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Phonological priming in children's picture naming*

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ABSTRACT

Two experiments examined phonological priming in children and adults, using a cross-modal picture-word interference task. Pictures of familiar objects were presented on a computer screen, while interfering words (IWs) were presented over headphones. In terms of their relation to target pictures, IWs were either phonologically related, unrelated, neutral (the word *go*), or identical. Ninety children (30 aged 4;11 to 5;11, 30 aged 6;11 to 7;11, and 30 aged 9;5 to 11;9) and 30 adults were instructed to name the pictures as quickly as possible while ignoring the IWs. In Experiment 1, related IWs shared onset consonants with the names of the pictures. Across ages, participants named pictures faster with related IWs than with unrelated IWs. In Experiment 2, related IWs rhymed with the targets. Here, only the youngest children (five to seven-year-olds) named pictures faster with related IWs than with unrelated IWs. The results indicate that priming effects reach a peak during a time when articulatory information is being consolidated in the output phonological buffer. The disappearance of the rhyme priming effect with age may reflect the gradual emergence of the onset as an organizing structure in speech production. This increased prominence of the onset can be viewed as one component of a just-in-time, incrementalist approach to speech production that allows adults to speak more fluently than children.

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INTRODUCTION

Word production is a basic building block in the language production process. In order to speak fluently, we must activate individual words, which we then need to piece together into sentences. Although it is notoriously difficult to study the production of complete sentences, it is much easier to gain experimental control over the lexicalization process. One way of doing this is simply to ask people to name pictures. Using this basic and natural technique, we can gain a high level of experimental control over many aspects of word production. As a result, picture naming studies have played an important role in the development of theories of language production. Picture naming studies have typically assumed that there are at least three components of the picture naming process: object identification, lexical access, and phonological encoding (Glaser, 1992). Although these processes may overlap each other in real time, object identification is a logical precondition to lexical access. Furthermore, lexical access must begin before phonological activation can initiate. The current study focuses on the third and final process in word naming – phonological encoding.

The usefulness of the picture naming technique was recognized many years ago in the context of studies of the development of reading. Several studies conducted in the mid 1970s (e.g. Rosinski, Golinkoff & Kukish, 1975; Posnansky & Rayner, 1977) utilized a picture-word interference task to study the reading abilities of elementary school age children. Rosinski *et al.* (1975) asked children to name pictures on which printed words were superimposed. Their principal finding was that second and sixth-grade children named pictures more slowly when they had words written on them. Ehri (1976) went on to show that picture-word interference effects were absent in poor second-grade readers, presumably because these children were able to name the pictures more quickly than they could read the printed words.

Although the picture-word interference task has taught us a great deal about lexical activation during reading, it is not an appropriate paradigm for the study of the development of language production in children. In the course of learning to talk, children are able to activate and produce words without access to their orthographic forms. Tasks that rely on reading to study lexical production may be crucially influenced by variables and abilities that are irrelevant to spoken communication. This problem can be overcome by using a cross-modal task in which the interfering words are presented auditorily rather than visually. The cross-modal picture-word interference task has been employed to study the process of word generation in adults (e.g. Schriefers, Meyer & Levelt, 1990; Meyer & Schriefers, 1991; Collins & Ellis, 1992). In this task, participants are presented with pictures to name. While they are looking at these pictures, they hear words presented auditorily via headphones. The participant's task is to name the pictures as quickly as possible, while ignoring the auditorily presented distracters. Because the additional word may create a Stroop-like interference effect (Stroop, 1935), it is often referred to as an 'interfering stimulus' or 'interfering word' (IW).

In studies using this task, phonologically related IWs, such as 'snake', when presented with 'snail', have been found to produce less interference than phonologically unrelated IWs, such as 'snake', when presented with 'house' (Schriefers *et al.*, 1990). Repetition primes, such as 'snake-snake' are even more effective in terms of producing positive facilitation. These effects have been observed in conditions in which the interfering word is presented simultaneously, or slightly after the picture to be named. These effects can be interpreted in the context of an incrementalist theory of language production that views articulations as gathering clarity and strength over time in an output articulatory buffer (Dell, 1986; Meyer & Schriefers, 1991; Gupta & MacWhinney, 1994). On the sentence level, incrementalism (Ferreira, 1996) holds that production begins as soon as the sentence formulator has composed the first few words of an utterance. On the word level, incrementalism holds that word production can begin as soon as the lexical formulator has composed the initial segments of the word.

The incrementalist view makes strong predictions regarding the types of phonological priming that should be most effective in speeding up word generation. In particular, it predicts that onset primes that match the initial segments of words, such as 'snake-snail' will be more effective in speeding up picture naming than offset or 'rhyme' primes that match the final segments of words, such as 'pail-snail'. This asymmetry has been reported by Meyer & Schriefers (1991) for adult subjects. It is unclear whether we should also expect to find this type of evidence for incrementalism in children. If incremental production is a basic, perhaps even innate, component of the speech production system, it should be present in school-aged children. Alternatively, incrementalism may emerge during the course of language development as a result of changes in lexical structures facilitating faster production. To the extent that children's lexical representations are holistic (i.e. without detailed phonological segmentation), their representations may not support a just-in-time incremental processing strategy. If this second alternative is true, we would expect to find less of an asymmetry in children between the facilitating effects of onset and rhyme primes.

The idea that lexical representations may be restructured during childhood has been endorsed by a number of researchers (Walley, 1993; Jusczyk, 1997; Metsala, 1997) and several studies have provided evidence that young children's lexical representations are more holistic than adults' (Treiman & Breaux, 1982; Walley, Smith & Jusczyk, 1986; Walley, 1988). Wijnen (1992) has observed that young children (two-year-olds) tend to make a disproportionate number of segment and feature errors involving the coda, whereas adult errors disproportionately involve the onset, suggesting a growth in the importance of word onsets over development. Other evidence of restructuring of lexical representations comes from studies of the development of phonological awareness skills. The ability to detect syllables and rhymes is well established by age five (MacLean, Bryant & Bradley, 1987). However, tasks requiring operations on individual phonological segments (e.g. 'What would *sport* sound like if you took away the first sound?') are not mastered until the school age years when children are learning to read (Bryant, MacLean, Bradley & Crossland, 1990).

The development of fine-grained, segmental representations seems to be a very gradual process, extending through the school age years (Walley, 1993; Metsala, 1997). A recent study by Metsala (1997) provides evidence of developmental change in the lexical representations underlying word recognition in children between the ages of seven and eleven years. The study used a gating paradigm in which, over a series of trials, participants listened to increasingly longer segments of words while attempting to identify target words. The amount of phonological information needed to recognize each word was treated as an index of the extent to which the word was represented segmentally rather than holistically. The rationale was that participants should require more acoustic information to identify words represented holistically. In Metsala's study the target words differed in terms of frequency and 'neighbourhood density' (i.e. as defined by the number of English words sharing phonological segments with the target word). Metsala found that, despite children having smaller vocabularies than adults, they required more acoustic-phonetic information for word recognition. Interestingly, words that were of high frequency and were from dense neighbourhoods (i.e. target words sharing many sounds with other English words) showed the smallest developmental differences. This finding suggests that restructuring does not occur in a system-wide fashion, but rather on an item-by-item basis, with high frequency words in dense neighbourhoods undergoing restructuring first.

When studying the development of lexical access in word production, it is very important to keep in mind the general speed-up of cognitive processing speed that occurs with development. Kail (1991, 1992) has shown that, throughout childhood and adolescence, processing speed increases in terms of a negative exponential function. It is reasonable to expect that this general speed-up effect would also extend to performance on the picture naming task. We should expect that, due to faster processing of the IWs with increasing age, the time of maximum sensitivity of the target to the IW would be earlier in adults than in children. In our experiments, the timing of the gap between the target and the IW is called the stimulus onset asynchrony or SOA. The particular values for the SOA used in the present experiments are identical to those employed in a previous cross-modal picture-word study with adults

(Schriefers *et al.*, 1990). Schreifers *et al.* used the cross-modal picture-word interference paradigm to explore the time course of semantic and phonological activation in lexical access. They observed that phonologically related IWs (i.e. words sharing the onset consonant(s) with the target picture names) affected picture naming latencies at later SOAs than semantically related IWs. They used this finding to support a serial model of lexical access, in which access to the form of a word occurs after access to its meaning. Although the goals of our study are quite different from those of Schriefers *et al.*, their study provides us with guideposts regarding the SOAs that produce robust phonological onset priming in adults.

In the present study, the nature of the phonologically-related IWs was varied across two experiments. In Experiment 1, phonologically-related IWs shared the onset consonants with the names of the target pictures. In Experiment 2, phonologically-related IWs shared the vowel and final consonants with the names of the pictures. Children were tested over multiple sessions to vary the interval between the onset of the picture and the onset of the auditory stimulus (SOA) within subjects. Because no reading was required, we were able to test children as young as five years of age. Moreover, we were able to test them using picture and word stimuli that were entirely familiar and natural.

EXPERIMENT 1: PHONOLOGICAL ONSET PRIMING

METHOD

Participants

Fifteen five-year-olds (mean 5;5, range 4;11–5;10), 15 seven-year-olds (mean 7;5, range 6;11–7;10), 15 older children (mean 10;7, range 9;5–11;9), and 15 undergraduates participated in this study. The children were recruited and tested at private schools in Pittsburgh, PA. The undergraduates were volunteers from the introductory psychology subject pool at Carnegie Mellon University.

Materials and design

The experimental pictures were 16 line drawings of common objects selected from the Snodgrass & Vanderwart (1980) set of standardized pictures. Four additional line drawings were used as practice pictures. The 20 pictures, as well as all items in the second experiment, were pictures that young children are able to name consistently (Cycowicz, Friedman, Snodgrass & Rothstein, 1997). All of the names of the pictures were monosyllabic words. The 16 experimental pictures comprised eight pairs with the names of each pair of pictures sharing the same onset consonant or consonant cluster. Each experimental picture was presented with each of four types of interfering words (IWs).

1. *Identical*. In this condition, the IW was the name of the target picture.
2. *Neutral*. In this condition, the IW was the word *go*.
3. *Onset-related*. In this condition, the IW was the name of the other picture in the response set which shared the onset consonant or consonant cluster with the name of the target picture.
4. *Unrelated*. In this condition, the IW was the name of another picture in the response set which was phonologically and semantically unrelated to the name of the target.

For a complete list of the experimental stimuli and the IWs each picture was paired with in the related and unrelated conditions, see Appendix A.

The IWs were presented auditorily at each of three SOAs (stimulus onset asynchronies): −150, 0 and +150 ms (the onset of the auditory stimulus was 150 ms prior to, simultaneous with, or 150 ms after the onset of the picture). SOA was manipulated in a blocked design so that each participant was presented one block of 16 practice trials and 64 experimental trials at each SOA, with order of presentation of SOA conditions counterbalanced. The 64 experimental trials comprised the 16 experimental pictures, each paired once with each of the four types of IWs (identical, neutral, onset-related and unrelated). Within each block of 80 trials, there were four sub-blocks of 20 trials. The first four trials in each sub-block were practice trials in which each practice picture was paired once with the neutral IW *go*. The next 16 trials consisted of the 16 experimental pictures, with four items paired with each of the four types of IWs. The order of presentation of the four sub-blocks within each block, as well as the ordering of the experimental items within each sub-block, was randomized.

Apparatus

The pictures were presented on a 15″ Apple computer monitor as black line drawings on an off-white background. The IWs were digitized and edited using SoundEdit 16 on a Macintosh Power PC. The IWs were presented using headphones. The experiment was run on a Macintosh Power PC using PsyScope software (Cohen, MacWhinney, Flatt & Provost, 1993) which controlled the presentation of the target pictures and IWs. Timing was accomplished using a button box timer connected to a voice-activated relay (a microphone). Reaction times to the nearest millisecond were measured from the onset of the target picture to the triggering of the voice key by the participant's response. In addition to the computer-generated stimuli, each experimental and practice picture was printed and mounted on a 3″ × 5″ flash card. These cards were used to provide the participants with practice in naming the pictures.

Procedure

Each child was tested individually in a quiet room at their school for three or four sessions lasting 20–30 minutes each. The sessions were typically spaced about three days apart and occurred within the span of two to three weeks. Adults were tested individually in a single 40-minute session at a laboratory at Carnegie Mellon University. At the beginning of the first session, participants were shown the pictures on flash cards one at a time and were asked to name each picture. On the rare occasions in which a child used a word different from the target picture name, the experimenter told the child the target name for the picture. The twenty flash cards were reviewed two or three times until the participants named the pictures consistently.

Next, participants were given practice naming the pictures on the computer and using the microphone. They were seated at a comfortable viewing distance from the monitor with the microphone approximately one inch in front of their lips. The position of the microphone was secured by a metal stand which could be adjusted to the participant's height. The pictures were presented one at a time and participants were told to name each picture as quickly as possible. Children who 'framed' the names of the pictures, by saying, for example, 'a dog' or 'the tree' instead of simply 'dog' and 'tree', were given additional instruction and practice naming the items until they learned to say only the names of the pictures. Children who failed to use the microphone correctly, for instance by putting the microphone in their mouth or whispering in too low of a voice to be audible, were also given additional practice trials. In general, most children practised naming the set of 20 pictures on the computer two times, while most adults went through the set once.

At this point the headphones were brought out and the picture-word interference task was introduced. The experimenter told the participants, 'Now you will hear words over the headphones while you name the pictures on the computer. You will often hear the word *go* which is a reminder to go as fast as you can and to keep going even if you get confused and make a mistake. Sometimes the word you will hear will be the name of the picture on the computer and sometimes it will be the name of another picture. Your job is to ignore the words as much as possible and to concentrate on naming what you see, and not what you hear.' The experimenter encouraged the children to use a strong voice when speaking into the microphone. The experimenter explicitly told the children not to talk, while wearing the headphones, except to name the pictures. During each block of trials, the experimenter sat behind the participant and recorded by hand any technical problems (computer or voice key) and any errors made. Periodically, the children were told that they were doing a good job.

Depending on the SOA condition, the onset of the IW began 150 ms before, simultaneous with, or 150 ms after the onset of the picture. Each target picture remained on the computer screen until the voice key was activated. Triggering of the voice key caused the picture to disappear. After two seconds, the next trial began. After each sub-block of 20 trials, the experiment paused so that the experimenter could talk to the children and adjust the microphone if necessary. At this time children were allowed to take off their headphones and talk to the experimenter if they wished. Children were given each of the three blocks of 80 trials in separate sessions. At the beginning of each session, the flash cards were reviewed to ensure that the children remembered the names of the pictures. If at any time a child appeared fatigued or was not having a good time, the session was terminated and the child was allowed to finish in a subsequent session.

General design format

Both experiments use essentially the same procedure, overall experimental design, and framework for data analysis. Because the analysis involves many factors and comparisons, it is helpful to review the overall shape of the design and analytic procedure in detail for this first experiment, understanding that this framework will apply to both experiments.

Both experiments used a mixed-model ANOVA design with two within-subjects factors and one between-subjects factor. The between-subjects factor involved a comparison of three age groups for the children and one age group for the adults. The two within-subjects factors were SOA with three possible levels and IW with four possible levels. The four levels of IW were always the same: neutral, identical, phonologically related and unrelated. The hypotheses tested revolve around effects (i.e. differences in RTs and error rates as a function of IW type) associated with these three comparisons between IW types:

1. *Phonological priming effects*. Facilitatory effects for phonological priming can be estimated by comparing the phonologically related and unrelated conditions. Of course, all of the IWs have a basic interfering effect on naming, but, if there is a priming effect, then interference should be less in the phonologically related condition.
2. *Identity priming effects*. The comparison of the neutral condition with the identical IW condition allows us to estimate the facilitatory effect at different ages and SOAs for identity priming. This comparison examines the extent to which individuals are faster at naming pictures when provided with the corresponding names of the pictures.
3. *Lexical competition effects*. The comparison of the neutral condition with the unrelated condition allows us to estimate the additional inhibitory effects of the mere presence of an additional word on lexical access.

For each of these three basic comparisons, we want to know how the effects vary with SOA, thereby revealing peaks in the sensitivity of lexical generation to interference and priming effects from the IW. We also want to know how these effects change with age, revealing aspects of the development of lexical generation. The basic analyses reported in the results section are summarized in the discussion sections which follow. For each experiment, we provide a table, which summarizes the results of the planned comparisons for the three IW comparison types listed above. Also, for each experiment, a figure is used to present the mean RT differences between the neutral condition, and the phonologically-related, unrelated and identical conditions. The summary tables and figures convey all of the central empirical results of the experiments.

General analysis format

The ANOVA results we report will be from analyses using subjects as the random factor. We also conducted a complete and parallel set of analyses with items as the random factor. In terms of the pattern of significant results, the item analyses yielded exactly the same results as our subject analyses. If a significant main effect of age was obtained in an ANOVA, *post hoc* Bonferroni comparisons were conducted at the 0·05 level. For each experiment, planned comparisons were conducted to compare IW types at each SOA; these tests always examined the three basic IW condition comparisons summarized just above.

Errors were trials in which participants used words other than the target names of the pictures (e.g. by repeating the IW), stuttered or repaired their utterances, or failed to make a response within four seconds. Trials in which the voice key malfunctioned or the computer crashed were considered lost trials and were not counted as errors. Trials in which the participant stopped performing the task and started talking to the experimenter were also coded as lost trials, rather than errors. On these occasions, the experimenter paused the experiment and resumed after the child had settled down. Error rates and numbers of lost trials were analysed using mixed-design analyses of variance (ANOVAs).

RESULTS

Reaction times

Mean response latencies for correct trials for each age group, SOA condition, and IW type are presented in Table 1. All values are given in milliseconds. Mean RTs were analysed in a mixed-design ANOVA with a between-subjects factor of age and within-subjects factors of SOA (-150, 0, $+150$) and IW type (identical, neutral, onset-related, unrelated). The overall ANOVA showed main effects of age, $F(3,56) = 89{\cdot}63$, $p < 0{\cdot}001$, SOA,

TABLE 1. *Mean RTs (in milliseconds) and percentages of errors per Stimulus Onset Asyncrony (SOA) and Interfering Word (IW) type in Experiment 1 (n = 15 at each age)*

	SOA −150				SOA 0				SOA +150			
	Identical	Neutral	Related	Unrelated	Identical	Neutral	Related	Unrelated	Identical	Neutral	Related	Unrelated
Five-year-olds												
RTs	1082	1164	1363	1320	1402	1543	1872	1996	1447	1658	1844	2039
errors	3·8	4·3	8·5	3·9	0·9	5·6	7·8	4·3	1·7	7·4	6·6	11·0
Seven-year-olds												
RTs	756	831	910	858	1134	1225	1296	1412	1161	1123	1239	1305
errors	0·4	0·8	3·4	1·2	0·4	2·9	3·1	5·9	0·4	4·2	3·3	6·7
Nine-to eleven-year-olds												
RTs	615	713	758	753	723	815	797	947	717	787	765	824
errors	0·0	2·1	3·3	2·6	0·4	1·7	5·1	10·9	2·5	3·8	4·2	7·1
Adults												
RTs	576	632	650	641	665	667	687	740	654	654	649	681
errors	0·4	0·9	1·2	0·4	0·9	0·4	1·2	2·6	1·2	1·7	0·4	1·3
Overall *M*												
RTs	757	835	920	893	981	1063	1163	1274	995	1056	1124	1212
errors	1·2	2·0	4·1	2·0	0·7	2·6	4·3	5·9	1·5	4·3	3·6	6·5

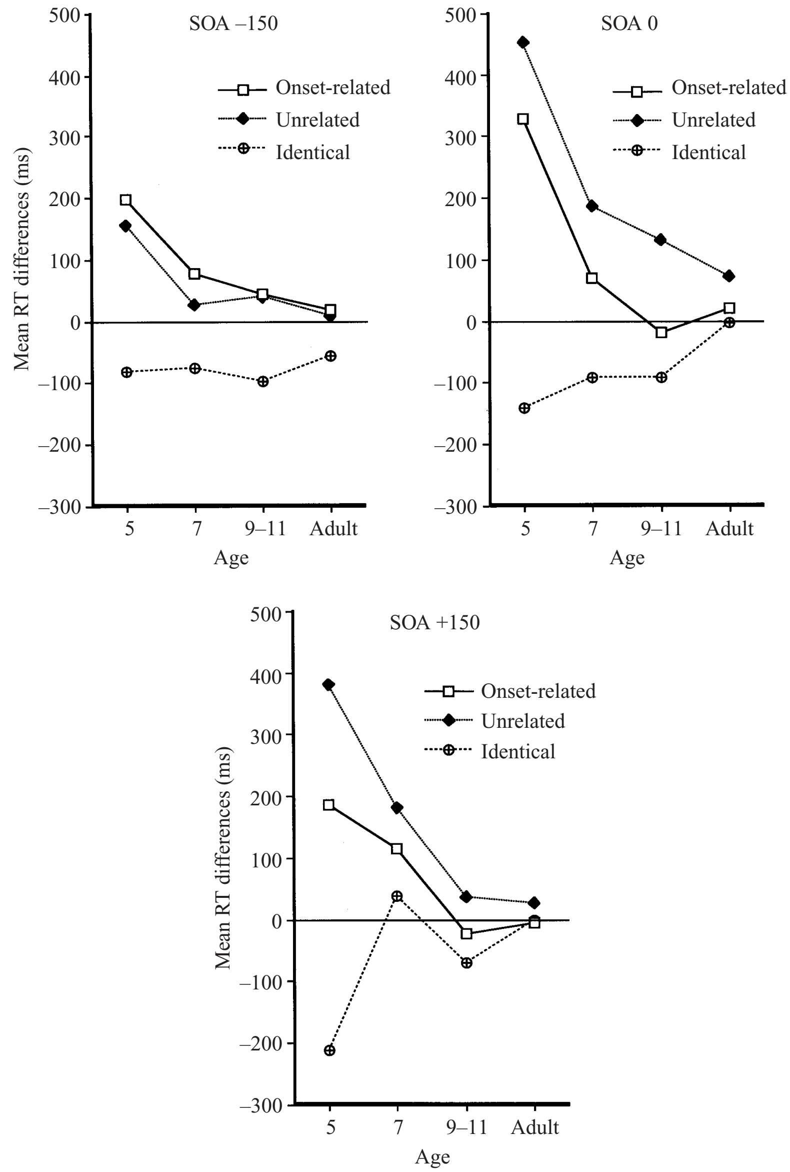

Fig. 1. Experiment 1: Mean RT differences (in milliseconds) between the neutral IW condition and onset-related, unrelated, and identical IW conditions as a function of SOA. (Positive values indicate interference relative to the neutral condition, and negative values indicate facilitation.)

$F(2,112) = 96.74$, $p < 0.001$, and IW type, $F(3, 168) = 101.64$, $p < 0.001$. *Post hoc* Bonferroni tests for the main effect of age indicated that the mean RTs for the three groups of children (1561, 1104, and 768 ms for the five-year-olds, seven-year-olds, and nine to eleven-year-olds, respectively) were significantly different from each other ($p < 0.05$). Although the mean RT for the adults (658 ms) was faster than the means of the five-year-olds and seven-year-olds, there was no difference between the nine to eleven-year-olds and the adults. Planned comparisons of the SOA conditions showed that, on average, RTs for SOA −150 were faster than for SOA 0 (851 vs. 1120 ms), $F(1, 112) = 157.65$, $p < 0.001$. Mean RTs for SOA 0 (1120 ms) and SOA +150 (1097 ms) did not differ significantly.

In addition to the main effects, the two-way interactions of age with SOA, $F(6, 112) = 18.46$, $p < 0.001$, age with IW type, $F(9, 168) = 21.28$, $p < 0.001$, and SOA with IW type, $F(6, 336) = 12.83$, $p < 0.001$, and the three-way interaction of age with SOA and IW type, $F(18, 336) = 4.52$, $p < 0.001$, were significant. Figure 1 presents the mean reaction time differences (in milliseconds) between the neutral IW condition and the onset-related, unrelated, and identical conditions, for each age group and SOA condition. In the figures presented, positive difference scores indicate interference relative to the neutral condition, and negative values indicate facilitation. Table 2 summarizes the results of the planned comparisons of IW conditions, in terms of significance levels, at each SOA condition and age. For the comparison of onset-related and unrelated conditions, at SOAs 0 and +150, all age groups named pictures paired with onset-related IWs faster than pictures paired with unrelated IWs, $Fs(1, 84) \geqslant 5.48$, $ps < 0.05$. In contrast, at SOA −150, there was no advantage for the onset-related condition, and the seven-year-olds showed somewhat faster naming of pictures paired with unrelated IWs, $F(1, 84) = 4.04$, $p < 0.05$.

Identical IWs tended to speed up picture naming relative to neutral IWs. Identity priming occurred at SOAs 0 and +150 for the five-year-olds, $Fs(1, 84) \geqslant 7.05$, $ps < 0.01$, at SOAs −150 and 0 for the seven-year-olds, $Fs(1, 84) \geqslant 8.48$, $ps < 0.01$, at all SOAs for the nine to eleven-year-olds, $Fs(1, 84) \geqslant 17.51$, $ps < 0.001$, and at SOA −150 for the adults, $F(1, 84) = 29.95$, $p < 0.001$. Naming latencies were longer for pictures paired with unrelated IWs than for pictures paired with neutral IWs: The interfering effect of lexical competition was significant at all SOAs for the five-year-olds, $Fs(1, 84) \geqslant 8.60$, $ps < 0.01$, at SOAs 0 and +150 for the seven-year-olds, $Fs(1, 84) \geqslant 50.12$, $ps < 0.001$, at all SOAs for the nine to eleven-year-olds, $Fs(1, 84) \geqslant 4.73$, $ps < 0.05$, and at SOAs 0 and +150 for the adults, $Fs(1, 84) \geqslant 7.26$, $ps < 0.01$.

TABLE 2. *Summary of significance levels for the principal results of Experiment 1*

	Phonological onset priming			Repetition Priming			Lexical Competition		
SOA	−150	0	+150	−150	0	+150	−150	0	+150
Response times									
Five-year-olds	—	0·05	0·001	—	0·01	0·001	0·01	0·001	0·001
Seven-year-olds	—*	0·001	0·05	0·01	0·001	—	—	0·001	0·001
Nine- to eleven-year-olds	—	0·001	0·001	0·001	0·001	0·001	0·05	0·001	0·05
Adults	—	0·001	0·01	0·001	—	—	—	0·001	0·01
Errors									
Five-year-olds	—*	—	—	—	0·05	0·01	—	—	—
Seven-year-olds	—	—	0·05	—	—	0·01	—	—	—
Nine- to eleven-year-olds	—	0·01	—	—	—	—	—	0·001	—
Adults	—	—	—	—	—	—	—	0·05	—

* The difference between onset-related and unrelated IW types was significant ($p < 0.05$), but was in the opposite direction from the predicted effect.

Lost trials

Lost trials accounted for 3·9% of the total trials for the five-year-olds, 1·2% for the seven-year-olds, 0·8% for the nine to eleven-year-olds, and 0·6% for the adults. Numbers of lost trials per SOA condition and IW type were analysed in a mixed-design ANOVA. Given that lost trials were often a consequence of off-task behaviour (e.g. talking during the experiment), it was not surprising that the main effect of age was significant, $F(3, 56) = 29{\cdot}30$, $p < 0{\cdot}001$. *Post hoc* Bonferroni tests indicated a greater number of lost trials for the five-year-olds than for the three older groups, and no other groups differed. The only other effect to reach statistical significance in the ANOVA was a weak interaction of age with IW type, $F(9, 168) = 2{\cdot}11$, $p < 0{\cdot}05$. To decompose the interaction, separate ANOVAs were conducted for each age group with SOA and IW type as within-subjects factors. In none of the ANOVAs were either of the main effects or their interaction significant. Thus, it appears that IW type was unrelated to the number of lost trials at each age; random fluctuations in the rates of lost trials per IW type across age groups were the source of the interaction.

Errors

The numbers of lost trials and the distribution of lost trials across IW types was different for each age. Therefore, error rates were adjusted in accordance with the actual number of trials completed. The adjusted error rates were equal to the number of errors made, divided by the number of correct trials plus errors. The adjusted mean percentages of errors for each SOA condition, IW type, and age group are presented in Table 1. The adjusted error rates were analysed in a mixed-design ANOVA. The proportions of errors were arcsine transformed prior to statistical analysis, as is recommended for proportional data (Cohen & Cohen, 1983). The ANOVA conducted on error proportions showed main effects of age, $F(3, 56) = 16{\cdot}29$, $p < 0{\cdot}001$, SOA, $F(2, 112) = 5{\cdot}69$, $p < 0{\cdot}01$, and IW type, $F(3, 168) = 24{\cdot}28$, $p < 0{\cdot}001$. *Post hoc* Bonferroni tests confirmed that errors decreased with age: The error rate of the five-year-olds (5·5%) was greater than that of the seven-year-olds (2·7%) or the adults (1·1%), and the nine to eleven-year-olds (3·6%) made more errors than the adults. Comparisons of the SOA conditions showed fewer errors at SOA -150 (2·3%) than at SOA 0 (3·4%), $F(1, 112) = 4{\cdot}45$, $p < 0{\cdot}05$. The error rates for SOA 0 (3·4%) and SOA +150 (4·0%) did not differ.

In addition to the main effects, there were significant two-way interactions of age with IW type, $F(9, 168) = 2{\cdot}83$, $p < 0{\cdot}01$, and SOA with IW type, $F(6, 336) = 4{\cdot}95$, $p < 0{\cdot}001$, and a three-way interaction of age with SOA and IW type, $F(18, 336) = 1{\cdot}63$, $p = 0{\cdot}05$. The results of the planned comparisons clarify the interactions and are presented in Table 2. In comparing the onset-related and unrelated conditions, at SOA −150, there was no advantage for the onset-related condition, and the five-year-olds actually produced a greater number of errors for pictures paired with onset-related IWs, $F(1, 84) = 5.58$, $p < 0.05$. Comparisons of onset-related and unrelated conditions yielded significantly lower error rates for pictures paired with onset-related IWs only for the seven-year-olds at SOA +150, $F(1, 84) = 5.62$, $p < 0.05$, and for the nine to eleven-year-olds at SOA 0, $F(1, 84) = 9.10$, $p < 0.01$.

Identical IWs led to lower error rates relative to neutral IWs at SOAs 0 and +150 for the five-year-olds, $Fs(1, 84) \geqslant 5.30$, $ps < 0.05$, and at SOA +150 for the seven-year-olds, $F(1, 84) = 7.66$, $p < 0.01$. Error rates were greater for pictures paired with unrelated IWs than for pictures paired with neutral IWs only at SOA 0 for the nine to eleven-year-olds, $F(1,84) = 31.43$, $p < 0.001$, and the adults, $F(1, 84) = 4.85$, $p < 0.05$.

DISCUSSION

This first study yielded clear developmental results. Both response latencies and error rates decreased uniformly with age. In addition to these overall age effects, both response latencies and error rates varied as a function of the timing of the IWs. As the time of presentation of the IW moved closer to the time of word production, increased interference produced higher response latencies and errors rates. Response latencies were fastest at SOA −150, when the IW preceded the picture to be named. They were slowest at SOAs 0 and +150, when the IW was heard as the participant was trying to name the picture. This effect is due to the fact that the presentation of the IW started to overlap more and more with the process of naming the picture. Error rates followed a similar pattern with fewer errors at SOA −150 than at SOAs 0 or +150. Again, at the later SOAs, increased interference led to increased errors.

Phonological priming

To compute phonological priming effects, onset-related and unrelated IW conditions were compared. This comparison showed that onset-related IWs produce less interference in picture naming than unrelated IWs when the IW occurs late, during the period of time when it is maximally interfering with picture naming. If the onset-related IW occurs too early, there will be no benefit at all in comparison with an unrelated IW. This time course for the phonological priming effect matches the one reported by Schriefers *et al.* (1990) in a similar study conducted with adults.

The most likely account for the phonological effect focuses on the role of speech generation in the output phonological buffer (Dell, 1986; Meyer & Schriefers, 1991; Gupta & MacWhinney, 1994). According to this account, the onset of the IW is used to prime the activation of a parallel onset in the output phonological buffer. Even before the rest of the word is filled in, the speaker can begin to produce the word starting with this pre-generated onset material. This account supposes that the output phonological form can be decomposed into onset and rhyme segments and that the onset of the word is available to actual output generation at a time when the rest of the word (the rhyme) is not yet completely determined. At SOAs 0 and +150, this emerging onset pattern is then further supported by the corresponding onset from the phonological prime and the combined activation of the two forms is then enough to lead to a facilitation in the speed of output generation.

While phonological priming occurred at SOAs 0 and +150 for all age groups, the effect peaked for the five-year-olds at SOA +150, and for the other age groups at SOA 0. In other words, the greatest RT difference between phonologically related and unrelated IW conditions occurred at an earlier SOA for the older groups. This pattern of results corresponds well with the basic change in processing speed that occurs across the developmental span (Kail, 1991).

Identity priming

The identical and neutral IW types were compared to examine the influence of identity priming. Pictures paired with identical IWs were named faster than pictures paired with neutral IWs across the range of SOAs examined. The identical IWs did not interfere with picture naming. Instead, they were actually facilitatory. The facilitating effect of the identical IWs was also manifest in lower error rates relative to the neutral condition. A plausible explanation of these identity priming effects is similar to the one suggested above for phonological priming effects. However, in the case of identity priming, both the onset and the rhyme are pre-generated in the output phonological buffer. As a result, the facilitation effect is stronger.

For identity priming, the greatest RT differences between identical and neutral IW conditions occurred at a later SOA for the youngest age group. This finding that the identity priming effect peaked later for the youngest group matches the results for phonological priming described above. Taken together, the time course of these effects provides further support for an incrementalist view of the gradual stabilization of the articulatory plan in the output buffer. For younger children the stabilization of the plan occurs over a longer time, so the effects can have an impact even when they arrive later.

Facilitation from identity priming resulted in lower error rates for pictures paired with identical IWs for the younger groups, especially at SOA +150. At SOA −150, the five-year-olds failed to show faster RTs for pictures paired with identical IWs, whereas identity priming was present at this SOA for the other groups. In fact, significant identity priming was found only at SOA −150 for the adult group. Again, these findings can be attributed to the increased speed of lexical generation found in the older groups.

Lexical competition

To examine the effect of 'lexical competition', unrelated and neutral IW types were compared. Across the range of SOAs used, pictures paired with unrelated IWs were named more slowly than pictures paired with neutral IWs. The inhibitory effect of lexical competition was also evident in the error data. Participants made more errors in naming pictures paired with unrelated IWs than for pictures paired with neutral IWs. These results indicate that the interference with naming is partially due to the presence of an incoming auditory form, but even more due to the processing of a competing lexical form.

EXPERIMENT 2: PHONOLOGICAL RHYME PRIMING

Experiment 1 provided evidence for developmental changes in the effects of phonological priming on lexical generation. The phonological correspondence between the IW and the target involved a match on the initial consonant cluster, but not on later segments in the picture name. If we look at the literature on lexical access in the related areas of reading and spelling, we find that research has often been able to distinguish the effects of initial consonant match or alliteration from the effects of rhyming (e.g. Treiman, 1985). In a pair such as 'boat-bag', there is an alliterative match on the initial consonant. However, in a pair such as 'boat-coat' there is a rhyming match in the vowel nucleus /o/, as well as in the coda /t/. Models of spoken word recognition uniformly emphasize the crucial role of the onset in facilitating lexical access (e.g. Marslen-Wilson, 1987; Norris, 1994; Gaskell, Hare & Marslen-Wilson, 1995) and there is evidence that onset overlap may help to organize competing lexical fields (Goldinger, Luce & Pisoni, 1989).

In view of these findings, we considered it important to examine the developmental shape of the onset-rhyme contrast using the cross-modal picture-word interference paradigm. A second study was constructed to parallel the first, while looking at the effects of a rhyme match, rather than an alliterative match. Our developmental prediction was that the rate of word generation would be more strongly influenced by the presence of a rhyme prime in younger participants, particularly at SOA levels that overlap with the period of phonological generation. In older participants, with greater reliance on the onset in facilitating lexical access, coupled with the overall speed up in phonological generation, the strength of the rhyme priming effect was predicted to decrease.

METHOD

Participants

Fifteen five-year-olds (mean 5;6, range 4;11–5;11), 15 seven-year-olds (mean 7;4, range 7;0–7;11), and 15 older children (mean 10;6, range 9;5–11;5), were recruited and tested at the same schools as in Experiment 1. An additional 15 Carnegie Mellon University undergraduates participated in the study. No children or adults participated in both experiments.

Materials and design

As in Experiment 1, the 16 experimental pictures and 4 practice pictures were selected from the Snodgrass & Vanderwart (1980) set of standardized line drawings. The names of the experimental pictures were eight pairs of words that rhymed. The design of the experiment was identical to Experiment 1. The names of the experimental pictures and the IWs each picture was paired with in the rhyme-related and unrelated conditions are shown in Appendix B.

Procedure

The procedure was the same as in Experiment 1.

RESULTS

Reaction times

Mean naming latencies for correct trials for each age group, SOA condition, and IW type are presented in Table 3. Mean RTs were analysed in a mixed-design ANOVA with a between-subjects factor of age and within-subjects variables of SOA (−150, 0, +150) and IW type (identical, neutral, rhyme-related, unrelated). The overall ANOVA showed main effects for age, $F(3, 56) = 63.73$, $p < 0.001$, SOA, $F(2, 112) = 90.02$, $p < 0.001$, and IW type, $F(3, 168) = 86.78$, $p < 0.001$. *Post hoc* Bonferroni tests indicated that the mean RTs for the three groups of children were significantly different from each other (1527, 1189, and 838 ms for the five-year-olds, seven-year-olds, and nine to eleven-year-olds, respectively). While the adults (701 ms) named pictures faster than the five-year-olds and seven-year-olds, there was no significant RT difference between the nine to eleven-year-olds and the adults. Planned comparisons of SOA conditions indicated that, on average, pictures were named faster at SOA −150 (866 ms) than at SOA 0 (1181 ms), $F(1, 112) = 150.11$, $p < 0.001$. Mean RTs for SOA 0 (1181 ms) and SOA +150 (1145 ms) did not differ.

TABLE 3. *Mean RTs (in milliseconds) and percentages of errors per Stimulus Onset Asyncrony (SOA) and Interfering Word (IW) type in Experiment 2 (n = 15 at each age)*

	SOA −150				SOA 0				SOA +150			
	Identical	Neutral	Related	Unrelated	Identical	Neutral	Related	Unrelated	Identical	Neutral	Related	Unrelated
Five-year-olds												
RTs	1061	1195	1195	1295	1524	1585	1710	1969	1555	1539	1710	1991
errors	0·4	3·9	2·5	7·3	1·0	7·0	3·1	4·7	2·2	6·9	3·4	8·0
Seven-year-olds												
RTs	843	934	944	925	1212	1245	1410	1566	1193	1221	1320	1459
errors	0·8	1·3	3·5	3·4	0·9	3·0	4·4	5·9	0·8	9·1	4·6	3·9
Nine to eleven-year-olds												
RTs	654	734	738	763	828	861	978	1005	832	836	925	906
errors	0·8	0·9	2·6	0·4	0·4	2·9	8·1	6·0	1·2	4·8	6·7	3·8
Adults												
RTs	572	655	679	664	691	707	790	813	670	685	750	731
errors	0·0	2·1	0·4	0·8	0·4	2·1	5·0	4·2	0·0	1·3	3·8	2·5
Overall *M*												
RTs	783	879	889	912	1064	1100	1222	1338	1062	1070	1176	1272
errors	0·5	2·0	2·3	3·0	0·7	3·7	5·1	5·2	1·1	5·5	4·6	4·6

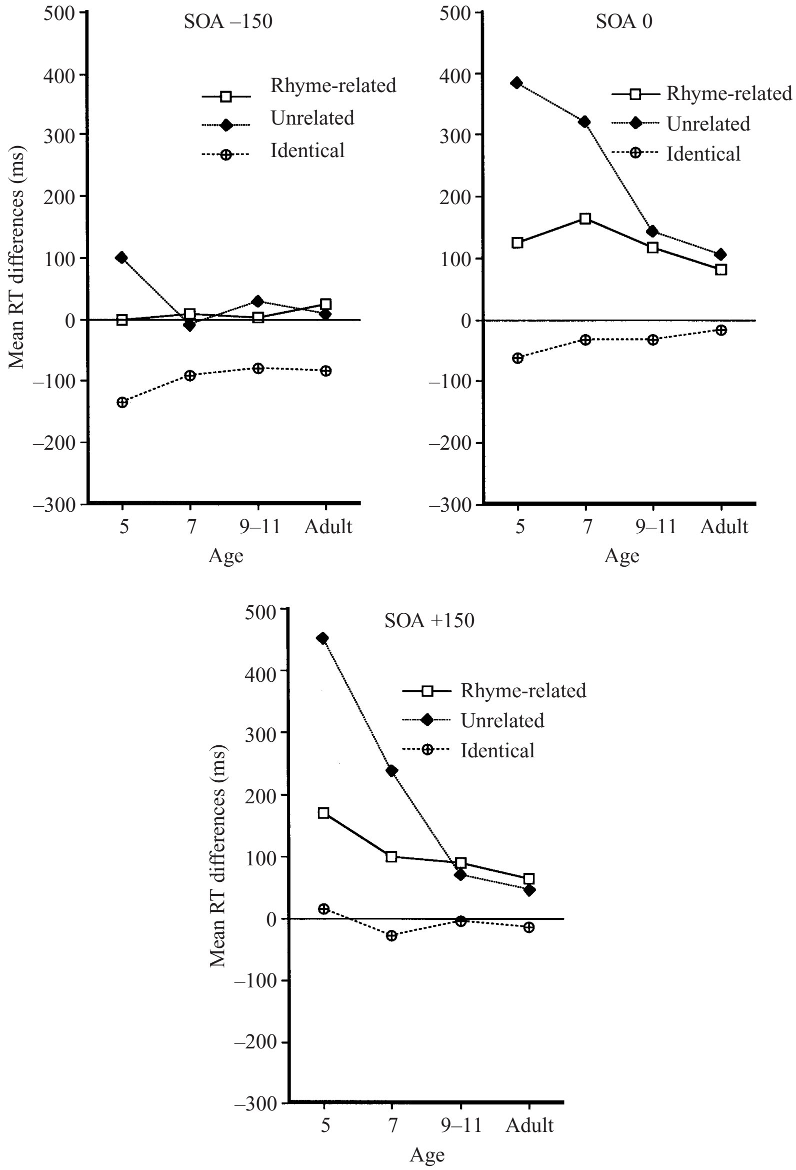

Fig. 2. Experiment 2: Mean RT differences (in milliseconds) between the neutral IW condition and rhyme-related, unrelated, and identical IW conditions as a function of SOA. (Positive values indicate interference relative to the neutral condition, and negative values indicate facilitation.)

The two-way interactions of age with SOA, $F(6, 112) = 10{\cdot}15$, $p < 0{\cdot}001$, age with IW type, $F(9, 168) = 9{\cdot}18$, $p < 0{\cdot}001$, and SOA with IW type, $F(6, 336) = 13{\cdot}10$, $p < 0{\cdot}001$, were significant, as was the three-way interaction, $F(18, 336) = 2{\cdot}25$, $p < 0{\cdot}01$. Figure 2 presents the mean reaction time differences (in milliseconds) between the neutral IW condition and the rhyme-related, unrelated, and identical conditions, for each age group and SOA condition. Table 4 presents a summary of the three planned comparisons of IW types, in terms of significance levels at each SOA and age. First, the RTs for the rhyme-related and unrelated IW types were compared. The five-year-olds and seven-year-olds named pictures paired with rhyme-related IWs faster than pictures paired with unrelated IWs at SOAs 0 and +150, Fs$(1, 84) \geqslant 15{\cdot}20$, ps $< 0{\cdot}001$. In contrast, for the two older groups (nine to eleven-year-olds and adults), there was no significant advantage for pictures paired with rhyme-related IWs. Hence, significant rhyme-based phonological priming was observed only for the two younger age groups.

Second, RTs for the identical and neutral IW types were compared. The planned comparisons at each age showed significantly faster RTs for pictures paired with identical IWs only at SOA −150, Fs$(1, 84) \geqslant 5{\cdot}11$, ps $< 0{\cdot}05$. No identity priming occurred at SOA 0 and +150. Third, at all ages, at SOAs 0 and +150, RTs for pictures paired with unrelated IWs were slower than for pictures paired with neutral IWs, Fs$(1, 84) \geqslant 9{\cdot}35$, ps $< 0{\cdot}01$.

Comparison of RT results for Experiments 1 and 2

To compare the RT results of the two experiments, we conducted an additional series of ANOVAs. We report here only effects that involve the factor of experiment. The first analysis was a mixed-design ANOVA with between-subjects factors of experiment and age and within-subjects variables of SOA and IW type. This overall ANOVA revealed significant three-way interactions of experiment, age, and IW type, $F(9, 336) = 4{\cdot}69$, $p < 0{\cdot}001$, and experiment, SOA, and IW type, $F(6, 672) = 2{\cdot}25$, $p < 0{\cdot}05$, and a four-way interaction of experiment, age, SOA, and IW type, $F(18, 672) = 1{\cdot}67$, $p < 0{\cdot}05$.

To break down the interactions involving IW type, we conducted ANOVAs for the three planned comparisons of IW types, including experiment, age, and SOA as additional factors. In the ANOVA comparing phonologically-related and unrelated IW types, there was a significant three-way interaction of experiment, age, and IW type, $F(3, 112) = 5{\cdot}42$, $p < 0{\cdot}01$. Additional ANOVAs, conducted for each age group separately, revealed significant two-way interactions of experiment and IW type for the five-year-olds, the nine to eleven-year-olds, and the adults, Fs$(1, 28) \geqslant 4{\cdot}85$, ps $< 0{\cdot}05$. For the five-year-olds the strength of the rhyme-priming effect was greater than the onset-priming effect, i.e. pictures paired with rhyme-related IWs

TABLE 4. *Summary of significance levels for the principal results of Experiment 2*

	Phonological rhyme priming			Repetition priming			Lexical competition		
SOA	−150	0	+150	−150	0	+150	−150	0	+150
Response times									
Five-year-olds	—	0·001	0·001	0·05	—	—	—	0·001	0·001
Seven-year-olds	—	0·001	0·001	0·05	—	—	—	0·001	0·001
Nine- to eleven-year-olds	—	—	—	0·001	—	—	—	0·001	0·001
Adults	—	—	—	0·001	—	—	—	0·001	0·01
Errors									
Five-year-olds	0·01	—	0·05	0·05	0·001	0·01	0·05	—	—
Seven-year-olds	—	—	—	—	—	0·01	—	—	—
Nine- to eleven-year-olds	—	—	—	—	—	0·05	—	0·05	—
Adults	—	—	—	—	—	—	—	—	—

were named faster than pictures paired with onset-related IWs (with mean RTs of1538 ms for the rhyme-related condition and 1693 ms. for the onset-related condition). In contrast, for the oldest child group and the adults, the strength of onset-priming was greater than rhyme-priming, i.e. pictures paired with onset-related IWs were named faster than pictures paired with rhyme related IWs (with mean RTs of 773 ms for the onset condition and 880 ms for the rhyme condition for the nine to eleven-year-olds, and 662 ms for the onset condition and 740 ms for the rhyme condition for the adults). The seven-year-olds were intermediate in their performance, showing equally strong onset and rhyme priming effects.

The ANOVA comparing identical and neutral IW types found a significant four-way interaction of experiment, age, SOA, and IW type, $F(6,224) = 2{\cdot}69$, $p < 0{\cdot}05$, which was followed-up by additional ANOVAs for each age group. The ANOVA conducted on the RTs of the five-year-olds showed a significant three-way interaction of experiment, SOA, and IW type, $F(2,56) = 3{\cdot}32$, $p < 0{\cdot}05$, with the identity priming effect occurring at later SOAs in Experiment 1 than in Experiment 2. The ANOVA for the nine-year-olds showed a significant two-way interaction of experiment and IW type, $F(1,28) = 4{\cdot}85$, $p < 0{\cdot}05$, indicating that the strength of the identity priming effect was greater in Experiment 1 than in Experiment 2. The ANOVAs for the seven-year-olds, and adults showed no significant effects involving the factor of experiment.

Finally, the ANOVA comparing unrelated and neutral IW types showed no significant effects involving factor of experiment, indicating that lexical competition exerted a highly consistent effect on RTs across the two experiments.

Lost trials

Lost trials accounted for 4·0 % of the total trials for the five-year-olds, 2·9 % for the seven-year-olds, 1·9 % for the nine to eleven-year-olds, and 0·8 % for the adults. Frequencies of lost trials were analysed in a mixed-design ANOVA. The main effect of age was again found to be significant, $F(3, 56) = 14{\cdot}27$, $p < 0{\cdot}001$: Bonferroni *post hoc* tests indicated that there were more lost trials for the five-year-olds than for the nine to eleven-year-olds and the adults, and the seven-year-olds lost more trials than the adults.

The only other significant effect in the ANOVA was a weak interaction of SOA with IW type, $F(6, 336) = 2{\cdot}29$, $p < 0{\cdot}05$. For the 12 cells defined by the interaction of SOA and IW type, lost trial rates ranged from 1·2 % for the neutral IW condition at SOA 0 to 3·2 % for the rhyme-related condition at SOA 0. Lost trial rates for the neutral IW condition were higher at the other two SOAs (3·0 % at SOA −150 and 2·7 % at SOA +150) and were lower at the remaining SOAs for the rhyme-related condition (2·2 % at SOA −150 and 1·8% at SOA +150). For the identical and unrelated conditions, lost trial rates were more stable across SOA conditions (ranging from 2·4 to 3·1% for the identity condition and 1·9 to 2·4% for the unrelated condition). These apparently random fluctuations were the source of the weak interaction.

Errors

Error rates were adjusted as in Experiment 1 to take into consideration the actual number of trials completed and are presented in Table 3. The arcsine transformed, adjusted proportions of errors for each SOA condition, IW type, and age group were analysed in a mixed-design ANOVA. The ANOVA yielded main effects of age, $F(3, 56) = 6{\cdot}60$, $p < 0{\cdot}001$, SOA, $F(2, 112) = 9{\cdot}78$, $p < 0{\cdot}001$, and IW type, $F(3, 168) = 18{\cdot}24$, $p < 0{\cdot}001$. *Post hoc* Bonferroni tests indicated that the overall error rate for the five-year-olds (4·2%) was significantly greater than that of the adults (1·9%). The error rates of the seven-year-olds (3·5%) and the nine to eleven-year-olds (3·2%) did not differ from any of the other ages. Planned comparisons of the SOA conditions indicated that fewer errors were made at SOA −150 (2·0%) than at SOA 0 (3·7%), $F(1, 112) = 14{\cdot}35$, $p < 0{\cdot}001$; the error rates at SOA 0 (3·7%) and SOA +150 (3·9%) did not differ. In addition to these main effects, only the interaction of age and IW type, $F(9,168) = 2{\cdot}44$, $p < 0{\cdot}05$, was significant.

Planned comparisons were used to examine the effects of phonological priming, identity priming, and lexical competition on error rates at each age and SOA. The results of these analyses are summarized in Table 4. Comparison of rhyme-related and unrelated conditions indicated that the five-year-olds produced fewer errors for pictures paired with rhyme-related IWs at SOAs −150 and +150, $F\text{s}(1, 84) \geqslant 6{\cdot}10$, $p\text{s} < 0{\cdot}05$. There was no advantage for pictures paired with rhyme-related IWs for any other age group at any SOA.

Error rates were lower for pictures paired with identical IWs than pictures paired with neutral IWs at all SOAs for the five-year-olds, $F\text{s}(1, 84) \geqslant 6{\cdot}33$, $p\text{s} < 0{\cdot}05$, and at SOA +150 for the seven-year-olds, $F(1, 84) = 9{\cdot}80$, $p < 0{\cdot}01$, and the nine to eleven-year-olds, $F(1, 84) = 4{\cdot}36$, $p < 0{\cdot}05$. Error rates were higher for pictures paired with unrelated IWs than for pictures paired with neutral IWs at SOA −150 for the five-year-olds, $F(1, 84) = 4{\cdot}80$, $p < 0{\cdot}05$, and at SOA 0 for the nine to eleven-year-olds, $F(1, 84) = 5{\cdot}10$, $p < 0{\cdot}05$.

Comparison of error results for Experiments 1 and 2

To compare error rates across the two experiments, we conducted an additional series of ANOVAs on the arcsine transformed, adjusted proportions of errors for each experiment. We report here only effects involving the factor of experiment. An overall ANOVA, with between-subjects factors of experiment and age and within-subjects variables of SOA and IW type, revealed significant three-way interactions of experiment, age, and IW type, $F(9,336) = 2.83$, $p < 0.01$, and experiment, SOA and IW type, $F(6, 672) = 2.12$, $p < 0.05$.

As in the RT analysis, to break down the interactions involving IW type, we conducted ANOVAs for the three planned comparisons of IW types, including experiment, age and SOA as additional factors. In the ANOVA comparing phonologically-related and unrelated IW types, there was a significant two-way interaction of experiment and age, $F(3, 112) = 2.86$, $p < 0.05$, and three-way interactions of experiment, age, and IW type, $F(3, 112) = 4.79$, $p < 0.01$, and experiment, SOA, and IW type, $F(6, 224) = 5.09$, $p < 0.01$. Additional ANOVAs were conducted for each age group separately. For the five-year-olds, there was a two-way interaction of experiment and IW type, $F(1, 28) = 7.90$, $p < 0.01$: Five-year-olds produced fewer errors for pictures paired with rhyme-related IWs than pictures paired with onset-related IWs (3 % vs. 8 %), with similar error rates for unrelated IWs across the two experiments (6–7 %). For the seven-year-olds and the nine to eleven-year-olds there were no significant effects involving experiment. Finally, for the adults, there was a main effect of experiment, $F(1, 28) = 5.11$, $p < 0.05$, with the adults producing fewer errors for related and unrelated IW conditions in Experiment 1 than Experiment 2 (1 % vs. 3 %).

The ANOVAs comparing identical and neutral IW types and unrelated and neutral IW types showed no significant effects involving factor of experiment, indicating that the effect of identity priming and lexical competition on errors were similar in the two experiments.

DISCUSSION

As in Experiment 1, response latencies and error rates decreased with age. The mean RTs for the three groups of children were significantly different from each other, whereas the means for the nine to eleven-year-olds and adults did not differ. Error rates also decreased gradually with age. As in Experiment 1, response latencies and error rates varied as a function of the timing of the IWs. RTs were faster when the IW preceded the picture to be named, in comparison to SOA conditions in which the word was presented simultaneously with or 150 ms after the picture. Error rates followed a similar pattern with fewer errors at SOA −150 than at SOAs 0 or +150.

Phonological priming

The most important result of Experiment 2 was that there was a significant effect of rhyme-based phonological priming for the two youngest groups and not for the two oldest groups. This effect was concentrated at the SOAs of 0 and +150, matching the SOA results for the onset-related IWs of Experiment 1. In addition to the RT differences, the five-year-olds showed a facilitating effect for rhyme priming in terms of lower error rates for the rhyme-related condition relative to the unrelated condition.

In the five-year-old group, rhyme priming produced greater facilitation in picture naming than onset priming. In contrast, the onset priming effect was much stronger than rhyme priming in the oldest children and adults. The absence of significant rhyme priming for the older age groups contrasts with Meyer & Schriefers (1991) who reported rhyme priming in adults at SOAs 0 and +150. However, the rhyme priming in Meyer & Schriefers (1991) was significant only when the stimuli were aligned such that the 'onset' of the word (for the sake of placing it in an SOA) was defined as the beginning of the overlapping material (i.e. the rhyme). Thus, the difference in results between our study and Meyer & Schriefers (1991) is most likely due to differences in the timing of the overlapping rhymes. Given this, it would be premature to overinterpret the absolute level of the rhyme priming effect in the older participants. However, we feel confident about interpreting the study-internal age effects we have found, as well as changes in the relative strength of onset versus rhyme priming as a function of age.

The effects of Experiments 1 and 2, when taken together, provide evidence of a developmental change in speech production strategies. Over the course of development, children come to organize their lexicon in a way that maximizes their ability to begin producing the name of the picture before the output phonological buffer is completely filled. This incrementalist approach to articulation emphasizes the role of the onset in lexical activation, as opposed to the rhyme. Because lexical generation is so fast in older children and adults, and because word generation cannot be initiated when only the rhyme is activated, we find no evidence for rhyme facilitation in older participants. However, for younger children, phonological activation in the output buffer operates in a more global fashion. At these younger ages, children have not yet structured their lexicon to facilitate maximally incremental articulation.

Identity priming

At all SOAs, the presentation of an identical IW did not lead to any interference. Thus, the presence of a complete phonological and semantic match between the identity prime and the target was sufficient to overcome the underlying effect of lexical competition. At SOA −150, there was a strong facilitatory effect, as there was in Experiment 1. At SOAs 0 and +150, identity priming blocked interference, but led to no additional facilitation of the target, although there was some evidence of facilitation in terms of lower error rates for pictures paired with identical IWs, especially at SOA +150.

These RT data contrast with the findings of facilitation at SOAs 0 and +150 in Experiment 1. One possible interpretation of the additional facilitation in Experiment 1 at SOAs 0 and +150 is that the identity priming effect was dependent upon the specific composition of the stimulus set. In half of the trials of Experiment 1 the picture was paired with either an onset-related IW or an identical IW, with both of these IW types sharing the onset consonant with the name of the picture. This fact may have focused the participants' attention to the onset cluster across trials. The contrasting results of the two experiments suggest that the structure of the lists may have influenced participants' pattern of responding to the identical IWs.

Lexical competition

Unrelated and neutral IW types were compared to compute the effect of lexical competition. Pictures paired with unrelated IWs were named more slowly than pictures paired with neutral IWs at SOAs 0 and +150. The presence of lexical competition at SOAs 0 and +150 in Experiment 2 matches up with parallel findings from Experiment 1. However, in Experiment 1, interference from lexical competition was also evident at SOA −150.

GENERAL DISCUSSION

The goal of the current study was to investigate developmental changes in the phonological encoding component of the word generation process. Two experiments used the cross-modal picture-word interference task to measure phonological priming in children's picture naming. In both, response latencies for pictures paired with phonologically-related IWs were compared with latencies for pictures paired with phonologically-unrelated IWs to compute the contribution of phonological priming. In Experiment 1, the phonologically-related IWs shared the onset consonant or consonant cluster with the names of the target pictures. In Experiment 2, the phonologically-related IWs rhymed with the names of the pictures. We predicted that, if incrementalist processes for articulatory production develop over time, older children and adults should become more influenced by onset-based phonological priming than by rhyme-based phonological priming. For younger children, on the other hand, the two types of priming should have roughly similar effects. The results of the two studies supported this prediction and the incrementalist model upon which it is based.

In Experiment 1, participants at all ages showed strong onset-based phonological priming at the SOAs of 0 and +150. However, the SOA yielding the maximum priming effect was delayed in five-year-olds, in comparison to older children and adults. We attributed this finding to increases in processing speed. Apparently, the younger children needed more time to encode the IWs before they could impact picture naming. In Experiment 2, only the five-year-olds and seven-year-olds were strongly influenced by rhyme based priming. The magnitude of the rhyme priming effect was enormous for the five-year-olds and was actually somewhat stronger than the effect of onset priming.

The observed differences in the strength of the rhyme priming effect can be attributed partially to developmental changes in the speed of initiation of articulatory plans. Older children and adults start to articulate the name of the picture so quickly that the rhyme has little effect. In contrast, younger children are still engaged in phonological encoding while they are processing the rhyme of the IW. As a result, they can benefit from rhymes even at later SOAs. This account predicts that older speakers should benefit from rhyme-priming when the SOA is shorter. Indeed, we found slight facilitation in older children and adults at SOA 0, and Meyer & Schriefers (1991) found significant facilitation when they defined the SOA in rhyme priming as the interval between the picture onset and the onset of the overlapping rhyme.

This research yielded two central findings. The first is that rhyme priming has a strong effect in young children, but not older children and adults. The second is that the peak effect of onset priming moves to earlier SOAs with increasing age. These two central findings both point in the same direction. They indicate that the phonological representations underlying word generation change qualitatively with development.

This qualitative developmental shift involves an increased emphasis on retrieval from the word's onset, as opposed to holistic retrieval (Walley, 1993; Jusczyk, 1997; Metsala, 1997). This shift allows children to speed up their articulation. By speaking more rapidly, children can participate more fully in rapid turn-taking and can successfully enter a conversation at turn-relevant junctures (Ochs, Schegloff & Thompson, 1996). Increases in the speed of word access also facilitate the smoothness of sentence planning and decrease tendencies toward disfluencies (Wijnen, 1992).

Speeded lexical access depends on a reorganization of the lexicon into an onset-based structure. Taft & Forster (1975) referred to this structure as the basic onset syllable structure (BOSS). It has figured prominently in many models of lexical retrieval, such as the Cohort Theory (Marslen-Wilson, 1987) and ShortList (Norris, 1994). Recently, Gupta & Dell (1999) have shown that languages come to adapt themselves to the importance of word onset by placing more information into initial position and less into final position.

During childhood, the size of the child's vocabulary grows from approximately 2500 to 3000 words at age four, to approximately 39000 to 46000 at age ten to eleven (Anglin, 1993). Throughout this extended period of vocabulary growth, the child's lexicon must continually adapt to increases in neighbourhood density. It must cope with increasing similarity across lexical items, as defined by the number of real words in the child's vocabulary which share phonological segments (Charles-Luce & Luce, 1990).

Neural network theory provides a detailed way of understanding these developmental shifts. One framework uses self-organizing feature maps (Miikkulainen, 1993) that are organized into topological spaces that correspond to cortical regions. As local maps become densely occupied with competing lexical items, gangs of competitors spread out to secondary neural projection areas that deal specifically with the competition between words that share a basic onset syllable structure. These secondary projections still communicate with the overall lexicon, while focusing attention on the competition among close relatives. In this way, the lexicon becomes reorganized in a way that facilitates quick retrieval of onsets. This neural network model captures similar informal statements from other students of lexical reorganization. For example, Walley (1993: 311) notes that words become increasingly cross-referenced with one another in terms of phonological and semantic similarity relations, such that 'representations of similar words (existing or new) are 'moved closer' to one another and relevant differences noted'. Similarly, Metsala's recent work (1997) provides evidence that segmental restructuring does not occur in an all-or-none, system-wide fashion. Instead, for a given word, the extent of segmentalization depends on the density of words sharing similar sounds. Words that are infrequent in the language and have few phonological neighbours are the last to be restructured.

In addition to this ongoing process of lexical restructuring, children also experience an overall increase in processing speed (Kail, 1991, 1992). One result of this is a growing ability to articulate words more quickly. Kawamoto, Kello, Jones & Bame (1998) and Kello, Plaut & MacWhinney (in press) have shown that adults working under a deadline can trigger an articulation before it would normally be produced. These findings show how increases in articulatory speed can arise from just-in-time access to articulatory forms, as well as improvements in lexical organization around onset syllable structures. Together, this research and the findings of the current study provide evidence that growth in articulatory speed over development depends on specific changes in both structure and process.

Apart from our specific findings regarding lexical development, this study also demonstrates the feasibility and importance of conducting 'on-line' language processing studies with very young children. While we have focused here exclusively on the process of word generation, similar techniques can be used to study the production of complex utterances. For example, Schriefers (1993) has recently shown how it is possible, with adults, to systematically track the production of larger syntactic units, such as noun phrases, using the picture-word interference paradigm. Extending tightly controlled experimental methodologies of this type to children will help us construct a fuller model of the development of linguistic structures and the language production process.

REFERENCES

Anglin, J. M. (1993). Vocabulary development: a morphological analysis. *Monographs of the Society for Research in Child Development, Serial No. 238, Volume 58, Whole No. 10*.

Bryant, P. E., MacLean, M., Bradley, L. L. & Crossland, J. (1990). Rhyme and alliteration, phoneme detection, and learning to read. *Developmental Psychology* **26**, 429–38.

Charles-Luce, J. & Luce, P. A. (1990). Similarity neighbourhoods of words in young children's lexicons. *Journal of Child Language* **17**, 205–15.

Cohen, J. & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

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**, 257–71.

Collins, A. F. & Ellis, A. W. (1992). Phonological priming of lexical retrieval in speech production. *British Journal of Psychology* **83**, 375–88.

Cycowicz, Y. M., Friedman, D., Snodgrass, J. G. & Rothstein, M. (1997). Picture naming by young children: norms for name agreement, familiarity, and visual complexity. *Journal of Experimental Child Psychology* **65**, 171–237.

Dell, G. S. (1986). A spreading activation theory of retrieval in language production. *Psychological Review* **93**, 283–321.

Ehri, L. C. (1976). Do words really interfere in naming pictures? *Child Development* **47**, 502–5.

Ferreira, V. (1996). Is it better to give than to donate? Syntactic flexibility in language production. *Journal of Memory and Language* **35**, 724–55.

Gaskell, M. G., Hare, M. & Marslen-Wilson, W. D. (1995). A connectionist model of phonological representation in speech perception. *Cognitive Science* **19**, 407–39.

Glaser, W. R. (1992). Picture naming. *Cognition* **42**, 61–105.

Goldinger, S. D., Luce, P. A. & Pisoni, D. B. (1989). Priming lexical neighbors of spoken words: effects of competition and inhibition. *Journal of Memory and Language* **28**, 501–18.

Gupta, P. & MacWhinney, B. (1994). Is the articulatory loop articulatory or auditory? Re-examining the effects of concurrent articulation on immediate serial recall. *Journal of Memory and Language* **33**, 63–88.

Gupta, P. & Dell, G. S. (1999). The emergence of language from serial order and procedural memory. In B. MacWhinney (ed.), *The emergence of language*. Mahwah, NJ: Erlbaum.

Jusczyk, P. W. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Kail, R. (1991). Processing time declines exponentially during childhood and adolescence. *Developmental Psychology* **27**, 259–66.

Kail, R. (1992). Processing speed, speech rate, and memory. *Developmental Psychology* **28**, 899–904.

Kawamoto, A., Kello, C., Jones, R. & Bame, K. (1998). Initial phoneme versus whole word criterion to pronunciation: evidence based on response latency and initial phoneme duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **24**, 862–85.

Kello, C., Plaut, D. & MacWhinney, B. (in press). The task-dependence of staged versus cascaded processing in speech production: an empirical and computational study of Stroop interference. *Journal of Experimental Psychology: General*.

MacLean, M., Bryant, P. E. & Bradley, L. (1987). Rhymes, nursery rhymes, and reading in early childhood. *Merrill-Palmer Quarterly* **33**, 255–82.

Marslen-Wilson, W. (1987). Functional parallelism in spoken word-recognition. *Cognition* **24**, 71–102.

Metsala, J. L. (1997). An examination of word frequency and neighborhood density in the development of spoken-word recognition. *Memory & Cognition* **25**, 47–56.

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**, 1146–60.

Miikkulainen, R. (1993). *Subsymbolic natural language processing*. Cambridge, MA: MIT Press.

Norris, D. (1994). Shortlist: a connectionist model of continuous speech recognition. *Cognition* **52,** 189–234.

Ochs, E. A., Schegloff, M. & Thompson, S. A. (1996). *Interaction and grammar*. Cambridge: C.U.P.

Posnansky, C. J. & Rayner, K. (1977). Visual-feature and response components in a picture-word interference task with beginning and skilled readers. *Journal of Experimental Child Psychology* **24**, 440–60.

Rosinski, R. R., Golinkoff, R. M. & Kukish, K. S. (1975). Automatic semantic processing in a picture-word interference task. *Child Development* **46**, 247–53.

Schriefers, H. (1993). Syntactic processes in the production of noun phrases. *Journal of Experimental Psychology : Learning, Memory, and Cognition* **19**, 841–50.

Schriefers, H., Meyer, A. & Levelt, W. (1990). Exploring the time course of lexical access in language production: picture-word interference studies. *Journal of Memory and Language* **29**, 86–102.

Snodgrass, J. G. & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, and visual complexity. *Journal of Experimental Psychology : Human Learning and Memory* **6**, 174–215.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology* **18**, 643–62.

Taft, M. & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior* **14**, 638–47.

Treiman, R. (1985). Onsets and rimes as units of spoken syllables: evidence from children. *Journal of Experimental Child Psychology* **39**, 161–81.

Treiman, R. & Breaux, A. M. (1982). Common phoneme and overall similarity relations among spoken word syllables: their use by children and adults. *Journal of Psycholinguistic Research* **11**, 581–610.

Walley, A. (1988). Spoken word recognition by young children and adults. *Cognitive Development* **3**, 137–65.

Walley, A. (1993). The role of vocabulary development in children's spoken word recognition and segmentation ability. *Developmental Review* **13**, 286–350.

Walley, A., Smith, L. B. & Jusczyk, P. W. (1986). The role of phonemes and syllables in the perceived similarity of speech sounds for children. *Memory & Cognition* **14**, 220–9.

Wijnen, F. (1992). Incidental word and sound errors in young speakers. *Journal of Memory and Language* **31**, 734–55.

APPENDIX A

STIMULI FOR EXPERIMENT 1

Target picture	Onset-related IW	Unrelated IW
bed	bell	clown
bell	bed	sock
car	cat	dog
cat	car	hand
clock	clown	train
clown	clock	bed
dog	door	car
door	dog	foot
foot	fork	door
fork	foot	hat
hand	hat	cat
hat	hand	fork
sock	sun	bell
sun	sock	tree
train	tree	clock
tree	train	sun

APPENDIX B

STIMULI FOR EXPERIMENT 2

Target picture	Rhyme-related IW	Unrelated IW
bear	chair	sock
cake	snake	moon
car	star	mouse
cat	hat	tree
chair	bear	house
clock	sock	star
hat	cat	spoon
house	mouse	chair
key	tree	snake
moon	spoon	cake
mouse	house	car
snake	cake	key
sock	clock	bear
spoon	moon	hat
star	car	clock
tree	key	cat