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Nelson Cowan
University of Massachusetts at Amherst

Martin D. S. Braine
New York University

Lewis A. Leavitt
University of Wisconsin-Madison

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Nelson Cowan
University of Massachusetts at Amherst

Martin D. S. Braine
New York University

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Abstract

The psychological representation of phonemes and syllables was examined with a special group of subjects having the ability to voluntarily "talk backward" by very rapidly rearranging units of speech, without visual aids or rehearsal. Thirteen subjects could reorder phonemes (Study 1), and one subject also could reorder syllables (Study 2). Through analyses of phonetic transcriptions of their unusual skills, it was possible to demonstrate how phonological and syllabic representations could be distinguished from an orthographic representation. Although the subjects' methods of speech reversal differed in some respects, they were also uniform in important ways, and both the uniformities and the differences help to reveal the subjects' mental representation of speech. Their speech representations proved to be abstract rather than derivable from the speech signal alone. Evidence of abstractness included the grouping of sounds into complex units (e.g., diphthongs and affricates) and the addition of sound distinctions not in the physical signal (e.g., context-dependent interpretation of neutralized consonants, and

hierarchical organization of syllables within words. There appear to be at least two levels of the mental representation of speech: a level that is the primary source of spoken language, and a secondary, metaphonological level mainly available to literate speakers. The data clarify aspects of both these representational levels.

Identifying Phonemes and Syllables: Evidence from People who Rapidly Reorder Speech

This paper provides one type of evidence about speakers' access to phonological structure. The evidence comes from adults and children with the unusual ability to voluntarily "talk backward" by rapidly reversing the order of speech units that occur in normal utterances. We use this evidence to help characterize the phonological analysis that subjects perform, and we also consider the implications of this analysis for models of speech representation. Some of these issues were previously addressed by Cowan, Leavitt, Massaro, & Kent (1982) and Cowan & Leavitt (1981, 1982), who reported four case studies in all. The issues are examined here more fully and with a much larger subject sample. We are particularly concerned with the size and level of abstraction of the phonemic units that are used by backward talkers, and how they perceive syllabic structure.

Lashley (1951) suggested that in order to perform a complex behavior, a subject must mentally represent the behavior as a series of simpler, discrete units to serve as a structure for motor sequencing. For example, typewriting is a complex behavior that can be represented as a series of successive keystrokes, even though in practice these keystrokes may temporally overlap. A similar case can be made for phonemic and syllabic units in speech. In a visually displayed acoustic signal, no clear division of speech into these units can be observed (e.g., Liberman, 1982). Nonetheless, speakers may well derive phonemes and/or syllables as abstractions that provide a structure for speech production and perception (cf. Linell, 1979, Chap. 3). The present research examines details of the subjects' mental representations of phonemes and syllables, in order to address several fundamental questions about speech processing.

The first question concerns the units to which speakers have access. If the "backward speech" utterances resembled a reversed tape recording, they might reveal nothing about units of speech. However, the results are quite different. Subjects appear to segment speech into units, and reverse the order of units while leaving intact the phonetic sequence within each unit. Therefore, the boundary points between units become clear. Moreover, in the backward speech skill the units are produced in new phonological contexts, enabling an observation of context-dependent vs. independent properties of speech units. Related to this, and possibly of greatest interest, is the extent to which the observed units are abstract rather than based literally on the speech signal alone.

Although the backward speech task clearly shows that speech units are used, it cannot be taken for granted that the units observed are the same as the units in ordinary speech comprehension and production, and we would like to know the relationship between the units in ordinary vs. backward speech. It is possible that the units of ordinary speech are directly available for backward speech, but if some or all of the units are unavailable, subjects must have to carry out a secondary analysis of some sort, presumably on the basis of easily observable aspects of speech (e.g., the most salient acoustic features and relevant cues from orthography). In that case, we would want to know how that secondary analysis is related to the phonological system used in ordinary spoken language.

Finally, an important aspect of speech representation is that it may be hierarchically organized. The phonemic units to which subjects have access may serve as the elements for the higher-order division of speech into syllables, morphs, and words. Consequently, the emphasis of the present research is not to determine which type of unit is the most fundamental. Instead, the goal is to specify the units available to subjects. Because the most useful evidence was obtained with respect to phonemes and syllables, important issues for these two types of units will be discussed further in the following sections.

Phonemes

Phonemes may be defined as the minimally distinct speech sound categories necessary to unambiguously transcribe all words within a particular language (cf. Ladefoged, 1982). This involves both the differentiation of sounds that form distinct phonemes, and the generalization of a phonemic category to cover multiple sounds with complementary distributions (allophones). To illustrate differentiation, the sounds /l/ and /r/ must be considered separate phonemes in English due to the existence of word pairs such as lice vs. rice. (In contrast, [l] and [r] are allophones in Japanese.) To illustrate generalization, the aspirated and unaspirated stop consonants such as [p^h] and [p] must be considered allophones of a single /p/ phoneme category in English, because they never contrast but are used in different phonological contexts.

However, there are important uncertainties about the relationship between linguistic phonological theory and psychological reality, and about the phonemic categories actually used by speakers of a language. Several issues in phonemic representation have recurred in the long and complex history of phonological theory. For a detailed review, see Fisher-Jørgensen (1975) and Makkai (1972). One issue is the mapping of phonetic elements into phoneme categories. There exist compound sounds such as diphthongs (two vowels conjoined) and affricates (a stop consonant and fricative conjoined) whose phonemic status is uncertain. Some theorists have argued that these compound sounds comprise single phonemes, whereas others have maintained that they represent two phonemes. Among the diphthongs found in English, three have been identified as more prominent than the others: /aɪ/ as in fine, /ɔɪ/ as in choice, and /aʊ/ as in mouse. Less prominent diphthongs include /eɪ/ as in weigh, /oʊ/ as in blow, and others found only in some dialects. In the Trager-Smith (1951) phonology, each diphthong was considered to be bi-phonemic; for Pike (1974a) the prominent diphthongs were considered to be bi-phonemic and the minor diphthongs were considered mono-phonemic; and for Jones (1950), each English diphthong was considered to be mono-phonemic. Similarly, Chomsky & Halle (1968) proposed that every diphthong in English is represented by a single monophthong in underlying phonemic structure, and the phonetic "diphthongization rules" convert this representation to the surface form. Another literature illustrates that the phonemic status of affricates also has been debated (Martinet, 1960; Hyman, 1975). The factors that have entered into discussions of the phonemic status of diphthongs and affricates include both the exact phonetic pronunciation and a more abstract structural description of the language in question.

A second issue that has recurred in phonological theory is the degree of abstractness that should be given to phonemes. An interesting example is the word-medial alveolar flap [ɾ] that appears, for example, in both ladder and latter, which are often pronounced identically. If sound quality were the only criterion for the classification, the flapped sound would always be counted as the same phoneme. However, there could be rules converting separate and more abstract phonemes, /d/ and /t/, to [ɾ] in medial position. A second example of the abstractness issue has to do with the representation of words with ng as in ring (Swadesh, 1934; Hyman, 1975). The sound actually produced is the velar nasal [ŋ] (e.g., [rɪŋ]). However, this sound is found only in some positions in English. For example, no words begin with [ŋ], unlike the nasals /m/ and /n/. A simplification in the distributional rule might be gained by proposing that [ŋ] is phonemically represented abstractly, by [ng]. The fact that no word begins with [ŋ] could then be considered parallel to the fact that no word begins with /mb/ or /nd/.

Most phonologists agree that phonemes are abstract units to some degree, but there has been a wide range of variation among theorists in the amount of abstraction to be permitted. Some degree of abstraction in phonology was proposed by Sapir (1933/1949) in examples similar to the above. For him, phonemes were functional categories that could be perceived and used by speakers of a language. However, the most abstract phonology is probably the "systematic phonemic" approach of Chomsky & Halle (1968), in which the underlying phonemic representation often differs greatly from the surface phonetic form. For example, the related words serene and serenity have a second vowel [i] and [ɛ], respectively, but nevertheless are said to share the underlying phonemic representation /ē/. Realization rules convert the abstract representation to a bundle of features directly underlying the speech output. In this approach, however, linguistic generality has been gained at the expense of making the underlying phonological representation very different from the surface form. The permissible degree of abstractness consequently is a topic of much debate in linguistics.

Syllables

The syllable is a paradoxical unit in that it seems to be intuitively available to untrained and even illiterate speakers (Morais, Carey, Alegria, & Bertelson, 1979) but is poorly understood linguistically. When one listens to speech one hears "pulses" corresponding to high-amplitude, vocally sonorant segments (i.e., vowels, and to a lesser extent, glides, liquids, and nasals) interspersed with segments in which the vocal stream is occluded (stop consonants, fricatives, and affricates). Generally, each of the sonorant pulses corresponds to the nucleus of a perceived syllable. However, the locations of boundaries between syllables are much less clearly perceptible. English dictionaries give one possible division of words into syllables, but the dictionary solutions may well be arbitrary from linguistic and psychological standpoints.

Some researchers have attempted to identify syllable boundaries on the basis of an acoustic analysis of the speech stream (e.g., Malmberg, 1955/1967). In general, however, it is not clear that the acoustic signal reliably affords syllabic boundary information. Moreover, many theorists since Pike (1947b) have postulated the existence of both "phonetic" syllables, based on acoustic/phonetic information such as silent gaps and the forcefulness and timing of boundary segments, and "phonemic" syllables, based on aspects of phonological structure. It is not clear what type of syllable actually is perceived by speakers of a language.

A justification for proposing the "phonemic syllable" as a basic unit in speech is that syllables may be necessary to describe phonotactic rules (i.e., rules for phoneme combination) within various languages. In English, for example, it is possible to begin a word with three consonants, but only with a restricted consonant sequence: /s/ followed by a voiceless stop

(/p/, /t/, or /k/) followed by a liquid (/l/ or /r/) (cf. Sloat Taylor & Hoard, 1978, p. 64). It seems likely that rules such as this apply as onset restrictions to every syllable within a word rather than just to word onsets. Other restrictions seem to apply to syllable endings. However, rules for syllable restrictions on phoneme sequencing logically must be preceded by rules for determining the division of words into syllables.

The importance of the syllable is not confined to the problem of segment sequencing or to the English language. (Examples of the role of syllables in the phonologies of various languages are provided by Hooper, 1976 and by Sloat et al., 1978, p. 57). Nonetheless, we lack a consistent linguistic procedure for syllabification. (For attempts to formulate a syllabification procedure, see Hooper, 1976; Kahn, 1976; and Pulgram, 1970.) One reason for our lack of a procedure for syllabification is that syllabic division may well depend upon a complex combination of universal and language-specific principles. Linguistic work on many of these principles of syllabification was reviewed by Fallows (1981) and will be discussed within Study 2 of the present paper. The study examines a single subject with the ability to rapidly reorder syllables in speech, a task that requires her to determine the boundaries between syllables.

Study 1 examines the division of speech into phonemes by some of the backward talkers in our sample of 50. The following questions were explored: (a) Does the backward speech produced by our subjects reflect a sound-based sequence in reverse, or does it reflect a reversal of the written representation? (b) If this backward speech does represent a sound-based representation, does it mimic the reversal of the acoustic waveform? How does it differ from a reversed waveform? Finally, (c) does this backward speech instead reflect a reversal of the order of <u>units</u> within speech? If so, what is the nature of these units? These questions were examined by asking subjects to reverse utterances that had critical diagnostic features.

STUDY 1: PHONEMES

Our first subject was a 31-year-old philosophy professor who was found serendipitously (reported in Cowan et al., 1982). Upon hearing an English word or sentence, he was able to reverse the order of segments within each word, so rapidly that a simultaneous translation into "backward" speech was possible. No rehearsal or written aids were used. This subject had difficulty only with some words having more than ten phonemes. Following a conference presentation of this man's abilities, he gained public media attention. To our surprise, other people (n = 50) contacted us from various parts of the United States and from abroad, and claimed to have similar talents with backward speech. These communications provided some information about the methods of backward speech used. (To convey the personal history and subjective report of backward speech, some of the written personal communications that we received are provided in the Appendix.) Additional information was obtained through interviews and testing sessions with 21 of the 50 backward talkers. Most of the subjects were adults, but they also included five children, 8 to 11 years of age (two of whom are described in Cowan & Leavitt, 1982) and four adolescents, 13 to 17 years of age. Most adult subjects thought they began talking backward in late childhood (7-11 years), and the remainder began in early adolescence (Cowan & Leavitt, 1982). The skill with backward speech varied quite a bit: Many backward talkers were about as adept as our first subject, but several (including the two children) were slower and had more severe word length limitations. Nevertheless, even the slowest subjects could reverse speech much faster than unpracticed adults. Five talked backward starting with the last word in each sentence; 20 left the words in forward order; and for 25 backward talkers, this information was unavailable.

The subjects were intelligent and generally interested in reading and verbal games. However, only two had formal linguistic training or were familiar with linguistic terminology. (These two were not tested further.) Many of the adults had "creative" occupations (e.g., medical anthropologist, journalist, corporation "headhunter," and a member of the House of Lords). The subjects had no dyslexias or other verbal problems, and never talked backward accidentally. None had special mirror-writing abilities. A few did have other special abilities: One was able to multiply and divide large numbers quickly, and another was able to rapidly alphabetize the letters within a word or phrase. Several reported special mnemonic abilities (e.g., remembering phone numbers). All except three backward talkers were native speakers of English whose backward speech abilities preceded fluency in any foreign language. The remaining three were native German speakers who later learned English.

Because we were interested in studying speakers' processing of phonemes, we wished to separate subjects into two groups: those who based their backward speech upon sound (who might provide information about phonemes) vs. those who based it upon spelling (who presumably could not yield information about phonemes.). Of the 34 English backward talkers for whom we had subjective reports, 13 said that they talked backward on the basis of sound (9 males, 4 females) and 22 on the basis of spelling (15 males, 7 females). These subjective reports were later found to be accurate in all cases. One male subject was able to use either sound or spelling, and was included in both counts.

Method

Subjects

It was possible to contact 20 of the English backward talkers for interviews and testing: ten who had reported spelling-based methods, and ten who used a sound-based method of speech reversal. The latter (6 males and 4 females, including an 8-year-old boy, a 16-year-old girl, and 8 adults ranging from 18 to 54 years of age) were tested in greater detail. Three German backward talkers (females aged 27, 64, and 66) also were interviewed.

Procedure

A variety of words, phrases, and sentences were presented to subjects for conversion to backward speech, which was recorded for later transcription. Each subject was told to rearrange the stimuli in his or her usual fashion. Subjects found to use a sound-based method also were given the digit span portion of the WAIS (Wechsler, 1955) or of the McCarthy Scale for Children (McCarthy, 1970). For ten subjects, including the sole subject of the second study, testing was conducted in person and sessions were tape recorded (7 on reel-to-reel and 3 on cassette). For the remaining 10 native English-speaking subjects, personal interviews were not possible and testing was conducted by telephone. A magnetic loop that fit over the earpiece of the telephone transferred the interview to a SONY TC-200 tape deck. The resulting recordings were consistently clear. Of the three German backward talkers, one (I.G.) was interviewed in person and one (H.F.) was tested with the telephone recording system. The third German backward talker (K.N.) lived in Berlin and was contacted briefly by phone.

A broad phonetic transcription was used, in the IPA notational system and including primary and secondary word stress. Transcriptions were carried out by an author (N.C.). Checks on the accuracy of transcription were described by Cowan & Leavitt (1982) and Cowan et al. (1982). (Reliability of transcription was high, and disagreements between transcribers primarily regarded the detailed vowel quality.) These sources also include quantitative measures of the speed of backward speech.

In the first phase of testing, subjects were interviewed and given a list of words (e.g., judge, xerox, bomb, island, and the like) to determine whether sound or spelling was used as a basis of backward speech. The ten English-speaking subjects who could use a sound-based method of reversal were given 30 to 53 additional stimulus words, as well as 8 to 10 sentences. The words on the list appear in Table 1. It includes a variety of

Table 1

Responses of English-Speaking Sound-Based Subjects to Words Relevant to Various Issues

ISSUE	EXAMPLE	FREQUENCY
1. Silent letters pronounced?		
bomb [bam]	[mab] vs. [bəmab]	10 vs. 0
island [aIlənd]	[dənəlaI] vs. [dənəl saI]	10 vs. 0
plague [pleg]	[gelp] vs. [jugelp]	10 vs. 0
weigh [we]	[ew] vs. [həgew]	7 vs. 0
ghost [gost]	[tsog] vs. [tsohəg]	9 vs. 0
though [ðo]	[oð] vs. [həguat]	8 vs. 0
thought [θɔt]	[taθ] vs. [təhəguat]	7 vs. 0
judge [dʒʌdʒ]	[dʒʌdʒ] vs. [ɛgdʌdʒ]	7 vs. 0[a]
2. Homographic sequences distinguished?		
g's in garage ([g], [ʒ])	[ʒarəg] vs. [garəg]	10 vs. 0
c's in cycle ([s], [k])	[ləkaIs] vs. [ləsaIs]	10 vs. 0
ough in though, thought ([-o], [-at])	[O-, ta-] vs. [həgua-,həgua]	7 vs. 0
ct in lecture, dictionary ([lɛktʃɚ], [dikʃənɛri)]	[-+ʃk-,-ʃk-] vs. both [-+ʃk-] or [-ʃk-]	7 vs. 3

Table 1 (continued)

	M. Begin ([e]) vs. begin ([i])	[e, i] vs. both [i] or [e]	10 vs. 0	
	use ([z]) vs. use ([s])	[z, s] vs. both [z] or [s]	10 vs. 0	
3.	Diphthongs /aI/, /ɔI/, & /aʊ/ preserved?		n = 8	n = 2
	fine [faIn]	[naIf] vs. [nIaf]	7 vs. 0	0 vs. 2
	eye [aI]	[aI] vs. [Ia]	7 vs. 0	0 vs. 2
	sky [skɐI]	[aIks] vs. [Iaks]	7 vs. 0	0 vs. 2
	buy [bɐI]	[aIb] vs. [Iab]	6 vs. 0	0 vs. 2
	island [ɐI̠ nd]	[dənəlɐI] vs. [dənəlIɐ]	8 vs. 0	1 vs. 1
	cycle [sɐɪkə l]	[əlkaIs] vs. [əlkIas]	8 vs. 0	1 vs. 1
	join [dʒɔIn]	[nɔIdʒ] vs. [nIɔdʒ]	8 vs. 0	0 vs. 2
	boy [bɔI]	[ɔIb] vs. [Iɔb]	8 vs. 0	0 vs. 2
	house, mouse [-ɐʊs]	[saʊ=] vs. [sʊa-]	8 vs. 0	1 vs. 1
	now [nɐʊ]	[aʊn] vs. [ʊan]	6 vs. 1	0 vs. 2
4.	Minor diphthongs preserved?			
	Words with [e^I], e.g., weigh	[e^Iw] vs. [Iew]	10 vs. 0	
	Words with [o^u], e.g., ghost	[tso^ug] vs. [ts^uog]	10 vs. 0	

Table 1 (continued)

5. /ju / preserved?		
use (v) [juz]	[zju] vs. [zui] or [zujə]	3 vs. 4
use (n) [jus]	[sju] vs. [sui] or [sujə]	3 vs. 4
youth [juθ]	[θju] vs. [θui] or [θujə]	2 vs. 6
6. Affricates preserved?		
judge [dʒʌdʒ]	[dʒʌdʒ] vs. [ʒdʌʒd]	10 vs. 0
join [dʒɔIh]	[hɔIdʒ] vs. [hɔIʒd]	8 vs. 0
giraffe [dʒəræf]	[færədʒ] vs. [færəʒd]	8 vs. 0
church [tʃɜ˞tʃ]	[tʃɜ˞tʃ] vs. [ʃtɜ˞ʃt]	8 vs. 0[c]
fetuccini [fɛtətʃini]	[initʃətɛf] vs. [iniʃtətɛf]	7 vs. 0
7. Sound sequence [ks]		
xerox [ziraks]	[skariz] vs. [ksariz]	6 vs. 4
examine [ɛgzæmIn]	[-zgɛ] vs. [-gzɛ]	6 vs. 2
locks, tacks, strikes	[-sk-] vs. [-ks-]	7 vs. 0

Table 1 (continued)

8.	Syllabic /l/ sound		
	castle [kæsəl]	[ləsæk] vs. [əlsæk]	4 vs. 3
	subtle [sʌɾəl]	[lətʌs] vs. [əltʌs]	3 vs. 3
	cycle [saIkəl]	[ləsaIk] vs. [əlsaIk]	5 vs. 5
	medal [mɛɾəl]	[lədɛm] vs. [əldɛm]	2 vs. 1
	metal [mɛɾəl]	[lətɛm] vs. [əltɛm]	4 vs. 2
9.	[r]-colored vowels		
	burn, turn [-ɝn]	[nrət] vs. [nɝt]	7 vs. 2
	dollars [daləʳz]	[srəlad] vs. [sɝlad]	6 vs. 1
	lecture [lɛktʃəʳ]	[rətʃkɛl] vs. [ɝtʃkɛl]	8 vs. 1
	ladder [læɾəʳ]	[rədæl] vs. [ɝdæl]	6 vs. 1
	latter [læɾəʳ]	[rətæl] vs. [ɝtæl]	6 vs. 1
	finger [fIŋgəʳ]	[rəgnIf] vs. [ɝgnIf]	4 vs. 1
10.	Homophonic medial letters "d" and "t"		
	ladder, latter ([ɾ, ɾ])	[d, t] vs. both [ɾ]	7 vs. 0
	medal, metal ([ɾ, ɾ])	[d, t] vs. both [ɾ]	3 vs. 1

Table 1 (continued)

11. The sound [ŋ]		
bank [bæŋk]	[kŋæb] vs. [knæb] or [kɔnæb]	1 vs. 6
finger [fIŋgɚ]	[-gŋIf] vs. [-gnIf] or [-gɔnIf]	1 vs. 4
ring [rIŋ]	[ŋIr] vs. [gnIr] or [gənIr]	4 vs. 6
aching [ekiŋ]	[ŋi-] vs. [gnI-] or [gɔnI-]	5 vs. 5
bang [bæŋ]	[ŋæb] vs. [gnæb] or [gɔnæb]	3 vs. 4
12. Phonemic alternation		
serene ([i]), serenity ([ɛ])	[-i-, -ɛ-] vs. both [i] or [ɛ]	6 vs. 1
educate ([t]), education ([ʃ])	[-t-, -ʃ-] vs. both [t] or [ʃ]	6 vs. 0
13. Stress differences		
contrast (n), contrast (v)	(a) ['tsærtnak], [tsært'nɔk]	0
	(b) [tsært'nak], ['tsærtnɔk]	1
	(c) both ['tsærthak]	4
	(d) both [tsært'nak]	1
present (adj), present (v)	Like (a), (b), (c), or (d) above	4, 2, 3, 1
content (n), content (adj)	Like (a), (b), (c), or (d) above	1, 1, 6, 0
permit (n), permit (v)	(Like (a), (b), (c), or (d) above	5, 1, 2, 0

(In all, stress contrast was maintained in 15 instances and omitted in 17 instances.)

Table 1 (continued)

14. Stress-related vowel quality differences		
contrast ([kɑ -], contrast ([kə -]	[-ɑk, -ək] vs. both [-ak]	2 vs. 4
present ([prɛ-]), present ([prə-])	[-ɛrp, -irp] vs. both [-ərp]	6 vs. 3
content ([ka-]), content ([kə-])	[-ɑk, -ək] vs. both [-ak]	4 vs. 4

Note. Row sums differ because it was impossible to give some subjects all of the words.

[a] Two subjects produced /dʒdʌdʒ/.

[b] As these responses demonstrate, eight subjects regarded diphthongs as single units, and two regarded them as two units each.

[c] Two subjects produced /həsrəs/.

words selected to determine if these subjects use phonemes as units of speech reversal, and if so, to provide a detailed description of the units used. The native German backward talkers received portions of the same English list as well as German word lists.

Results and Discussion

Subjects Using Sound vs. Spelling Methods

Ten of the eleven subjects who said they used a spelling-based method also maintained that they visualized the words before reversing them. The exception was the subject who was able to use either method: He did not know if he visualized. The subjects who said they used a sound-based method denied that they visualized, with the exception of R.B., the subject of Study 2. In the reversed speech of the sound-based group, silent letters were not pronounced (e.g., the s in island, the b in bomb, and the e in judge; see Table 1). In contrast, subjects in the orthographic group always pronounced silent letters. In illustration, the word bomb was reversed as /mab/ only by sound-based subjects, but as /bəmab/ only by orthographic subjects. Orthographic subjects rarely took into account auditory aspects of language (e.g., although the letter g represents both /ɡ/ and /ʒ/ in the word garage, it was typically reversed by orthographic subjects as /ɛgəræg/). In contrast, sound-based subjects preserved sound distinctions in homographs, and garage was typically reversed as /ʒarəɡ/. Similarly, though and thought were reversed as /həɡuahət/and /təhəɡuahət/ by orthographic backward talkers but as /o / and /taθ/ by sound-based backward talkers. The one subject who claimed to be able to use either method of backward speech in fact could rapidly produce responses typical of either group.

Treatment of Diphthongs and Affricates

Having identified 10 backward talkers within the native English-speaking group who used sound-based reversal methods, we tried to determine the size of sound-based units. The major options occurred with diphthongs (complex vowels with a smooth transition from one target to another) and affricates (stop consonants conjoined with homorganic fricatives). Subjects might either (a) preserve the structure within these compound units, or (b) reverse the order of elements within them.

Each subject evidenced a great deal of internal consistency, but there were stable differences among them. Most importantly, eight subjects preserved the structure within the diphthongs /aɪ/, /ɔɪ/, and /aʊ/ 98.6% of the time, whereas the other two subjects generally reversed the order of sounds within these diphthongs, although with 15 % failures to reverse them (Table 1, Section 3).

For example, the words fine and join were reversed as /naɪf/ and /nɔɪdʒ/ by eight subjects, but as /nɪaf/ and /nɪɔdʒ/ by the other two subjects.

On the other hand, all ten subjects preserved rather than reversed the structure within the minor diphthongs /o^w/ as in though and /e^I/ as in weigh. Further, all subjects preserved rather than reversed the order of sounds within the affricates /dʒ/ as in judge and /tʃ/ as in church. For example, no subject produced /nɪɔʒd/ for join, which would be closest to a complete phonetic/acoustic reversal.

Fluency differences related to the treatment of diphthongs. The two subjects who reversed elements within diphthongs (although inconsistently) were not fluent: They were not able to talk backward at a normal speech rate, and thus could not carry out a "simultaneous" translation to backward speech. In contrast, all seven of the adult subjects who preserved diphthongs were consistent and could carry out simultaneous translation, even when long words such as automobile and pneumonia were introduced. The difference in fluency between the two groups was probably not due simply to a memory difference. On the WAIS digit span, the seven adults who preserved diphthongs had mean forward and backward spans of 7.43 (s.d. = 1.13) and 6.29 (s.d. = 1.80), respectively. The two adults who reversed elements within diphthongs, although they were less fluent in backward speech, had higher mean forward and backward digit spans: 8.5 and 7.5. Thus, the style of talking backward in which the diphthongs /aɪ/, /ɔɪ/, and /aʊ/ are reversed may not serve as a suitable substrate for rapid, automatic backward speech as does the method in which those diphthongs are preserved. It is possible that the same representation exists as in the other subjects, but in these two subjects has been overcome through conscious reflection to afford a more accurate reversal of speech. The backward speech of subjects of both types seemed otherwise similar.

Other Aspects of Speech Representation

In contrast to the diphthongs /aɪ/, /ɔɪ/, and /aʊ/, the table shows that there is a good deal of inconsistency in subjects' representaiton of /ju/. Some subjects analyzed /ju/ as two units and reversed them, whereas other subjects analyzed it as a single unit that was preserved. Subjects' representation of /ju/ also seems to have been influenced by orthography. When it was represented by a single letter, as in the word use, about half of the subjects treated it as a single unit. However, when /ju/ was represented by several letters in the word youth, more subjects treated it as two units. Notice that unlike /ju/, the representation of /aɪ/, /ɔɪ/, and /aʊ/ is entirely independent of orthography (see Table 1). It may be that /ju/ is more likely to be treated as two units when /j/ is thought to be a consonant rather than a vowel (i.e., when it is represented by a letter y).

Although these subjects' responses could not possibly have resulted from a pronunciation of the written forms of words in reverse, it is nevertheless possible that their knowledge of orthography sometimes influences their phonological representation. An interesting example is the letter x, which typically represents two phonemic units (/ks/, as in fox, or /gz/, as in examine). As shown in Table 1, Section 7, about one third of the time x was taken to represent a single unit (e.g., xerox was reversed as [ksariz] as well as [skariz]). Nevertheless, x was more often analyzed as /ks/ (reversed as [sk]).

In some instances, it is not clear if orthography has played a role. For example, the unstressed syllable /-l/ (Table 1, Section 8) that occurs in words like cycle was reversed either as [lə -] or as [əl -]. The [əl -] pronunciation could reflect orthography. Alternatively, though, subjects might have a phonemic representation /-l/, as in Bloomfield's (1933) phonology, and might disagree in how to realize the reversal phonetically (e.g., whether to pronounce the difficult sequence /l̩kaɪs/ as [əlkais] or [ləkais]). Another case in which orthography may or may not influence phonological representation is that of the "r-colored" vowels, which can have the orthography -ur, -er, -ir, or -ar. Subjects' reversals indicate that they generally perceive these as two units, i.e., as a vowel plus /r/ (Table 1, Section 9).

Some features illustrated in the table help to determine the degree of abstractness of phonological units. One such case is the word-medial alveolar flapped [ɾ] sound, which can be orthographically represented by d (e.g., medal) or by t (e.g., metal). Subjects' reversals of these words usually contained either [d] or [t] rather than [ɾ], and therefore provided no evidence for [ɾ] as a psychologically valid phoneme (Table 1, Section 10).

Another important case is the sound [ŋ], in words containing ng or nk. Interestingly, the treatment of this speech sound depended upon the phonological context in which it occurred (Table 1, Section 11). In two words, finger and bank, [ŋ] was followed by a velar stop. For these words, there was a strong tendency to reproduce [ŋ] abstractly, as /n/ (e.g., bank [bæŋk] was usually reversed with /kn/, not /kŋ/). However, in words without a following velar stop, subjects more accurately reproduced [ŋ] (e.g., bang was reversed as [ŋæb] almost half the time). In words like finger and bank, subjects may think that the [ŋ] sound is a phonetic variation of /n/. Note that the presence vs. absence of a velar stop is not signalled in the orthography.

Lastly, subjects consistently maintained surface distinctions in word alternations such as the /i/ vs. /ɛ/ in serene vs. serenity (Table 1, Section 12). Thus, subjects do not seem to base their reversals upon the abstract phonemes proposed by Chomsky & Halle (1968), despite the fact that the orthography is consistent with Chomsky & Halle in these examples.

In general, then, the units for which there is evidence can be described as intermediate in their level of abstraction. They are more abstract than surface phonetic or "taxonomic" phonemic categories, but much less abstract than the systematic phonemes of Chomsky and Halle (1968). It also seems that although subjects' choice of units is not dictated by the orthography (which could not account for subjects' treatment of silent letters, homographs, major diphthongs and affricates, or words with ng), subjects do prefer a unitization that can easily be reconciled with the orthography.

Suprasegmental properties. A final issue illustrated in Table 1 is how subjects map English stress and intonation onto their backward speech productions. Subjects varied in this regard. Sentence-length intonations were never produced in reverse: Most subjects preserved the forward sentence intonation contour, superimposing it on their backward speech. A few subjects used a more monotonic "list" contour that did not resemble a normal speech contour either forward or backward. To examine word stress, word pairs differing only in stress and meaning were examined (e.g., the noun "Contrast" vs. the verb "contrast"), and are shown in Table 1, Section 13. Subjects sometimes reversed the stress pattern within words. An example would be the noun contrast (/'kɑntræst/) reversed as /tsært'nɑk/ and the verb contrast (/kən'træst/) reversed as /'tsærtnək/. However, Table 1 indicates that subjects more frequently superimposed the forward stress pattern on the reversed word (e.g., contrast reversed as /'tsærtnak/) or else failed to use stress distinctively (e.g., contrast and contrast reversed identically). The data suggest, therefore, that stress and intonation both are separate from the sequence of phonemes within most subjects' mental representation of language.

German Backward Talkers

The three native speakers of German were not included in Table 1. They reported having spoken German backward as a childhood game. Two of them later learned English and lived in the United States. They found it possible to speak English backward as well, although somewhat more slowly than German. The third German backward talker, who lived in Germany, used a bidirectional tape recorder to guide her backward pronunciation, so her backward speech will not be discussed in detail. The two German-American backward talkers were tested with an extensive English word list that included all of the words in Table 1, and also with a set of German words (taken primarily from two sources: Moulton, 1962; Herbst, Heath, & Dederding, 1979, pp. 105-112). The results with English words clearly indicate that both subjects used sound-based rather than spelling-based methods of speech reversal. For example, they omitted silent letters and consistently distinguished homographs. The variety of evidence is smaller in the German corpus, because German has a closer letter-to-sound correspondence than English does. Nevertheless, whenever a homograph did occur, the two pronunciations were maintained. For example, the letter s may be pronounced /s/ (e.g., in aus) or /ʃ/ (e.g., in Stein), and this distinction was always maintained in the reversals. There were many vowel homographs in the sample, and these distinctions also were consistently maintained.

The German-American backward talkers differed from most of the English backward talkers in their treatment of diphthongs: they consistently reversed the order of elements within the major diphthongs /aɪ/, /ɔɪ/, and /aʊ/ in both languages. For example, in the English list, both of them reversed the word fine as /nɪaf/. A possible reason why the German speakers were able to analyze diphthongs into smaller elements is that in German, unlike English, each of the major diphthongs always is represented by two or more letters. Because a reversal of elements within diphthongs generally would result if the subject were to read German from right to left, there could be a contribution of orthography. The only available exception to this situation is the diphthong /ɔɪ/, which can be represented in German by eu, as in heute and Eule. These two words were reversed phonetically as [ətjɔ] and [əljɔ] by one subject, but with an apparent orthographic influence as [ətjʊɛ] and [əljʊɛ] by the other subject. The German subjects were also tested on a variety of German affricates ([ks], [ts], [tz], and [pf]), and it was found that they did not consistently preserve or reverse these forms.

Lastly, it is of interest to examine the treatment of a pronunciation rule in German. Consonants that would ordinarily be voiced must be pronounced as voiceless in syllable-final position (e.g., Tag = [taᵏ]). If subjects perceive abstract underlying phonemes, they should re-voice such words in the reversals (e.g., Tag reversed as [gat]). In contrast, if subjects perceive and manipulate surface phones, they should not re-voice these words (e.g., Tag reversed as [kat]). In five examples administered to one German-American subject and three examples administered to the other, they were inconsistent: re-voicing took place for some words but not others. Exact figures cannot be given, because the subjects often used intermediate amounts of voicing.

Summary and Conclusions

Although both sound and spelling were used as bases for backward speech, it was clearly possible to classify each subject's skill as basically sound- or spelling-based. The main conclusions of this study come from 12 backward talkers who used sound-based methods of reversal. At issue is the nature of speech units used. For these subjects, the goal of reordering speech typically was to speak in a way that would match as closely as possible a speech recording played in reverse. This was sometimes stated explicitly by the subjects. However, their reorderings were further from a reversed recording than would be motorically possible (e.g., it would be possible to reverse elements within diphthongs). The most likely explanation is that their analysis of speech into units constrained their productions (e.g., their analysis was not fine-grained enough to perceive separately the vowels within diphthongs.) For the affricates (/dʒ/ and /tʃ/), the pattern of results was especially clear. All twelve subjects preserved the order of elements within affricates ($\underline{p} < .001$, binomial test).

Other aspects of the data offer clues to the nature of speech units and the extent of individual variation. The pronunciations in the reversed forms generally were in keeping with the phonetic forms in forward speech (e.g., see Table 1, Section 2: Homographic Sequences). However, most subjects used segments that could be considered to reflect abstract representations. Examples are the use of /ng/ for [ŋ], as in ring, and the use of /d/ vs. /t/ to replace [ɾ], as in metal vs. medal. On the other hand, no subject used speech sounds that would directly represent the level of "systematic phonemics" described by Chomsky & Halle (1968). Instead, subjects seem to be using a less abstract level of representation, closer to the level described by Sapir (1949). Moreover, the native language of the speaker (English vs. German) seemed capable of influencing that representation in the case of major diphthongs.

STUDY 2: SYLLABLES

The second study examined the responses of one subject (R.B.) who reordered speech in such a way that we could determine her method of dividing language into syllables. Our study was designed partially to address questions put forth by Fallows (1981), who reviewed recent theories of syllabification and carried out an empirical study to assess them. Fallows found that these theories each focused upon one or more influences on syllabification, the most important being (a) phonotactic constraints, (b) the principle of maximal syllabic onset, (c) the effect of word stress, and (d) the principle of ambisyllabicity. These influences are described in turn.

Phonotactic contraints. Fallows' first principle is that segment sequences found within syllables must obey the same constraints as are found at word boundaries. For example, in English one cannot begin a word or a syllable with the sequence /pt/, though one can end with it (e.g., empty could not be segmented as /ɛm.pti/).

Maximal onset. The second principle discussed by Fallows (presumed universal) states that each syllable retains the maximal onset cluster allowed by the sequencing constraints. For example, consider the word basket, which has three possible points of syllabic division. Phonotactic constraints prevent the syllabification /bæ.skɛt/, because regular English words (and presumably syllables) cannot end in stressed lax vowels such as /I/, /ɛ/, /æ/, or /ʌ/. Maximal onset would dictate the syllabification /bæs.kɛt/ rather than /bæsk.ɛt/, because the former division provides the maximal allowable cluster for the second syllable.

Stress. The third principle refers to the syllabic stress. Stressed syllables tend to attract the maximal number of consonants in both their initial and final positions. This principle sometimes conflicts with the maximal onset principle. For example, in the word basket, a stress principle would favor /bæsk.ɛt/ over /bæs.kɛt/, in contrast with the maximal onset principle. An important theoretical task is to determine precisely how phonotactic constraints, maximal onset, and stress are prioritized.

Ambisyllabicity. A fourth and final principle described by Fallows (1981), ambisyllabicity, provides a possible solution for some conflicts between syllabification principles. This principle states that a syllabic boundary may fall within a single consonant, in effect making the consonant part of two syllables. The principle permits single intervocalic consonants to be assigned to both syllables, e.g., /lem.mən/ for lemon.

Fallows tested these principles by administering a list of 71 bisyllabic words with critical features to children 4-5 and 9-10 years of age. For each stimulus word presented (e.g., chipmunk) her subjects were required to pronounce the word with the first syllable repeated ("chipchipmunk") or the second syllable repeated ("chipmunkmunk"). All of the Fallows' stimuli were included in the list presented to R.B. for reordering, and Fallows' results provide a framework to guide the analysis of R.B.'s method of syllabification.

Method

Subject

Only one subject (R.B., a 29-year-old female who said that she began her special skill at 8 years of age) reordered speech in a way that required segmentation into syllables (as well as phonemes). She fluently transformed speech in three ways that will be described in the results.

Procedure

A new set of 230 stimulus words and 37 sentences and phrases were selected in order to examine issues in the syllabification of speech. R.B. was instructed to reorder each stimulus utterance in her own way. These data were supplemented with a session in which many of the words were re-administered, and R.B. was asked to explain to the best of her ability the rationale or basis of many of her syllabic divisions.

Results and Discussion

It is first necessary to describe the unusual skill of R.B. Upon hearing a word or phrase for the first time, she transformed each utterance in three ways, in rapid succession: (a) first, the order of syllables within the utterance was reversed; (b) next, the order of phonemes within each syllable was reversed, but the syllables themselves were put in their normal forward order; and (c) finally, the order of phonemes in the utterance was completely reversed. Alternatively, if requested to do so, R.B. could produce any one of the three reorderings in isolation. In each reordering, a normal forward stress and intonation pattern seemed to be superimposed on the reordered phoneme string.

Two one-word utterances and a multiword utterance to which R.B.'s response speeds are typical appear in Table 2. These utterances were stored digitally (cf. Cowan et al., 1982) to permit a determination of the response times, which are also shown in the table. Her reordered speech began promptly after the forward model ended and moved fluently from one type of reordering to another, with few hesitations or pauses between or within reorderings.

R.B.'s skill requires her to make rapid decisions about the syllabification of words. For example, consider the word "basket" (/bæskɛt/). It might be divided as /bæ.skɛt/, /bæs.kɛt/, or /bæsk.ɛt/. If R.B. selected /bæ.skɛt/, she would produce [skɛtbæ, æbtɛks, tɛksæb]. However, if she selected /bæs.kɛt/ she would produce [kɛtbæs, sæbtɛk, tɛksæb]. Finally, the syllabification /bæsk.ɛt/ would result in the production of [ɛtbæsk, ksæbtɛ, tɛksæb]. Given R.B.'s reorderings of a particular utterance, one can determine her syllabification of the utterance. Of course,

Table 2

Three Stimulus Utterances Reordered by Subject R. B.

EVENT		
End of forward model	0	interesting
Beginning of Reversal 1	1200	'IŋIstɚIn
Beginning of Reversal 2	2100	'nIrətsIŋI
Beginning of Reversal 3	3050	'ŋɪtsɚə tnI
End of Reversal 3	4050	. /'In.tɚ.Ist.Iŋ /[a]
End of forward model	0	elephantitis
Beginning of Reversal 1	800	tɪstaɪfənt'ˀIˀɛl
Beginning of Reversal 2	2350	lɛˀ Itnɪf'ˀə ItsIt
Beginning of Reversal 3	4000	sIʃəItnI'f ɪlɛ
End of Reversal 3	5200	. /ˌɛl.I.fənt.'taI.tIs/[a]
End of forward model	0	urban and rural cultures
Beginning of Reversal 1	900	ˌtʃɜ zkʌlˀəl,rurˀæ nd'bInˀɚ
Beginning of Reversal 2	3200	ˌrʊnɪbdnɛ, rurlə'lʌkzrʊtʃ
Beginning of Reversal 3	5600	ˌzrʊtʃlʌklə,rurdnɛ'nɪbrʌ
End of Reversal 3	7900	. /ˌɜ.bɪn.ænd.ˌrur.əl.'kʌl.tʃɚz/[a]

Note: The times are running counts measured from the end of the forward model.

[a]Syllabic representation of the stimulus, which can be determined from Reversals 1 and 2.

it is theoretically possible for R.B. to use one syllabic division for the first reordering and a different division for the second reordering of the same word. However, such inconsistencies occurred in very few (<2%) of her responses.

Comparison with Fallows' results. Transcriptions and analyses of R.B.'s responses to Fallows' stimuli suggest that they were quite similar to the responses of Fallows' subjects. Consonant sequencing constraints of English (e.g., the division eve.ning rather than /i.vnɪŋ/ or /ivn.ɪŋ/) were preserved 98% of the time by Fallows' subjects and 99% by R.B. For words in which consonant sequencing rules permitted either an open or a closed first syllable, vowel quality and stress both played a role. For example, Fallows reported that when a stressed first syllable contained a lax vowel (e.g., in father) subjects closed the first syllable 85% of the time, but in unstressed first syllables (e.g., in machine) closure occurred only 35% of the time. In Fallows' stimuli, R.B. similarly closed stressed syllables containing lax vowels 77% of the time and unstressed syllables 33% of the time. Fallows also examined cases in which the stress and maximal onset principles worked together or in opposition. When stress and maximal onset worked together, Fallows' subjects made the appropriate division (e.g., e.nough) 94% of the time, and R.B. did so 83% of the time. When stress and maximal onset were in conflict (e.g., sof.a vs. so.fa) maximal onset was obeyed 66% of the time by Fallows' subjects and 69% of the time by R.B. Finally, ambisyllabic responses were made 22% of the time by Fallows' subjects and 14% of the time by R.B. on the same words. Thus, in sum, there is no apparent conflict between the syllabification methods of R.B. vs. the children studied by Fallows.

On the other hand, Fallows did not report several important aspects of the data. For example, she did not examine the contribution of orthography. Although R.B. generally divided words according to sound rather than spelling, we found that with very few exceptions R.B. made ambisyllabic responses if and only if a word had geminate spelling. This should not have been the case for Fallows' younger (preliterate) subjects, but the means were not reported for the two age groups separately.

Several steps were taken to gain a better understanding of the syllabification principles that R.B. used. For example, her responses to the stimulus words that were not part of Fallows' list provided additional insight (e.g., because some of them had more than two syllables). Most of the important aspects of the data are summarized in Table 3. It indicates where she placed the division between the first two syllables, separately for words with different combinations of stress, vowel quality, and number of intervocalic consonants. The responses are expressed as

Table 3

Proportion of First Syllabic Divisions Having Various Properties

	Vowel of First Syllable					
	Stressed					
Structural Aspect	Tense	n[b]	Lax	n	Un-Stressed	n
One intervocalic Consonant						
Proportion Open						
All	0.59	(37)	0.16	(57)	0.65	(26)
Morphs & Teminates Excluded	0.79	(28)	0.33	(27)	1.00	(17)
Proportion Ambisyllabic[a]						
Nongeminate spelling	0.01	(39)	0.04	(35)	0.00	(18)
Geminate spelling	----	(0)	1.00	(26)	1.00	(8)
Intervocalic Clusters						
CV.C(C)(C)	0.00		0.00		0.50	
vs						
CVC.C(C)	1.00	(2)	1.00	(3)	0.50	(4)
CVC.C(C)	0.66		1.00		1.00	
vs						
CVCC.(C)	0.33	(3)	0.00	(16)	0.00	(8)

NOTE: Because R.B. always obeyed English consonant sequencing constraints, illegal sequences were not included in the proportions (e.g., Sa.nta is impossible, so this word was excluded from the computation of the proportion of CV.C(C) (C), but San.ta and Sant.a both are possible, so this word did enter into the second comparison under intervocalic clusters). Words with 4-colored vowels in the first intersyllabic position also were excluded. If a word was left open on one occasion and closed on another, it was omitted from the computation of percent open, and words with consonant clusters divided two ways were excluded from the relevant cluster comparison. However, if a word was divided ambisyllabically one one of two occasions, it counted 0.50 in the percent ambisyllabic.

[a]Three words divided ambisyllabically were not included in the table: pretzel, /prɛt.tsəl/; acquainted, /ək.kweint.əd/; and elephantitis, /el.ə.fənt.taɪ.tɪs/.

[b]The number of examples of each type = n.

proportions of the available opportunities to make each type of division, where an "opportunity" is defined as a stimulus for which consonant sequencing constraints do not prevent the division.

The top row of the table suggests that the vowel quality and stress may affect syllabification of words with one intervocalic consonant. However, that row includes words in which the syllabification could be affected by a morpheme boundary or by geminate spelling. In the second row of the table, such cases were omitted, and the outcome is clearer. Specifically, in words with a stressed first syllable, the syllable was left open (i.e., ended in a vowel) much more often when the vowel was tense rather than lax, $\chi^2(1) = 9.63$, $\underline{p} < .005$. However, the first syllable always was left open when it was unstressed (in which case the tense/lax distinction does not apply), which was significantly more often than in stressed syllables with a lax vowel, $\chi^2(1) = 19.15$, $\underline{p} < .001$. The difference between tense and unstressed vowels was only marginally significant after Yates' Correction was applied, $\chi^2(1) = 3.29$, $\underline{p} < .1$. In sum, syllable closure is most important for lax vowels in stressed syllables and least important for unstressed syllables, in keeping with _a priori_ expectations.

The remainder of the table indicates that in other situations, orthography or cluster division are important considerations. First, when there was a geminate consonant spelling between the first two syllables, ambi-syllabicity always was used, but it rarely was used otherwise, $\chi^2(1) = 134.7$, $\underline{p} < .001$ (with items divided two ways excluded). Geminate spelling between syllables other than the first two also resulted in ambi-syllabicity, the only exception being the words _parallel_ and _parallelogram_. Second, when there were two or more intervocalic consonants, subjects much preferred to split the cluster after the first consonant (i.e., CVC.C(C)) rather than after two or more consonants (i.e., CVCC.(C)), $\underline{p} < .001$ (sign test). Table 3 shows that this preference was maintained in each vowel condition. Subjects also avoided leaving the first syllable open whenever it was stressed, but there were only 5 examples of words with consonant clusters for which an open first syllable would be phonotactically permissible (see Table 3).

Several additional findings do not appear in the table. There was an interesting effect of stress within words with three or more syllables. With them, it was possible to present word pairs in which a suffix resulted in a stress change. These pairs demonstrated quite clearly that stress affects syllabification. For example, R.B.'s reordered speech indicated that _photograph_ vs. _photography_ were represented as /fot.ə.græf/ vs. /fə.tɑ.grə.fi/ (/t/ shifted), and _telegraph_ vs. _telegraphy_ as /tɛl.ə.græf/ vs. /tə.lɛ.grə.fi/ (/l/ shifted).

In R. B.'s division of sentences and phrases, it was found that no syllable spanned more than one word (i.e., that syllables were restricted by word boundaries). For example, in the phrase shown in Table 2, "urban and rural cultures," the maximal onset principle might predict the division, /ɝ.bə.nænd.../ spanning the first two words. However, this type of response never occurred within the 37 sentences and phrases administered. Another interesting case is the stimulus phrase "contrast two colors." The phonetic pronunciation includes only one [t] at the first word boundary, but it represents two /t/ phonemes in the underlying morphophonemic representation. In this example. R.B. preserved both of these boundary phonemes, which were of course no longer adjacent to one another in her first two reordered forms.

R.B.'s responses also were strongly influenced by morphology. In 6 words presented to her, it would be necessary to leave a syllable open to preserve a morpheme boundary (e.g., in *a.sleep* or *free.dom*), and she consistently did so (6/6, $p < .1$) even though two syllabifications were possible. Conversely, in 25 words, two syllabifications were possible but the morpheme boundary would be preserved by closing a syllable (e.g., in *final.ize*), and R.B. usually did so (21/25, $p < .001$, sign test). Inspection of individual examples indicated that morphological units were important regardless of the phonological context.

Thus to summarize, R.B.'s syllabifications reveal influences on several levels. They are sensitive to consonant sequencing constraints and to a constraint against open stressed syllables with lax vowels. They are always hierarchically organized within words and, in most instances, within morphemes. Additionally, in the case of words with geminate consonants, her syllabifications apparently are influenced by orthography. Despite this variety of observed influences on syllabification, the present data are consistent with previous empirical work (Fallows, 1981).

Interview and reliability data. When asked to explain the basis on which she reorders language, R.B. produced several apparent contradictions. In one part of the conversation, she said that she attempts to match the dictionary's syllabic divisions. In keeping with this, she maintained that she visualizes words so vividly before reordering them that she can testify exactly how they appear to her (in lower case, sometimes with dots between the syllables). Recall that ambisyllabic divisions almost always occurred in words with geminate consonants, and rarely occurred elsewhere, further indicating a role of orthography. R.B. reported that she sometimes felt inclined to divide other words within a consonant, but refrained from such a response due to the spelling. However, at another point in the conversation, she asserted that her divisions depended a great deal on the exact *pronunciation* that the tester used. Further, R.B.'s reorderings were usually true to the phonetic properties of the forward model. For example, words with the letter combination ng were consistently reversed with /ŋ/; the letter x representing /ks/ or /gz/ was always reversed as /sk/ or /zg/; neutralized vowels in unstressed syllables generally remained neutralized in the reorderings; and specific vowels in stressed syllables were carefully reproduced in the reorderings. This paradox, R.B.'s reference to an orthographic vs. phonetic basis of reordering, actually may be symptomatic of a compound mechanism in R.B.'s syllabification. Indeed, we have demonstrated that her syllabification is influenced by phonetic features (stress, vowel quality), by phonemic features (consonant sequencing rules), and by morphological, lexical, and orthographic features. R.B.'s subjective report seems to contain elements from each of these types of influence.

Finally, when tested twice on a word, R.B. sometimes divided the word differently the second time. Nonetheless, on both trials her three responses usually were fluent and were valid, consistent reorderings. This rules out the possibility that R.B. simply has memorized a large vocabulary of reordered words. Instead, R.B. must rapidly apply reordering operations at the time of testing.

GENERAL DISCUSSION

Types of Representation of Speech

The most important conclusion to be drawn from the present data is that subjects displayed a sensitivity to several types of linguistic information and combined this information to produce a segmentation of speech into units. We will examine each type of linguistic information, and then will discuss a model of subjects' segmentation skill.

Orthography

Subjects were sensitive to orthographic information in limited instances. In Study 1 (on phonemes), some subjects were sensitive to the orthography only, rather than to any aspect of sound representation, and these subjects were excluded from the final investigation. However, even among subjects sensitive primarily to auditory properties of speech, there was a limited reliance on orthography. Subjects sometimes treated words with the letter x representing /ks/ or /gz/ as a single unit, and sometimes analyzed the sound pair /ju/ as one vs. two units depending on the spelling. One German subject reversed the German diphthong /ɔɪ/ according to its eu spelling. In Study 2 (on syllables), R.B. almost always divided words in the middle of consonants having a geminate spelling, which rarely happened in words without geminate spelling.

In a number of other responses a role of orthography was possible but uncertain. Examples are the reversal of words with the letters ng as /nəg/ rather than /ŋ/ by some subjects, the pronunciation of words with the flap /ɾ/ as /d/ or /t/ depending on the spelling, and the reversal of words with r-colored vowels (e.g., burn) as /r + vowel/ (e.g., /nrəb/ rather than /nɝb/). In these examples, it is not possible to determine whether the key factor is orthography or an abstract phonemic representation that matches the orthography better than it matches the surface phonetic form.

Responses were by no means dominated by spelling in either study. This is clear in both studies from subjects' treatment of words with silent letters and with homographs. Many subjects (including R.B.) also used the [ŋ] sound in the reversals, a response that could not be orthographically based.

Morphology

There also was a sensitivity to the morphological characteristics of speech. The only clear evidence of this in Study 1 was that most subjects reversed each word separately. Words with more than one morpheme were nonetheless reversed as a single unit. Sensitivity to morphology was shown in the second study in that R.B. avoided dividing words in the middle of morphemes.

Surface Phonetics

Subjects also displayed a sensitivity to the surface phonetic properties of speech. For example, most subjects preserved at least some characteristics of stress and intonation found in the forward speech stimuli. In both studies, subjects often preserved the sound quality of vowels, so that neutralized vowels in non-stressed syllables remained neutralized in the reversal, and distinct, non-neutralized vowels remained so.

Phonology

Reversals were not dominated by surface phonetics. If they had been, subjects would have identically reversed word pairs such as medal vs. metal, rather than making the /d/ – /t/ distinction. Furthermore, subjects aspirated or de-aspirated voiceless stop consonants depending upon the location of the consonant in the reversed form. These examples suggest that an influential type of knowledge in both studies was phonological structure. In Study 1, this was evident also in subjects' treatment of diphthongs, which were preserved by most native English-speaking subjects, and affricates, which were preserved by all native English-speaking subjects. An apparent language specificity (i.e., that the native German backward talkers reversed major diphthongs, unlike eight of ten native English-speaking subjects) may be a clue that an interesting language difference in phonemic structure exists. Lastly, in the reversal of word pairs with phonemic alternations discussed by Chomsky & Halle (1968), subjects consistently failed to display systematic phonemic (morphologically influenced) responses (e.g., the /i/ vs. /ɛ/ distinction was maintained in serene vs. serenity). In sum, then, the evidence points to phonological units more abstract than "taxonomic" phonemic categories, but considerably less abstract than the "systematic" phonemes of Chomsky and Halle.

A further sensitivity to phonological structure was evident in Study 2. For example, R.B.'s syllabic division always obeyed consonant sequencing constraints, and were sensitive to stress and to the differential sequencing properties of tense vs. lax vowels.

Toward a Model of Levels of Phonological Representation

The present results clearly show that the subjects are sensitive to multiple levels of speech representation, including acoustic phonetics, phonology, morphology, and orthography, which were used in combination in order to reverse speech. Our final aim in this paper is to go beyond that conclusion, to determine if the data place constraints upon the possible accounts of speech representation. We shall assume that subjects place into working memory some representation of each word as a sequence of units of some type(s), and then scan this sequence in reverse or else reoder the units in the sequence. The major challenge, then, is to determine exactly what units are placed into working memory and what processes help to put them there. These general questions about the units of speech depend upon three more specific issues to be addressed in turn.

1. Source of Representation

The first issue is the source of the representation used in backward speech. One possibility is that subjects transfer a lexical representation from long term memory to working memory, and then reverse that represenation in working memory. Another possibility is that subjects have a set of analytic procedures that will map an auditory image of a word into a string of phonological units. It would then be the output of these procedures that is put into working memory and reversed. Several facts favor the second of these possibilities. First, subjects are able to reorder nonsense words and words in foreign languages

(Cowan & Leavitt, 1981; Cowan et al., 1982), even though no pre-established lexical representation could exist. Further, the lexical entry is presumably stable from one occasion of use to another, yet in Study 2, the subject sometimes used different syllabic representations for a single word presented on two occasions. Similarly, it is unlikely that either [ks] spelled with an x or [ju] spelled with a u alternate sporadically between one vs. two units in the lexical representation; however, there were examples in which a subject used both representations. Thus, some analytic procedures seem to intervene on-line between the presentation of the stimulus and the presence in working memory of a string of units to be reversed.

Even so, there is evidence that lexical identification can facilitate backward speech. Subjects inquired when they were uncertain of a word's identity. Moreover, in an examination of reaction time in the initial subject's backward speech (Cowan et al., 1982), it was found that the silent response lag was inversely related to word length, presumably because long words can be identified before they end. The resolution of all these findings may be that the subjects can use the lexical identity, but that it is used only to supplement or clarify the acoustic input, which is then analyzed through a set of procedures which are themselves independent of lexical identity.

2. Status of Phonology and Orthography

The second issue is the relative status of phonology and orthography within the subjects' analysis procedures and representations. For this issue, it is possible to offer an empirical description of the way in which phonology and orthography were combined, and then to address tentatively more theoretical aspects of representation. The data suggest that subjects sometimes used orthography as a "notation system" for phonological structure, but that some phonological information was available beyond what was marked by the orthography. The phonology seemed to determine lower limits for the size of speech units, but the orthography determined upper limits (i.e., the largest units present were phoneme groups represented by a single letter). Demonstrating lower limits, the major English diphthongs and affricates were treated as single units, even when they were represented by multiple letters (as in choice). Similarly, monophonemic letter groups like sh and th were always treated as single units. Exemplifying upper limits, the sequence [ks] was treated as a single unit only when represented by a single letter (e.g., in tax but not tacks) and [ju] was treated as a single unit by more subjects when it had a single-letter spelling (e.g., in use more often than youth).

These results can be used to assess several alternative conceptions of the relationship between phonology and orthography. In the first, phonology and orthography would be completely separate systems of rules and representations in ordinary language tasks like speaking, listening, and writing. However, they would be weighed or combined during "backward speech." According to a second conception, the adult has a single complex system that combines phonology and orthography. In the course of learning to read and write, the child's lexical representations and phonological rules would become fundamentally restructured (e.g., the child might form a more abstract phonological system that incorporates regularities of orthography). A third conception, which seems intermediate between the other two, states that the child has a preliterate system of lexical representations and phonological rules that serve comprehension and production. These continue without fundamental change as literacy is acquired. However, with literacy comes a secondary level of representations that includes spelling, orthographic regularities, and letter-to-sound correspondences. This level would provide access to phonological structure in a way that could be used in ordinary language to aid reading and writing of words whose spelling or pronunciation is unknown, as well as to produce or appreciate relationships between words and factors of style and esthetics in language. However, the units formed by this secondary level of analysis might not always be the same as the phonemic units of the primary level. In the "backward speech" task, this secondary level, rather than the primary phonemic level, would determine the segmentation of speech.

The first two models do not seem to account for our results well. If phonology and orthography were separate sources of information available to be combined for the sake of backward speech, one would expect complete phonological information to be available. The availability of orthographic information should not obscure the fact that the letters x for [ks] or [gz] and u for [ju] each represent two phonemes. Moreover, the first model would allow that a different, more phonologically accurate form of backward speech should be possible for preliterate speakers, but no such cases were found. A final factor tending to contradict the first model is that, unlike the basically "orthographic" backward talkers, the "phonemic" backward talkers denied that they visualized words during speech reversal. If a separate orthographic source of information were used, at least some subjects might be expected to report visualization. The second model, that literacy restructures the phonological system, cannot comfortably account for both ordinary language use and backward speech. There is no evidence for any sharp change in vocal speech comprehension or production as a consequence of literacy, or between literate and illiterate adults. To assume that [ks] and [ju] each could sporadically become one unit with literacy, or that the syllable boundaries of some simple words would change as geminate spellings are acquired, seems odd (and contradicts any previous linguistic analysis).

Rather than a modified form of phonological representation in literate speakers, the most parsimonious view seems to be that they have another level of procedures and representations (e.g., the third model). In this model, the subject might operate as follows. The smallest units perceived within speech would be phonemes, but phonemes would not be immediately available for use in working memory (i.e., for backward speech). Instead, the subject would have to apply a secondary analysis to the string of phonemes in order to generate the units available to working memory (and these units would sometimes differ from units in the primary system). In support of this model, it has been shown that illiterate adult speakers do not have access to segmentation sufficient to divide words into phonemes (Morais et al., 1979), and that beginning readers are better able to segment speech into phonemes if taught by a phonic method rather than a whole-word method (Alegria, Pignot, & Morais, 1982). Thus written language seems capable of making some form of segmental analysis available for a variety of uses.

The relationship between reading and access to phonological units has been discussed by a number of investigators (Bradley & Bryant, 1983; Gleitman & Rozin, 1977; Hakes, 1980; Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Read, 1978). In some of these sources (e.g., Hakes, 1980), access to linguistic structure has been referred to explicitly as "metalinguistic ability," of which "metaphonological ability" is one variety. However, there might be several kinds of metaphonological ability. If the task were to straightforwardly indicate how one believes words should be segmented, then the necessary metaphonological ability would be a conscious awareness of some type of segmental analysis. However, the task is often one in which segmentation is needed implicitly for some other purpose, as in the phonological decoding of written language. This would seem to be the case also in the backward speech skill. Accordingly, in the remainder of this paper, the term "metaphonological knowledge" will be used to discuss the source of the units placed into working memory for the backward speech task, whether or not the subject is consciously aware of these units. Much of this metaphonological system apparently results from regularities in the spoken system that written language helps the child to observe.

Because preliterate children can talk reasonably well, it appears that the metaphonological access that accompanies literacy is not needed for odrinary speech. However, the primary phonological system (i.e., the one that precedes literacy) clearly places constraints upon the secondary, metaphonological system. An indication of these constraints in our data is that subjects preserved as single units the major diphthongs and affricates, the phonemes /θ/, /ð/, and /ʃ/, and often the phoneme /ŋ/, even though English orthography provides no clue to the integrity of these speech units. Similarly, the naive transcriber perceptions reported by Sapir (1933) suggest that speakers' analyses of their native language are influenced by phonological segments and structure in the primary system.

3. Processing in Backward Speech vs. Ordinary Language

The third issue to be addressed is the way in which information is processed in backward speech vs. ordinary language production and comprehension. The following description of processing seems most in keeping with the points addressed above. Both incoming speech and words retrieved from long-term storage are automatically parsed into phonemes, but this representation is not directly available for conscious manipulation in working memory. It can be used to comprehend or produce words, however. In literate speakers, this string of phonemes also serves as the input to a metaphonological analysis process, which results in a string of units available in working memory. In the ordinary language of literate speakers, this metaphonological representation may be used to observe regularities in the input or to "edit" the output, and is especially important in reading. In backward speech, the units within the metaphonological representation are rearranged. The new sequence of units then must be converted into the corresponding sequence of phones. Thus, the same levels of representation are used in ordinary and backward speech, but they are used differently.

We wish to emphasize that the backward speech corpus is relevant to both of these levels of speech representation. Insofar as the subjects are uniform in the representations indicated by their backward speech styles, the primary phonological system presumably is involved. The representation of diphthongs and affricates as indivisible units by English-speaking subjects is perhaps the best example of this. On the other hand, aspects of individual difference in representation presumably must reflect a secondary analysis of speech.

One final important issue remains to be discussed. It would appear to require a tremendous working-memory capacity to retain words of up to 10 phonemic units (e.g., <u>philanthropy</u>) or more, while manipulating the units. After all, most people cannot perform these reversals even slowly, let alone rapidly. However, the subjects did not display truly extraordinary memory in conventional tasks (e.g., in digit span). It seems likely that the subjects recode sequences of units into higher-order chunks whose reversals have been memorized. For example, the subject might have memorized the reversed pronunciation of such frequent sequences as [kw], [ɛst], [Iŋ], and [pl]. This could reduce the load in working memory to a reasonable limit.

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Footnote

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Appendix

Transcripts of Letters from Backward Talkers and Their Acquaintances

"Rick has been [talking backward] for about four or five years now [since the age of 12 or 13]. He began when he realized that our family name ... was a stage name that my father contrived [which consisted of his original name backward]. He began to sing pop songs backward spontaneously as he listened to them on the radio, and has amazed his friends and teachers with this type of thing throughout high school." -- Father of R.N. "I have been [talking backward] for the past 25 years, since I was ten years old. In addition, I can take complete sentences and spell them backwards and also take all the letters in a given sentence and immediately place them in alphabetical order ... I also have a friend who can speak backwards and from time to time we have backwards conversations with no problems understanding each other." -- L.P. "I learned to talk backward as a young girl when I lived in my home town in Austria. We, my sister and brothers, had much fun talking to each other in this way, especially in front of other friends, who could never figure out what language we were talking (Swedish). Later I married an American and talked then in English backwards, to myself only. But I still prefer to talk it in German, which is the classical language for backward talking." -- H.F. "I know a child -- I think ten years old, possibly eleven -- who has the same ability to reverse words ... The mother told me of hearing the child's voice from his bedroom one night. She assumed that he was saying his prayers but investigated when things continued, beyond the usual length of time. He turned out to be practicing 'supercalifragilistic'...etc." -- J.C. "[My backward talking ability] dates back to about age 9, during a long elevator ride when I perceived OTIS as SITO, and has progressed from that point with little conscious effort." -- B.P. "I have been speaking backwards (with myself, of course -- there are few people with whom one can converse that way) since I was in elementary school. I developed this skill after seeing Professor Backwards several times on the Mike Douglas Show during the mid-1960s." -- D.S. "When I was a kid I occasionally amused myself (most often while putting myself to sleep) by practicing a backwards speech that would sound as close as possible to ordinary speech when played backwards ... I unfortunately never had the opportunity to check the accuracy of my reconstruction." --J.L. "I am 16 years old now, and I have been talking backwards since the age of seven. When I first discovered I could do this, I was puzzled because I didn't know how I was able to do it, so I kept it a secret for a long time." -- C.B. "As children my brothers and I used this language regularly and were quite fluent. I remember vividly the day when on the nursery floor I suddenly said to my brothers, 'Why do we not all speak backwards?' I must have been under 10 because we left that house when I reached that age ... [My brothers] were three and five years older than myself. We began to practice immediately and kept up our fluency till we were all grown up. -- From an elderly female member of the House of Lords, England. "It's something that I discovered I could do a long time ago [$<$12 years old]. I don't remember the very first time that I realized I could do it, but the first time that I did it fluently was when Kruschev was in the United States. He had a simultaneous interpreter and I wanted to be able to do what the interpreter could do. The interpreter gave absolutely simultaneous translations, and it turns out that English backwards sounds very much like Russian." -- Andrew Levine on the Johnny Carson Show, December 30, 1980. "I guess I first became aware I could talk backwards when I was riding in a car on a long trip with my parents [when she was about eight years old]. I saw signs going by and just to pass the time, I flipped them backwards in my mind ... Your brain kind of puts the words together on a screen. You can just see it, like a ticker tape machine in your head." -- M.B., an orthographic backward talker. "When I was at my preparatory school ... in the years 1920-24, there was also a boy who could talk backwards." -- G.C. "We boys had a language in which we turned the words around, as: boy = yob.. Thus, if a boy got very much vexed and wanted to be expressive, he said 'mad-dog'" (Chrisman, 1893).