

Effects of semantic predictability on children's preservation of a phonemic voice contrast*

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ABSTRACT

We investigated the effects of semantic predictability on children's preservation of the /t/-/d/ phonemic voice contrast in American English. In Experiment 1, a total of 36 seven-, nine-, and twelve-year-olds produced minimal pairs differing in intervocalic /t/ and /d/ in semantically biasing and semantically neutral passages. The seven-year-olds preserved the phonemic contrast in both passage types. However, for the nine- and twelve-year-olds, total word duration and preceding vowel duration preserved the /t/-/d/ contrast, but this interacted with semantic predictability. The contrast was preserved in the biasing and not in the neutral passages. The production results from the older children replicated previous findings from adults, demonstrating that semantic predictability influences speech production at both a lexical and a segmental level. In Experiment 2, listeners identified the tokens produced in Experiment 1. The identification results suggested that differences produced by speakers may not necessarily have a functional role for listeners. An interactive activation framework is proposed to account for the semantic effects on older children's and adults' production. For the youngest children, however, we suggest that pragmatic compensation and task demands interact with the effects of interactive activation.

INTRODUCTION

We selected three groups of school-aged children to examine the effects of semantic predictability on children's speech production. Research from the

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last 25 years clearly demonstrates that children are capable of modifying their speech production according to different pragmatic and semantic contexts. Shatz & Gelman (1973) found that four-year-old children modified their syntax in different pragmatic situations. Like caregivers using child-directed speech with children, four-year-olds used shorter, less complex utterances when speaking to two-year-olds than when speaking to their mothers or to peers of the same chronological age.

Sachs & Devin (1975) also demonstrated that children's speech style differed when talking to an infant or a doll compared to talking to a peer or adult (see also Andersen, 1984). In particular, children (ages 3;9–5;5) modified their speech and produced more simplified speech patterns when talking to dolls or to children younger than themselves. The structure of the speech addressed to the doll and infant was found to be less complex in form than speech addressed to the mother.

Children's ability to adjust the phonetic aspects of their speech production according to pragmatic context has also been found. For example, children younger than five years acoustically alter their requests to sound 'less harsh' in order to manipulate a listener's reaction (Bates, 1976) or use less errors when the listener appears not to understand (Weiner & Ostrowski, 1979). Furrow (1984) also showed that children used prosodic elements of speech for communicative purposes. Specifically, when young children aged 1;1 to 2;1 maintained eye contact with a person, their speech production was on the average judged to be greater in loudness and higher and more variable in pitch compared to their production made at other times. Furrow concluded that even very young children were aware of the social versus non-social function of speech and adjusted their use of prosody accordingly. Thus, preschool children are able to manipulate speech style and syntax, as well as the acoustic-phonetics properties of speech production for communicative purposes (see also Maratsos, 1973; Menig-Peterson, 1975).

In addition to adjusting their speech in different pragmatic contexts, there is also evidence that children are sensitive to semantic information and modify their production depending on information content. For example, semantic information interacts with the phonology of children. Leonard (1971) observed one six-year-old subject who inconsistently omitted /z/. He noted that omissions of /z/ were associated with the information content of the lexical item. Omissions generally occurred less in words bearing high information content (e.g. *nose*) and occurred more in words bearing less information content (e.g. *was*).

Cambell & Shriberg (1982) also found that speech-delayed children used phonological processes less frequently during the production of the newest information or most semantically informative aspect of the discourse. Comparatively, phonological processes were used more frequently during production of presupposed, or semantically old, information in the discourse.

An earlier study by McGarr (1981) is particularly relevant to the present investigation. McGarr found that adult listeners were better able to comprehend words excised from the speech of normally developing children when the words had been produced in sentences with high semantic predictability relative to targets produced in sentences with no or minimal semantic predictability. Two age groups of normally developing children, one group of eight- to ten-year-olds and another group of thirteen- to fifteen-year-olds, produced 18 high predictability sentences and 18 low predictability sentences. In one experiment, the individual words were excised from their contexts and presented in isolation to adult listeners for identification. Percent correct identification of the tokens from both children's age groups was better for words produced in the high predictability sentences. This suggested that a sentence that semantically predicted the target word was more clearly articulated by the children. Thus, even the excised words from the high predictability sentences were more intelligible relative to those excised from the low predictability sentences.

However, McGarr's findings are problematic for two reasons. First, the set of excised target words that listeners identified were not identical from the two semantic contexts. Thus, any conclusions based on word duration may be confounded with varying place and manner of articulation of segments per word that occurred across the high and low predictability contexts. Secondly, when listeners were asked in a second experiment to identify the whole sentence containing the target words produced by the children, percent identification was not better for the high predictability sentences relative to the low predictability sentences. The latter result contradicts McGarr's results from the excised words presented in isolation that identification was better on words from high predictability vs. from low predictability sentences. In other words, there was no difference between high vs. low predictability in the identification of sentences but there was for individual words excised from these sentences. Thus, while McGarr's (1981) results may suggest that semantic predictability influences speech production strategies in speakers at a young age, a more systematic investigation is needed in children.

In addition to McGarr's study, however, there is a large body of evidence demonstrating the effects of semantic predictability on adult speech production. Shields & Balota (1991) had adults produce sentences in which the target words were repetitions of earlier words in the sentence, were preceded by semantically related words, or were preceded by semantically unrelated words. The target words were shortest in duration when they were repetitions, longest when preceded by unrelated primes, and intermediate when preceded by related primes. Lieberman (1963), Fowler (1988), and Balota, Boland & Shields (1989) also showed that words preceded by semantically related information were shorter in total word duration than the

same words preceded by semantically unrelated information. These findings suggest that adult speakers adjust their articulation on the basis of the semantic predictability present in a single sentence.

Charles-Luce (1997) examined the effects of semantic predictability on adults' production of minimal pairs like *writer* and *rider* when produced in passages. Two types of experimental passages were constructed for each target word: biasing passages that semantically predicted the target words and neutral passages that did not semantically predict the target words. The results showed a lexical effect such that overall word duration was longer in neutral contexts than in biasing contexts. This finding paralleled earlier results demonstrating that word duration is longer in contexts having a low degree of semantic predictability but shorter in contexts having a high degree of predictability (Lieberman, 1963; Fowler & Housum, 1987; Fowler, 1988; Balota *et al.*, 1989; Shields & Balota, 1991).

Moreover, Charles-Luce & Dressler (1999) examined the effects of semantic predictability on speech production in young adults (college-age) and older adults (age 60–78) and again found the same pattern of word duration results using a different set of biasing and neutral passages from those used in Charles-Luce (1997). For both the young adults and older adults, target word duration was longer in the semantically neutral contexts relative to the duration of the same target words produced in the semantically biasing contexts.

Thus, the majority of the earlier studies investigated the effects of semantic predictability on the production of words. Charles-Luce (1997) and Charles-Luce & Dressler (1999), in addition to lexical level effects, also investigated a segmental level effect, namely how semantic predictability affects the production of segments and phonological processes. They examined how semantic predictability interacts with phonology and the preservation of the /t/-/d/ voice contrast. The results from young adults in both studies showed that preceding vowel duration distinguished phonemic voicing in pairs like *writer* and *rider*. However, this was not independent of semantic passage type. In the biasing passages, the voice contrast was preserved. Vowel duration was longer preceding /d/ than preceding /t/. In the neutral passages, the phonemic voice contrast was not preserved. Neither preceding vowel duration nor closure duration of the /t/ or /d/ preserved the voice contrast. (The older adults in Charles-Luce & Dressler (1999) preserved the voice contrast in both types of semantic contexts.)

In summary, Charles-Luce (1997) and Charles-Luce & Dressler (1999) found for young adults that word duration shortened in biasing passages and lengthened in neutral passages, thereby replicating previous work. Moreover, for the shorter words produced in biasing passages, preceding vowel duration preserved the phonemic contrast. For the longer words produced in neutral

passages, the phonemic contrast was lost. Semantic predictability appears to affect both a lexical level and a segmental level of representation.

In the present study, we investigated the effects of semantic predictability on children's speech production. We were interested in examining how semantic predictability affects children's production at a lexical level and a segmental level after their neuro-motor coordination matures and articulatory variability due to an immature system decreases. Rimac & Smith (1984) showed that seven- and eight-year-old children have fairly good motor control of segmental production. Kent & Forner (1980) suggested that by the age of 11 or 12 years children's precision of motor control is essentially adult-like and performance variability decreases. Thus, variability in production resulting from immature articulatory abilities begins to decrease and stabilize in school-aged children as motor skills are perfected (Smith, 1978; Smith & McLean-Muse, 1987). We hypothesized that only after children have achieved a relatively high level of articulatory control will we notice the effects of cognitive influences like speaker sensitivity to semantic content on speech production.

Our specific goal was developmentally to follow-up Charles-Luce (1997) and Charles-Luce & Dressler (1999) in order to examine the effects of predictability on children's production. We examined the effects of semantic predictability on school-aged children's production of words. Furthermore, we examined the effects of predictability on their production of segments and, specifically, a phonemic voice contrast.

Again, we used the optional phonological process of flapping to determine the effects of semantic predictability on a phonemic contrast. Flapping, theoretically, is defined as the acoustic-phonetic realization of both phonemes /t/ and /d/ as the flap, [ɾ]. When flapping applies, the /t/-/d/ phonemic voice contrast in pairs like *writer* and *rider* is lost, or neutralized, and both words are produced as homonyms, i.e. [ɹaɪɾə]. Our intent was not to determine if children use flapping, which is commonly found in American English. We know that children are capable of producing flaps. For example, Rimac & Smith (1984) investigated seven- and eight-year-olds' production of alveolar flaps and found that children this young could motorically produce flaps, although longer durations were associated with children's production of flaps compared to adults'. However, as we did in Charles-Luce (1997) and Charles-Luce & Dressler (1999), we used flapping as a diagnostic to evaluate effects of semantic predictability on a segmental level of representation. Examining how children apply the optional process of flapping may allow us to gain some insight into children's control and precision of producing a phonemic contrast as a function of their sensitivity to semantic predictability.

Experiment 1 investigated children's production of the /t/ and /d/

contrast in bisyllabic words when produced in semantically biasing and neutral passages. Experiment 2 investigated adult listeners ability to correctly identify the bisyllabic words produced in Experiment 1 by the children.

EXPERIMENT 1

METHOD

Subjects

A total of 36 young males and females from three different children's age groups participated as paid subjects. Twelve subjects were seven-year-olds (range seven- to eight-year-olds and in second-grade), 12 were nine-year-olds (range nine- to ten-year-olds and in fourth-grade), and 12 were twelve-year-olds (range twelve- to thirteen-year-olds and in seventh-grade). The young subjects were recruited as children of faculty at the University at Buffalo and as the children's friends. In addition, 12 adults served as a control group. The adults were undergraduate students attending the University at Buffalo and were paid for their participation. All young and adult subjects were native American English speakers and reported no history of speech, language, or hearing difficulties. Although reading skills were not assessed formally, fluency was informally evaluated by the experimenters during the practice session.

Materials

Two minimal pairs were selected as target words. These included: *pedal/petal* and *rider/writer*. The pairs were bisyllabic words with an intervocalic /t/ or /d/ and a stressed first syllable. We used minimal pairs that differed in intervocalic /t/ and /d/ for three reasons: (1) children have the motoric capability to produce flaps; (2) flapping is an optional process in American English and, as such, we can use it as a diagnostic of when speakers preserve the contrast and then they do not; and (3) we know how semantic predictability affects these pairs in adult production.

Two types of semantic passages, biasing and neutral, were constructed individually for each target word. This resulted in a total of eight experimental passages. All experimental passages are given in the Appendix. The four biasing passages were story-like and descriptive. These passages semantically predicted the target word. Conversely, the four neutral passages consisted of a string of unrelated sentences and were presented in a paragraph format. Importantly, the neutral passages did not semantically predict the target word. Unlike the biasing passages, either member of the minimal pair could occur in the slot reserved for the target word in the neutral passages.

All passages were eight sentences long and all target words occurred in the sixth sentence of the passage. Each target had six syllables preceding it in the sentence in which it occurred and seven syllables following it. Local phonetic environments were controlled also. All target words were preceded by a word ending in /ə/. All target words were followed by a word beginning with /t/.

Each of the eight passages was constructed for a fourth-grade reading level, contained on the average only high frequency content words, and was normed for its semantic content. The fourth-grade reading level was selected because it was the median of the three children's age groups. Accordingly, we hoped that the fourth-grade level would provide interest to the nine-year-olds, but not be too boring or trivial for the twelve-year-olds. Before the experiment began, we acknowledged that we might need to eliminate some seven-year-olds' data from analysis because of their emerging reading skills and potential disfluency or that we might need to coach this age group on some of the target words. This, however, turned out not to be necessary (see below).

In addition, each passage was constructed such that, on the average for a fourth-grade reading level, it contained high frequency words. To obtain an average frequency per passage, a random set of eleven content words was selected to determine the average frequency of each passage according to the norms provided by Carrol, Davies & Richman (1971). A STANDARD FREQUENCY INDEX (SFI) was then calculated for each passage. The SFI represents an estimate of the relative frequency of type per million tokens in written text at a given grade level. For example, an SFI of 60 equals the value that would occur once in 10000 tokens. (An SFI of 60 is equivalent to 100 occurrences per 1 million in Kučera & Francis (1967), which is considered to be high frequency.) All of the experimental passages had a mean SFI of 57 or above according to a fourth-grade reading level.

Finally, each passage was rated by naive adult judges on how well it did or did not predict the target words. Judges used a 5 point rating scale. A score of '1' indicated that the passage did not predict the target at all, '2' very little, '3' somewhat, '4' well, and '5' indicated that the passage predicted the target very well. Thirty-six students attending the University at Buffalo participated as judges. Only passages scoring an average of 4 or 5 were accepted as biasing passages and only passages scoring a 1 or 2 were accepted as neutral. Individual passages were altered by the experimenters and re-judged until they met the criterial score.

Procedure

Subjects were tested one at a time. The subjects were instructed that they would be doing a reading task. Each subject was asked to read a randomized

set of all passages (the eight experimental passages and four filler passages) out loud at a normal rate of speech and at a comfortable voice level. A short break was taken following one complete reading of all passages. The subject then read all passages again under the same conditions. Before the experiment proper began and following the instructions, subjects were given two practice passages to familiarize themselves with the reading task. There were a total of 192 experimental stimuli (4 target words \times 2 passages \times 2 repetitions \times 12 subjects) per age group.

Because the passages were gauged at a fourth-grade reading level, during the practice session the seven-year-olds (second-graders) were shown pictures of the target words to ensure that they knew each target word and its meaning. (The cartoon pictures were attached to the passages and were present for all age groups during the experiment.) These pictures were not intended to heighten the readers' sensitivity to the target words. They were used to engage the seven-year-olds in conversation about the picture in order to ensure that they knew the targets and their meanings. Thus, for example, included with the biasing passage for 'writer' was a cartoon picture of a man sitting at a desk in an office and typing on a computer keyboard; included with the biasing passage for 'pedal' was a cartoon of a whole bicycle. The pictures strengthened the semantic context but did not focus only on the target word. They, nonetheless, allowed the experimenter to query the seven-year-old about the target word. Conversely, for the neutral passages the cartoon was unrelated to the text or related to only one sentence of the text. For example, for the neutral 'petal,' the cartoon pictured five children standing below the flag of the United States. None of the text made reference to this image or action. Again, the seven-year-olds were engaged in conversation about this cartoon as well, but this remained semantically neutral to the text.

All seven-year-olds knew the target words and their meanings. None of our subjects had any unusual difficulty reading the target words or passages. In addition, during the practice session, all children were judged informally to be fluent readers for their age. The adult subjects were not told that the passages were written for a fourth-grade level. However, when questioned informally after the experiment, all adults told us that the passages were very simple. All of our original subjects were used in the data analysis. No subject for any of the four age groups was eliminated because they had difficulty reading the set of experimental passages or because of reading disfluency.

Measurements

Subjects were recorded one at a time using a Shure SM2 microphone and a Marantz PMD430 portable cassette deck. Subjects' speech was then digitized

at a sampling rate of 20 kHz per second, via a 16 bit analogue-to-digital converter (Gradient Technology, Inc. DeskLab TM216 SCSI Audio). Measurements were made on a VAX Workstation (4000 Model 60) from a visual waveform display using a digital waveform editor.

For each target word, three acoustic measurements were made: (1) total word duration, (2) vowel duration preceding the intervocalic alveolar stop (/t/ or /d/), and (3) closure duration of the alveolar stop (/t/ and /d/). The segmentation criteria for the measurements are described below (cf. Charles-Luce, 1985, 1993, 1997 for similar dependent variables and segmentation criteria).

Because of a few mispronunciations, extraneous noise, etc. which made measurement difficult, some of the target words from three of the four age groups were deleted from the data. This resulted in the deletion of 4% of the target words from the seven-year-olds' and the nine-year-olds' data and 2% from the adults' data. No target words were deleted from the twelve-year-olds' data. An age-appropriate mean for each dependent variable was then substituted for the deleted data. These means were computed from the remaining voice-appropriate /t/ or /d/ words produced in the same passage type as the deleted item.

Total word duration

For all target words, onset of the word was measured from an increase in the amplitude of the waveform and/or a visual change in the cyclic pattern of the waveform between previous word and target word. Offset of the target word was marked by a decrease in the amplitude of the waveform and/or a visual change in the cyclic pattern of the waveform between the target word and the following word.

Preceding vowel duration

For the target pair, *rider/writer*, the initial non-lateral liquid was included as part of the vowel duration. Because it was difficult consistently to segment the offset of the liquid from the onset of the vowel, this consonant was included as part of the vowel measurement. For this pair, then, onset of the preceding vowel duration was also the onset of word duration (see above). For the pair *pedal/petal*, the initial stop was not included. Onset of preceding vowel duration was defined by a marked increase in the amplitude of the waveform following release of the stop closure and any aspiration present.

Offset of the vowel for all words was indicated by a marked decrease in the amplitude of the waveform.

TABLE 1. *Word duration, preceding vowel duration, and closure duration (ms) for each target word produced in the biasing and neutral passages for each age group^a*

	Word	Vowel	Closure
Seven-year-olds			
Biasing			
petal	513	123	67
pedal	457	122	56
writer	535	253	54
rider	576	279	46
Mean	520	194	56
Neutral			
petal	570	128	72
pedal	516	126	46
writer	541	293	55
rider	575	298	49
Mean	551	212	53
Nine-year-olds			
Biasing			
petal	373	113	25
pedal	349	109	24
writer	363	205	36
rider	421	236	34
Mean	377	165	30
Neutral			
petal	397	118	28
pedal	348	118	25
writer	410	212	39
rider	429	229	35
Mean	396	169	32
Twelve-year-olds			
Biasing			
petal	330	90	23
pedal	330	124	25
writer	354	170	33
rider	392	212	34
Mean	352	149	29
Neutral			
petal	375	98	25
pedal	332	109	22
writer	369	191	26
rider	383	207	29
Mean	365	151	26
Adults			
Biasing			
petal	318	75	28
pedal	299	90	20
writer	345	187	33
rider	350	203	32
Mean	328	139	28
Neutral			
petal	318	89	26
pedal	288	84	22
writer	352	187	31
rider	332	202	27
Mean	323	141	27

^a Each cell is averaged across two repetitions of the target item.

Alveolar stop closure duration

Closure duration of the /t/ and /d/ was measured according to one of two criteria depending on the presence of an identifiable stop burst release. If there was a clear burst release, closure duration was measured from offset of the preceding vowel to onset of the release burst of the final stop, as indicated by a high-energy peak in the waveform. If there was no identifiable release burst, the low amplitude cyclic pattern occurring between the stop's preceding and following vowels was measured. Onset of this was marked by a decrease in amplitude from the preceding vowel AND change in cyclic pattern and offset was marked by an increase in amplitude AND change in cyclic pattern in the waveform for the following vowel.

By measuring preceding vowel duration and closure duration, as known correlates of the phonemic voice contrast in American English (Luce & Charles-Luce, 1985), we could determine the effects of semantic predictability on phonology. If the contrast was preserved, we predicted that vowel duration preceding /d/ would be longer than vowel duration preceding /t/ and/or closure duration would be longer for /t/ than for /d/. Finally, measuring word duration allowed us to compare our results with previous studies that examined the effects of semantic predictability on word duration (Charles-Luce, 1997 and references therein).

To examine the reliability in our acoustic measurements, 5 % of the target words from Experiment 1 were remeasured. These were randomly selected from all speakers. Mean measurement error was then determined for total word duration, preceding vowel duration, and closure duration. Mean measurement error was computed by subtracting the remeasurement from the original measurement to obtain a difference score. No single difference score exceeded 36 ms for word duration, 23 ms for vowel duration, and 14 ms for closure duration. Mean difference scores were then computed for each of the three duration intervals. Total mean measurement errors did not exceed 21 ms for word duration, 3 ms for vowel duration, and 3 ms for closure duration.

RESULTS

Two-way repeated measures analyses of variance (passage type \times phonemic voicing) were performed separately on vowel duration, closure duration, and word duration with subjects as the random factor. Age and repetition (to evaluate order effect) were treated as grouping factors. Repetition was not a significant factor ($F < 1.0$) for any of the three temporal intervals measured. The following results are therefore collapsed across the repetition. One-way analyses of variance were performed on interactions and used in planned comparisons.

Items analyses were not computed because the number of items used was too small to produce reliable effects. The small number of items resulted because of two constraints, the need to choose familiar target items for all age groups and the need to construct biasing and neutral contexts for the target items. Table 1 shows the data per age group averaged across repetition and subjects for each target word produced in the biasing and neutral passages.

Vowel duration

There were main effects of age ($F(3, 92) = 20.68, p < 0.0001$) and passage type ($F(1, 3) = 3.98, p < 0.05$). Table 2 shows the results of average vowel

TABLE 2. *Average vowel durations (ms) and standard deviations as a function of passage type and age*

	Biasing	Neutral	Mean
Seven-year-olds	194 (43)	212 (41)	203 (42)
Nine-year-olds	165 (36)	169 (47)	167 (42)
Twelve-year-olds	150 (50)	152 (32)	151 (42)
Adults	139 (25)	141 (28)	140 (26)

duration as a function of passage type and age. Vowel duration was longer when produced in neutral passages relative to biasing passages for each age. Table 2 also shows the results of vowel duration by age averaged across the two passage types. Vowel duration shortened progressively as age increased.

In addition, there was a main effect of phonemic voicing ($F(1, 3) = 27.07, p < 0.0001$) and a two-way interaction involving age and voicing ($F(1, 3) = 2.61, p < 0.05$). A one-way analysis of variance revealed differences in preservation of phonemic voicing by age of speaker. Preceding vowel duration was not significantly different for the seven-year-olds ($F(1, 11) = 1.16, p < 1.0$). However, vowel duration was significantly longer preceding /d/ than /t/ for the nine-year-olds ($F(1, 11) = 6.65, p < 0.02$), twelve-year-olds ($F(1, 11) = 15.73, p < 0.0006$), and adults ($F(1, 11) = 23.27, p < 0.0001$).

However, planned comparisons showed that when vowel duration distinguished phonemic voicing in the nine- and twelve-year-olds and adults, it was dependent on the passage type. Table 3 shows the results of vowel duration preceding /t/ and /d/ as a function of passage type and age. Vowel duration distinguished /t/ and /d/ only in the biasing passages and not in the neutral passages: nine-year-olds (biasing ($F(1, 11) = 4.11, p < 0.05$); neutral

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TABLE 3. *Average vowel durations (ms) preceding /t/ and /d/ and standard deviations as a function of passage type and age^a*

	Biasing	Neutral
Seven-year-olds		
/t/	188 (41)	211 (42)
/d/	201 (44)	212 (39)
Nine-year-olds		
/t/	159 (39)*	165 (43)
/d/	173 (32)	174 (52)
Twelve-year-olds		
/t/	130 (23)*	145 (23)
/d/	169 (61)	158 (38)
Adults		
/t/	132 (23)*	138 (28)
/d/	147 (26)	143 (28)

^a * indicates voicing was distinguished ($p < 0.05$) within the passage type.

($F(1, 11) = 1.62, p < 1.0$); twelve-year-olds (biasing ($F(1, 11) = 18.01, p < 0.0003$); neutral ($F(1, 11) = 2.10, p < 1.0$); adults (biasing ($F(1, 11) = 8.20, p < 0.009$); neutral ($F(1, 11) = 1.52, p < 1.0$)).

Closure duration

One subject was eliminated because of the difficulty in obtaining consistency in the measurements according to our criteria. To equalize cell numbers, one subject from each of other three age groups was randomly deleted.

There were significant main effects of age ($F(3, 84) = 20.44, p < 0.0001$) and phonemic voicing ($F(1, 3) = 11.25, p < 0.001$). Passage type was not significant ($F(1, 3) = 1.35, p < 1.0$). The last column of Table 4 shows the results of closure duration by age averaged across passage type and voicing. Among the children, closure duration shortened progressively as age increased.

In addition, there was a two-way interaction involving age and voice ($F(1, 3) = 5.2, p < 0.002$). A one-way analysis of variance revealed that closure duration was significantly longer for /t/ than for /d/ for the seven-year-olds ($F(1, 10) = 8.56, p < 0.008$) and adults ($F(1, 10) = 6.29, p < 0.02$). However, closure duration did not distinguish /t/ and /d/ for the nine-year-olds ($F(1, 10) = 1.43, p < 1.0$) or the twelve-year-olds ($F < 1.0$).

Table 4 also shows the results of closure duration for /t/ and /d/ as a function of passage type and age. Planned comparisons showed that when closure duration distinguished /t/ and /d/ for the adults, it was dependent on the passage type. It was significantly longer for /t/ only in the biasing

TABLE 4. *Average closure durations (ms) preceding /t/ and /d/ and standard deviations as a function of passage type and age^a*

	Biasing	Neutral	Mean
Seven-year-olds			
/t/	60 (32)*	64 (34)*	55 (30)
/d/	51 (25)	43 (26)	
Nine-year-olds			
/t/	30 (8)	34 (9)	31 (10)
/d/	29 (10)	30 (12)	
Twelve-year-olds			
/t/	28 (11)	26 (10)	27 (11)
/d/	29 (9)	26 (11)	
Adults			
/t/	31 (9)*	29 (8)	28 (8)
/d/	26 (8)	25 (6)	

* indicates voicing was distinguished ($p < 0.05$) within the passage type. The last column shows age collapsed across passage type and voicing.

TABLE 5. *Average word durations (ms) and standard deviations as a function of passage type and age*

	Biasing	Neutral	Mean
Seven-year-olds	520 (73)	551 (81)	535 (78)
Nine-year-olds	377 (52)	396 (59)	387 (56)
Twelve-year-olds	352 (44)	365 (54)	359 (49)
Adults	328 (47)	323 (48)	326 (48)

passages (biasing ($F(1, 10) = 9.58$, $p < 0.006$); neutral ($F(1, 10) = 3.88$, $p < 0.10$)). However, when closure duration distinguished /t/ and /d/ for the seven-year-olds, it was independent of passage type. Closure duration was significantly longer for /t/ in BOTH biasing ($F(1, 10) = 4.53$, $p < 0.05$) and neutral passages ($F(1, 10) = 16.10$, $p < 0.0006$) for the seven-year-olds.

Word duration

There were significant main effects of age ($F(3, 92) = 71.77$, $p < 0.0001$) and passage type ($F(1, 3) = 22.58$, $p < 0.0001$). Phonemic voicing was not significant ($F < 1.0$). No interactions involving age or voicing were significant. Table 5 shows the results of average word duration as a function of passage type and age. The last column shows word duration by age averaged across passage type. Like vowel duration, word duration was longer when produced

in neutral passages relative to biasing passages for the children. For the adults, passage type was not significantly different ($F < 1.0$). Also like vowel duration, word duration shortened progressively with increasing age.

DISCUSSION OF EXPERIMENT I

Our results demonstrate that semantic predictability affects speech production at a lexical and segmental level for school-aged children and adults. Moreover, for older children and adults, predictability interacts with the preservation of a phonemic contrast. It is possible that the results from the seven-year-olds, more so than from the nine- and twelve-year-olds, may be confounded with the fact that they are less experienced readers. This inexperience may have resulted in more careful articulation of the printed word and individual graphemes. Thus, the task demands and the orthographic correspondence of /t/ and /d/ to the phonemic voice difference may have contributed to the age-related differences. However, even if seven-year-olds were somehow more tied to the reading task, they still modified their production of vowel and word duration as a result of semantic predictability, producing longer word and vowel durations in the neutral passages than in the biasing passages. This was similar to the nine- and twelve-year-olds and the adults in this study and to previous results from adults (Lieberman, 1963; Fowler, 1988; Balota *et al.*, 1989; Shields & Balota, 1991; Charles-Luce, 1997; Charles-Luce & Dressler, 1999). Duration is longer in low predictability contexts and shorter in high predictability contexts.

With regards to the phonemic voice contrast and children's productions, the three age groups did not behave completely alike. In particular, the seven-year-olds used closure duration differences to preserve the voice contrast regardless of the semantic predictability of the context. However, as children get older, our results suggest they do not use closure duration to preserve differences in the stops themselves. Nonetheless, the voice contrast still was preserved in certain passages by the older children. Specifically, nine-year-olds and twelve-year-olds used preceding vowel duration to preserve the phonemic voice contrast BUT ONLY in the biasing context. Thus, the results from the older children and adults show an interaction between semantic predictability and the preservation of a phonemic contrast.

It is possible that our results are not due to the speakers' sensitivity to the semantic content but rather are an artifact of rate of articulation differences introduced by our text materials. However, we believe that our results are not an effect of rate differences between the neutral and biasing passages. Umeda (1975), Klatt (1976), and Luce & Charles-Luce (1985) demonstrated that the magnitude of vowel duration differences as a correlate to phonemic voicing in American English are larger in phrase-final positions relative to non-

phrase-final positions. For example, Luce & Charles-Luce (1985) found that vowels were 68 msec longer preceding voiced compared to voiceless stops in phrase-final position but 42 msec longer preceding voiced compared to voiceless stops in non-phrase-final sentence position. This suggests that preceding vowel duration produced in connected speech may be a better correlate of voicing when it is produced in an environment where rate of speech slows down and duration lengthens (Klatt, 1976). Thus, from these results, one would predict that any voicing differences found in our data would occur in the neutral passages where average word and vowel durations were longer. However, we found the opposite effect. Vowel duration distinguished voicing in the biasing passages in which average word and vowel durations were shorter. Furthermore, word duration was not significantly different between words produced in the neutral and biasing passages for the adults (see Table 1). Nonetheless, preceding vowel duration preserved the voice contrast in the biasing passages but not in the neutral passages, even though the adults did not produce the target words at different rates between the two types of passages.

Finally, the present results from the nine- and twelve-year-olds and the adults replicated the pattern of results found for adults in Charles-Luce (1997) and for the young adults in Charles-Luce & Dressler (1999). Using three different sets of biasing and neutral passages, we have shown that semantic predictability affects duration at a lexical and segmental level, as well as interacting with preservation of a phonemic voice contrast.

EXPERIMENT 2

Experiment 2 examined whether listeners could perceive the durational differences that distinguished the /t-/d/ contrast found in Experiment 1. To reiterate, the seven-year-olds used closure duration to preserve the contrast in both passage types. They never used vowel duration to preserve the contrast. The nine- and twelve-year-olds (and the adults) used preceding vowel duration to preserve the contrast but did so in only one out of two passage types. The nine- and twelve-year-olds never used closure duration to distinguish the /t-/d/ contrast.

METHOD

Subjects

Sixteen adult, native American English speakers participated as paid listeners. Listeners were students at the University at Buffalo at the time of testing. No history of speech, language, or hearing disorders were reported by any of the listeners.

Materials

All target words were excised from the passages in which they were originally produced. From each age group (7, 9, 12, and adults), this resulted in a total of 192 /t/ and /d/ bisyllabic target words. Because of a few mispronunciations, extraneous noise, etc., some of the 192 words from the seven- and twelve-year-olds and adults were excluded from auditory presentation. In addition, 96 monosyllable words containing either a word-final /t/ or /d/ were presented as filler items. These also had been produced in Experiment 1 by each of the four age groups. They were digitized and excised for auditory presentation in the same manner as the target bisyllables.

Presentation of the auditory stimuli was blocked by age group for a between-subjects design. Four groups of four listeners each heard tokens from one age group only. Thus, one group of listeners heard the seven-year-olds' tokens (total 281 stimuli, 185 target bisyllables), one heard the nine-year-olds' tokens (total 280 stimuli, 184 target bisyllables), one heard the twelve-year-olds' tokens (total 288 stimuli, 192 target bisyllables), and one heard the adults' (total 284 stimuli, 188 target bisyllables).

Procedure

A two-alternative forced-choice perceptual identification task was used. Listeners were told that all the stimuli they would hear contained a /t/ or a /d/. Their task was to listen to each stimulus and to decide if it contained a /t/ or /d/ and then press the appropriately labelled button on the response box in front of them. They were instructed to respond as quickly as possible and to respond to all stimuli. Each listener was cued for an upcoming stimulus by a light in the centre of the response box.

The experimental stimuli were presented auditorily over Telephonics headphones to listeners at a comfortable listening level. To control for any biasing effects, response handedness was counterbalanced. Half of the 16 listeners responded /t/ with the right hand and half responded /t/ with the left hand. In addition, each listener received a different randomization of the stimuli. The randomization, presentation of the stimuli, and collection of responses were controlled by a Macintosh Centris 650.

RESULTS

A two-way analysis of variance (passage type \times phonemic voicing) was performed on per cent correct identification of the /t/ and /d/ bisyllabic target words. Age was a grouping factor. The main effect of passage type was not significant ($F < 1.0$), but voicing was ($F(1, 3) = 18.32$, $p < 0.001$).

Listeners were better at identifying /d/ words (72 %) than /t/ words (49 %). There was no interaction.

The main effect of age was significant ($F(3, 12) = 10.46$, $p < 0.001$). Although percent correct identification was significantly above chance for all age groups ($x = 36.35$, d.f. = 1, $p < 0.001$), identification was best for the seven-year-olds' tokens. Percent correct identification was 67 % for the seven-year-olds', 62 % for the nine-year-olds', 56 % for the twelve-year-olds', and 59 % for the adults' tokens. Planned comparisons showed that identification was not significantly better for the seven-year-olds' tokens compared to the nine-year-olds' ($F(1, 6) = 1.19$, $p < 1.0$). However, identification was significantly better for the seven-year-olds' tokens compared to the twelve-year-olds' and adults ($F(1, 6) = 29.87$, $p < 0.002$ and $F(1, 6) = 14.49$, $p < 0.009$, respectively). Identification among the other age groups did not differ: nine- vs. twelve-years ($F(1, 6) = 1.96$, $p < 1.0$), nine- vs. adults ($F < 1.0$), twelve- vs. adults ($F(1, 6) = 1.89$, $p < 1.0$).

DISCUSSION OF EXPERIMENT 2

The results of Experiment 2 suggest that listeners were best able to correctly identify the stimuli for which stop closure duration distinguished phonemic voicing, i.e. best for the seven-year-olds' tokens. The vowel duration differences found to distinguish voicing in the biasing passages for the nine-, twelve-year-olds, and adults may have helped listeners as suggested by listeners' ability to correctly identify the stimuli above chance. However, given that vowel duration did not distinguish /t/ and /d/ for the seven-year-olds but closure duration did and that percent correct identification was best for the stimuli produced by the seven-year-olds, closure duration may have been the better perceptual cue in Experiment 2. This may be because closure duration distinguished voicing in both biasing and neutral passages (thus, two out of two contexts).

Why identification was better for the /d/ words compared to the /t/ words is unclear. The production differences from Experiment 1 did not yield a significant main effect in voicing ($F < 1.0$). Averaged across all four age groups and passage types, the /d/ words were 415 ms (s.d. = 93) and the /t/ words were 417 msec (s.d. = 93).

Finally, as we have argued elsewhere (Charles-Luce, 1993, 1997), production differences may not always have a functional role for listeners (see also Rimac & Smith 1984). Our evaluation of the effects of semantic predictability provides us with data on words and segments whose acoustic-phonetic realizations are influenced by cognitive factors. Whether or not any of the differences we found in production were perceptually functional for the listener does not undermine what we believe is a behavioural reflection of

the interaction of cognitive processing and speech production in children and adults.

GENERAL DISCUSSION

Among the children, we found age-related effects in the influence of semantic predictability on the preservation of a phonemic voice contrast. Specifically, seven-year-olds preserve a difference between the /t/ and /d/ in pairs of bisyllabic words like *writer* and *river*. Closure duration of the stops themselves distinguished voicing in both biasing and neutral passage types. For the nine-year-olds and twelve-year-olds, neither closure duration nor preceding vowel duration preserved the /t/-/d/ contrast in the neutral passages. However, for these same two age groups, vowel duration (but not closure duration) distinguished /t/ and /d/ in the semantically biasing passages.

We cannot rule out, of course, that the reading task and/or the orthography may have influenced the seven-year-olds' production. Second-graders are very focused on reading, spelling, and phonics (Chall, 1983). However, comprehension skills are emerging by this age and stage of reading. Doehring (1976) showed that seven-year-olds read meaningful word groups faster than random word strings, indicating that this age recognized differences in semantic content or, at least, in text coherence. Moreover, our seven-year-olds had no difficulty with the task, the level of reading, nor did they express frustration or show any other behaviour that would have led us to believe any of the passages were beyond their reading abilities.

Furthermore, in Experiment 1, both the results from preceding vowel duration and total word duration indicate that seven-year-olds' were sensitive to semantic differences between the passage types and this had consequences for their production. Both vowel and word duration averaged across voicing were longer when produced in the neutral passages relative to the biasing passages. This was also true for the nine- and twelve-year-olds and the adults in the present investigation, as well as for adults in Charles-Luce (1997) and the young adults in Charles-Luce & Dressler (1999). Thus, differences in semantic predictability result in durational modifications at lexical and segmental levels in the speech production of older school-aged children and adults.

In addition, the present set of durational results replicates previous research showing age-related effects of children's productions of basic vowel and closure durations (Smith, 1978; Kent & Forner, 1980). Measurements of vowel duration preceding stops, closure duration of stops, and total word duration of bisyllabic words were significantly longer for the seven-year-olds compared to the nine- and twelve-year-olds. This replicates previous findings of younger vs. older children's production of segments (Smith, 1979) and parameters correlated with voicing (Kewley-Port & Preston, 1974). With increased age and production experience, duration decreases

(Kent & Forner, 1980; Smith & McLean-Muse, 1987; Smith & Kenney, 1994).

Our production results also corroborate previous findings showing that young speakers of American English use adult phonological processes like alveolar flapping, although the youngest age did not in this study (we will return to this below). Thus, young children do flap. However, children's use of flapping was not the motivation for our investigation. We were interested in determining when cognitive factors affect children's use of the phonological processes. Rimac & Smith (1984:395) suggested that some 'linguistic learning' is required before children know when to use phonological flapping. We suggest that the cognitive level effects of semantic content and predictability on speech production and phonology may be a part of this 'linguistic learning.' More specifically, as children continually build linguistic representations in memory, the internal organization of their linguistic system begins to resemble the adult organization. In essence, children's use of flapping, or preservation vs. loss of a voice contrast as we argue, is the result of internal connections between linguistic information like meaning, phonemic categories, etc.

We suggest, then, that children's use of the flapping process is governed by cognitive factors and that their effects on speech production may be interpreted according to a general interactive activation framework (Dell, 1986). This is a connectionist model of speech production that accounts well for the adult data on which this study is predicated (Charles-Luce, 1997). Thus, we are using this framework as a description for similar kinds of children's data and are not necessarily advocating interactive activation as a developmental approach superior to others. We adopt it in order to interpret children's production because it provides a general mechanistic explanation for lexical and segmental phenomena.

According to a general interaction activation framework, words activated in memory will activate other semantically associated words. Activation at the lexical level also will result in facilitatory activation of the phonological, phonetic, and motor codes of semantically related words, which are necessary for implementation by the speaker. Thus, the semantic content of the biasing passages facilitate activation of target words and their segmental representations and codes for implementation stored in memory. Prior activation results in a target word being pre-assembled and readied for articulation before it is required for output (cf. Levelt, 1989). Because of the pre-assembled state, absolute word and vowel duration is shorter. (Our data show no trend for segmental level differences for closure duration as a consequence of semantic predictability.)

In addition, at the segmental level, we see evidence of the phonological process of flapping. By our definition, flapping occurs when the voice contrast is completely lost and flapping does not occur when the contrast is

preserved in any manner (Charles-Luce, 1997; see also Fourakis, 1984). In the biasing passages, the effect of facilitatory activation is to 'enhance' the phonemic categories in memory by sharpening their category boundaries, and thereby reducing ambiguity among similar phonemes (e.g. /t/ and /d/). Consequently, the speaker phonetically implements each category in ways that preserve the phonemic contrast. For example, vowel duration is lengthened preceding the phonemic voiced category /d/. In this case, flapping is not evident because it does not result in the complete loss of the /t/-/d/ contrast. This interpretation accounts for the older children's and adults' production in which target words (e.g. *writer* and *rider*) and vowels produced in biasing passages were shorter in duration compared to their production in neutral passages and the phonemic difference was implemented as long vowel before /d/ and short vowel before /t/.

However, in the absence of facilitatory activation, as would be the case in the neutral passages, a target word is not activated prior to the time required for output. Consequently, it is not pre-assembled and its phonemic categories are not activated early. Moreover, phonemic boundaries are not sharpened in memory. Rather the target word, its individual segments, and their implementation codes are activated only at the time that the speaker is outputting them. The lack of semantic activation is reflected in longer word and vowel duration as the word is assembled during the speaker's articulation of it. Moreover, the lack of early activation results in the loss of the /t/-/d/ contrast because of the on-line activation of two sets of phonologically and phonetically similar motor codes, one set for /t/ and one for /d/. Because neither set has been well-specified by prior semantic context, aspects of both are realized and this, effectively, results in neutralization of a clear phonemic category. This accounts for the pattern of results we found for target words produced in the neutral passages by the nine- and twelve-year-olds and the adults, namely, longer overall word and vowel duration but loss of the /t/-/d/ contrast.

As it stands, interactive activation can account for all the data from older children and adults. It can also account for the seven-year-olds word and segmental durational modifications, but not for their results showing they preserved the /t/-/d/ contrast in both semantic contexts. Again, like the older children, the seven-year-olds showed effects of semantic predictability at both the lexical and segmental levels. Both overall word duration and vowel duration were affected by semantic predictability. Thus, priming and spreading activation among linguistic levels operates in children at least as young as seven. However, the youngest children did not show the asymmetrical loss of the /t/-/d/ contrast in the neutral passages and the preservation of it in the biasing ones.

A likely explanation for why the seven-year-olds preserved the /t/-/d/ contrast in both passage types involves the demands of the reading task we

used to elicit subjects' tokens in Experiment 1. Because of the youngest age group's attention to the reading task, a relatively new cognitive task compared to the older children and adults, the youngest children pragmatically compensated for their production of the /t-/d/ contrast. The seven-year-olds may have hyperarticulated the contrast made transparent by the orthography of American English (cf. Lindblom, 1990). Thus, semantic priming affected word duration at the lexical level and vowel duration at the segmental level. However, hyperarticulation cancelled the phonological process of flapping. Pragmatic compensation for the task manifested as hyperarticulation interacted with the effects from interactive activation (Charles-Luce, 1997).

Charles-Luce & Dressler (1999) also found that older adults pragmatically compensated and preserved the phonemic /t-/d/ contrast in both semantically biasing and neutral passages. Older adults may have cognitive difficulties in processing the differences between biasing and neutral passages (Cohen, 1988; Salthouse, 1990). In particular, if older adults have general cognitive problems with processing and integrating the linguistic content of texts, then the semantic predictability difference between the passage types may not be transparent to older adults. Furthermore, if the text coherence of neutral passages does not make logical or semantic sense to older adults, then they may decide not to process and integrate the semantic information in the neutral passages. Charles-Luce & Dressler (1999) suggested that older adults adopted a strategy for the whole experiment of processing and producing all the experimental passages at a lower, surface level, allowing them to attend to phonological differences like the /t-/d/ contrast in the target words. Likewise, the seven-year-olds may have over-ridden flapping by focusing attention on the task of reading and, in particular, of reading the /t-/d/ words out loud with precision. Flapping is an optional process in American English, and, as such, is easy for a speaker to manipulate. It would be interesting to examine children's precision of articulation when obligatory processes are involved (for example, palatalization of /k/ in the context before /i/ as in the word 'key').

In conclusion, we found effects of semantic predictability on seven-, nine-, and twelve-year-olds' production at the lexical and segmental levels of representation. Furthermore, we found an interaction of predictability and the phonological process of flapping for nine- and twelve-year-olds. We suggested, however, that seven-year-olds may have hyperarticulated the /t-/d/ contrast because of the reading task, thereby overriding phonological flapping. An interactive activation framework provides a mechanistic account of how semantic predictability affects the lexical and segmental levels of representation for adults and school-aged children who have, to a large degree, mastered the neuro-motor co-ordination necessary for speech production. We suggest that once variability due to an immature articulatory

system decreases, cognitive influences on speech production should become more apparent.

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APPENDIX

THE FOUR BIASING PASSAGES

For the target words petal and pedal

Spring is my favourite time of year. If you watch the flowers pop up you can see all their parts. First, a flower will grow a long stem to hold it up. Next you see the bud that opens into a little flower. You might think that the bud is the prettiest part, but you will be surprised. The colours found in the petal take on all kinds of colours. They make the flower pretty. I guess that is why I really like flowers and spring.

Joe asked his parents for a new bike. When his birthday came, Joe's father went to the store with him to pick one out. He was careful to pick one with reflectors on the tires and the seat. His dad also checked the chain and the brakes to see if they worked. The bike looked a little too big for Joe, so he

asked him to sit on it. His feet couldn't reach the pedal to make the bicycle go. After they moved the seat, the bike was the right size. Joe decided it was the best bike he had ever had.

For the target words writer and rider

Mike's dad doesn't work in a big office like many dads. Instead, he spends most of his time at the library reading all kinds of books, fairy tales and poems, and taking notes about them. When he gets home, he goes into his little office and takes out a lot of paper, a few pencils and a big eraser. He works very hard to make up new stories for children. He always makes sure to read them over. Mike's father works as a writer to make books for kids to read. He doesn't mind not having a big office like other dads. He just likes making children happy.

Sue's grandparents live on a horse ranch. She loves all animals, but her favourites are the horses. Every time she visits, Sue watches the cowboys who take care of them. First, they brush and feed the horses, and then they clean the saddles and bridles. To be a cowboy they must be able to get on a horse with a saddle and bareback. Each cowboy must be a rider to exercise the horses. It is important because the horses need exercise everyday. Someday Sue hopes to learn to ride so she can work on the ranch too.

THE FOUR NEUTRAL PASSAGES

For the target words petal and pedal

The T.V. was too loud for her to sleep so she got up. They learned about frogs in school. The lion in the zoo roared loudly as people walked past it. Jim found a penny in the corner of his desk. His keys were somewhere in his bag but he couldn't find them. She bent down and picked up a petal to glue to her picture book. The book was a story about a princess and pea. He had trouble with his homework so he asked for help.

She always ordered french fries when they went out to eat. The kite went high into the sky. She went to the new museum to see the dinosaurs. Her kitten slept with her in her bed. He went to the library to find a book about cars. The girl could not reach the pedal to start the little toy car. They went skating on the pond behind her house. Her baby sister did not like carrots.

For the target words writer and rider

He went on a trip to Disney World with his parents. The girl went shopping in a store by her house. The football game can be a lot of fun if you watch with friends. Her grandmother was tall and thin. There was a nice pool in the backyard. His friend acted like a writer telling stories to his sons. Jack lost his

ball at the park by the school. Her favourite dessert was chocolate cake with frosting.

Susan forgot to make her bed in the morning. They liked to play tag in the street. The sun was very hot in July so they went swimming. Yesterday, he visited his two best friends. The old dog walked slowly into the room and barked. The little boy asked the rider to sit down when the bus moved. His favourite shirt was blue and green. Chris liked to listen to the radio.