Phonological Priming with Nonwords in Children With and Without Language Impairment

Patricia J. Brooks

College of Staten Island and The Graduate Center, CUNY

Liat Seiger-Gardner

Lehman College, CUNY

Rita Obeid

The Graduate Center, CUNY

Brian MacWhinney

Carnegie Mellon University

Author Note:

The research was supported by a Shuster Fellowship awarded to L. Seiger-Gardner. The authors thank the families that participated, and Olidia Valencia, Christine Neumayer, Arianna Miskin and Christina Grenoble for their assistance with data collection.

Please address correspondence to:

Patricia J. Brooks, Department of Psychology, CSI/CUNY, 2800 Victory Blvd. 4S-103, Staten Island, NY 10314; patricia.brooks@csi.cuny.edu

Abstract

Purpose: The cross-modal picture-word interference task can be used to examine contextual effects on spoken-word production. Previous work documents phonological interference in children with SLI when a related distractor (e.g., *bell*) occurs prior to a picture-to-be-named (e.g., a bed). Here we examine whether atypical effects persist using nonwords as distractors.

Method: In Study 1, children with SLI (N=20; 7;1–11;0) and age-matched controls named pictures accompanied by (1) phonologically-related nonwords, (2) unrelated nonwords, or (3) the word *go* (baseline). Stimulus Asynchrony (SA) varied across blocks, with distractors occurring prior to (–300ms, –100ms) or after the pictures (+100ms, +300ms). In Study 2, a cross-sectional sample of children (N=48, 5;3–10;9) and adults (N=16) performed the same task.

Results: Child and adult control participants showed phonological priming effects at early and late SAs, whereas children with SLI showed effects only at late SAs. Effect sizes correlated with language skills (CELF scores). 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 impact speech fluency in children with SLI.

Phonological Priming with Nonwords in Children

With and Without Language Impairment

Specific Language Impairment (SLI) is associated with deficits in lexical and phonological processing (Schwartz, 2009). Children with SLI are slower to acquire words (e.g., Nash & Donaldson, 2005; Oetting, Rice, & Swank, 1995); they show atypical encoding of word forms (Alt & Suddrath, 2011; Maillart, Schelstraete, & Hupet, 2004); and they often experience difficulties in accessing the words they know (e.g., Dockrell, Messer, George, & Wilson, 1998; German 1984; Rice, Buhr, & Nemeth, 1990). These difficulties have been linked to deficits in phonological short-term memory (Gathercole & Baddeley, 1990) and to varied aspects of executive functioning, such as sustained attention and verbal working memory (e.g. Ebert and Kohnert, 2011; Hoffman & Gillam, 2004; Montgomery, 2000).

Lexical access is strongly driven by contextual cues, with words previously spoken, heard, or read determining how efficiently a target word may be accessed (Meyer & Schvanefeldt, 1971). Evaluating the impact of contextual cues allows researchers to evaluate how the time course of lexical access might differ for children with SLI relative to their peers. In lexical access, multiple words compete for retrieval until one reaches sufficient strength and a decision is made in favor of its production (Magnuson, Dixon, Tanenhaus & Aslin, 2007). Incrementalist approaches to lexical access propose that stored words become activated and compete for retrieval as soon as their initial segments are phonologically encoded (Marslen-Wilson, 1987; Meyer & Schriefers, 1991). Researchers have suggested that due to weak phonological representations, children with SLI may utilize incremental processing strategies in lexical access to a lesser extent than their typical peers (Edwards & Lahley, 1996). Studies of spoken-word production can shed light on this issue by examining how children with SLI utilize phonological context cues.

Information Processing Deficits in SLI

SLI is not a disorder limited to language impairments; research has shown that that children with SLI show a broad range of impairments in executive functioning (Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Marton, 2008), including information processing capacity, attention, working memory, problem solving, and organization (Ebert and Kohnert, 2011; Hoffman & Gillam, 2004; Marton & Schwartz, 2003). Kail (1994) put forth the generalized slowing hypothesis suggesting that individuals with SLI have slower information processing speed compared to their typical peers. In support of this hypothesis, Miller, Kail, Leonard, and Tomblin (2001) found that children with SLI performed slower on both linguistic and non-linguistic information processing tasks. Other researchers have focused on limitations in verbal short-term and working memory as contributing to executive functioning deficits in SLI (Archibald and Gathercole, 2006). In comparison to their typical peers, children with SLI display deficits on a wide range of verbal working memory tasks (e.g., Weismer, Evans, and Hesketh, 1999); and it has been argued that poor verbal working memory is a clinical marker for SLI (Montgomery 2003; Gillam, Montgomery, & Gillam, 2009).

Researchers have often emphasized the role of phonological encoding for supporting working memory (Gathercole & Baddeley, 1990; Gupta & MacWhinney, 1997). Such approaches suggest that the verbal working memory deficits observed in SLI could stem, at least in part, from inaccurate phonological representations, limited phonological storage capacity, and a rapid decay of auditory traces (e.g. Faust, Dimitrovsky & Davidi, 1997; German, 2002; Joanisse & Seidenberg, 1998; McGregor, 1994; McMurray, Samelson, Lee, & Tomblin, 2010).

Indeed, poor nonword repetition, assessed in a task in which children are asked to repeat back nonsense words, has been found to be one of the strongest clinical predictors of SLI (Bishop, North, & Donlan, 1996; Conti-Ramsden, Botting, & Faragher, 2001; Donagham & Campbell, 1998; Gathercole & Baddeley, 1990), and may be especially useful in distinguishing different subtypes of SLI (Bishop, Adams & Norbury, 2006).

Another method for examining children's phonological representations is through priming experiments, which reveal how lexical access is affected by information held in working memory. 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 typical peers, the 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 indicate that children with SLI fail to benefit from phonologically related cues occurring prior to their targets. This pattern contrasts with evidence of intact phonological priming children with SLI in the cross-modal picture-word interference (PWI) task when the auditory distractor occurred 150 ms after the picture-to-be-named (Seiger-Gardner & Brooks, 2008).

The Cross-Modal PWI Task

The cross-modal PWI task is a variant of the Stroop task (Van Maanen, Van Rijn, & Borst; 2009; see Stroop, 1935) widely used with children in studies of spoken-word production (e.g., Brooks & MacWhinney, 2000; Brooks, Seiger-Gardner, & Sailor, 2014; Jerger, Martin, & Damian, 2002; Jerger, Martin, & Pirozzolo, 1988; Hanauer & Brooks, 2003, 2005; Seiger-

Gardner & Schwartz, 2008; Seiger-Gardner & Brooks, 2008). Participants are instructed to name a series of pictures while ignoring auditory distractors; the PWI task is a dual-task paradigm wherein participants must suppress activation of distractors while focusing attention on naming target pictures. By manipulating the timing of the distractor relative to the picture-to-be-named, i.e. the stimulus asynchrony (SA), one may examine how contextual information is utilized in the process of preparing a spoken word response (Maas & Mailend, 2012; Schriefers, Meyer, & Levelt, 1990). For example, Hanauer and Brooks (2003), using in a cross-modal version of the Stroop color-naming task, documented developmental changes in the efficiency with which children could inhibit auditory distractors, with young children (4- to 5-year-olds), but not older children and adults, showing Stroop interference when the auditory distractor (another color word) occurred well in advance (500 ms) of the color-to-be-named (a colored square). In contrast, all age groups showed significant Stroop interference when the distractor occurred simultaneous with the color-to-be-named. Whether children with SLI have similar difficulties in inhibiting auditory distractors remains understudied.

Seiger-Gardner and Brooks (2008) employed the cross-modal PWI paradigm to examine effects of phonologically related words on lexical access in 7 to 11-year-olds with SLI. Overall, children with SLI required more time and made more errors in picture naming 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., *bell* paired with a picture of a bed) faster than pictures paired with unrelated distractors. The timing of this phonological priming effect matched previous findings for children and adults (Brooks & MacWhinney, 2000; Schriefers et al., 1990), which suggests that children with SLI show intact priming of information in the phonological output buffer, where phonological segments are held as they are sequenced for spoken word production (Dell, 1986). However, when the distractor terminated 150 ms prior to the picture-to-be-named (early SA condition –150), children with SLI, but not controls, also showed a phonological interference effect, with slower naming of pictures paired with onset-related vs. unrelated distractors (see also Seiger-Gardner and Schwartz, 2008). Studies of spoken word recognition also report greater phonological competition between words sharing onsets (i.e., members of the same phonological cohort) in children and adolescents with SLI compared to age-matched controls (Mainela-Arnold, Evans, & Coady, 2008; McMurray et al., 2010), which suggests overlap in the phonological difficulties associated with SLI across production and comprehension tasks.

The present study sought to further explore effects of early vs. late distractors in the PWI task in children with SLI. In order to reduce lexical competition effects between distractor–target pairs with overlapping sound patterns (e.g., *bell* and *bed*), we used nonwords (e.g., *besh*) as distractors. Presentation of a phonologically related nonword was expected to 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 weak phonological priming in SLI (e.g., Gray et al., 2012; Velez & Schwartz, 2010).

Study 1

Method

Participants. Forty children (24 boys, 16 girls, *M* = 8 years; 6 months, *SD* = 1;1, range 7;0 to 11;0) 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, 6 girls) ranged in age from 7;1 to 11;0 (*M* = 8;7). Controls with typical language development (TLD) (10 boys, 10 girls) ranged in age from 7;0 to 11;0 (*M* = 8;5). All children were drawn from households where American English was the primary language, as verified through a language background questionnaire. Children were administered the Test of Nonverbal Intelligence, Fourth Edition (TONI-III; Brown, Sherbenou, & Johnson, 1997), the Peabody Picture Vocabulary Test Revised (PPVT-4; Dunn & Dunn, 2007), and the Clinical Evaluation of Language Fundamentals (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 the mean) on the Clinical Evaluation of Language Fundamentals, CELF 4 (Semel, Wiig, & Secord, 2003).

Table 1 about here

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 vs. TONI, $t(19) = -10.98$, $p < .001$; PPVT vs. TONI, $t(19) = -3.93$, $p < .001$. Furthermore, their comprehensive language assessment scores were lower than their receptive vocabulary scores: CELF vs. 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.

Materials and Design. Target pictures were 64 b/w line drawings of common objects from a standardized set (Cycowicz, Friedman, Snodgrass, & Rothstein, 1997), with an additional 4 pictures serving as practice items. For each target, we created a phonologically related nonword distractor, which shared the onset consonant(s) and vowel as the name of the picture. These nonwords, and the word *go*, were recorded by a female native speaker of English, with average duration = 510 ms (SD = 69).

Across trials, each target picture was paired with three distractors: (1) a phonologically related nonword that sounded like the name of the target (e.g., *truv* paired with a picture of a truck); (2) an unrelated nonword that was related to the name of a different picture in the response set, and unrelated to the target (e.g., *besh* paired with a picture of a truck); and (3) the word *go* (baseline), 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: Each list had 16 pictures per distractor condition, and omitted 16 pictures, see Appendix.

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

Apparatus. The experiment was run on a Dell PC computer using *E-Prime* 1.1 software (Schneider, Eschman, & Zuccolotto, 2002), and utilized a voice key connected to a button box timer. 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 or premature triggering of the voice key from breathing.

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 non-target 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.

PWI trials were blocked by SA condition, with 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 8 targets per distractor condition (phonologically related, unrelated, baseline). The order of the two sub-blocks within each block, as well as order of the trials within each sub-block, was randomized. Each target remained on the computer screen for four seconds or until the voice key was activated by the child's response. A research assistant, seated behind the child, provided encouragement and reminders to name the pictures as quickly and accurately as possible. Children were allowed a short break (e.g., to drink water) after each sub-block of 25 trials.

Data Analysis. Statistical analyses were conducted on error rates and RTs. Proportions of errors were arcsine transformed, as recommended by Cohen (1967). Due to the skewed distribution of RTs, we used median RTs (ms) for each condition as the dependent variable. Trials involving a naming error, speech disfluency, or failure to respond within four seconds were counted as errors and excluded from RT analyses. Lost trials due to experimenter or computer error (e.g., premature triggering of the voice key due to ambient noise) were not counted as errors and were removed from analyses.

To examine early and late priming effects 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. Preliminary analyses comparing the baseline and related distractor conditions failed to show significant differences at any SA for either SLI or TLD groups. For brevity, the baseline condition is excluded from reported analyses.

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. A mixed-design analysis of variance (ANOVA) was conducted on arcsine transformed error proportions, with group (SLI, TLD) 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 than controls, 10.5% vs. 6.1%, F (1, 38) = 15.10, $p < .001$, $MSE = .274$, $\eta_p^2 = .28$. Children (TLD & SLI) made fewer errors when pictures were paired with phonologically related vs. unrelated nonwords (5.8% vs. 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), wherein the picture was presented first, and both the picture and distractor were processed simultaneously.

Table 2 about here

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, $p = .004$, $MSE = .066$; and +300: F(1, 57) = 14.58, $p < .001$, $MSE = .066$, but did not approach significance at early SAs: –300: F(1, 57) = 1.83, $p = .18$, $MSE = .066$, –100: F(1, 57) = 1.45, $p = .23$, $MSE = .066$. TLD controls produced significantly fewer errors in naming pictures paired with phonologically related nonwords at the earliest SA –300, F (1, 57) = 6.93, $p = .011$, $MSE = .079$, and at both late SAs: +100: F (1, 57) = 25.59, $p < .001$, $MSE = .079$; and +300: F (1, 57) = 10.20, $p = .002$, $MSE = .079$. The effect at SA –100 was not significant, F(1, 57) = 1.62, $p = .20$, $MSE = .079$.

Errors were coded qualitatively as non-target, disfluency, or no response. Non-target 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 doubling the word onset or saying *um* before the target response. No response comprised trials for which the child failed to name the picture after 4 sec. Both groups showed similar distributions of error types, with the 48% non-target, 35% disfluency, and 17% no response in the SLI group; and 49% non-target, 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 individual children's median RTs. A mixed-design analysis of variance (ANOVA) was conducted on median RTs with group as a between-subjects variable, and SA condition and distractor type as within-subjects variables. RT analysis revealed significant main effects of distractor type, F (1, 38) = 54.92, $p < .001$, *MSE*= 17751, $\eta_p^2 = .60$, and SA, F (3, 114) = 17.64, $p < .001$, *MSE*= 54147, $\eta_p^2 = .32$, and an interaction of SA and distractor type, F (3, 114) = 7.25, $p < .001$, *MSE*=10247, $\eta_p^2 = .16$. Overall, pictures paired with phonologically related nonwords were named faster 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. Additionally, 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*= 54147, $\eta_p^2 = .07$, and distractor type and group, F(1, 38) = 4.55, p = .039, *MSE*= 17751, $\eta_p^2 = .11$.

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 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 faster when they were paired with phonologically related nonwords at both late SAs: +100: F (1, 57) =16.38, $p < .001$; +300: F (1, 57) = 5.08, $p = .028$, MSE = 15105, but failed to show an effect of distractor type at early SAs: –300: F (1, 57) = 1.64, $p = .204$, MSE = 15105; –100: F (1, 57) = .25, $p = .618$, MSE = 15105. Hence, anticipatory effects of early phonologically related distractors were absent in the SLI group.

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 = 5389; –100: F (1, 57) = 19.92, $p < .001$, MSE = 5389; +100: F (1, 57) = 107.60 , $p < .001$, MSE = 5389; and +300: F (1, 57) = 21.56, $p < .001$, MSE = 5389.

Figure 1 about here

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 based on 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; these correlation coefficients are shown in Table 3. CELF scores correlated positively with effect sizes 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 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, nonverbal intelligence failed to correlate significantly with effect sizes.

Table 3 about here

Discussion

The purpose of the study was to examine whether children with SLI show atypical processing of phonologically related nonword distractors in the PWI task, as earlier studies (Seiger-Gardner & Brooks, 2008; Seiger-Gardner & Schwartz, 2008) reported an atypical phonological interference effect in SLI when a phonologically related word occurred in advance of the picture to be named (early SA condition). In several respects, the two groups performed similarly, with the nonword distractors having maximal impact at SA +100, as shown in Figure 2. That is, 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 interference effect substantially, which suggests that a shorter interval may be critical for priming elements in the phonological output buffer (cf. Dell, 1986; Schriefers et al., 1990). The identical time course of the peak impact of the distractors on spoken-word production across the groups suggests similarities in the efficiency of assembling phonological segments for speech production. Indeed, across SA conditions, there were no overall group differences in RTs, although the children with SLI were more error prone than their typical peers.

By using nonwords to eliminate the lexical status of the distractors, we sought to evaluate whether early distractors were processed differently 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. No priming effects were evident at the early SAs; hence, usage of nonwords as opposed to lexical distractors eliminated the early phonological interference effect (slower RTs for pictures paired with phonologically related vs. unrelated words) reported by Seiger-Gardner & Brooks (2008), yet failed to yield a faciliatory priming effect.

In contrast, the TLD control group showed robust priming effects in error rates and RTs across early and late SA conditions. The magnitude of 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). Additionally, there was a weak correlation with TONI scores at SA –300, which suggests a possible role for nonverbal intelligence in anticipatory processing that needs to be confirmed in future studies.

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 whether the response profile of children with SLI is typical for children at earlier stages of language development. To address this issue, we re-analyzed data from an earlier cross-sectional study (Brooks & MacWhinney, 1994) that administered the same task to children as young as 5 to 6 years.

Study 2

Method

Participants. Four age groups were recruited with 16 participants in each group: 5/6-year-olds (5 boys, 11 girls; *M* = 5;9, range: 5;3–6;2), 7/8-year-olds (9 boys, 7 girls; *M* = 7;6, range: 7;0–8;3), 9/10-year-olds (6 boys, 10 girls; *M* = 10;0, range: 9;4–10;9), and adults (10 men, 6 women). Children were recruited and tested at private schools in Pittsburgh, PA; adults were undergraduates from the psychology subject pool at Carnegie Mellon University.

Materials and design. The stimuli and design were identical to Experiment 1.

Apparatus. The experiment was run on an Apple computer using PsyScope experimental software (Cohen, MacWhinney, Flatt & Provost, 1993). Reaction times 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 arc-sine 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 percentage of errors as a function of distractor type and SA condition for each age group. A mixed-design analysis of variance (ANOVA) was conducted on arcsine transformed error rates 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, η_p^2 = .13. On average, 5/6-year-olds made 5.4% errors across trials, compared to 3.9% in 7/8-year-olds, 3.5% in 9/10-year-olds, and 3.2% in adults.

Table 4 about here

There were also significant main effects of distractor type, F (1, 60) = 21.55, p < .001, MSE = .070, η_p^2 = .26, and SA, F (3, 180) = 3.10, p = .028, MSE = .090, η_p^2 = .05. 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, η_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 vs. unrelated nonwords. For the 5/6-year-olds, error rates were significantly lower for the related condition at SA +100: F (1, 45) = 10.26, p = .003, MSE = .078, and marginally lower at

SA+300: *F* (1, 45) = 3.09, *p* = .086, *MSE* = .078; for the 7/8-year-olds, error rates were marginally lower for the related condition at SA +100, *F* (1, 45) = 3.51, *p* = .068, *MSE* = .079 and significantly lower at +300 *F* (1, 45) = 7.63, *p* = .008, *MSE* = .079; for the 9/10-year-olds, error rates were significantly lower for the related condition at SA –100, *F* (1, 45) = 4.27, *p* = .045, *MSE* = .080; for the adults, error rates were significantly lower for the related condition at SA +100, *F* (1, 45) = 7.21, *p* = .010, *MSE* = .081.

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. A mixed-design analysis of variance (ANOVA) was conducted 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* = 182736, η_p^2 = .79, with RTs decreasing with age. In particular, the 5/6-year-olds produced RTs (*M* = 1421 ms) that were markedly longer than participants at other ages (Age 7/8: *M* = 962; Age 9/10: *M* = 847; Adults *M* = 644). There was also a main effect of distractor type, *F* (1, 60) = 88.95, *p* < .001, *MSE* = 10099, η_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* = 49649, η_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* = 10099, η_p^2 = .26, between age group and SA, *F* (9, 180) = 10.88, *p* < .001, *MSE* = 49649, η_p^2 = .35, and between distractor type and SA, *F* (3, 180) = 9.64, *p* < .001, *MSE* = 10296, η_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.

Figure 2 about here

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 were marginal at the early SAs: –300, F (1, 45) = 3.84, p = .056, MSE = 29876, and –100: F (1, 45) = 2.84, p = .099, MSE = 29876, but were highly significant at SA +100: F (1, 45) = 18.09, p < .001, MSE = 29876. There was no effect at SA +300: F (1, 45) = .63, p = .43, MSE = 29876. For the 7/8-year-olds, effects were highly significant at SA –300: F (1, 45) = 8.04, p = .007, MSE = 7114; –100: F (1, 45) = 10.24, p = .002, MSE = 7114; and +100: F (1, 45) = 71.45, p < .001, MSE = 7114; but not at SA+300: F (1, 45) = .52, p = .47, MSE = 7114. For the 9/10-year-olds, effects were significant at SA –300: F (1, 45) = 20.94, p < .001, MSE = 3001; –100: F (1, 45) = 7.56, p = .009, MSE = 3001; and +100: F (1, 45) = 17.89, p < .001, MSE = 3001; but not at +300, F (1, 45) = .06, p = .81, MSE = 3001. Likewise, the adults showed significant effects at SAs –300: F (1, 45) = 16.11, p < .001, MSE = 1194; –100: F (1, 45) = 16.70, p < .001, MSE = 1194; and +100: F (1, 45) = 5.19, p = .03, MSE = 1194; but not at SA +300: F (1, 45) = .16, p = .69, MSE = 1194.

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 larger difference in RTs for pictures paired with related vs. unrelated nonwords. At the other SAs, there was no relationship between the magnitude of the priming effect and age, *r's* (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, where children with SLI failed to show a significant effect of distractor type. Although all age groups showed effects in the predicted direction (faster RTs for pictures paired with related nonwords), the effects for the 5/6-year-olds were marginal at both early SA conditions (i.e., significant only with one-tailed tests). 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 point of maximal interference from unrelated nonwords peaked at SA +100, and did not vary as a function of age. This suggests that phonological representations of the target word were being assembled 100ms after the picture to be named, with a similar time course of phonological processing in children from 5/6 years to adults. In contrast to Study 1, wherein 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 younger age groups.

General Discussion

The present study sought to elucidate processes involved in spoken-word production in children with SLI by examining effects of phonologically related distractors presented at varying stimulus asynchrony (SA) conditions in a cross-modal picture-word interference (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) had reported an atypical phonological interference effect in school-age children with SLI at an early SA condition, with slower RTs for pictures paired with phonologically related words vs. unrelated words, we eliminated the lexical status of the distractors by using nonwords. First, we compared performance of school-aged children with SLI with age-matched controls to determine whether atypical performance persisted at early SAs, and second, we used cross-sectional data to examine age trends in task performance.

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 the nonword was available just as relevant phonological segments were being selected in preparation for producing the target picture name. As shown in Figures 2 and 3, 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; Meyer & Schriefers, 1991; Schriefers et al., 1990); its magnitude was uncorrelated with age in the cross-sectional data, suggesting similar processes of phonological assembly in spoken-word production across middle childhood.

In both experiments, group differences were more evident at the early SA conditions wherein 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. 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. Notably, there was no effect of age within the range sampled (7;0-11;0). In the cross-sectional dataset, anticipatory effects were marginal 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 years, 3 months to 10 years, 9 months, 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 processing is likely to disrupt the fluency of conversational speech, as speakers tend to reuse linguistic expressions they have just processed as listeners when formulating their responses (Garrod & Pickering, 2004).

It has been proposed that children with SLI show generalized slowing in information processing, as reflected in their performance on non-verbal as well as verbal tasks, including picture naming (Kail, 1994; Lahey & Edwards, 1996; Miller et al., 2001). Although some PWI studies have observed slower RTs in children with SLI relative to their typically developing peers (e.g., Brooks et al., 2014; 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 typical peers, which is suggestive of a speed-accuracy trade-off. Importantly, 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, which rules out generalized slowing as an explanation.

As outlined in the Introduction, numerous research findings implicate weak phonological representations, limited verbal working memory capacity, and/or rapid decay of auditory traces as contributing to the language learning and processing deficits of children with SLI (cf. Bishop & Snowling, 2004; McMurray et al., 2010; Montgomery, 2003, for reviews). Weak representations of auditory stimuli (or their rapid decay) might plausibly account for the varying effects of staggered vs. simultaneous presentation of distractor-target pairs across priming studies. In priming paradigms, such as cued shadowing or primed verbal repetition, wherein presentation of primes and targets is staggered, thus requiring the prime to be held temporarily in verbal working memory, research has consistently shown an absence of phonological or semantic priming in children with SLI (e.g., Gray et al., 2010; Hennessey, Leitão and Mucciarone, 2010; Velez & Schwartz, 2010). In contrast, in the PWI task, with the target picture available prior to the onset of the auditory distractor (late distractor conditions), children with SLI have shown effects of phonologically related vs. unrelated distractors that are indistinguishable from typical controls (Study 1; Seiger-Gardner & Brooks, 2008).

Other PWI studies are consistent in showing weak anticipatory priming effects in children with SLI, where the presence of an early distractor is expected to facilitate retrieval of the name of the target picture. Brooks et al. (2014) examined 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 (Meyer & Schvaneveldt, 1971). When the semantic associate occurred in advance of the picture-to-be-named, children with typical development showed faster RTs and lower error rates relative to targets paired with unrelated distractors, whereas children with SLI showed the facilitative effect only in their error rates. For RTs, standardized effect sizes correlated with scores on both the CELF and PPVT assessments. In a related study that included trials where the distractor was the name of the target picture (Brooks, Seiger-Gardner, & Valencia, 2012), typical 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 occurring in advance of 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 identical (or nearly identical, as in Study 1) to their targets.

If indeed children with SLI have difficulties learning contingencies between distractors and targets that are separated in time, then impaired sequence learning might be an underlying mechanism. Ullman and Pierpont (2005) have proposed that impaired procedural learning underlies the phonological and grammatical difficulties of children with SLI. This hypothesis is supported by findings linking poor sequence learning in children with SLI, relative to controls, with measures of language ability (e.g., Tomblin, Mainela-Arnold, & Zhang, 2007; Evans, Saffran, & Robe-Torres, 2009, Mainela-Arnold & Evans, 2014; see also Lum, Conti-Ramsden, Morgan, & Ullman (2014) for a meta-analysis of impaired sequence learning in SLI, as measured using the Serial Reaction Time (SRT) task). Indeed, in a recent study of children with and without SLI, Mainela-Arnold and Evans (2014) found poor sequence learning to be predictive of larger lexical-phonological competition effects in a spoken word recognition task (i.e., more intrusions of non-target responses from a phonological cohort).

The procedural memory system has also been linked to implicit learning of distractor-target contingencies in the Stroop task: Musen and Squire (1993) reported that amnesic patients who lack declarative memory (but have intact procedural learning) showed decreased Stroop interference over time when the incongruent color word paired with the color-to-be-named was held constant over trials, and, like controls, showed increased Stroop interference when these contingencies were changed. As the PWI task is a variation of the Stroop task, we expect that response set contingencies are learned implicitly, with considerable impact on task performance. To date, there have been few studies of developmental changes in sensitivity to response set characteristics in the PWI task. Hanauer and Brooks (2005, Experiment 3) reported that adults, but not children, showed Stroop-like interference when the distractor was unrelated to the target picture, but was the name of different picture in the response set (as opposed to an unrelated word that was not the name of one of other pictures). That is, when the distractor was a candidate response for naming one of a small set of pictures that repeated over trials, it slowed naming of the target to a greater extent than a word that could be excluded as a possible response. We would predict that for children with SLI the learning of such distractor–target contingencies would prove to be especially difficult.

Implications for Treatment

Online methods, like the cross-modal PWI task, have great potential to shed light on information processing deficits associated with SLI by providing detailed information about the time course of utilization of contextual cues in speech production. Our results implicate weak anticipatory processes as impacting lexical access in speech production of children with SLI, and call for future PWI studies to track implicit learning of distractor-target contingencies in children with SLI, by varying the predictability of targets as a function of their distractors and assessing 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 speech fluency and decreasing speech errors in children with SLI is unknown.

References

Alt, M., & Suddarth, R. (2012). Learning novel words: Detail and vulnerability of initial representations for children with specific language impairment and typically developing peers. *Journal of Communication Disorders*, *45*(2), 84-97. doi:10.1016/j.jcomdis.2011.12.003.

Archibald, L. M., & Gathercole, S. E. (2006). Visuospatial immediate memory in specific language impairment. *Journal of Speech, Language, and Hearing Research*, *49*(2), 265-277. doi: 1092-4388/06/4902-0265

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, *105*(1), 158-173. doi: 10.1037/0033-295X.105.1.158

Bishop, D., Adams, C. V., & Norbury, C. F. (2006). Distinct genetic influences on grammar and phonological short-term memory deficits: evidence from 6-year-old twins. *Genes, Brain and Behavior, 5*, 158-169. doi: 10.1111/j.1601-183X.2005.00148.x

Bishop, D. V. M., North, T., & Donlan, C. D. (1996). Nonword repetition as a behavioural marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Psychiatry*, *37*(4), 391-403. doi: 10.1111/j.1469-7610.1996.tb01420.x

Bishop, D. V. M. & Snowling, M. (2004). Developmental dyslexia and specific language impairment. *Psychological Bulletin, 130*(6), 858-886. doi: 10.1037/0033-2909.130.6.858

Brooks, P. J. & MacWhinney, B. (2000). Phonological priming in children's picture naming. *Journal of Child Language, 27,* 335-366. Retrieved from: http://journals.cambridge.org/abstract_S0305000900004141

Brooks, P. J. & MacWhinney, B. (1994, November) Phonological and semantic priming in children's picture naming. Poster presented at the 35th Annual Meeting of *The Psychonomic Society*, St. Louis, MO.

Brooks, P.J., Seiger-Gardner, L., & Sailor, K. (2014). Contrasting effects of associates and coordinates in children with and without language impairment: A picture-word interference study. *Applied Psycholinguistics, 35* (3), 515-545. doi: 10.1017/S0142716412000495

Brooks, P. J., Seiger-Gardner, L. & Valencia, O. (2012, July). Boys and girls are friends: Associative priming in the picture-word interference task in children with and without language impairments. Poster presented at the *International Workshop on Language Production '12*, New York, NY.

Brown, L., Sherbenou, R.J., & Johnson, S.K. (1997). *The Test of Nonverbal Intelligence: A Language Free Measure of Cognitive Ability* (3rd ed.). Pro-Ed: Austin, TX.

Cohen, J. (1967). An alternative to Marascuilo's "large-sample multiple comparisons" for proportions. *Psychological Bulletin, 67* (3), 199-201. doi: 10.1037/h0020418

Cohen, J., MacWhinney, B., Flatt, M. & Provost, J. (1993). PsyScope: an interactive graphical system for designing and controlling experiments in the Psychology laboratory using

Macintosh computers. *Behavioral Research Methods*, *Instrumentation*, *and Computers* *25*, 257-271. doi: 10.3758/BF03204507

Conti-Ramsden, G., Botting, N., & Faragher, B. (2001). Psycholinguistic markers for specific language impairment (SLI). *Journal of Child Psychology and Psychiatry*, *42*(6), 741-748. doi: 10.1111/1469-7610.00770

Cycowicz, Y., Friedman, D., Rothstein, M., & Snodgrass, J. (1997). Picture naming by young children: Norms for name agreement, familiarity, and visual complexity. *Journal of Experimental Child Psychology, 65,* 171-237. doi: http://dx.doi.org/10.1006/jecp.1996.2356

Damian, M.F., & Martin, R.C. (1999). Semantic and phonological codes interact in single word production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25* (2), 345-361. doi:10.1037/0278-7393.25.2.345

Dell, G.S. (1986). A spreading activation theory of retrieval in sentence production. *Psychological Review, 93*, 283–321. doi: http://dx.doi.org/10.1037/0033-295X.93.3.283

Dockrell, J.E., Messer, D. George, R., & Wilson, G. (1998). Children with word-finding difficulties – prevalence, presentation and naming problems. *International Journal of Language and Communication Disorders, 33*, 445-454. doi:10.1080/136828298247721

Dunn, L. & Dunn, L. (2007). *Peabody Picture Vocabulary Test, 4rth Edition*. Minneapolis, MN: Pearson.

Ebert, K.D., & Kohnert, K. (2011). Sustained attention in children with primary language impairment: A meta-analysis. *Journal of Speech, Language, and Hearing Research*, *54*(5), 1372-1384. doi: 10.1044/1092-4388

Edwards, J., & Lahey, M. (1996). Auditory lexical decisions of children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *39*(6), 1263-1273. doi:10.1044/jshr.3906.1263

E-Prime 1.1 (SP3) (2003). Psychology Software Tools. https://www.pstnet.com

Evans, J.L., Saffran, J.R., Robe-Torres, K. (2009). Statistical learning in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 52,* 321-335. doi: http://dx.doi.org/10.1044/1092-4388(2009/07-0189)

Faust, M., Dimitrovsky, L., & Davidi, S. (1997). Naming difficulties in language-disabled children: Preliminary findings with the application of the tip-of-the-tongue paradigm. *Journal of Speech, Language, and Hearing Research*, *40*(5), 1026-1036. doi: 10.1044/jslhr.4005.1026

Garrod, S. & Pickering, M. J. (2004). Why is conversation so easy? *Trends in Cognitive Sciences, 8*(1), 8-11. doi:10.1016/j.tics.2003.10.016

Gathercole, S.E. & Baddeley, A.D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29*(3), 336–360. doi: http://dx.doi.org/10.1016/0749-596X(90)90004-J

German, D.J. (1984). Diagnosis of word-finding disorders in children with learning disabilities. *Journal of Learning Disabilities, 17*, 353-359. doi:10.1177/002221948401700609

Gillam, R.B., Montgomery, J.W., & Gillam, S.L. (2009). Memory and attention in child language disorders. In: Schwartz, R. G. (Eds.). *Handbook of child language disorders* (201-215). New York, NY: Psychology Press.

Gray, S., Reiser, M., & Brinkley, S. (2012). Effect of onset and rhyme primes in preschoolers with typical development and specific language impairment. *Journal of Speech, Language and Hearing Research*, *55*(1), 32-44. doi:10.1044/1092-4388(2011/10-0203)

Gupta, P. & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59*(2), 267–333. doi: http://dx.doi.org/10.1006/brln.1997.1819

Hanauer, J.B. & Brooks, P.J. (2003). Developmental change in the cross-modal Stroop effect. *Perception & Psychophysics, 65*, 359-366. doi: http://dx.doi.org/10.3758/BF03194567

Hanauer, J.B., & Brooks, P.J. (2005). Contributions of response set and semantic relatedness to cross-modal stroop-like picture-word interference in children and adults. *Journal of Experimental Child Psychology, 90*, 21-47. doi:10.1016/j.jecp.2004.08.002

Hennessey, N.W., Leitão, S., & Mucciarone, K. (2010). Verbal repetition skill in language impaired children: Evidence of inefficient lexical processing? *International Journal of Speech-Language Pathology, 12* (1), 47-57. doi: 10.3109/17549500903431766

Hoffman, L.M., & Gillam, R.B. (2004). Verbal and spatial information processing constraints in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *47*(1), 114. doi: 1092-4388/04/4701-0114

Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. *Child Development, 77*(6), 1822-1841. doi: 0009-3920/2006/7706-0022

Joanisse, M.F., & Seidenberg, M.S. (1998). Specific language impairment: a deficit in grammar or processing? *Trends in Cognitive Sciences*, *2*(7), 240-247. doi: 10.1016/S1364-6613(98)01186-3

Kail, R. (1994). A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech and Hearing Research*, *37*(2), 418-421. doi:10.1044/jshr.3702.418

Lahey, M & Edwards, J. (1996). Why do children with specific language impairments name pictures more slowly than their peers? *Journal of Speech, Language, and Hearing Research*, *39,* 1081-1098. doi:10.1044/jshr.3905.1081

Lum, J.A., Conti-Ramsden, G., Morgan, A.T., & Ullman, M.T. (2014). Procedural learning deficits in specific language impairment (SLI): A meta-analysis of serial reaction time task performance. *Cortex*, *51,* 1-10. doi:10.1016/j.cortex.2013.10.011

Maas, E., & Mailend, M. L. (2012). Speech planning happens before speech execution: Online reaction time methods in the study of apraxia of speech. *Journal of Speech, Language, and Hearing Research*, *55*(5), 1523-1534. doi:10.1044/1092-4388

Maillart, C., Schelstraete, M.-A., & Hupet, M. (2004). Phonological representations of children with SLI : a study of French. *Journal of Speech, Hearing and Language Research, 47,* 187-198. doi:10.1044/1092-4388(2004/016)

Mainela-Arnold, E. & Evans, J. L. (2014). Do statistical segmentation abilities predict lexical-phonological and lexical-semantic abilities of children with and without SLI? *Journal of Child Language, 41*(2), 327-351. doi: 10.1017/S0305000912000736

Mainela-Arnold, E., Evans, J. L., & Coady, J.A. (2008). Lexical representations in children with SLI: Evidence from a frequency-manipulated gating task. *Journal of Speech, Language and Hearing Research*, *51*(2), 381-393. doi:10.1044/1092-4388(2008/028)

Magnuson, J., Dixon, J., Tanenhaus, M., & Aslin, R. (2007). The dynamics of lexical competition during spoken word recognition. *Cognitive Science, 31,* 133-156. doi: http://dx.doi.org/10.1080/03640210709336987

Marslen-Wilson, W.D. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*(1), 71-102.

Marton, K. (2008). Visuo-spatial processing and executive functions in children with specific language impairment. *International Journal of Language & Communication Disorders*, *43*(2), 181-200. doi:10.1080/16066350701340719

Marton, K., & Schwartz, R. G. (2003). Working memory capacity and language processes in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *46*(5), 1138-1153. doi:1092-4388/03/4605-1138

McGregor, K. K. (1994). Use of phonological information in a word-finding treatment for children. *Journal of Speech and Hearing Research*, *37*(6), 1381-1393. doi:10.1044/jshr.3706.1381

McMurray, B., Samelson, V. M., Lee, S. H., & Tomblin, J. B. (2010). Individual differences in online spoken word recognition: Implications for SLI. *Cognitive Psychology*, *60*(1), 1-39. doi:10.1016/j.cogpsych.2009.06.003

Meyer, A. S., & Schriefers, H. (1991). Phonological facilitation in picture-word interference experiments: Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(6), 1146-1160. doi:10.1037/0278-7393.17.6.1146

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90,* 227-234. doi: http://dx.doi.org/10.1037/h0031564

Miller, C. A., Kail, R., Leonard, L. B., & Tomblin, J. B. (2001). Speed of processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *44*(2), 416-433. doi:10.1044/1092-4388(2001/034)

Montgomery, J. W. (2000). Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language and Hearing Research*, *43*(2), 293-308. doi:1092-4388/00/4302-0293

Montgomery, J. W. (2003). Working memory and comprehension in children with specific language impairment: What we know so far. *Journal of Communication Disorders, 36*, 221-231. doi:10.1016/S0021-9924(03)00021-2

Musen, G., & Squire, L. R. (1993). Implicit learning of color-word associations using a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(4), 789-798. doi:0278-7393/93/53.00

Nash, M., & Donaldson, M. L. (2005). Word learning in children with vocabulary deficits. *Journal of Speech, Language & Hearing Research*, *48*(2), 439-458. doi:1092-4388/05/4802-0439

Oetting, J. B., Rice, M. L., & Swank, L. K. (1995). Quick incidental learning (QUIL) of words by school-age children with and without SLI. *Journal of Speech and Hearing Research*, *38*(2), 434-445. doi:0022-4685/95/3802-0434

Rice, M. L., Buhr, J. C., & Nemeth, M. (1990). Fast mapping word-learning abilities of language-delayed preschoolers. *Journal of Speech and Hearing Disorders*, *55*(1), 33-42. doi:10.1044/jshd.5501.33

Sailor, K., Brooks, P. J., Bruening, P. R., Seiger-Gardner, L., & Guterman, M. (2009). Exploring the time course of semantic interference and associative priming in the picture–word interference task. *The Quarterly Journal of Experimental Psychology*, *62*(4), 789-801. doi:10.1080/17470210802254383

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime user's guide.* Pittsburgh: Psychology Software Tools.

Schriefers, H., Meyer, A. S., & Levelt, W. J. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, *29*(1), 86-102. doi:10.1016/0749-596X(90)90011-N

Schwartz, R. G. (2009). *Handbook of child language disorders*. New York, NY: Psychology Press.

Seiger-Gardner, L. & Brooks, P. J. (2008). Effects of onset- and rhyme-related distractors on phonological processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 51* (5), 1263-1281. doi: http://dx.doi.org/10.1044/1092-4388(2008/07-0079)

Seiger-Gardner, L., & Schwartz, R. G. (2008). Lexical access in children with and without specific language impairment: a cross-modal picture–word interference study. *International Journal of Language & Communication Disorders*, *43*(5), 528-551. doi: 10.1080/13682820701768581

Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical Evaluation of Language Fundamentals – CELF-4*. San Antonio, TX: Psychological Corporation.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology,18*, 643–662.

Tomblin, J.B., Mainela-Arnold, E., & Zhang, X. (2007). Procedural learning in adolescents with and without specific language impairment. *Language Learning and Development, 3*(4), 269-293. doi: http://dx.doi.org/10.1080/15475440701377477

Ullman, M.T., & Pierpont, E.I. (2005). Specific language impairment is not specific to language: The procedural deficit hypothesis. *Cortex*, *41*, 399-433. doi:10.1016/S0010-9452(08)70276-4

Van Maanen, L., van Rijn, H., & Borst, J. P. (2009). Stroop and picture—word interference are two sides of the same coin. *Psychonomic Bulletin & Review*, *16*(6), 987-999. doi: 10.3758/PBR.16.6.987

Weismer, S. E., Evans, J., & Hesketh, L. J. (1999). An examination of verbal working memory capacity in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *42*(5), 1249-1260. doi:10.1044/jslhr.4205.1249

Table 1.

Mean standardized scores and range for language and non-verbal intelligence assessments, with t-test results comparing groups.

N=20 in each group. Standard deviations in parentheses.

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

*$p < .05$, **$p < .001$

Table 2.

Median (standard deviation) reaction times (ms) and error rates (%) for SLI and TLD groups (N=20 in each) as a function of stimulus asynchrony and distractor type.

		Stimulus Asynchrony			
		Early		Late	
	Distractor	–300	–100	+100	+300
SLI	Related	800 (172)	875 (248)	984 (311)	870 (360)
		8.5% (7.5)	10.0% (9.6)	6.7% (6.0)	8.1% (7.6)
	Unrelated	850 (206)	895 (224)	1141 (330)	958 (442)
		10.4% (6.9)	12.2% (9.6)	12.6% (10.1)	15.8% (7.7)
	Baseline	810 (156)	903 (244)	967 (242)	889 (324)
		9.1% (8.6)	9.7% (8.7)	12.0% (11.3)	12.9% (8.2)
TLD	Related	730 (161)	762 (200)	900 (257)	987 (359)
		4.1% (4.7)	3.8% (6.3)	1.9% (3.6)	3.1% (5.2)
	Unrelated	847 (211)	866 (230)	1141 (348)	1095 (447)
		9.1% (7.4)	5.6% (7.6)	11.6% (10.2)	9.4% (9.8)
	Baseline	775 (171)	815 (210)	946 (341)	1027 (416)
		5.3% (5.5)	7.5% (7.5)	5.7% (6.4)	7.8% (7.0)

Table 3.

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

		CELF				
SA	Age	Expressive	Receptive	Total	TONI	PPVT
–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. Sig: † $p < .09$, *$p < .05$, **$p < .01$.

Table 4.

Median (standard deviation) 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.

		Stimulus Asynchrony			
		Early		Late	
	Distractor	–300	–100	+100	+300
5/6-year-olds	Related	1079 (135)	1186 (189)	1575 (292)	1595 (344)
		3.6% (4.8)	4.8% (5.9)	2.7% (6.8)	5.3% (5.6)
	Unrelated	1198 (141)	1290 (253)	1835 (474)	1643 (446)
		4.4% (3.8)	5.6% (4.6)	8.4% (8.2)	8.3% (5.5)
	Baseline	1125 (195)	1231 (201)	1673 (258)	1624 (362)
		3.9% (4.5)	11.5% (7.4)	9.4% (10.9)	5.9% (7.4)
7/8-year-olds	Related	848 (94)	866 (93)	1049 (271)	866 (237)
		2.5% (4.2)	2.8% (4.0)	2.0% (3.0)	3.5% (5.1)
	Unrelated	933 (109)	961 (104)	1301 (344)	888 (291)
		3.6% (4.6)	2.8% (4.0)	5.9% (7.4)	7.8% (5.3)
	Baseline	912 (115)	934 (136)	1094 (208)	898 (253)
		2.4% (4.6)	5.2% (5.9)	5.1% (4.7)	9.1% (5.6)
9/10-year-olds	Related	751 (75)	750 (87)	926 (205)	844 (272)
		4.0% (4.0)	2.3% (5.0)	2.8% (4.6)	3.5% (5.1)
	Unrelated	839 (101)	803 (92)	1008 (234)	848 (268)
		2.0% (3.0)	5.1% (4.7)	2.8% (4.0)	5.1% (5.7)
	Baseline	810 (111)	809 (85)	932 (164)	849 (217)
		3.6% (4.0)	1.2% (3.4)	4.3% (4.4)	6.0% (6.5)
Adults	Related	617 (76)	632 (71)	648 (171)	604 (64)
		2.0% (3.8)	2.4% (3.2)	2.3% (3.9)	2.7% (3.9)
	Unrelated	666 (65)	677 (76)	676 (144)	609 (57)
		2.7% (4.5)	2.3% (3.9)	7.1% (6.2)	4.0% (4.6)
	Baseline	647 (63)	666 (62)	667 (136)	626 (72)
		2.7% (3.9)	3.6% (4.6)	2.0% (3.0)	5.5% (4.6)

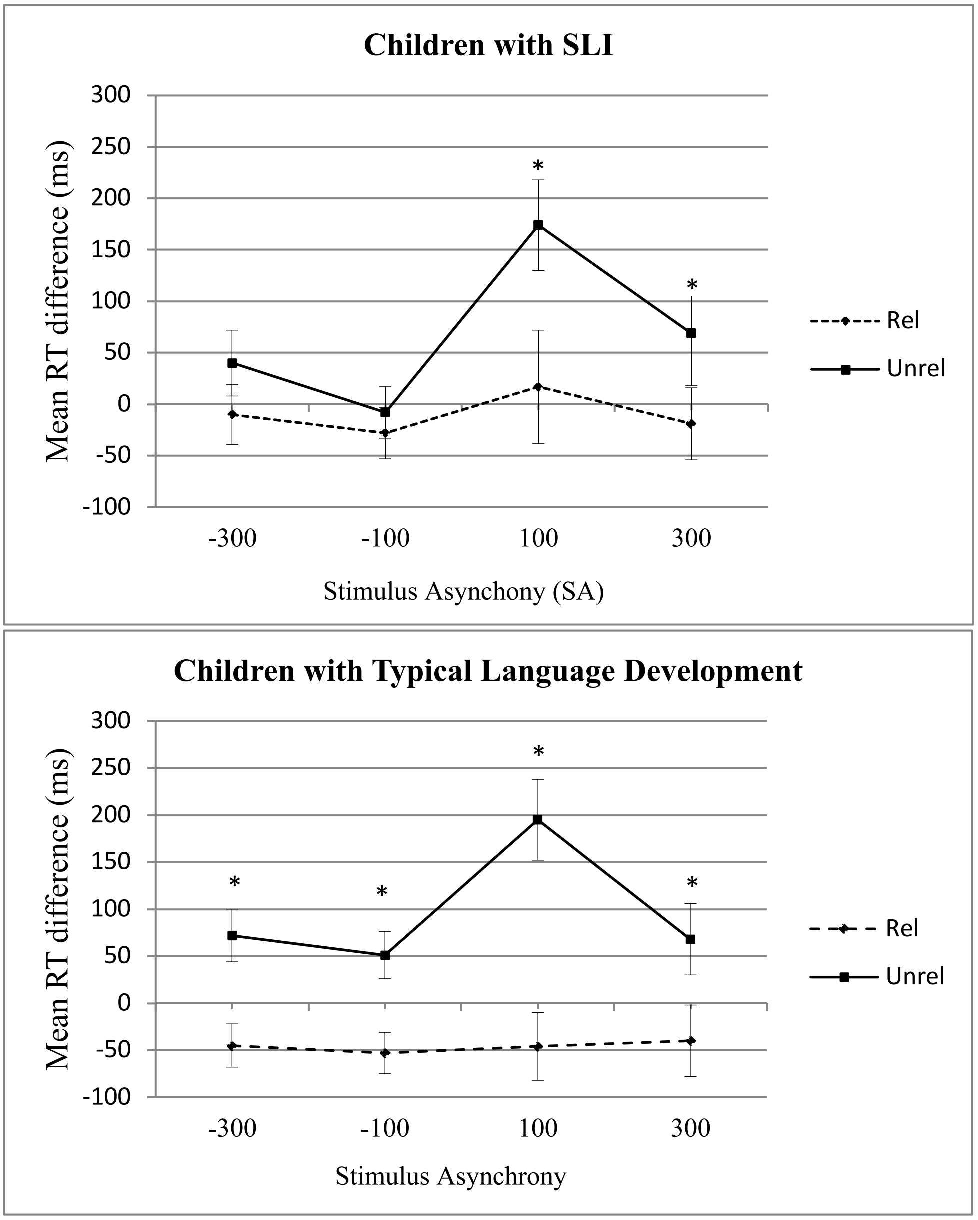

Figure 1. Mean RT differences (ms) between the related and unrelated distractor types as a function of SA. Positive values indicate interference relative to the baseline condition, negative values indicate facilitation.

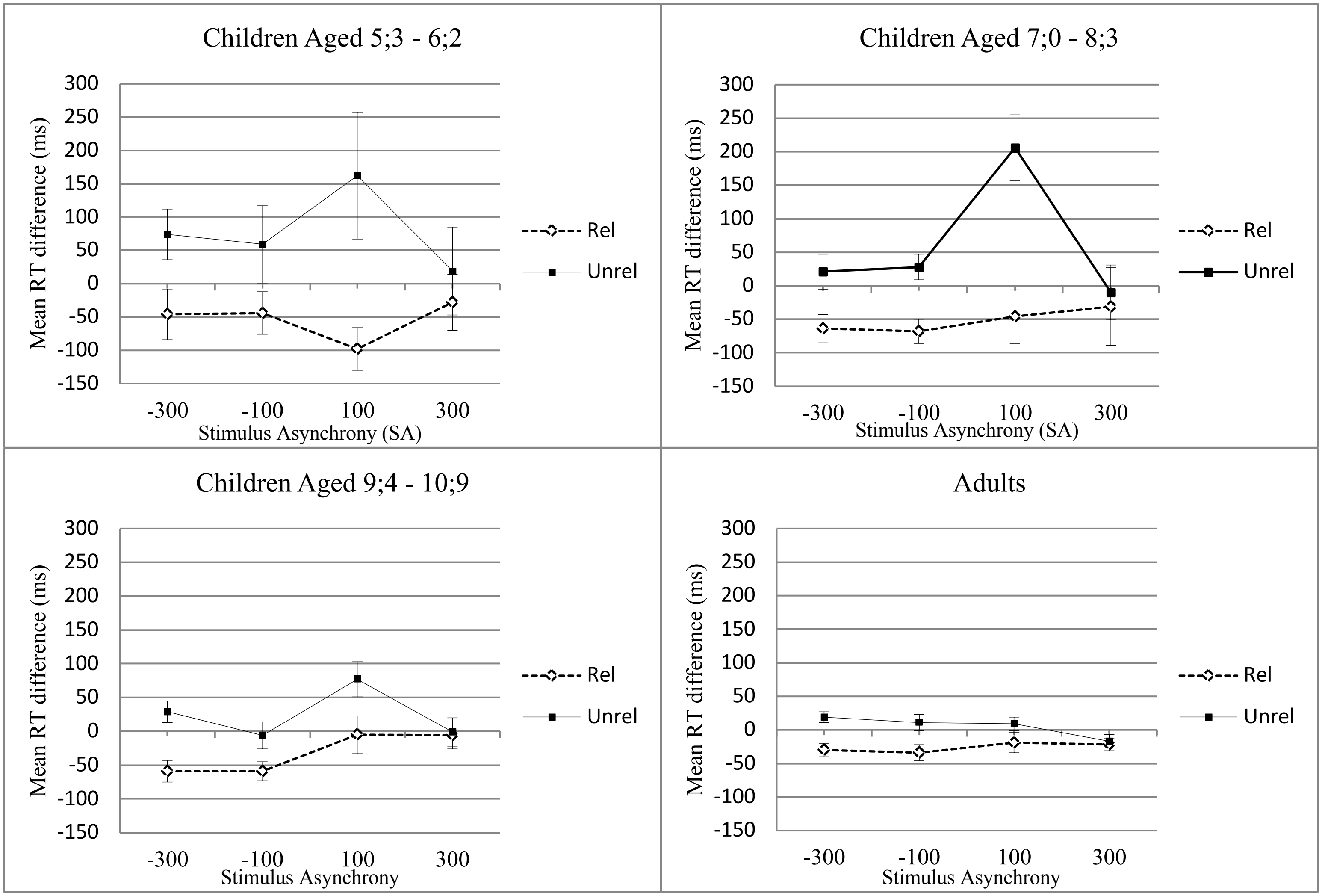

Figure 2. Mean RT difference (ms) between the related and unrelated distractor types as a function of SA across four age groups.

Positive values indicate interference relative to the baseline condition, and negative values indicate facilitation.

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	closs	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	closs	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