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Effects of Concurrent Motor, Linguistic, or Cognitive Tasks on Speech Motor Performance

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This study examined the influence of 3 different types of concurrent tasks on speech motor performance. The goal was to uncover potential differences in speech movements relating to the nature of the secondary task. Twenty young adults repeated sentences either with or without simultaneous distractor activities. These distractions included a motor task (putting together washers, nuts, and bolts), a linguistic task (generating verbs from nouns), and a cognitive task (performing mental arithmetic). Lip movement data collected during the experimental conditions revealed decreases in displacement and velocity during the motor task. The linguistic and cognitive tasks were associated with increased spatiotemporal variability and increases in the strength of the negative correlations between upper and lower lip displacements. These findings show that distractor tasks during speech can have a significant influence on several labial kinematic measures. This suggests that the balance of neural resources allocated to different aspects of human communication may shift according to situational demands.

KEY WORDS: lip kinematics, language, cognition, motor control, divided attention

Much of the research in human communication and its disorders has focused on speech and language separately. Few investigators have examined how language demands may influence the physical production of speech. In a recent article, Lieberman (2001) stressed the importance of the way speech and language are integrated, noting that "the neural bases of human language are intertwined with other aspects of cognition, motor control, and emotion" (p. 33). The authors of several studies have indicated the need for further research in the areas of linguistic and cognitive processes and their relationship to speech motor control in order to better understand the production of spoken language (Maner, Smith, & Grayson, 2000; Strand, 1992; Strand & McNeil, 1996).

Previous work has shown that the way speech movements are executed may be compromised when language processing demands increase. Maner et al. (2000) found that increased utterance length and complexity resulted in greater spatiotemporal variability in a phrase repeated by their speakers. These findings revealed that nonmotoric processes such as language and cognition can have a measurable influence on speech kinematics. Crystal (1987) proposed an analogy of a language-disordered child having a bucket being overfilled with too many processing demands, leading to performance breakdowns. Crystal's limited

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capacity theory suggests that the demands of language, cognition, and motor processes must be met by a finite pool of resources. In those with normal communication, these resources are adequate for the task. However, in the case of speech or language disorders, the available resources fail to meet the combined cognitive, linguistic, and motor demands of communication. Because everyday communication requires that a speaker smoothly coordinate the demands of message formulation and sound production, and because this frequently occurs along with walking, driving, or other activities, typical speaking could be considered a type of divided attention task.

The allocation of attention to simultaneous tasks has been studied in some detail in the field of cognitive psychology. For several decades there have been models to account for the way people perform two tasks at the same time. The two main views have been either that there is a pool of cognitive resources that can be divided or shared as needed across competing tasks, or that the brain processes stimuli serially, resulting in a processing bottleneck, because only one task can receive attention at a time (Kahneman, 1973; Wickens, 1984). The ability of individuals to simultaneously perform two apparently continuous tasks has led to refinements of these models, including the suggestion that there may be multiple processors that can be dedicated to different tasks (McLeod, 1977). Some theories have taken into account what is known about cortical localization in language and motor control. Thus, if the left hemisphere is occupied with communication, it has been reasoned that performance of the right hand, which it controls, would deteriorate more than the left in a concurrent speaking and manual task. Several studies have provided support for this theory (Friedman, Polson, & Dafoe, 1988; Hiscock, Kinsbourne, Samuels, & Krause, 1985), and one extended the findings to include similar effects for right versus left foot movements (Carnahan, Elliott, & Lee, 1986).

Some of the dual-task studies involving speech have required participants to either produce syllables repeatedly (Chang & Hammond, 1987) or to perform verbal shadowing by repeating single words they have just heard (Carnahan et al., 1986; Elliott, Weeks, Lindley, & Jones, 1986). Others have required more demanding speech, such as describing a picture, reading, or speaking a monologue (Simon & Sussman, 1987). These speech tasks have typically been performed while measures are made of manual tapping rate (Seth-Smith, Ashton, & McFarland, 1989) or of accuracy in the manual tracking of a visual target (McLeod, 1977). The influence of a concurrent task on speech itself has been the focus of relatively few investigations. Some authors have noted that there were occasional word shadowing errors (Elliott et al., 1986) in a dual-task experiment, but only a few studies have included direct measures of speech performance as the variable of interest.

Of the studies that have evaluated changes in speech performance when individuals were distracted with a concurrent task, some have evaluated perceptible errors, such as self-corrections in articulation and word-selection, or overall speech quality (Jou & Harris, 1992). Others have noted changes in speech rate (LaBarba, Bowers, Kingsberg, & Freeman, 1987). Oomen and Postma (2001) studied the effects of performing a tactile identification task during speech. They found an increased number of filled pauses and repetitions in the dual-task condition compared with speech produced without distractions.

Few investigators have evaluated the influence of concurrent tasks on instrumental measures of speech production. Some effects may be relatively subtle and not result in perceptibly obvious changes, yet still reveal important insights into the way speech is produced. A recent study of individuals with Parkinson's disease revealed that performing a visual tracking task led to decreases in speech intensity and rate, even when they were instructed to speak loudly (Ho, Iansek, & Bradshaw, 2002). A study of labial kinematics revealed that the speech of individuals who stutter became more variable in its execution in a linguistically challenging context (Kleinow & Smith, 2000). The same study found no similar effect for speakers in the control group who did not stutter. A study comparing children with adults with normal speech found that when a target phrase was embedded in a longer sentence, kinematic variability across repetitions increased (Maner et al., 2000) and that children were more adversely affected than adults.

It becomes clear from the studies of divided attention involving speech either as a primary or secondary task, that its production demands resources that might otherwise be used to meet a variety of needs. The purpose of the present study was to compare three different types of distractor tasks to evaluate their influence on speech movements. Each type of distractor was anticipated to require different processing resources, which might then result in different effects on motor performance. A motor task was selected that would require potentially distracting manual activity without substantial cognitive demands. At this preliminary stage, there was no intent to compare right- and left-hand effects, given the established literature documenting greater interference with the right than with the left hand (Feyereisen, 1997; Friedman et al., 1988; Kosaka, Hiscock, Strauss, & Wada, 1993). Because speech motor performance was the focus of this investigation, no measures were made of manual activity. Because speech is the primary means of expressing language in everyday communication, a linguistically challenging condition was devised to determine how simultaneous language processing might affect speech movements. Previous neuroimaging studies (De Nil, Kroll, & Houle, 2001) have used verb generation from nouns as a means to activate language centers in the brain, and this task was reasoned to be appropriate for the purposes of the present investigation. Finally, a primarily cognitive task was chosen to challenge participants by having them do mental arithmetic while speaking.

Any differences in the impact of these three classes of distractors on speech motor performance may allow inferences regarding neural resource allocation during speech production. Without attempting to quantify mutual interference between speech and simultaneous tasks, the goal of this initial study was to quantify speech performance as a function of a specific distractor demand condition. It was hypothesized that each distractor task would have an impact on speech movements. However, the previously published work in dual-task paradigms did not allow specific predictions to be made about the nature of the speech movement differences across the experimental conditions. The present investigation, therefore, served as a preliminary exploration of the way that different distractions influence speech movements. Learning how individuals with normal speech respond to such challenges may reveal important information about human communication and potentially lead to new insights in treating its disorders.

Method

Participants

Ten male and 10 female young adult (*M* = 22.7 years, *SD* = 1.69 years) native speakers of English participated in this study. Six additional people participated in the study but could not complete the cognitive task successfully. Participants reported having no history of speech, language, or hearing disorders. Each passed a hearing screening bilaterally at 20 dB HL at 0.5, 1, 2, and 4 kHz, and gave written informed consent to take part in the experiment.

Instrumentation

Participants were seated in a sound booth for the experiment. Lip and jaw movements were transduced with a head-mounted strain gauge system (Barlow, Cole, & Abbs, 1983). Inferior–superior displacements of the upper lip, lower lip, and jaw were recorded with this system using cantilever beams instrumented with strain gauges attached to the head-mounted frame. The orientation of the strain gauge apparatus was visually judged to be perpendicular to the occlusal plane. The single channel instruments did not allow any measurement of the degree to which labial movements may have departed from the vertical (e.g., during lip protrusion). The cantilevers for the lips were inserted through a small bead attached at midline with double-sided adhesive tape at the vermillion border of the upper and lower lips. The cantilever for the jaw was attached to the skin under the chin, although the signal from this transducer was not included in the analysis for the present report. A microphone was mounted onto the headset frame to capture the speech signal. A sound level meter was placed in the sound booth 100 cm from the participant's mouth. The three channels from the tracking system were connected to a Windaq 720 (DATAQ Instruments, Akron, OH) analog/digital converter, which digitized the sound level meter signal, upper lip, lower lip, and jaw signals at 1 kHz. This system also digitized the microphone signal at 25 kHz, after it was low-pass filtered at 12 kHz. Experimental materials included six nuts, six bolts, and 18 washers for the motor task.

The strain gauge cantilevers were calibrated using a linear micrometer that measured movements of each of the three cantilevers in millimeters. The measurements in millimeters were compared with the voltage output for each channel to calculate a calibration factor used in subsequent analyses.

Procedures

The experiment consisted of four different conditions: one speech-only task, and three speech tasks performed simultaneously with either a motor, linguistic, or cognitive task. The speech-only task was performed once before each combined task so that there were six trial blocks in all. The order of the three combined conditions was randomized across participants to reduce sequencing effects, but each always followed a speech-only condition. The experimental conditions were preceded by instructions and examples of the procedures. The experimental blocks included five practice trials of the speech utterance, so that utterance novelty would presumably not be a significant factor.

In the speech-only task, the participant was instructed to repeat 15 times, at a comfortable rate and loudness, the following utterance: “Mr. Piper and Bobby would probably pick apples.” The first five utterances—being practice trials—were not included in the kinematic analysis. A pacing beep set at 3-s intervals was used to prompt the participant when to say the next utterance. In the combined speech tasks, the participant performed a motor, cognitive, or linguistic task while saying the utterance “Mr. Piper and Bobby would probably pick...”. The last word of the utterance varied with the nature of the task. For the speech-only task, *apples* was used at the end of the utterance. For the motor task, the word *apples* was also used at the end of the utterance. For the linguistic task, the speakers produced verbs that were related to the target nouns presented to them via loudspeaker. For the cognitive task, the last word of the utterance was a number in a sequencing task.

In the combined tasks, instructions were given on how to perform either the motor, linguistic, or cognitive task. Once the participant demonstrated understanding of the task, he or she was instructed to perform it while simultaneously repeating the utterance.

In the motor task, six nuts, six bolts, and 18 washers were placed on a table in front of the speaker in the sound booth. These were separated into six groups of one nut, one bolt, and 3 washers each. The speaker was instructed to pick up a bolt, put 3 washers on it, and then screw on the nut until it was tight. This task was selected because it required the participant to perform a task that was more complex than the simple finger-tapping used in a number of previous studies of dual-task performance (Chang & Hammond, 1987; Friedman et al., 1988; Hiscock et al., 1985). Because the primary focus of the present work was on speech motor behavior, a manual distractor task that lent itself to quantification (such as tapping rate) was not essential. The speaker repeated the target utterance 15 times while performing the motor task. There were no time constraints for this task that might influence the rate of speech. A series of 15 beeps set at 3-s intervals was used to pace the utterances.

In the linguistic distractor condition, the speaker performed a verb generation task. A list of nouns was selected from a neuroimaging study by De Nil et al. (2001) that involved generating verbs from nouns. The participant was presented with 15 nouns that were recorded onto a Computerized Speech Lab (Model 4400; Kay Elemetrics, Lincoln Park, NJ) system at 4-s intervals (see the Appendix for the list of nouns). After presentation of the noun, the task required the participant to think of a verb related to it and say it at the end of the carrier phrase. For example, if the noun was *book*, the participant would say, "Mr. Piper and Bobby would probably pick *read*" or "Mr. Piper and Bobby would probably pick *buy*".

In the cognitive task, the speaker was instructed to count backwards from 100 by sevens. The participant was instructed to start with 100 and say each number at the end of the utterance. Thus, the participant would say, "Mr. Piper and Bobby would probably pick ninety-three, Mr. Piper and Bobby would probably pick eighty-six," and so forth. Beeps set at 3-s intervals were used to pace the utterances.

Data Analysis

The upper lip, lower lip, and jaw movement signals, which were digitized at 1 kHz per channel, were exported as binary files and imported into MATLAB (ver. 6.1; The Mathworks, Inc., 2001) for analysis with custom routines. Although data from all three articulators were recorded, the present analysis is focused on the movements of the lower lip and the correlation between the upper and lower lip signals. The lower lip signal represents a combination of the lower lip and jaw movements, and the two components were not decoupled. The combined movements were used to allow simple tracking of relatively large displacements over time (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995). The dependent measures included the utterance duration as well as the displacement and peak velocity for the lower lip movements during a specified articulatory gesture in the target phrase, as described below. The kinematic records were displayed on a computer monitor for segmentation and extraction of the dependent measures. The displacement waveforms consisted of the 15 target utterances elicited under each of the four conditions. The audio signal was not analyzed acoustically, but served as a guide during the kinematic analysis. All kinematic analyses were completed on 10 repetitions (the final 10 of the 15 productions) of the carrier phrase "Mr. Piper and Bobby would probably pick." Tokens with any visible abnormalities in the lower lip kinematic record of the target phrase were excluded from the analysis and replaced with normally produced tokens from the first five that were spoken. A token was judged to be abnormal when there were extra or missing peaks or troughs in the displacement or velocity signal. During STI computation, all tokens were displayed both before and after time-normalization, which allowed any records with unusual peaks or troughs to be identified. The count of visibly abnormal tokens was compared across the speaking conditions.

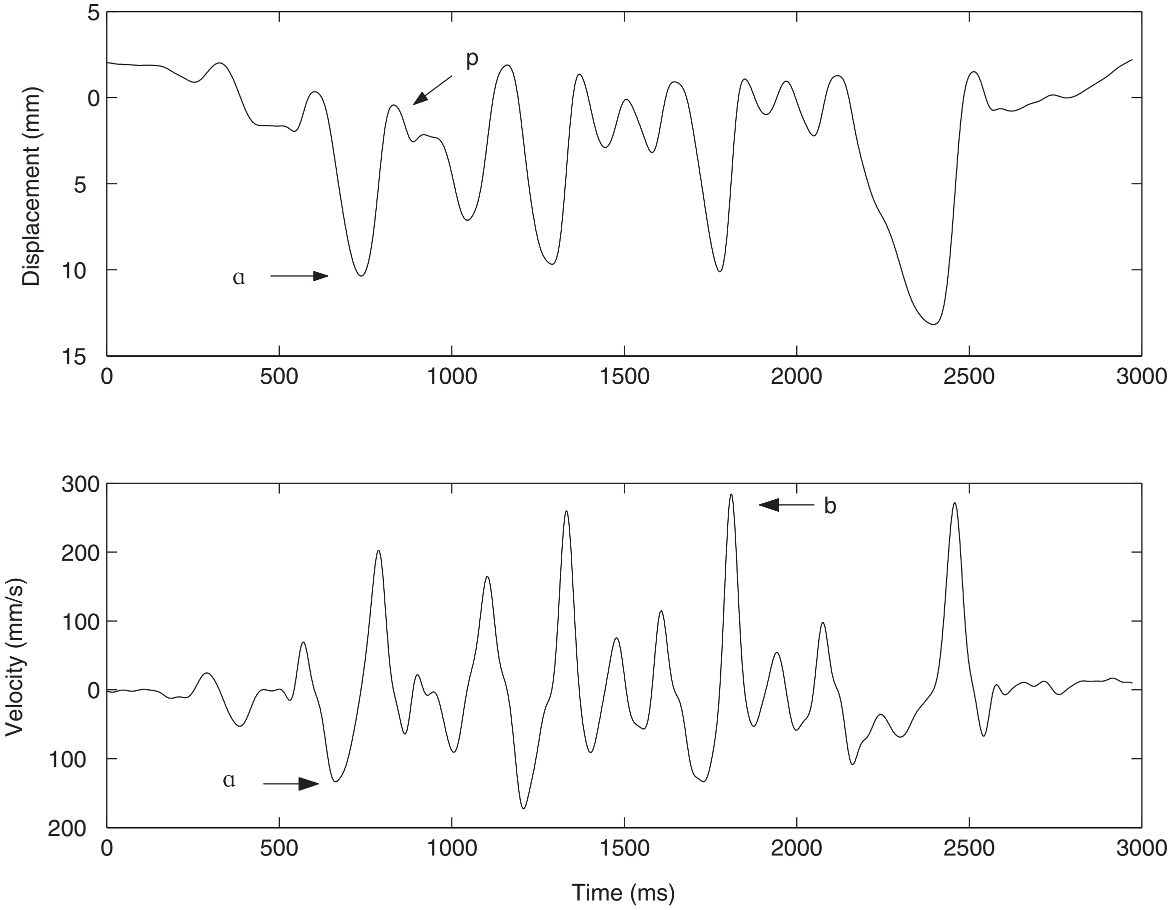
Duration

The utterance duration was measured from the peak velocity of the first opening movement (release of the /p/ in the word *Piper*) to the peak velocity of the last closing movement (closure of the first /b/ in the word *probably*). These kinematic landmarks allowed simple and reliable segmentation of the record because of the relatively large velocities associated with labial opening or closing. Figure 1 shows the starting and ending segmentation points in the lower lip velocity record in the lower pane. The duration measure was made to allow insights into possible speaking rate changes under the different experimental conditions.

Displacement and Velocity

Displacement was measured for the closing movement of the second /p/ in the word *Piper*, and peak velocity during the same movement was computed using a

Figure 1. Lower lip displacement (upper panel) and velocity (lower panel) during one token of the entire target utterance. The "a" and "p" arrows in the upper panel show the maximal downward displacement for the diphthong and the bilabial closure for the second /p/, respectively, in the word *Piper*. In the lower panel, the "a" arrow shows the opening velocity peak in the first syllable of the word *Piper* and the "b" arrow shows the closing velocity peak for the first /b/ in the word *probably*. These were the starting and ending points used to segment the waveform for duration, spatiotemporal, and correlation analyses.

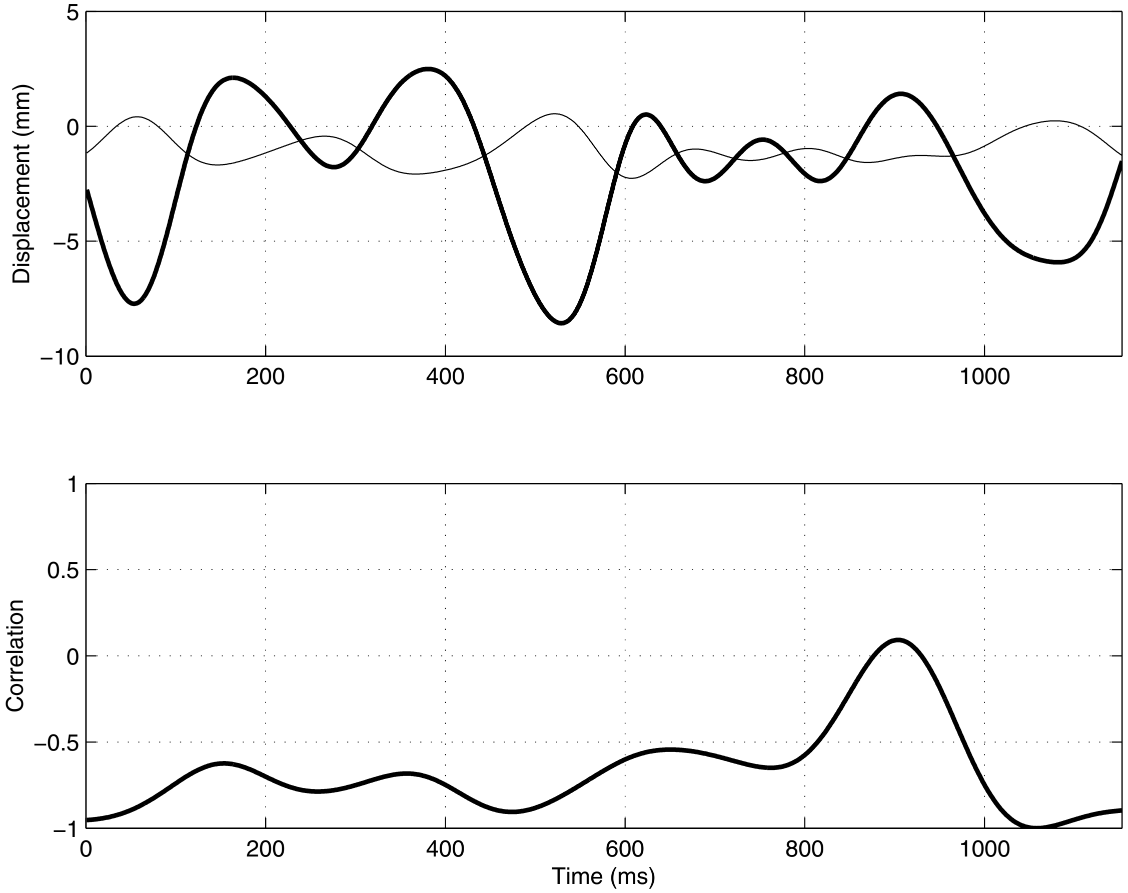


simple two-point difference method in MATLAB (see Figure 1). Point measures for specific gestures in a kinematic record have long been used as a means of comparing performance across conditions in a straightforward way. The gesture selected for measurement was readily identifiable because of the large closing movement early in the waveform. Differences in displacement and velocity could give insights into articulatory undershoot that may occur when speakers are distracted with the demands of a concurrent task.

Correlation

A running Pearson correlation function was computed between upper lip and lower lip displacement using a 5-point window that was moved along the entire kinematic record for the utterance. The upper panel of Figure 2 shows the lip displacement records, and the lower panel shows the continuous correlation function. This display reflects the degree to which upper lip and lower lip movements are out of phase with each other throughout the phrase. A single correlation coefficient was also calculated for the upper and lower lip displacements for the complete utterance. Thus, a correlation of –1 would mean that the lips parted and approximated in perfect synchrony during the utterance. The purpose of the correlation measure was to quantify at least in a gross sense the coordination of labial movements, although it is recognized that the movements of the lips at points other than during bilabial approximation would not necessarily require that they be 180° out of phase. Previous work using correlation as a dependent measure has revealed larger deviations from the theoretical –1 value in disordered speech compared to controls (Tingley & Dromey, 2000), and it was reasoned that a distraction during speech might similarly affect the upper and lower lip correlation in the present study.

Figure 2. Upper lip (thin line) and lower lip (thick line) displacement during the extracted analysis segment for one token are shown in the upper panel. The lower panel shows the continuous correlation function for the displacement of the two lips.



Spatiotemporal Index (STI)

The 10 displacement waveforms for the lower lip from each condition were time and amplitude normalized. Amplitude normalization was accomplished by subtracting the mean and dividing by the standard deviation of each record. Time normalization was achieved by a linear interpolation technique described by Kleinow and Smith (2000). A standard deviation was computed for the displacement across the 10 tokens at 50 equally spaced points along the record. The sum of these 50 standard deviations was the STI (Smith et al., 1995). The STI is an index of the consistency of the movements across 10 repetitions of an utterance. One reason for choosing the STI as a dependent measure was to allow comparisons with previous studies of speech under different conditions of linguistic load (Kleinow & Smith, 2000; Maner et al., 2000) that have also reported this index. Limitations of the STI have been identified previously (Lucero, Munhall, Gracco, & Ramsay, 1997). These limitations relate primarily to the fact that the STI involves linear time normalization across a kinematic record, although it is known that natural modifications to speech such as rate adjustment or speaking more clearly can result in nonlinear changes (Cutler & Butterfield, 1991; Flege, 1988). The STI does not differentiate between amplitude and temporal variability, but rather provides a simple overall measure of the degree to which multiple repetitions of a phrase are either similar or different. It was reasoned that this measure would allow a quantitative comparison of speech kinematic behavior across the experimental conditions of the study beyond the information available from the point measures described above.

Because the MATLAB analyses automatically extracted the dependent measures from the imported files, repeated measurements provided identical results, and experimenter reliability statistics were, therefore, not calculated. All signals examined during measurement were plotted and visually inspected to confirm the absence of errors in segmentation or software peak-picking.

The results were tested for significance with SPSS. A repeated-measures analysis of variance (ANOVA) was computed to compare each speech-plus-distractor task to its paired speech-only condition. The upper lip–lower lip correlation coefficients were z transformed to normalize their distribution prior to testing (Edwards, 1973). Gender was included as a between-subjects factor to test for differences between males and females for each task, because previous studies have found subtle male–female differences in tasks requiring the allocation of attentional resources to motor, cognitive, and verbal performance (Elliott et al., 1986; Naglieri & Rojahn, 2001).

Results

Descriptive statistics for the dependent variables were calculated for each condition and are summarized in Tables 1, 3, and 5. Repeated-measures ANOVA results are summarized in Tables 2, 4, and 6. No significant differences were found between the three speech-only conditions that served as baseline comparisons for the divided attention tasks.

Table 1. Means and standard deviations for men and women in the speech-only and speech-plus-motor distractor conditions.

Variable	Speech only		Speech plus motor	
	M	*SD*	*M*	*SD*
Duration (ms)				
Women	1103.92	124.01	1091.08	109.28
Men	1100.67	99.90	1115.38	161.54
Total	1102.30	109.61	1103.23	134.81
LL displacement (mm)				
Women	8.95	2.57	8.48	2.25
Men	11.29	2.48	10.48	2.22
Total	10.12	2.73	9.48	2.40
LL velocity (mm/s)				
Women	142.15	34.99	137.65	30.96
Men	179.75	45.43	168.55	38.78
Total	160.95	43.93	153.10	37.65
LL STI				
Women	10.96	3.71	11.02	2.62
Men	11.38	1.60	12.44	2.76
Total	11.17	2.79	11.73	2.72
UL–LL correlation				
Women	−.42	.31	−.45	.27
Men	−.61	.18	−.65	.15
Total	−.52	.26	−.55	.24
Token errors				
Women	0.70	1.06	0.60	0.84
Men	1.20	0.92	1.00	0.82
Total	0.95	1.00	0.80	0.83

Note. LL = lower lip; STI = spatiotemporal index; UL = upper lip.

Table 2. Repeated-measures analysis of variance main and interaction effects for speech-only and speech-plus-motor distractor conditions.

Variable	Motor		Motor × Gender interaction	
	F	*p*	*F*	*p*
Duration	0.003	.954	0.748	.398
LL displacement	12.563	.002**	0.909	.353
LL velocity	10.580	.004**	1.922	.183
LL STI	0.877	.361	0.705	.412
UL–LL correlation	3.546	.076	0.298	.592
Token errors	0.191	.668	0.021	.886

Note. Degrees of freedom are 1, 18 for all tests.

**$p < .01$.

Motor Distractor Effects

Lower lip displacement and velocity decreased significantly for the motor distractor task when compared to the speech-only condition (see Tables 1 and 2). However,

Table 3. Means and standard deviations for men and women in the speech-only and speech-plus-linguistic distractor conditions.

Variable	Speech only		Speech plus linguistic	
	M	*SD*	*M*	*SD*
Duration (ms)				
Women	1112.44	101.52	1112.83	119.72
Men	1075.81	83.34	1125.12	128.05
Total	1094.13	92.33	1118.98	120.82
LL displacement (mm)				
Women	8.83	2.33	8.76	2.39
Men	10.74	2.07	11.15	2.99
Total	9.78	2.36	9.95	2.91
LL velocity (mm/s)				
Women	140.71	32.19	141.04	32.45
Men	170.75	35.27	174.27	46.54
Total	155.73	36.30	157.65	42.60
LL STI				
Women	11.24	2.45	13.17	2.93
Men	12.11	2.69	17.00	3.40
Total	11.67	2.54	15.08	3.66
UL–LL correlation				
Women	−.35	.36	−.43	.33
Men	−.59	.22	−.62	.20
Total	−.47	.32	−.53	.28
Token errors				
Women	0.90	0.99	2.10	1.60
Men	0.70	0.82	2.10	0.99
Total	0.80	0.89	2.10	1.29

Table 4. Repeated-measures analysis of variance main and interaction effects for speech-only and speech-plus-linguistic distractor conditions.

Variable	Linguistic		Linguistic × Gender interaction	
	F	*p*	*F*	*p*
Duration	2.350	.143	2.277	.149
LL displacement	0.570	.460	1.195	.289
LL velocity	0.547	.469	0.376	.547
LL STI	27.791	<.001**	5.243	.034*
UL–LL correlation	5.042	.038*	2.395	.139
Token errors	13.226	.002**	0.078	.783

Note. Degrees of freedom are 1, 18 for all tests.

$^*p < .05$. $^{**}p < .01$.

there were no changes to the STI during the motor task. The negative correlation between upper and lower lip displacement became somewhat stronger for the motor task, but this increase was not significant at the $p < .05$ level.

Linguistic Distractor Effects

The STI for the lower lip increased significantly while participants performed the linguistic distractor task (see Tables 3 and 4). A significant gender interaction was found, which involved greater increases in STI values for men than women on the linguistic distractor task. The linguistic distractor task was associated with a significantly stronger negative correlation between the upper and lower lip.

As noted above, tokens that were visibly different in the lower lip waveform from the others under the same speaking condition were excluded from further analysis and replaced with others that were normally produced. A count was made of the excluded tokens to determine whether their frequency of occurrence was related to the speaking condition. Analysis revealed that there were significantly more rejected tokens in the linguistic distractor condition than in the speech-only condition.

Cognitive Distractor Effects

Individuals spoke significantly faster when distracted with the cognitive task (see Tables 5 and 6). The STI for the lower lip increased significantly while participants performed the cognitive distractor task. There was a significant gender interaction, which involved greater increases in STI for men than women on the cognitive distractor task. This condition led to a significantly stronger negative correlation between the upper and lower lip.

Table 5. Means and standard deviations for men and women in the speech-only and speech-plus-cognitive distractor conditions.

Variable	Speech only		Speech plus cognitive	
	M	*SD*	*M*	*SD*
Duration (ms)				
Women	1112.52	112.74	1061.48	93.36
Men	1107.39	118.18	1038.64	105.90
Total	1109.96	112.44	1050.06	97.87
LL displacement (mm)				
Women	8.76	2.77	8.42	2.49
Men	10.88	2.61	10.68	2.47
Total	9.82	2.83	9.55	2.68
LL velocity (mm/s)				
Women	138.72	36.24	135.67	33.70
Men	172.78	40.08	172.06	41.29
Total	155.75	41.09	153.87	41.16
LL STI				
Women	11.50	2.26	12.88	2.44
Men	11.33	1.91	15.81	3.34
Total	11.41	2.04	14.34	3.22
UL–LL correlation				
Women	−.39	.33	−.47	.26
Men	−.58	.20	−.65	.22
Total	−.48	.28	−.56	.25
Token errors				
Women	1.40	1.17	1.70	1.64
Men	1.00	1.25	1.40	1.26
Total	1.20	1.20	1.55	1.43

Discussion

The aim of this experiment was to determine how three types of distractor tasks performed simultaneously with speaking influenced the labial movements of

Table 6. Repeated-measures analysis of variance main and interaction effects for speech-only and speech-plus-cognitive distractor conditions.

Variable	Cognitive		Cognitive × Gender interaction	
	F	*p*	*F*	*p*
Duration	21.659	<.001**	0.473	.500
LL displacement	1.837	.192	0.137	.716
LL velocity	0.500	.488	0.190	.668
LL STI	21.527	<.001**	5.978	.025*
UL–LL correlation	6.246	.022*	0.090	.767
Token errors	1.145	.299	0.023	.880

Note. Degrees of freedom are 1, 18 for all tests.

$^*p < .05$. $^{**}p < .01$.

healthy, young adult speakers. The data show that the distractor tasks had a significant influence on a number of the dependent variables. In addition, the linguistic and cognitive distractor tasks had a greater influence on the consistency of lip movements in men than in women.

Motor Distractor Effects

The finding of reduced lip displacement and velocity in the motor distractor condition suggests that this task demanded enough processing capacity to affect the performance of the speaking task. Although the changes in displacement were not large, they were nevertheless clearly significant and they may reflect a subtle undershoot of articulatory targets when speakers are distracted with other motor demands. These reduced movement amplitudes may be comparable with the reduced speech intensity reported in a study of individuals with Parkinson's disease in a dual-task condition requiring hand movements (Ho et al., 2002). The speakers in their study had been instructed to speak consistently loudly. Ho and colleagues suggested that the distraction of a dual-task condition caused their speakers to pay less attention to loud speech production, allowing vocal effort to decline. Although no instructions were given to speakers in the present study regarding articulation, the subtle changes in lip movement amplitude may be a reflection of attentional resources being diverted to a cognitively simple but motorically demanding task.

Ebersbach, Dimitrijevic, and Poewe (1995) conducted a study involving a dual-task approach comparing gait with other combined cognitive and motor tasks. They found a significant decline in gait stride time during a rapid finger-tapping task. They attributed this change in performance (i.e., reduced stride time) in the dual-task condition either to limited attentional capacity or "to structural interference due to specific attentional interactions between the secondary and the primary task" (Ebersbach et al., 1995, p. 108). Although the gait rhythm remained consistent, the reduction in velocity of the gait pace found during fast finger-tapping may represent an interference in the subcortical areas that control both gait and finger movements. The lip movement changes reported in the present study for the manual distractor task may reflect a similar type of interference.

Smith, McFarland, and Weber (1986) found that changes in amplitude in speech had predictable effects on simultaneous finger movements, but changes in finger movements did not have the same effect on speech. Their data suggest that a motor control hierarchy may exist, with the control of speech taking precedence over finger movement. However, other authors have identified a bidirectional interaction between finger movements and speech production (Chang & Hammond, 1987; Kelso, Tuller, & Harris, 1983), suggesting that speech motor control can be influenced by manual activity. In the present study, the motor distractor task affected different speech movement variables from the cognitive or linguistic challenges. When participants were engaged in the manual task, their lip movements decreased in amplitude and peak velocity, whereas for the other dual-task conditions, the STI increased. The STI serves as a general index of the degree to which speech movements are consistent across multiple repetitions. Moving the hands in a purposeful way did not affect this consistency, whereas the other distractor tasks did. This may be related to the nature of the motor task itself. The functional distance hypothesis examined in previous work (LaBarba et al., 1987) suggests that when two simultaneous tasks make demands on the same regions of the brain, task interference will be the greatest. Presumably, the finger movements involved in assembling washers, nuts, and bolts did not interfere with the consistency of movement sequencing that affects the STI measure, whereas cognitive or linguistic requirements may have led to competition for these resources.

It is possible that the complexity of the manual motor task was not sufficient to significantly affect the consistency of the speech movements as reflected in the STI. The studies that have found finger movements to influence speech production have typically involved rapid or rhythmic unimanual finger tapping rather the more complex—but also more natural—bimanual task used in the present study. Because no measures were made of manual performance in this study, it is not possible to comment on any decrements in manual dexterity that speech may cause. Future experimental work involving quantification of manual activity would allow additional insights into any potential mutual effects of speech and hand movements, including the left–right asymmetries documented by previous investigators (Friedman et al., 1988).

Linguistic Distractor Effects

The fact that STI values increased significantly on the linguistic distractor task is consistent with the findings of Maner et al. (2000), who suggested that the consistency of speech movements across multiple repetitions is influenced by higher order processes such as language, cognition, and motor planning. The high STI values reflect less repeatable speech movements during the linguistic distractor task. It appears reasonable to suggest that the elevated STI values are a direct result of the simultaneous linguistic distractor task, because the length and the complexity of the target utterance remained the same as in the control condition.

As noted above, the influence of the linguistic and cognitive distractors was different from that of the manual task. The higher frequency of visible kinematic token errors in the linguistic distractor condition suggests that this task may have challenged speakers in different ways from the other tasks. When speakers were required to generate verbs from nouns, their lip displacements and peak velocities did not change, but the STI increased. This suggests that the neural resources dedicated to the production of consistent speech movements are also involved at least partly in the generation of language components.

Of necessity, laboratory measures of speech movement consistency require that stimuli be repeated, which is hardly representative of typical speech communication. Nevertheless, the requirement that speakers actively work on a language task while speaking is perhaps one step closer to the natural condition, and thus may be slightly more representative of daily speech production than the simple repetition of phrases that vary in grammatical complexity (Kleinow & Smith, 2000). The nature of the present task did not allow any indication of whether language performance declines as a function of speech production requirements, and future studies that manipulate articulatory demands (e.g., producing "tongue-twisters" vs. easier words) during a quantifiable language generation task may allow insights into any mutual interactions.

Cognitive Distractor Effects

The decreased duration in the cognitive distractor task indicates that the participants spoke significantly faster when cognitively distracted with an arithmetic task. It is possible that these findings are due to the beeps that were set at 3-s intervals to pace the utterances. It was observed that several of the participants had difficulty keeping pace with the beeps while trying to think of the next number in the sequence. As a result, the participants had to speed up the utterances to stay on track with the beeps. Six individuals who completed the remaining portions of the experiment successfully were excluded from the study because they were unable to accurately count backwards and keep up with the timing beeps.

As was found with the linguistic distractor task, the STI values increased significantly for the cognitive task, but the displacements and peak velocities did not change as they did for the motor distractor condition. In order to determine whether the STI increase might be linked to the more rapid speech rate, a Pearson correlation was calculated between the change in utterance duration and the increase in STI across speakers. The lack of a correlation ($r = .07$), indicated that speech rate was not linked to changes in STI. A rerun of the ANOVA with rate change as a covariate similarly failed to alter the outcome of the test. The results from the math task, therefore, reveal the impact that cognitive processes can have on motor performance (Maner et al., 2000; Smith & Goffman, 1998) independently of any change in rate. Baddeley (1992) explained how working memory is needed to execute complex tasks involving cognitive, linguistic, and motor skills, and that working memory's primary function is the coordination of information from different systems. The similar effects in the present study of cognitive and linguistic secondary tasks on speech kinematics may reflect overlaps in the demands each makes on the brain.

Baddeley's (1992, 1998) model of working memory posits a central executive that regulates two major subsystems: a phonological loop and a visual sketchpad. Participants in the present study may have involved the phonological loop in both the language and cognitive distractor conditions. One recent study (Seitz & Schumann-Hengsteler, 2000) suggested that performing more challenging mental arithmetic would involve the phonological loop as individuals silently repeat the numbers to themselves as they work through the problem. The present data suggest that the cognitive and linguistic challenges were more alike than either was to the manual task. The manual task was the only one that would involve the visual system. According to Baddeley's (1992, 1998) model, there would be less interference from this task, because it would not make demands on the phonological loop, which is presumably kept active in repeating the target utterances.

Upper Lip–Lower Lip Correlation

Perhaps the most surprising results of the present study were found in the correlation coefficients between the upper and lower lip movements. For the linguistic and cognitive distractor tasks, there was a significantly stronger negative correlation between the upper and lower lips. In other words, the upper lip and lower lip were more clearly out of phase across the utterance for these two distractor tasks than for the speech-only condition. This is contrary to our expectation that the upper lip and lower lip would be more negatively correlated on the speech-only tasks, because a strong negative correlation typifies normal patterning of lip movements, involving approximately 180° out-of-phase movements of the lips (Tingley & Dromey, 2000). We had anticipated that the demands of a concurrent task would degrade the speech motor performance in such a way that the lip movements might not be as fully coupled. However, this was not the case.

It is difficult to speculate why the lip movements became more negatively correlated in these distractor conditions. It is possible that when distracted, speakers relied on a more rigid coordination of labial movements, possibly involving different neural circuits, because more cortical resources were allocated to the distractor task. However, the STI also increased at the same time, indicating that movements from one repetition to the next were not as consistent as in the speech-only condition. This argues against a more rigid form of articulation when speakers were distracted. The STI and correlation measures both reflect activity throughout the entire utterance and, as such, do not allow conclusions to be drawn about the specific factors that cause them to change across conditions. Clearly, they represent different aspects of the labial movements, and thus may not necessarily be expected to follow similar patterns of change.

A qualitative examination of the correlation patterns (see the example in Figure 2) revealed that the largest deviations from a theoretical –1 correlation often occurred at times when lip movements (especially the upper) were modest in size. During these phonetic segments, precise movement coordination may not play an important role in sound production. It is noteworthy that the manual motor distractor task did not significantly affect the lip correlations. This suggests that it might have been qualitatively different from the other two tasks in its effects on labial kinematics. This would be consistent with the finding that it did not affect the STI, but did influence the displacement and peak velocity of the movements.

Gender Interactions

The gender interaction in which the STI increased more for men than for women in the linguistic task suggests that men may not be able to divide their attention between speaking and a distracting linguistic task as easily as women. A similar gender interaction found in the cognitive distractor task also implies that men have more difficulty than women in dividing their attention between speaking and cognitively distracting tasks. These implications allow us to speculate that women may be better at activities that require divided attention capabilities. Previous studies of dual-task performance have found either minimal (Elliott et al., 1986) or no differences (Seth-Smith et al., 1989) between men and women. Clearly, more research is needed in this area to extend the present findings.

An investigation of STI values measured from different speech rates (fast, normal, and slow) found that STI increased for men and not for women in the fast condition (Smith et al., 1995). Although their study did not examine divided attention effects on speech movements, the findings lend support to our speculation that women have more consistent speech movements under demanding conditions.

Developmental or Clinical Relevance

A number of previous studies have compared the speech production of younger children with older children, adults with children, or fluent with nonfluent speakers. All have attempted to examine speech motor performance in the context either of increased task demands or developmental or pathology-related differences. Green, Moore, and Reilly (2002) examined the displacements of the upper lip, lower lip, and jaw of 1-, 2-, and 6-year-olds and adults and found that 2-year-olds were actually less adult-like in their jaw movements than 1-year-olds. The authors suggested that 2-year-olds might experience a phase of reduced stability while they are gaining new lexical items at this age. Thus, the demands of language may necessitate compromises in speech motor performance. Kleinow and Smith (2000) investigated the influences of length and syntactic complexity on the speech stability of adults who stutter and found that adults who stutter had higher STI values for all experimental conditions than normally fluent adults. The presence of a communication disorder may limit the available communicative resources in such a way as to make motor output less consistent. Ellis Weismer and Evans (2002) provided evidence for processing capacity limitations in children with specific language impairment when they were faced with task demands that surpassed their level of processing capacity. Such findings are consistent with Crystal's (1987) model of resource allocation in spoken language production. They support the hypothesis that linguistic and cognitive loads have direct influences on other aspects of communication, similar to the increased speech motor variability in the dual-task conditions of the present study. It is interesting to note from the results of the present study that even in college-age, normally speaking individuals, the impact of linguistic, cognitive, and motor demands can be significant. Future experiments involving children who are acquiring speech and language skills or individuals with communication disorders could allow more direct insights into the relationships between task demands and breakdowns in performance. Research along these lines may potentially lead to improvements in clinical intervention.

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Appendix. List of nouns used to generate verbs in the linguistic distractor task.

House	Dog	School
Table	Money	Bridge
Tree	Key	Father
Ball	Letter	Leg
Hair	Hotel	Doctor