ABSTRACT: Under natural speaking conditions, or speaking alone (SA), vowels following word-initial voiced stop consonants are longer in duration than vowels following word-initial voiceless stops. This study investigated vowel durations following the production of word-initial voiced and voiceless stop consonants produced during simultaneous communication (SC) by recording inexperienced sign language users during SC and SA. Although the results indicated longer sentence and vowel durations for SC than SA, they showed no differences in the relative duration of vowels following voiced or voiceless stops. Vowel durations following voiced stop consonants were uniformly longer than vowel durations following voiceless stops across both speaking conditions. This finding is consistent with previous research indicating that global temporal alterations observed in SC do not degrade important temporal cues of spoken English. The findings are also consistent with the findings of D. E. Metz et al. (2006), who investigated experienced signers’ vowel durations under identical experimental conditions as the present study.

KEY WORDS: simultaneous communication, voice onset time (VOT), vowel duration, VOT-vowel duration trade-off, inexperienced signers
a slowing of speech (Vernon & Andrews, 1990). A specific criticism of the effects of SC on oral communication was levied by Huntington and Watton (1984), who observed that teachers who use SC showed disruptions of normal speech prosody. They concluded that SC may not always expose deaf children and children with hearing impairment to the typical prosodic and segmental features of normal speech.

Research with experienced and inexperienced signers has demonstrated that speech that is produced during SC is slower in rate than speech produced alone (SA) and has longer interword intervals, longer vowel durations (Whitehead, Schiavetti, Whitehead, & Metz, 1995; Whitehead, Schiavetti, Metz, & Farrell, 1999), and longer voice onset times (VOTs) (Schiavetti, Whitehead, Metz, Whitehead, & Mignerey, 1996; Schiavetti, Whitehead, Metz, & Moore, 1999). Whitehead et al. (1995), however, discussed the importance of determining whether this slowing of the rate of speech during SC results in violations of the linguistic temporal rules of spoken English. The simple slowing of speech may actually improve the speaker’s intelligibility when speaking to persons with hearing impairment (Picheny, Durlach, & Braida, 1986; Volaitis & Miller, 1992). If, however, specific linguistic timing rules of spoken English are violated, then it could be argued reasonably that SC presents a poor speech model to persons who are deaf or have a hearing impairment.

Several studies have examined potential violations of selected linguistic temporal rules of spoken English during SC. These linguistic temporal rules include the effect of vowel height and voicing characteristics of the following consonants on vowel duration (Whitehead et al., 1995; Whitehead, Schiavetti, et al., 1999), VOT differences between voiced and voiceless members of cognate pairs of plosives (Schiavetti et al., 1996, 1999), vowel durations preceding voiced and voiceless syllable-final stops (Metz et al., 1997), second formant transitions following stop consonant production (Baillargeon, McLeod, Metz, Schiavetti, & Whitehead, 2002), and vowel durations following voiced and voiceless stop consonants (Metz, Allen, Kling, Maisonet, McCullough, Schiavetti, & Whitehead, 2006). In general, the results of the above studies indicated that speech was slower in SC conditions than in SA conditions, but there was no evidence of linguistic temporal rule violations.

In an effort to increase the external validity of the above research findings, this investigation examined vowel durations following voiced and voiceless stop consonants by systematically replicating the experimental procedures used by Metz et al., (2006). Metz et al. investigated whether changes in speaking rate associated with SC would have an effect on the relative duration of vowels following voiced and voiceless stop consonants produced by experienced signers. During natural speaking conditions, or SA, there is a trade-off relationship between the duration of the VOT interval and the duration of the vowel following the stop consonant. Vowels following voiced stop consonants are longer in duration than vowels following voiceless stops when isolated words are produced (Allen & Miller, 1999), when words are embedded in a carrier phrase (Peterson & Lehiste, 1960), and when words are produced in connected speech (Crystal & House, 1988). The present study examined the effect of changes in speaking rate induced by the use of SC on vowel durations following voiced and voiceless stop consonants produced by persons who had recently completed an introductory course in manual communication (inexperienced signers).

### METHOD

#### Speakers

Speakers for this study were 10 normally hearing female college-age adults. Each speaker had recently completed an introductory course in manual communication in which they were introduced to finger spelling and a variety of signs. Due to the introductory level of the course, these speakers were considered to be inexperienced in the use of speech combined with signed English and finger spelling, or SC. None of the speakers had prior experience or instruction in manual communication.

#### Speech Stimuli

The speech samples investigated consisted of the carrier sentence, “I can say ____ again” and 12 monosyllabic (stop consonant-vowel-stop consonant, or CVC) experimental words embedded in the blank slot in the carrier sentence. The list of experimental words contained the initial stop consonants /p/, /t/, /k/, /b/, /d/, and /g/ preceding the high and low vowels /u/ and /a/. The final stop consonant was either a /p/ or /t/. These experimental words were the same as the monosyllabic words shown in the appendix in Schiavetti et al. (1996). Each CVC word was produced by each speaker in two experimental conditions—SA and SC.

#### Recording Procedures

The experimental words embedded in the carrier phrase were produced at a comfortable conversational loudness level as they were presented on flash cards. Audio recordings were made in a sound-treated booth using an Audio-Technica AT-816 microphone that was positioned 15 cm from each speaker’s mouth. The microphone was connected to a Tascam 20MKII tape deck. The speakers produced each group of sentences under the two experimental conditions: SA versus SC. In the SC condition, speakerscombined speech with sign language for “I can say” and “again” and with finger spelling for the 12 experimental words. The sentences were presented on flash cards in a different random order for each speaker and experimental speaking condition (SA vs. SC), and the order of experimental speaking condition was counterbalanced across the speakers. The speakers were familiarized with the experimental words before the recording session so they could practice signing the carrier phrase and fingerspelling the experimental words to be used in SC.
Sentence Duration Analysis

The duration of all SA and SC experimental sentences was measured to verify that the speech rate was slower in the SC than in the SA condition. For each of the 240 speech samples (12 words × 2 conditions × 10 speakers), total sentence duration for the carrier phrase and experimental word was measured in milliseconds (ms). The acoustic audio signal was digitized with 16-bit precision at a sampling rate of 20 kHz with a Kay Elemetrics Computerized Speech Lab (CSL Model 4300B). When the digitizing process is initiated, the CSL applies an appropriate low-pass anti-aliasing filter to the raw acoustic signal (at a sampling rate of 20 kHz, the upper frequency cutoff is 8 kHz), stores the digital record in memory, and displays the resultant waveform on a graphics monitor.

Sentence durations were measured by visually isolating the first positively going portion of the waveform associated with the initiation of speech. The location of this initiation point was marked with a cursor. This position was then stored, the cursor was moved to the end of the sentence, and the last positively going portion of the waveform was visually isolated, marked and saved as the second cursor position. The temporal interval between the two cursor points was taken as the value for total sentence duration. Intraobserver, interobserver, and intraspeaker reliability of these sentence duration measurements have been reported previously (Schiavetti et al., 1996; Whitehead et al., 1995).

Vowel Duration Analysis Procedure

Vowel durations of the 240 experimental words from both speaking conditions (SA and SC) were measured by visually isolating the experimental word in the carrier sentence. One cursor was then placed on the waveform at the onset of the noise burst associated with production of the initial stop consonant’s release, and a second cursor was placed at the end noise burst associated with production of the final stop consonant. The entire word was then displayed on the graphics terminal screen. Measurement of vowel duration was accomplished by visually isolating the first positively going portion of the waveform associated with the vowel production following the initial stop. The location of this initiation point was marked with a cursor. This position was then stored, the cursor was moved to the end of the vowel, and the last positively going portion of the waveform was marked and saved as the second cursor position. The temporal interval (in ms) between the two cursor points was taken as the vowel duration value.

Interobserver and Intraobserver Vowel Duration Measurement Reliability

Vowel duration measurement reliability was examined by randomly selecting one male and one female speaker and remeasuring all of their vowel productions in each speaking condition. To establish interobserver reliability, a trained research assistant made replicate vowel duration measurements. These vowel duration measurements were collapsed across the participants for each speaking condition. The mean difference between the original and replicate measurements was .82 ms for the SA condition and 2.69 ms for the SC condition. Paired t tests revealed no significant differences between the original and replicate measures for the SA condition (t = 1.08; df = 23; p = .290) and SC condition (t = .59; df = 23; p = .564).

To establish intraobserver reliability, replicate vowel duration measurements were made by the researcher who made the original measurements. These vowel duration measurements were collapsed across the participants for each speaking condition. The mean difference between the original and replicate measurements was .417 ms for the SA condition and .458 ms for the SC condition. Paired t tests revealed no significant differences between the original and replicate measures for the SA condition (t = .62; df = 23; p = .541) and SC condition (t = .53; df = 23; p = .601).

RESULTS

Sentence Duration

Each participant’s average sentence duration was computed for the SA and SC experimental communication modes. A paired samples t test revealed a significant effect of communication mode on sentence duration (t = –10.29; df = 9; p < .00001; d = 3.65). Across-participant mean sentence duration in the SA condition was 1591 ms (SD = 125 ms); across-participant mean sentence duration in the SC condition was 2704 ms (SD = 305 ms). These data indicate that sentence duration was significantly longer in the SC condition than in the SA condition because of the slowing of speech that occurs when speakers sign and speak at the same time.

Vowel Duration

A 2 (communication mode) × 2 (stop consonant voicing) analysis of variance with repeated measures revealed that (a) all vowel durations were significantly longer in the SC condition than in the SA condition, F = 10.17; df = 1.9; p = .011; η² = .533; (b) vowels following voiced consonants were longer than vowels following voiceless consonants in both the SC and SA conditions, F = 95.95; df = 1.9; p < .0001; η² = .914; and (c) there was no significant interaction between vowel durations and speaking conditions, F = 1.149; df = 1.9; p = .3116; η² = 0.113, indicating that the relative vowel durations following voiced and voiceless stop consonants were equivalent across the SA and SC conditions.

DISCUSSION

The results of the present investigation demonstrated that despite the temporal slowing of speech during SC, the trade-off relationship between VOT and vowel duration as a
function of syllable-initial voicing was maintained by the inexperienced signers; increases in VOT were accompanied by a decrease in vowel duration. This finding is consistent with research that has shown that the VOT and vowel duration trade-off relationship is maintained under both fast and slow speaking conditions (Allen & Miller, 1999). The findings of the present study are also consistent with the findings of Metz et al. (2006), who examined the trade-off relationship between VOT and vowel duration as a function of syllable-initial voicing with experienced users of SC. Considered collectively, the present findings and the findings of Allen and Miller indicate a robust relationship between VOT and vowel duration as a function of initial consonant voicing.

The present results are also consistent with previous research that indicated a temporal slowing of speech when using SC (Windsor & Fristoe, 1989, 1991) and the general maintenance of the temporal rules of spoken English (Schiavetti et al., 1996; Whitehead et al., 1995; Whitehead, Schiavetti, et al., 1999; Whitehead, Whitehead, Schiavetti, Metz, & Farinella, 1999). It therefore seems reasonable to conclude that the global slowing of speech during SC does not adversely disrupt the phonetic pattern of spoken English. This conclusion is buttressed by research that has shown no deleterious effects of using SC on vowel formant frequency patterns (Schiavetti, Metz, et al. 2004), cognate-pair VOTs (Schiavetti et al., 1996, 1999), anticipatory fricative duration (Whitehead, Whitehead, et al., 1999), voiced and voiceless consonant-vowel interactions (Whitehead et al., 1995; Whitehead, Schiavetti, et al., 1999), consonant-vowel second formant transitions (Baillargeon et al., 2002), and consonantal spectral moments (Kardach et al., 2002).

Schiavetti, Whitehead, and Metz (2004) suggested the need to further examine additional acoustic parameters of consonants and vowels during SC to determine if reduced speaking rates untowardly affect the timing rules of spoken English. This study partially satisfies the call for such research and has strengthened the external validity of research that was previously conducted using experienced signers as speakers. Future research should, however, investigate the timing rules of spoken English during conversational speaking tasks. A strong argument for the appropriateness of SC could be put forth if the findings of systematic replications of extant investigations also suggest that the timing rules of spoken English are not violated during SC.

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