6)	903 (244)	9.7 (8.7)	967 (242)	12.0 (11.3)	889 (324)	12.9 (8.2)
TLD	Related	730 (161)	4.1 (4.7)	762 (200)	3.8 (6.3)	900 (257)	1.9 (3.6)	987 (359)	3.1 (5.2)
	Unrelated	847 (211)	9.1 (7.4)	866 (230)	5.6 (7.6)	1141 (348)	11.6 (10.2)	1,095 (447)	9.4 (9.8)
	Baseline	775 (171)	5.3 (5.5)	815 (210)	7.5 (7.5)	946 (341)	5.7 (6.4)	1,027 (416)	7.8 (7.0)

individual children's median RTs. First, we compared RTs for the baseline condition, using a mixed-design ANOVA with group as a between-subjects variable and SA condition as a within-subjects variable. The main effect of group did not approach significance, $F(1, 38) < 1$, as overall RTs at baseline were nearly identical for SLI ($M = 892$ ms) and TLD ($M = 890$) groups. There was a main effect of SA, $F(3, 114) = 9.19$, $p < .001$, $\eta_p^2 = .19$, with RTs increasing from early to late SA conditions that was qualified by an interaction of SA and group, $F(3, 114) = 3.34$, $p = .022$, $\eta_p^2 = .08$. Whereas the TLD group showed a steady increase in RTs over SA conditions ranging from -300 to $+300$, the SLI group showed an unexpected decrease in RTs at SA $+300$.

To examine the effects of nonword distractors on RTs, we conducted a mixed-design ANOVA with group as a between-subjects variable and SA condition and distractor type as within-subjects variables. This analysis revealed significant main effects of distractor type, $F(1, 38) = 54.92$, $p < .001$, $MSE = 17,751$, $\eta_p^2 = .60$, and SA, $F(3, 114) = 17.64$, $p < .001$, $MSE = 54,147$, $\eta_p^2 = .32$, and an interaction of SA and distractor type, $F(3, 114) = 7.25$, $p < .001$, $MSE = 10,247$, $\eta_p^2 = .16$. Overall, pictures paired with phonologically related nonwords were named more quickly than those paired with unrelated nonwords. The effect of SA reflected the costs of processing two stimuli at the same time: When the distractor and the picture were separated in time (early SA conditions), RTs were faster than when they overlapped (late SA conditions), with peak interference from the distractor at SA $+100$. In addition, although the main effect of group did not approach significance, $F(1, 38) < 1$, there were significant two-way interactions between SA and group, $F(3, 114) = 2.97$, $p = .035$, $MSE = 54,147$, $\eta_p^2 = .07$, and distractor type and group, $F(1, 38) = 4.55$, $p = .039$, $MSE = 17,751$, $\eta_p^2 = .11$.

Figure 1 depicts the mean RT differences between the related and unrelated distractor conditions for the SLI and TLD groups at each SA, plotted as RT differences relative to baseline (cf. Seiger-Gardner & Brooks, 2008). Subtracting out the baseline condition allows one to examine the effects independent of individual differences in RTs. Values that are positive in the figure show interference effects relative to baseline, whereas negative values show facilitation. As shown in Figure 1, both groups showed a similar pattern of peak interference from unrelated nonwords at SA $+100$.

Figure 1 shows the results of planned comparisons of phonologically related versus unrelated distractor types at each SA condition, with significant differences between distractor types indicated by asterisks. The SLI group named pictures more quickly when they were paired with phonologically related nonwords at both late SAs: $+100$: $F(1, 57) = 16.38$, $p < .001$, $r = .47$; $+300$: $F(1, 57) = 5.08$, $p = .028$, $MSE = 15,105$, $r = .29$, but failed to show an effect of distractor type at early SAs: -300 : $F(1, 57) = 1.64$, $p = .204$, $MSE = 15,105$, $r = .17$; -100 : $F(1, 57) = 0.25$, $p = .618$, $MSE = 15,105$, $r = .07$. Hence, anticipatory effects of early phonologically related distractors were absent in the SLI group.

Figure 1. Mean response time differences (ms) between the related (Rel) and unrelated (Unrel) distractor types as a function of stimulus asynchrony. Positive values indicate interference relative to the baseline condition; negative values indicate facilitation. $*p < .05$.

In contrast, the TLD group named pictures faster when paired with phonologically related nonwords at all SA conditions: -300 : $F(1, 57) = 25.20$, $p < .001$, $MSE = 5,389$, $r = .55$; -100 : $F(1, 57) = 19.92$, $p < .001$, $MSE = 5,389$, $r = .51$; $+100$: $F(1, 57) = 107.60$, $p < .001$, $MSE = 5,389$, $r = .81$; and $+300$: $F(1, 57) = 21.56$, $p < .001$, $MSE = 5,389$, $r = .52$.

Standardized Effect Sizes

To examine individual differences in the magnitude of the effect of distractor type at each SA while controlling for speed of processing, we transformed each participant's median RTs into z scores on the basis of their distribution of RTs and computed standardized effects at each SA by subtracting z scores for unrelated and phonologically related distractor conditions. At the early SAs, the effect of distractor type was smaller for children with SLI than for TLD controls: SA -300 : $t(38) = -2.30$, $p = .027$; SA -100 : $t(38) = -2.61$, $p = .013$. In contrast, at the late SAs, z scores confirmed the absence of any significant group differences.

Next, we examined whether the standardized assessment scores (CELF, PPVT, TONI) were predictive of the effects of distractor type at each SA in the combined sample of 40 children; these correlation coefficients are shown in Table 3. CELF scores correlated positively with effect sizes

Table 3. Pearson correlation coefficients between age, assessment tests, and standardized effect sizes (response time differences for unrelated and related distractor types) at each SA.

SA	Age	CELF			TONI	PPVT
		Expressive	Receptive	Total		
–300	.08	.32*	.44**	.39*	.28	.22
–100	.04	.33*	.22	.33*	.13	.41**
+100	.06	.31	.35*	.29	.09	.13
+300	–.17	.22	.13	.17	.03	.14

Note. CELF = Clinical Evaluation of Language Fundamentals; PPVT = Peabody Picture Vocabulary Test; SA = stimulus asynchrony.
* $p < .05$. ** $p < .01$.

at SAs –300, –100, and +100, with larger effects (i.e., faster RTs for related vs. unrelated distractors) associated with higher standardized scores on the comprehensive language assessment test. PPVT scores, measuring receptive vocabulary, correlated significantly with effect sizes only at SA –100, which suggests that sensitivity to distractor types was better predicted by overall language skills than by receptive vocabulary. Although the children varied in age, there were no significant correlations between age in months and the magnitude of the effects at any SA. Furthermore, although SLI and TLD groups differed in TONI scores, non-verbal intelligence failed to correlate significantly with effect sizes.

Discussion

Previous research (Seiger-Gardner & Brooks, 2008) reported lexical–phonological interference in children with SLI but not TLD controls when a phonologically related word occurred prior to a picture to be named (early SA condition). This interference effect suggested that children with SLI experience lexical–phonological competition within a cohort of words sharing onsets to a greater extent than their TLD peers. The current study succeeded in eliminating lexical–phonological competition between the distractor and target picture by using nonwords as distractors. This allowed us to evaluate utilization of phonological information in picture naming as a function of the timing of the distractor relative to its target.

In several respects, the children with SLI performed similarly to their TLD peers, with the nonword distractors having maximal impact at SA +100, as shown in Figure 2. Specifically, when unrelated distractors were presented 100 ms after the onset of the picture to be named, children showed an exaggerated interference effect, which suggests that the irrelevant segments were being processed just as the phonological representation of the target picture name was being assembled. Delaying the onset of the distractor by 200 ms (SA +300) decreased the magnitude of the effect substantially, which suggests that a shorter interval may be critical for affecting the assembly of phonological segments in the phonological output buffer (cf. Dell, 1986; Roelofs,

1997). The identical time course of the peak impact of the distractors on spoken-word production across the groups suggests similarities in incremental processing in spoken word production. Indeed, across SA conditions, there were no overall group differences in RTs, although the children with SLI were more error-prone than their TLD peers.

Using nonwords eliminated lexical–phonological competition between the distractor and its target. This allowed us to evaluate whether early phonological cues were utilized less efficiently in children with SLI relative to their peers. In both error and RT analyses, children with SLI showed priming effects (fewer errors and faster RTs for pictures paired with phonologically related vs. unrelated nonwords) that were restricted to the late SA conditions with the picture occurring prior to the distractor. At the early SAs, usage of nonwords as opposed to lexical distractors eliminated the lexical–phonological interference effect (slower RTs for pictures paired with phonologically related vs. unrelated words) yet failed to yield anticipatory priming.

In contrast, the TLD group showed robust priming effects in error rates and RTs across early and late SA conditions. In the combined sample of children with SLI and TLD, the magnitude of the anticipatory effect was linked to individual differences in language skills, with standardized effects correlating more strongly with results of a comprehensive language assessment (CELF scores) than with vocabulary size (PPVT scores).

Despite the large age range of the participants, we found no evidence that priming effects varied as a function of child age. Nevertheless, as we included only an age-matched control group, we cannot determine whether the lack of anticipatory effects reflects an immature response pattern—that is, we could not assess if the response profile of children with SLI is typical for children at earlier stages of language development. Study 2 addressed this issue.

Study 2

The purpose of Study 2 was to determine whether the response profile of children with SLI resembles that of younger TLD controls with intact phonological priming at late SA conditions in combination with weak anticipatory processing at early SAs. For this purpose, we examined data from an unpublished cross-sectional study (Brooks & MacWhinney, 1994), which used identical procedures with children as young as 5 years of age.

Method

Participants

Four age groups were recruited with 16 participants in each group: 5-/6-year-olds (five boys, 11 girls; $M = 5;9$, range: 5;3 to 6;2), 7-/8-year-olds (nine boys, seven girls; $M = 7;6$, range: 7;0 to 8;3), 9-/10-year-olds (six boys, 10 girls; $M = 10;0$, range: 9;4 to 10;9), and adults (10 men, six women). Children were recruited and tested at private schools in

Figure 2. Mean response time difference (ms) between the related and unrelated distractor types as a function of stimulus asynchrony across four age groups. Positive values indicate interference relative to the baseline condition; negative values indicate facilitation. * $p < .05$. † $p < .06$.

Pittsburgh, PA; adults were undergraduates from the psychology subject pool at Carnegie Mellon University.

Materials and Design

The stimuli and design were identical to Study 1. The experiment was run on an Apple computer using PsyScope experimental software (Cohen, MacWhinney, Flatt, & Provost, 1993). RTs were measured using a voice key connected to a button box timer.

Procedure

The procedure was identical to Study 1 with the exception that the session was not recorded. Instead, the experimenter kept a log of errors while running the session.

Data Analysis

Mixed-design ANOVAs were used to examine effects of nonword distractors on picture naming at different SA conditions, using arcsine-transformed error rates and median RTs as the dependent variables. Planned comparisons of related and unrelated distractor conditions were used to examine early and late priming effects at each age.

Results

Errors

Table 4 shows the mean percentages of errors as a function of distractor type and SA condition for each age group. To examine the effects of nonword distractors on error rates, we conducted a mixed-design ANOVA on arcsine-transformed error rate proportions with age group as a between-subjects variable and distractor type and SA condition as within-subjects variables. Results showed that error rates differed significantly across age groups, $F(3, 60) = 2.93$, $p = .041$, $MSE = .123$, $\eta_p^2 = .13$. On average, 5-/6-year-olds made 5.4% errors across trials compared with 3.9% in 7-/8-year-olds, 3.5% in 9-/10-year-olds, and 3.2% in adults.²

There were also significant main effects of distractor type, $F(1, 60) = 21.55$, $p < .001$, $MSE = .070$, $\eta_p^2 = .26$, and SA, $F(3, 180) = 3.10$, $p = .028$, $MSE = .090$, $\eta_p^2 = .05$.

²The error rates in Study 2 were much lower than in Study 1. We suspect that the experimenter may have missed errors while running the sessions due to inattention. The lack of session recordings limits any further conclusions that can be drawn regarding the observed error rates.

Table 4. Median (SD) reaction times (ms) and error rates (%) for unpublished data by age groups ($n = 16$ in each group) as a function of stimulus asynchrony and distractor type.

Age group	Distractor	Early stimulus asynchrony				Late stimulus asynchrony			
		-300		-100		+100		+300	
		Median (SD)	Error rate, % (SD)	Median (SD)	Error rate, % (SD)	Median (SD)	Error rate, % (SD)	Median (SD)	Error rate, % (SD)
5-/6-year-olds	Related	1,079 (135)	3.6 (4.8)	1,186 (189)	4.8 (5.9)	1,575 (292)	2.7 (6.8)	1,595 (344)	5.3 (5.6)
	Unrelated	1,198 (141)	4.4 (3.8)	1,290 (253)	5.6 (4.6)	1,835 (474)	8.4 (8.2)	1,643 (446)	8.3 (5.5)
	Baseline	1,125 (195)	3.9 (4.5)	1,231 (201)	11.5 (7.4)	1,673 (258)	9.4 (10.9)	1,624 (362)	5.9 (7.4)
7-/8-year-olds	Related	848 (94)	2.5 (4.2)	866 (93)	2.8 (4.0)	1,049 (271)	2.0 (3.0)	866 (237)	3.5 (5.1)
	Unrelated	933 (109)	3.6 (4.6)	961 (104)	2.8 (4.0)	1,301 (344)	5.9 (7.4)	888 (291)	7.8 (5.3)
	Baseline	912 (115)	2.4 (4.6)	934 (136)	5.2 (5.9)	1,094 (208)	5.1 (4.7)	898 (253)	9.1 (5.6)
9-/10-year-olds	Related	751 (75)	4.0 (4.0)	750 (87)	2.3 (5.0)	926 (205)	2.8 (4.6)	844 (272)	3.5 (5.1)
	Unrelated	839 (101)	2.0 (3.0)	803 (92)	5.1 (4.7)	1,008 (234)	.8 (4.0)	848 (268)	5.1 (5.7)
	Baseline	810 (111)	3.6 (4.0)	809 (85)	1.2 (3.4)	932 (164)	4.3 (4.4)	849 (217)	6.0 (6.5)
Adults	Related	617 (76)	2.0 (3.8)	632 (71)	2.4 (3.2)	648 (171)	2.3 (3.9)	604 (64)	2.7 (3.9)
	Unrelated	666 (65)	2.7 (4.5)	677 (76)	2.3 (3.9)	676 (144)	7.1 (6.2)	609 (57)	4.0 (4.6)
	Baseline	647 (63)	2.7 (3.9)	666 (62)	3.6 (4.6)	667 (136)	2.0 (3.0)	626 (72)	5.5 (4.6)

Participants made fewer errors in naming pictures paired with related nonwords (3.1%) as compared to unrelated ones (4.9%). Participants made somewhat fewer errors in the early SA conditions (-300: 3.1%, -100: 3.5%) as compared to the late SAs (+100: 4.2%, +300: 5.0%). In addition to these main effects, there was significant a two-way interaction effect between SA and distractor type, $F(3, 180) = 2.77, p = .043, MSE = .079, \eta_p^2 = .05$, with a larger effect of distractor type on error rates at the late SAs (see Table 4).

Planned comparisons conducted at each SA compared error rates for pictures paired with related versus unrelated nonwords. Error rates for the 5-/6-year-olds were significantly lower for the related condition only at SA +100: $F(1, 45) = 10.26, p = .003, MSE = .078, r = .43$. For the 7-/8-year-olds, error rates were significantly lower for the related condition only at +300: $F(1, 45) = 7.63, p = .008, MSE = .079, r = .38$. For the 9-/10-year-olds, error rates were significantly lower for the related condition only at SA -100: $F(1, 45) = 4.27, p = .045, MSE = .080, r = .29$. For the adults, error rates were significantly lower for the related condition only at SA +100, $F(1, 45) = 7.21, p = .010, MSE = .081, r = .37$.

RTs

Table 4 displays mean RTs for each distractor and SA condition at each age; these group means are the averages of individual children's median RTs. To examine the effects of nonword distractors on RTs, we conducted a mixed-design ANOVA on the median RTs with age group as a between-subjects variable and distractor type and SA condition as within-subjects variables. RT analyses showed a significant main effect of age group, $F(3, 60) = 77.25, p < .001, MSE = 182,736, \eta_p^2 = .79$, with RTs decreasing with age. In particular, the 5-/6-year-olds produced RTs ($M = 1,421$ ms) that were markedly longer than participants at other ages

(age 7/8 years: $M = 962$; age 9/10 years: $M = 847$; adults $M = 644$). There was also a main effect of distractor type, $F(1, 60) = 88.95, p < .001, MSE = 10,099, \eta_p^2 = .60$, with pictures named faster when paired with related as opposed to unrelated nonwords, as well as a main effect of SA, $F(3, 180) = 35.48, p < .001, MSE = 49,649, \eta_p^2 = .37$, with longer RTs at the late SA conditions.

In addition to these main effects, there were significant two-way interactions between age group and distractor type, $F(3, 60) = 7.07, p < .001, MSE = 10,099, \eta_p^2 = .26$, between age group and SA, $F(9, 180) = 10.88, p < .001, MSE = 49,649, \eta_p^2 = .35$, and between distractor type and SA, $F(3, 180) = 9.64, p < .001, MSE = 10,296, \eta_p^2 = .14$. Figure 2 shows, for each age group, mean RT differences between related and unrelated distractor conditions as a function of SA. These group means are plotted as RT differences relative to the baseline condition to facilitate comparison of effects across age groups that have markedly different baseline RTs. Positive values in the figure indicate interference relative to the baseline condition; negative values indicate facilitation.

Planned comparisons of related versus unrelated distractor types were conducted at each SA condition, with significant effects of distractor type indicated by asterisks in Figure 2. Across age groups, priming effects were present at all SA conditions except for SA +300. For the 5-/6-year-olds, effects showed a trend toward significance at SA -300, $F(1, 45) = 3.84, p = .056, MSE = 29,876, r = .28$; the effect was not significant at SA -100: $F(1, 45) = 2.84, p = .099, MSE = 29,876, r = .24$, but was highly significant at SA +100: $F(1, 45) = 18.09, p < .001, MSE = 29,876, r = .54$. There was no effect at SA +300: $F(1, 45) = 0.63, p = .43, MSE = 29,876, r = .10$. For the 7-/8-year-olds, effects were highly significant at SA -300: $F(1, 45) = 8.04, p = .007, MSE = 7,114, r = .39$; -100: $F(1, 45) = 10.24,$

$p = .002$, $MSE = 7,114$, $r = .43$; and $+100$: $F(1, 45) = 71.45$, $p < .001$, $MSE = 7,114$, $r = .78$; but not at SA $+300$: $F(1, 45) = 0.52$, $p = .47$, $MSE = 7,114$, $r = .11$. For the 9-/10-year-olds, effects were significant at SA -300 : $F(1, 45) = 20.94$, $p < .001$, $MSE = 3,001$, $r = .56$; -100 : $F(1, 45) = 7.56$, $p = .009$, $MSE = 3,001$, $r = .38$; and $+100$: $F(1, 45) = 17.89$, $p < .001$, $MSE = 3,001$, $r = .53$; but not at $+300$, $F(1, 45) = .06$, $p = .81$, $MSE = 3,001$, $r = .04$. Likewise, the adults showed significant effects at SAs -300 : $F(1, 45) = 16.11$, $p < .001$, $MSE = 1,194$, $r = .51$; -100 : $F(1, 45) = 16.70$, $p < .001$, $MSE = 1,194$, $r = .52$; and $+100$: $F(1, 45) = 5.19$, $p = .03$, $MSE = 1,194$, $r = .32$; but not at SA $+300$: $F(1, 45) = 0.16$, $p = .69$, $MSE = 1,194$, $r = .06$.

Standardized Effect Sizes

To examine whether the magnitude of the priming effects varied as a function of age while controlling for developmental changes in speed of processing, we transformed each participant's median RTs across conditions into z scores using each participant's distribution of RTs. We computed standardized difference scores for the related and unrelated conditions at each SA and computed correlations between the standardized difference scores at each SA and child age (i.e., excluding the adult group). At SA -300 , the magnitude of the priming effect correlated significantly with child age, $r(N = 48) = .33$, $p = .023$, with older children showing a greater reduction in RTs when naming pictures paired with related versus unrelated nonwords. At the other SAs, there was no relationship between the magnitude of the priming effect and age, $rs(N = 48) \leq .07$, $p \geq .630$.

Discussion

Study 2 examined developmental changes in the effects of nonword distractors in the PWI task. We were especially interested in the effects of early distractors at SA -300 and -100 , when children with SLI failed to benefit from phonologically related distractors. Although in the predicted direction (faster RTs for pictures paired with related nonwords), the effects for the youngest group of 5-/6-year-olds only showed a trend toward statistical significance at early SA conditions (i.e., significant only with one-tailed tests). In contrast, all of the older age groups showed significant anticipatory priming effects at SAs -300 and -100 . Correlational analyses of standardized effect sizes revealed an effect of child age on the magnitude of the priming effect at SA -300 , but not at SA -100 .

As in Study 1, the maximum interference from unrelated nonwords occurred at SA $+100$ and did not vary as a function of age. This suggests that phonological representations of the target word were being assembled 100 ms after the picture to be named with a similar time course of phonological processing in children from 5 to 6 years to adults. In contrast to Study 1, in which children showed late priming effects extending to SA $+300$, none of the age groups in Study 2 showed a significant effect of distractor type on RTs at SA $+300$, although the effect was evident in the error rates of the 7-/8-year-olds.

General Discussion

The present study sought to elucidate processes involved in spoken-word production in children with SLI by examining effects of phonologically related nonword distractors presented at varying SA conditions in a cross-modal PWI task. We compared effects of early distractors (occurring 300 or 100 ms prior to the onset of the picture to be named) with late distractors (occurring 100 or 300 ms after the onset of the picture). Because previous work (Seiger-Gardner & Brooks, 2008) reported lexical-phonological interference in school-age children with SLI at an early SA condition with slower RTs for pictures paired with phonologically related words versus unrelated words, we eliminated the lexical status of the distractors by using nonwords. The use of nonword distractors eliminated lexical-phonological competition between the distractor and the target as nonwords were not candidate names for the pictures in the response set. First, we compared performance of school-aged children with SLI with age-matched controls to determine how phonological cueing of the name of the target picture varied in SLI as a function of the timing of the distractor relative to its target. Second, we used cross-sectional data to examine age trends in task performance to determine whether the SLI response profile of intact phonological priming at late SA conditions in combination with weak anticipatory priming at early SAs resembles that of children at an earlier stage of language development.

In line with our first hypothesis, across both studies, the effect of distractor type peaked at SA $+100$ —that is, with the onset of the nonword occurring 100 ms after the onset of the picture to be named. At this interval, the phonological information contained in the nonword was available just as relevant phonological segments were being selected in preparation for producing the target picture name. As shown in Figures 1 and 2, this peak effect appears to be due to increased interference from unrelated distractors—that is, accessing phonological segments that mismatched the target disrupted assembly of the target word in the phonological output buffer as opposed to the presence of a related nonword facilitating its production. The time course of the peak effect was in the range observed in previous studies with children as well as adults (Brooks & MacWhinney, 2000; A. S. Meyer & Schriefers, 1991; Schriefers et al., 1990); its magnitude was uncorrelated with age in the cross-sectional data, suggesting similar incremental processes of phonological assembly in spoken-word production across middle childhood in children with and without SLI.

In both experiments, group differences were more evident at the early SA conditions in which the distractor occurred well in advance of the picture to be named (i.e., with its termination 300 or 100 ms prior to the onset of the picture) than at the late SAs. In support of our second hypothesis, children with SLI failed to show significant anticipatory effects of related nonwords at either early SA. Standardized effect sizes were significantly smaller for children with SLI than for age-matched controls and correlated with language assessment scores in the combined sample.

It is important to note that there was no effect of age within the range sampled (7;0 to 11;0). In the cross-sectional data set, anticipatory effects showed a trend toward significance for the 5-6-year-olds (i.e., significant only with one-tailed tests) but robust at other ages. At SA -300 , but not SA -100 , effect sizes correlated significantly with child age. Thus, given an age range that included children from 5;3 to 10;9, anticipatory effects at the longer interval were shown to increase with age. Taken together, these results suggest that the lack of anticipatory priming in children with SLI might resemble, in part, the less efficient use of contextual cues by younger children to anticipate an upcoming stimulus. Weak anticipatory priming is likely to disrupt language fluency as speakers tend to reuse the linguistic expressions they have just processed as listeners when formulating their responses (Branigan, Garrod, & Pickering, 2014; Garrod & Pickering, 2004).

Although other cross-modal PWI studies have reported slower RTs in children with SLI relative to TLD peers (e.g., Brooks, Seiger-Gardner, & Sailor, 2014; de Hoog, Langereis, van Weerdenburg, Knoors, & Verhoeven, 2015; Seiger-Gardner & Brooks, 2008), we failed to confirm this finding (see also Seiger-Gardner & Schwartz, 2008). However, despite comparable RTs across SA conditions, children with SLI made about twice as many errors as their TLD peers, which is suggestive of a speed-accuracy trade-off. It is important that the group differences in the priming effects at the early SA conditions remained when standardized scores were used to eliminate individual differences in overall RTs.

Phonological Processing and Implicit Learning in SLI

As outlined in the introduction, research implicates inefficient phonological processing as contributing to the word learning and word finding difficulties of children with SLI (e.g., Bishop & Snowling, 2004; McMurray et al., 2010). Weak phonological representations of auditory stimuli or their rapid decay in short-term memory provide an account of the varying effects of staggered versus simultaneous presentation of distractor-target pairs across priming studies. In paradigms that require the prime to be held temporarily in phonological short-term memory, research has consistently shown an absence of phonological or semantic priming in children with SLI (e.g., Gray et al., 2012; Hennessey, Leitão & Mucciarone, 2010; Velez & Schwartz, 2010). However, when the target picture is available prior to the onset of the auditory distractor, children with SLI have shown effects of phonologically related versus unrelated distractors that are indistinguishable from TLD controls (Study 1; Seiger-Gardner & Brooks, 2008).

Other PWI studies are consistent in showing weak anticipatory priming effects in children with SLI when the presence of an early distractor is expected to facilitate retrieval of the name of the target picture. Brooks et al. (2014) examined the effects of semantic associates (e.g., *nest* paired with a picture of a bird) that are hypothesized to facilitate

lexical access through spreading activation at a conceptual level (D. E. Meyer & Schvaneveldt, 1971). When the semantic associate occurred prior to the picture to be named, children with TLD showed faster RTs and lower error rates relative to targets paired with unrelated distractors whereas children with SLI showed an effect of distractor condition only in their error rates. For RTs, standardized effect sizes for the associative priming effect correlated with scores on both the CELF and PPVT assessments. In a related study that included trials in which the distractor was the name of the target picture (Brooks, Seiger-Gardner, & Valencia, 2012), TLD controls named pictures paired with their own names (e.g., *spoon* paired with spoon) faster than baseline (i.e., the word *good*) at early SAs, whereas children with SLI showed this priming effect only at late SAs with the target picture appearing prior to its name. Thus, across studies, we have observed poor utilization of contextual cues to predict upcoming stimuli in children with SLI even when a substantial proportion of trials (25% to 33%) presented distractors that were semantic associates, identical, or nearly identical (as in the current study) to their targets.

The observed difficulties of children with SLI in learning distractor-target contingencies in the PWI task may stem from impaired implicit, procedural learning (Lum et al., 2014). The PWI task is a variation of the Stroop color-naming task (van Maanen, van Rijn, & Borst, 2009), and the learning of distractor-target contingencies in the Stroop task has been linked to the procedural memory system in studies of amnesic individuals who lack declarative memory but demonstrate intact procedural learning (Musen & Squire, 1993). To more fully understand the putative impairment in implicit learning of distractor-target contingencies in children with SLI, future studies should vary the predictability of targets as a function of their distractors and assess cumulative learning over blocks of trials. Given deficits in implicit learning, training paradigms may be developed to improve children's skills in utilizing auditory cues to predict upcoming targets. Whether or not such training will be effective in improving language fluency and decreasing speech errors in children with SLI remains to be tested.

Conclusions

The cross-modal PWI task, in simulating the exchange of information from speaker to listener, provides a method for examining how incoming speech held in phonological short-term memory affects the efficiency of spoken-word production. In contrast to previous PWI investigations of lexical access in children with and without SLI (Brooks & MacWhinney, 2000; Seiger-Gardner & Brooks, 2008), the current study used nonwords as distractors to eliminate lexical competition between the distractors and their targets. We observed a broad time course of phonological priming effects over SAs ranging from -300 to $+300$, which contrasts with the restricted time course of phonological priming effects documented in the literature (A. S. Meyer & Schriefers, 1991; Schriefers et al., 1990; but see Damian & Martin, 1999). The presence of anticipatory priming with

nonword distractors but not lexical distractors suggests that lexical competition at the early SAs may cancel out the effect of phonological priming when the distractors are real words.

Across participant groups, the peak effect of a nonword distractor coincided with its onset occurring 100 ms after the onset of the target picture. The similar results for children with and without SLI suggest that both groups engaged in an incremental process of phonological assembly in spoken-word production. In contrast to the consistency of priming effects at SA +100, only children with TLD showed anticipatory priming at early SAs. This result implicates weak anticipatory processes in lexical access in children with SLI and informs treatment studies utilizing phonological cues to aid word retrieval (German, 2002; Gray, 2005; McGregor, 1994) by underscoring the importance of timing parameters in their design. Thus, phonological cues may need to be available just in time for spoken-word production (i.e., slightly after their targets) to reduce the word-finding difficulties and improve the language fluency of children with SLI.

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Appendix

Lists of Pictures and Distractors Presented

Distractor type	List A		List B		List C		List D	
	Picture	Distractor	Picture	Distractor	Picture	Distractor	Picture	Distractor
Neutral	bell	go	bear	go	arm	go	ball	go
Neutral	bike	go	belt	go	bed	go	book	go
Neutral	bird	go	bus	go	brush	go	bread	go
Neutral	bowl	go	car	go	cake	go	broom	go
Neutral	comb	go	clown	go	chair	go	cat	go
Neutral	corn	go	coat	go	cup	go	church	go
Neutral	desk	go	door	go	deer	go	clock	go
Neutral	drum	go	flag	go	dog	go	crown	go
Neutral	fish	go	hat	go	fork	go	dress	go
Neutral	frog	go	horse	go	heart	go	duck	go
Neutral	gun	go	leaf	go	house	go	foot	go
Neutral	moon	go	pig	go	kite	go	hand	go
Neutral	nose	go	plane	go	lamp	go	lock	go
Neutral	sled	go	ring	go	shirt	go	pen	go
Neutral	star	go	spoon	go	sock	go	snake	go
Neutral	sun	go	truck	go	train	go	wheel	go
Related	arm	arb	ball	bawth	bell	bepp	bear	beark
Related	bed	besh	book	buup	bike	bize	belt	belk
Related	brush	brug	bread	breg	bird	birm	bus	buth
Related	cake	caish	broom	broove	bowl	bowm	car	carf
Related	chair	chairk	cat	cak	comb	coag	clown	clowf
Related	cup	cuth	church	churg	corn	corf	coat	coab
Related	deer	deerp	clock	cross	desk	desp	door	dorp
Related	dog	dosh	crown	crowp	drum	drub	flag	flaz
Related	fork	forp	dress	drev	fish	fik	hat	hab
Related	heart	harg	duck	dus	frog	frozz	horse	hork
Related	house	houf	foot	fook	gun	guz	leaf	leath
Related	kite	kipe	hand	hamp	moon	moog	pig	piv
Related	lamp	lant	lock	losh	nose	noke	plane	plabe
Related	shirt	shirf	pen	pez	sled	slek	ring	rint
Related	sock	sov	snake	snaze	star	starf	spoon	spume
Related	train	trabe	wheel	weeb	sun	suf	truck	truv
Unrelated	ball	pez	bell	corf	bear	leath	arm	lant
Unrelated	book	dus	bike	moog	belt	hab	bed	shirf
Unrelated	bread	cross	bird	frozz	bus	rint	brush	chairk
Unrelated	broom	fook	bowl	starf	car	piv	cake	deerp
Unrelated	cat	broove	comb	suf	clown	dorp	chair	caish
Unrelated	church	drev	corn	guz	coat	truv	cup	trabe
Unrelated	clock	weeb	desk	birm	door	clowf	deer	cuth
Unrelated	crown	hamp	drum	bepp	flag	beark	dog	forp
Unrelated	dress	cak	fish	coag	hat	belk	fork	dosh
Unrelated	duck	breg	frog	noke	horse	spume	heart	kipe
Unrelated	foot	losh	gun	bowm	leaf	plabe	house	brug
Unrelated	hand	crowp	moon	slek	pig	carf	kite	houf
Unrelated	lock	buup	nose	drub	plane	buth	lamp	besh
Unrelated	pen	bawth	sled	fik	ring	coab	shirt	arb
Unrelated	snake	churg	star	desp	spoon	hork	sock	harg
Unrelated	wheel	snaze	sun	bize	truck	flaz	train	sov