Title:

Speech production in people who ***stutter***: Testing the motor plan assembly hypothesis.

Authors:

van Lieshout, Pascal H. H. M., Nijmegen Inst of ***Cognition*** & Information, Nijmegen, Netherlands

Hulstijn, Wouter

Peters, Herman F. M.

Source:

Journal of Speech & Hearing Research, Vol 39(1), Feb, 1996. pp. 76-92.

Abstract:

Tested the hypothesis that persons who ***stutter*** compared with nonstutterers are less able to assemble abstract motor plans for short verbal responses. 12 men who ***stutter*** and 12 age- and sex-matched controls were tested on naming pictures and words using a choice reaction time (RT) paradigm. Speech RTs, word durations, and relative timing of specific motor events in the respiratory, phonatory, and articulatory sub-systems were measured. Results show that, in spite of longer speech RTs for ***stutterers***, there is no interaction with word size. Word durations were longer for ***stutterers***, and there was an interaction of group with word size. Both findings were associated with longer delays for ***stutterers*** in the onset of upper lip integrated electromyographic (IEMG) activity and thoracic compression, and a group effect on the order of upper lip and lower lip IEMG onset. ***Stutterers*** may use different motor control strategies to compensate for reduced verbal motor skill.

Nijmegen Institute of Cognition and Information and University Hospital, Department of Voice and Speech Disorders Nijmegen, The Netherlands, Wouter Hulstijn Nijmegen Institute of Cognition and Information and University of Nijmegen The Netherlands, Herman F.M. Peters, University Hospital, Department of Voice and Speech Disorders and University of Nijmegen The Netherlands

The main purpose of the present study was to test the hypothesis that persons who stutter, when compared to persons who do not stutter, are less able to assemble abstract motor plans for short verbal responses. Subjects were adult males who stutter and age-and sex-matched control speakers, who were tested on naming pictures and words, using a choice-reaction time paradigm for both tasks. Words varied in the number of syllables (1,2,and 3 syllables) and, for the bisyllabic words, also in the number of consonants (one or more) at the onset of the second syllable. Measurements consisted of speech reaction times, word durations, and measures of relative timing of specific motor events in the respiratory, phonatory, and articulatory subsystems.

Results indicated that, in spite of longer speech reaction times for persons who stutter in comparison to control speakers, there was no interaction with word size, a finding that does not lend support to the above mentioned hypothesis. Word durations were found to be longer for persons who stutter, and, in addition, there was an interaction of group with word size. Both findings were associated with longer delays for persons who stutter in the onset of upper lip

integrated electromyographic (IEMG) activity and thoracic compression, and a group effect on the order of upper lip and lower lip IEMG onset. Findings are taken to suggest the possibility that persons who stutter may use different motor control strategies to compensate for a reduced verbal motor skill, and although the nature of this reduced skill is unknown, it is speculated that it relates to the processes involved in the integration of sensory-motor information.

KEY WORDS: speech motor control, stuttering, linguistic effects, speech physiology

From a behavioral point of view, stuttering involves an involuntary disruption in the motor production of speech. It would seem, therefore, thai in order to explain stuttering, a theoretical framework is needed in which variables that are known for their impact on stuttering are accounted for in terms of their influence on speech motor control (see also Smith, 1990). One of the most salient factors in this respect is word size (e.g., see Peters, Hulstijn, & Starkweather, 1989; Prins, Hubbard, & Krause, 1991; Soderberg, 1966; and also see Andrews et al., 1983, Starkweather, 1987; Young, 1985 for reviews). In general, the effect is assumed to occur because long words are considered to be more complex than shod words. Complexity, however, can be defined in a number of ways.

One more or less traditional view in speech motor research claims that this complexity arises from the fact that long words have more production units (e.g., syllables or sounds), which will affect the time needed to prepare the motor commands for speech (see Klapp, 1977; Monsell, 1986; Shaffer, 1984; and for a more general theoretical account, see Schmidt, 1988; Van Galen, 1991). For normal speaking subjects, evidence in support of this claim was found in both simple (Sternberg, Monsell, Knoll, & Wright, 1978; Sternberg, Wright, Knoll, & Monsell, 1980; Watson, Freeman, & Dembowski, 1991) and choice reaction time studies (Klapp, 1974; Klapp, Anderson, & Berrian, 1973; Rosenbaum, Gordon, Stillings, & Feinstein, 1987). The fact that word size effects are found in both simple and choice reaction time tasks, is explained by Verwey (1994) by assuming that the length of a verbal sequence can influence the processing time of two different stages. On a general level, the first stage involves the creation and buffering of an abstract (verbal) motor plan, starting at the phonological encoding process using word form information from the mental lexicon (see also Levelt, 1989). The second stage involves the subsequent translation of the abstract motor plan into the appropriate muscle commands (see also Verwey, 1994). To avoid the usual confusion in terminology that arises from words like planning and programming, the first stage will be referred to by motor plan assembly and the second stage by muscle command preparation.

Peters et al. (1989) argued that the longer verbal reaction times often found in persons who stutter, especially with more complex utterances, relates to increased demands on motor programming, as they called it. Although Peters et al. did not precisely specify what stage in speech production they were referring to, it seems that it comes very close to what is called here motor plan assembly. To test their hypothesis, Peters et al. compared verbal reaction times of a group of persons who stutter and a group of matched control speakers for monosyllabic words, polysyllabic words, and sentences. Both groups showed a significant increase in reaction time for the polysyllabic words and sentences, but especially for the polysyllabic words (one vs. three-/four-syllable words) this effect was clearly stronger for the person who stutter (but see also Young, 1994, for an alternative analysis of these data). Because their data further indicated that the effect was primarily located in the early parts of the reaction time interval, Peters et al. (1989) concluded that their data supported the claim that persons who stutter may have problems in assembling abstract motor plans. More recently, Dembowski and Watson (1991) and Watson, Pool, Devous, Freeman, and Finitzo (1992) were only partially successful in finding the same effect of word size on reaction time differences between persons who do and do not stutter. In both studies the equivocal results were attributed to subgroup differences within the experimental group. However, apart from that, these studies differed in a number of ways from the study of Peters et al. (1989)--for example, in the type and number of stimuli, the duration of intertrial intervals (ITIs), and the type of reaction time task (simple vs. choice).

The present study tested whether persons who stutter, in comparison with control speakers, have more problems in assembling abstract motor plans. Although in many ways similar to the study of Peters et al. (1989), this research involves some important modifications. First, sentences were not used to avoid confounding with prosodic and syntactic factors that operate at the sentence level. Second, instead of comparing monosyllabic words with three- and four-syllable words as in Peters et al., this study used a more refined range of word size, varying the number of syllables per word (one vs. two vs. three) in steps of one. This way it could be determined more precisely whether each extra syllable really counts in its influence on the word size effect, or, alternatively, that the word size effect is more generally based on short (monosyllabic) versus long (polysyllabic) words, without a clear difference between words with more than one syllable (see also Klapp & Wyatt, 1976; Sternberg et al., 1978). Although the number of syllables is generally considered to be more critical to eliciting the word size effect (e.g., see Klapp et al., 1973; Levelt & Wheeldon, 1994), it is in theory possible that phonemes and not syllables form the basic unit in motor plan assembling. Therefore, the number of phonemes per word was varied by using bisyllabic words differing in the number of consonants (one vs. two or three) at the onset of the second syllable.

Longer words may not only affect the assembly of the motor plan, they may also be more difficult to articulate (e.g., having less familiar articulatory patterns and/or more complex prosodic patterns). This was noticed earlier by Soderberg (1966), who stated that "the more complex phonetic structure of longer words makes such words generally more difficult to pronounce and consequently more susceptible to being stuttered" (pp. 586-587). Persons who stutter have been found to have not only delayed reaction times but also delays in speech execution (e.g., see Borden, 1983; McMillan & Pindzola, 1986; Pindzola, 1987; Postma, Kolk, & Povel, 1990; Zimmermann, 1980), and this effect might be increased by word complexity. Therefore, in addition to speech reaction times, word duration as a general estimate of speech execution time was measured.

Another important difference from the study by Peters et al. (1989) was the use of two different naming tasks. In general, word-naming tasks as used by Peters et al. may introduce confounding effects at the level of motor plan assembly, with possible reading time differences between words that vary in the number of graphemes (Eviatar & Zaidel, 1991; Naveh-Benjamin & Ayres 1986; but see Hudson & Bergman, 1985 and Rossmeissl &. Thelos, 1982). In the present study, word naming was compared to picture naming (see Glaser, 1992 for an extensive review of this type of task). For the latter task, effects of word complexity can be determined independently from the visual features of the stimulus (Klapp et al., 1973). For both tasks a choice reaction time paradigm was used. This is claimed to be more suitable than simple RT tasks to study effects of motor plan assembly (Hulstijn, 1987; Klapp et al., 1979; Sheridan, 1981; Verwey, 1994).

As argued by Peters et al. (1989) and others (Borden & Watson, 1987; Shipp, Izdebski, & Morrissey, 1984; Smith, 1990; Watson & Alfonso, 1987), group differences in speech reaction time can be evaluated more precisely by studying temporal variations in the three underlying subsystems of speech motor production (respiration, phonation, and articulation). To accomplish this, recordings were made of movements of the abdominal and thoracic chest wall by means of mercury strain gauges, of laryngeal activity by means of electroglottography (EGG), and of integrated electromyographic (IEMG) activity of upper and lower lip by means of surface EMG. Peters et al. (1989) did not use measures of respiration, but several studies (e.g., Holt, Solomon, & Hixon, 1993; Watson & Alfonso, 1983, 1987; Shipp et al., 1984) have shown that speech-related respiration is importantly related to the timing of other speech motor events.

In sum, the main purpose of the present study was to assess the hypothesis that persons who stutter have problems in the assembly of an (abstract) motor plan for a word. It was predicted that words with more syllables or sounds would show relatively stronger delay effects on naming latencies in persons who stutter, as compared to matched control speakers. Simultaneous measures in the respiratory, phonatory, and articulatory domain were used to qualify group differences in naming latencies and execution times in the light of the relative timing and sequencing of specific motor events. In doing so, the present study focused on perceptually fluent speech to avoid a contamination with physiological events that arise as a result of a dysfluency (see also McClean, 1990). It is in this respect an advantage that in the type of reaction time experiment that is used in the present study most persons who stutter (except those with a very severe stutter) will not produce many dysfluencies at all. Of course, the disadvantage is that a test on the effect of word size on stuttering frequency becomes rather dubious with so little data and a high between-subject variability. But, it has to be noticed that even if there were a sufficient number of dysfluencies across all subjects, finding a difference in stuttering frequency between short and long words would only indicate and confirm that longer words are apparently more difficult[1] to handle for persons who stutter. Whether this difficulty relates to aspects of motor plan assembly or to aspects of muscle command preparation and execution remains unclear. It is for that reason that the measures that are used in the present study were chosen, because they do offer the possibility of making such a distinction (see also Dembowski & Watson, 1991; Peters et al., 1989).

Method

Subjects

Subjects were 12 males who stutter (mean age 27.2 years, SD = 7.3), and 12 age- and gender-matched persons who do not stutter. The subjects of both groups were also matched on educational level. All subjects had normal hearing acuity, normal language and voice quality, and normal vision. None of the persons who stutter had been in treatment during the preceding year. They were selected from a clinical population of people who stutter and were evaluated before participating in the experiment in the ENT clinic of the academic hospital in Nijmegen.

Stuttering severity was determined by an experienced speech-language pathologist using the Stuttering Severity Instrument (SSI; Riley, 1972) scores on oral reading and conversational speech, both recorded on video before the experiment. Of the persons who stuttered, 5 were classified as very mild, 2 as mild, and 5 as moderate. All subjects were volunteers and were payed 10 Dutch guilders per hour for their participation.

Design and Procedure

Stimuli. Word responses could be elicited either by printed words or by pictures used as stimuli in the two naming tasks. Word size was manipulated by using words varying in number of syllables (one, two, or three) and, for bisyllabic words, also in number of consonants at the onset of the second syllable (see Appendix). All words were relatively low-frequency nouns (< 70/million), based on 42 million tokens in CELEX, a computerized Dutch lexical database (Burnage, 1990). For the two naming tasks different words[2] were used, but they were carefully matched on number of phonemes, primary stress (first syllable), word class (nouns), and initial sound.

The monosyllabic words (1 syl) occurred as the first syllable in the two- (2 syl) and three- (3 syl) syllable words, which were in fact compounds. There were two types of bisyllabic words. One type had a single consonant at the onset of the second syllable (2 syl/s), and the other had multiple (2 or 3) consonants at the onset of the second syllable (2 syl/m). The onset of a word was either a consonant (/b/ or /m/) or a vowel (/o:/ or /u:/). All four initial phonemes were combined with all four levels (1 syl, 2 syl/s, 2 syl/m, and 3 syl) of the word size factor. To measure lip EMG activity, word-initial voiced bilabials and central/back rounded vowels were used, thus maintaining voicing constant for all measured words. The mean number of graphemes for the words in the word-naming task was 3.9 (SD = .64) for the monosyllabic words, 7.4 (SD = .92) for the bisyllabic words with single consonant onset at the second syllable, 8.9 (SD = .99) for the bisyllabic words with multiple consonants onset at the second syllable, and 9.8 (SD = 1.16) for the trisyliabic words.

For the picture-naming task, pictures (see Appendix in Lankhorst, Van Lieshout, Peters, & Hulstijn, 1992) were drawn by a professional artist, adjusted in size, and attached to a plastic frame of 10 x 10 cm to allow a clear view of the picture during the experiment. Because word criteria were rather strict, it was impossible to use a set of normalized pictures (e.g., see Snodgrass & Vanderwart, 1980). Subjects were familiarized with the pictures before the experimental condition to avoid problems in naming (see Tasks).

Procedure. Preliminary to the experiment, persons who stutter were asked to read aloud a standard text, and subsequently they were engaged in a brief dialogue with the experimenter. These speech tasks were videotaped and used afterwards for estimating the stuttering severity of all stuttering subjects.

In general, a subject was instructed to respond immediately to a stimulus on the screen (arrow or word), presented simultaneously with a beep (Go-signal). The subject's response consisted of naming the correct picture label or reading the word aloud. The subject was asked to fixate his eyes on a dot in the middle of the screen. Both speed and accuracy were emphasized, that is, the subject was told that correct performance was as important as fast performance. The subject was also informed about the short intervals between successive trials. Reaction times were monitored using voice-key data. When subjects appeared to loose their concentration (as demonstrated by a gradual general slowing down of reaction times compared with previous trials), the experimenter who monitored the voice-key reaction times repeated the instruction to respond fast and accurately. The two naming tasks were presented in a single session, separated by a short break. The order of the tasks was balanced across subjects. Each task was preceded by a practice session of 20 trials, using pictures and words that were different from the experimental stimuli. During the experiment the subject was seated in front of the monitor in the presence of one experimenter. Another experimenter controlled the equipment in an adjacent room.

Tasks. A choice reaction-time paradigm was used for both naming tasks, in which feedback on reaction times was not provided, As mentioned, before the start. of an experimental block in the picture-naming task, subjects were familiarized with a set of pictures and their verbal labels, which were a monosyllabic, bisyllabic (two different types), or trisyllabic word. For a given set of words, the plastic frames with the attached drawings were presented to the subject one by one in random order, after having been told the correct verbal label for each picture. Once subjects could give the correct label for all pictures in three successive trials and when they indicated that they felt confident about having mastered the combinations, the pictures were placed at their appropriate position (see below) on a plastic support to start the naming task. Of course, the number of different picture-word combinations that can be learned for one block of trials is limited. In the present experiment it was set to four, according to what has been reported in literature for a similar type of task (cf. Levelt & Wheeldon, 1994). In general, learning for one set of 4 different picture-word combinations was accomplished in less than five trials for members of both groups.

As explained above, word-size levels were not confounded with initial sound, that is, four different word-initial phonemes (/o:/, /u:/, /m/, and /b/) were used for each complexity level. For practical reasons, the number of different words per initial phoneme level was limited to one for the picture-naming task, which results in a total of 16 different words (see Appendix). These 16 words were assigned to four sets of four different picture-word combinations, such that within a set the four word-size levels were presented with a different initial phoneme (e.g., meer, bierkan, oorsprong, oerwouden). This prevented subjects from adopting a fixed a priori lip position during an experimental block. The four different picture-word sets were presented in a balanced order across the experimental subjects, but for each subject only the data from the first set was analyzed for reasons discussed below. An experimental block consisted of one set of four picture-word combinations, from which each picture had to be named 24 times in a random order, for a total of 96 trials interrupted by a short break at midpoint.

Each of the four pictures in a set was inserted in a holder attached to one of the corners of a hard-plastic support (45 x 40 cm), placed directly in front of a computer display, thus leaving a central 15 x 10 cm rectangle of the screen uncovered (see Figure 1).

The pictures remained in sight during all 96 trials of a block. The intertrial interval (ITI) was 1500 ms. A trial started with a 1000 Hz tone of 100 ms duration indicating the appearance of an arrow in the center of the screen. The arrow pointed in random order to one of the four pictures on the frame (see Figure 1). As soon as the arrow appeared, the subjects had to speak the verbal label for the indicated picture. The distance from arrow point to picture was equal (9 cm) for all positions. After 1 s the arrow disappeared from the screen, signaling to the subject the end of the trial. The subject was told to finish his response, even when the arrow had disappeared. It was assumed that given the relatively short and fixed ITI subjects would remain highly alert and willing to react as fast as possible to the Go-signal. This is in contrast to the study by Peters et al. (1989), in which variable and relatively long ITI and foreperiod durations were used.

The monitor with the frame to which the pictures were attached was placed at a distance of 1 m in front of the subject. The set-up of the picture-naming task, with pictures remaining in sight and the arrow shifting directions, was designed so that the directional information of the pointing arrow was sufficient to identify the picture at that particular frame position. Possible differences in visual complexity among the four pictures of a set could thus be minimized. Across subjects, the frame position of pictures representing a specific word-size level was varied in a balanced order, to minimize a left to right and top to bottom gaze-direction bias that might have influenced reaction times.

In the word-naming task, apart from word-selection criteria, there is no critical limitation on the number of different words that can be named, in contrast to the picture-naming task, where subjects first had to learn a particular picture-word combination. Therefore, the number of different words per word-size level was increased to eight, for a total of 32 different words for this task. The ITI for the word-naming task was 2000 ms, that is, 500 ms longer than in the picture-naming task. Unfortunately, this task difference was not detected until after the experimental sessions, and therefore remained uncorrected.[3]

Before the start of the word-naming task, subjects had to read aloud all the items that were to be used. In this way; errors that were due to incorrect pronunciation or linguistic stress assignment could be noticed and corrected. During the task, words were presented one by one in 1 cm uppercase letters in the central uncovered part of the screen. This setup was identical to the experimental setup of the word-naming tasks of Peters et al. (1989), to allow for a more direct comparison. Each of the 32 words was repeated three times, resulting in 96 trials, presented in a random order and interrupted at midpoint by a short break. After 1 s, the word disappeared from the screen.

Instrumentation. The presentation of the stimulus (arrow or word) on a monochrome (green) graphics monitor, the acoustic Go-signal, the starting and stopping of a 14-channel FM instrumentation recorder (TEAC), and the registration of voice-key reaction times, were under control of an Apple lie microcomputer. Voice-key data were used by the experimenter to monitor the subject's reaction time and were not displayed to the subject.

Movements of the rib cage and abdomen were tracked by mercury strain gauges similar to those described by Cavallo and Baken (1985; see also Baken, 1987). The strain gauges were positioned across the anterior chest wall at the level of the nipples (thoracic signal) and the umbilicus (abdominal signal). Only temporal measures were taken. The output of the strain gauges was amplified by a bridge amplifier (Honeywell, Accudata 143).

Vocal fold impedance for EGG measures was recorded using a Fourcin Laryngograph (Fourcin, 1981). To this end, gold-plated circular electrodes were placed on the subject's skin, over the thyroid cartilage, one on each side, and equidistant from the midline. The electrodes were held in place by a velcro-fastened elastic band around the subject's neck.

Lip EMG activity was recorded using small (0.4 mm) silverball electrodes (Sanel Sokki, Inc.). These were attached bilaterally with flexible tape at the junction of the vermilion border for upper lip and lower lip, approximately 1.25 cm from the median raphe (see also Peters et al., 1989 and Van Lieshout, Peters, Starkweather, & Hulstijn, 1993). For other purposes, not discussed here., surface EMG electrodes (Beckmann) were positioned 3 cm lateral to and equidistant from the midline on the thyroid lamina at the level of the thyroid notch. For the EMG measurements a reference electrode was positioned on the skin covering the mastoid. EMG electrodes were connected to differential preamplifiers (Honeywell, EMG preamplifier). The output of the preamplifiers was fed to amplifiers (Honeywell, Accudata 135) set at a frequency range of 50-500 Hz. Analog EMG signals were rectified and integrated with a time constant of 40 ms.

Finally, the acoustic speech signal was recorded using an AKG (type 451 E) condenser microphone, which was placed approximately 30 cm in front of the subject's mouth. All signals, including a pulse signal indicating the start and stop of a trial, were recorded on the FM instrumentation recorder. In addition a hard copy of the signals was made by means of a seven-channel polygraph recording (Elema-Schoenander) with a high frequency cut-off of 700 Hz and a paper recording speed of 50 mm/s.

Fluency Criteria and Data Analysis

Time measures, similar to those described by Peters et al. (1989) and Watson and Alfonso (1987), were taken from the polygraph paper recordings, using a Calcomp 2500 digitizer (resolution 0.4 mm), in combination with a cross-hair stylus, both connected to an Atari 1040 ST personal computer. For the purpose of this study, only those utterances were analyzed that were perceptually judged to have been spoken fluently. As described in Peters et al. (1989), in order to be considered fluent an utterance had to satisfy two criteria. First, there should be no visible signs of struggle in the subject's face or body just before or during the trial sequence. Every instance of such signs was noted during the experimental sessions. Second, the utterance should not contain audible hesitations, prolongations, repetitions, or any other perceptual sign of speech dysfluency. During the experimental sessions, dysfluencies were noted and checked afterwards by an experienced speech-language pathologist who listened repeatedly to audio recordings of the subject's speech. In total, 7.3% of the picture-naming data and 3.2% of the word-naming data were classified as dysfluent and excluded from further analysis. Next, all trials in which subjects made naming errors were excluded. In addition, for the respiratory EGG and IEMG signals to be included, there could be no signs of electrode movement artifacts, abnormal activity (e.g., a generalized excessive IEMG background activity), or any other signal disruptions. This way, it was expected that in addition to recording artifacts, (clear) instances of subperceptual stuttering could be excluded from the data. Subjects who stutter were not explicitly asked to indicate if they detected a (subperceptual) dysfluency in their performance. We wanted to avoid putting them in a dual-task situation in which a secondary task (monitor speech performance) would interfere with their performance on the actual naming task and thus bias their data.

An example of a trial displaying the temporal measures that were taken is shown in Figure 2. All responses were analyzed twice, and temporal markers had to be agreed on by both experimenters, according to the criteria given below, before they were included in the final data analysis (see Watson & Alfonso, 1987 for a similar method). Below is a list of temporal measures that were used as dependent variables in the present study. For each measure the percentage of missing values is given in parentheses (1152 trials = 100%). These missing values involve dysfluent responses as well as naming and signal errors. For each measure, missing values are given separately for picture naming (PN) and word naming (WN), and for control speakers (NS) and persons who stutter (ST).

ACOUSTIC SPEECH ACTIVITY (microphone signal):

1. Speech reaction time (RTs): the time between the onset of the Go-signal and the onset of the acoustic signal (NS: PN = 2.1%, WN = 7.5%; ST: PN = 13.7%, WN : 12.9%).
2. To calculate word duration, the offset of the acoustic signal was measured (NS: PN = 2.3%, WN = 8.1%; ST: PN = 13.8%, WN = 12.9%).

MOTOR EVENTS:

Laryngeal/phonatory activity (EGG signal):

1. Initial glottal closure: the time between the onset of the Go-signal and the onset of the first rapid oscillation in the EGG signal (NS: PN = 52.1%, WN = 52.6%; ST: PN = 59.1%, WN = 58.6%). It should be noted that in most cases the initial glottal closure could only be measured for vowel onsets (see also Peters et al., 1989), which accounts for the high percentage of missing values.
2. Onset of phonation: the time between the onset of the Go-signal and the onset of vocal fold oscillations in the EGG signal (NS: PN = 3.3%, WN = 10.9% ; ST: PN = 13.8%, WN = 15.5%).

Lip activity (IEMG signals):

1. Upper lip IEMG latency: the time between the onset of the Go-signal and the onset of upper lip IEMG activity (NS: PN = 4.9%, WN = 9.0%; ST: PN = 17.8%, WN = 16.9%).
2. Lower lip IEMG latency: the time between the onset of the Go-signal and the onset of lower lip IEMG activity (NS: PN = 9.4%, WN = 11.5%; ST: PN = 16.2%, WN = 17.7%).

Respiration activity (mercury strain gauge signals):

1. Thoracic inspiration latency: the time between the onset of the Go-signal and the onset of a marked upward deflection[4] in the thoracic trace (NS: PN = 4.0%, WN = 11.8%; ST: PN = 17.3%, WN = 15.6%).

2. Thoracic expiration latency: the time between the onset of the Go-signal and the onset of a marked downward deflection in the thoracic trace (NS: PN = 4.0%, WN = 10.5%; ST: PN = 17.4% WN = 14.9%).
3. Abdominal inspiration latency: the time between the onset of the Go-signal and the onset of a marked upward deflection in the abdominal trace (NS: PN = 12.2%, WN = 18.5%; ST: PN = 16.4%, WN = 14.6%).
4. Abdominal expiration latency: the time between the onset of the Go-signal and the onset of a marked downward deflection in the abdominal trace (NS: PN = 12.1%, WN = 18.7%; ST: PN = 16.4%, WN = 14.6%).

Inspection of the data revealed no imbalances across word-size levels that would have influenced the results of the analyses. As mentioned above, only the data of the first block for each subject in the picture-naming task were used. This was done to equate for the total number of trials (24) per word-size level in the two naming tasks. Furthermore, it prevented a bias in the picture-naming data due to a general sequence effect (practice, fatigue, transfer of training, etc.) that could affect word-size effects across the four blocks, in spite of the counterbalancing of block order (cf. Winer, 1962). Such an effect was suggested by an inspection of voice-key reaction time data across the four blocks. Because of the balanced order of the four different word sets across subjects, group comparisons could be made without a systematic bias of a particular word set on word-size effects. Although the number of trials per word-size level was the same for both tasks, it has to be taken into account that because of the different task requirements (see above), each subject had only 3 repetitions per individual item (32 in total) in the word-naming task, as opposed to 24 repetitions per single item (4 in total) in the picture-naming task. Thus, within-block practice effects on single items will be stronger for picture naming.

Statistical Analysis

Variations in initial sound might influence reaction times (Dembowski & Watson, 1991; Peters et al., 1989), but as already mentioned, in the experiment described here initial sound and word-size levels were not confounded. Therefore, all data were pooled across the initial sound variations.

In order to reduce susceptibility to outliers in the data, median values were calculated per subject (Ferguson, 1984), separately for each task and word-size level, across a maximum of 24 trials for each level. When the median could not be calculated because of missing data, it was replaced by the group median value for that particular task's specific word-size level. This strategy was used for 37 (1.9%) out of a total of 24 x 2 x 4 x 10 = 1920 cells (i.e., 24 Subjects x 2 Tasks x 4 Conditions [1 syl, 2 syl/s, 2 syl/m, 3 syl] x 10 Dependent variables).

Analyses of variance were performed separately for picture naming and word naming, following a two-factor mixed design with repeated measures on speech reaction time and word duration. Group (persons who stutter and matched control speakers) was the between-subject factor, and word size (4 levels) formed the within-subject factor. F-values on word-size main and interaction effects are based on the multivariate tests (Hotellings T^2). For :significant group effects, Eta Squared (eta^2), that is, the percentage of the total variation that is attributed to group membership, and Omega Squared (pi^2) values, that is, the percentage of total variation accounted for in the population from which the subjects were randomly sampled, as well as 95% confidence intervals (CI) and the percentage of subjects misclassified (PM) are given (see Young, 1994 for more details). For word-size main effects, planned post hoc orthogonal comparisons were made on the difference between 2 syl/s and 2 syl/m words, between I syl words and the average of polysyllabic words, and between the average of bisyllabic words (2 syl/s and 2 syl/m) and 3 syl words.

To test for group differences in relative timing, separately for each task, a multivariate step-down analysis of variance was used on the dependent measures mentioned in the above list under the heading of motor events, ordered according to the temporal sequence shown by the control speakers (see also Figure 2). By removing the effects of previous variables on the F-value of a particular variable (not the first), the unique contribution of each variable to group differences can be estimated. In line with Stevens (1972) and Bochner and Fitzpatrick (1980), information on the between-variables correlations, as well as on the step-down univariate measure of association (eta^2) was added.

In most studies on speech breathing the focus is on the timing of abdominal and thoracic compression onset (e.g., see Baken & Cavallo, 1981; Baken, Cavallo, & Weissman, 1979; Hixon, Goldman, & Mead, 1973). For inspiration such a differentiation seems less crucial, and with respect to possible group differences, Watson and Alfonso (1987) showed that persons who stutter were not differentiated from control speakers in the timing of the onset of thoracic and abdominal expansion. Also, as indicated by Zemlin (1981), "In most persons, the abdomen and lower and upper thorax all expand during inhalation, but there is not much question that the region of predominant expansion may vary from individual to individual" (p. 115). Therefore, the average of abdominal and thoracic expansion onset was taken as a general estimate of the onset of inspiration. For all tests a significance level of 0.05 was used.

Results

Speech Reaction Time and Word Duration

Picture naming. Figure 3(A) shows the group and word-size effects for persons who stutter and control speakers in the picture-naming task for the speech reaction time. The corresponding means and standard deviations can be found in Table 1.

In general; when compared to the control speakers, persons who stutter showed significantly longer speech reaction times (group difference: 120 ms), $F(1,22) = 6.66$, $p = .017$, $eta^2 = 23.2$, $omega^2 = 19.1$, CI = (23.54)-(215.96), PM = 29.8. Although word size did seem to have some influence,the main effect was not significant, $F(3,20) = 2.51$, $p = .09$, and neither was the group-by-word-size interaction, $F(3,20) = 1.32$, $p = .30$.

With respect to word duration [see Figure 3(C) and Table 1], it was found that persons who stutter had significantly longer durations than control speakers (group difference: 86 ms), $F(1,22) = 9.30$, $p = .006$, eta^2 : 29.7, $omega_2 = 25.7$, CI = (27.71)-(145.35), PM = 26.4. As could be expected, word size had a clear effect on execution time, $F(3,20) = 201.08$, $p < .001$. More interestingly, there was also a significant group-by-word-size interaction, $F(3,20) = 5.24$, p =

.008. Planned orthogonal comparisons revealed that this interaction effect was based on a significant group effect for the difference between the monosyllabic and the three polysyllabic words, $F(1,22) = 13.13$, $p = .002$. This indicates that persons who stutter, compared with persons who do not stutter, showed a greater increase in word duration from monosyllabic to polysyllabic words--see also Figure 3(C). Also notice that for monosyllabic words, the group difference was very small (17 ms).

Word naming. For the word-naming task, Figure 3(B) shows the effects for speech reaction time (see also Table 1). In contrast to the picture-naming task, there was no significant group effect, $F(1,22) = 2.62$, $p = .12$. The word-size main effect was significant, $F(3,20) = 17.60$, $p < .001$, but as with the picture-naming task, the interaction with group was not, $F(3,20) = .58$, $p = .63$. Planned orthogonal comparisons on main word-size effects revealed a significant difference of 30 ms between monosyllabic words and the average of the polysyllabic words, $F(1,20) = 46.15$, $p < .001$.

For word duration, group and word-size effects are shown in Figure 3(D)--see also Table 1. The group mean difference (127 ms)was significant, $F(1,22) = 23.17$, $p < .001$, $eta^2 = 51.3$, $omega^2 = 48.0$; CI = (72.13)-(181.31); PM = 16.4, as was the expected main effect for word size, $F(3,20) = 301.80$, $p < .001$. There was a significant group-by-word-size interaction, $F(3,20) = 4.99$, $p = .01$. Planned orthogonal comparisons revealed that this interaction, as in picture naming, was based on a significant group effect for the difference between monosyllabic and polysyllabic words, $F(1,22) = 16.32$, $p = .001$. As can be seen in Figure 3(D), persons who stutter showed a greater increase in word duration for longer words than did control speakers. Also, notice the longer word duration of persons who stutter (70 ms) for the monosyllabic words, in contrast to the much smaller group difference found in picture naming.

Group Differences in the Relative Timing of Speech Motor Events

Figure 4(A) shows the group differences on the sequencing and timing of respiratory, phonatory, and articulatory events for picture naming, and 3(B) for word naming. Group means, standard deviations, univariate F-values for group effect, including eta^2, $omega^2$, CI, and PM values, are given in Table 2.

In addition, this table presents step-down F-values and step-down eta^2 values. For the step-down analysis, the dependent variables were ordered according to the sequence of motor events as shown by the control speakers for a particular task. Pearson product moment correlations between the dependent variables are shown in Table 3, separately for picture naming and word naming.

Picture naming. For picture naming, the univariate analysis showed significant group effects for the onset of upper lip IEMG, lower lip IEMG, phonation, and thoracic compression. The group difference in the onset of inspiration (140 ms) was nearly identical to the group difference in upper lip IEMG onset (142 ms), but because of its larger between-subject variation it was not significant. As can be seen in Figure 4(A) for the initial glottal closure, persons who stutter did not show an overall delay of the same magnitude in all motor events. Figure 4(A) data indicate that the delay in IEMG latencies was of the same magnitude as the delay in the onset of inspiration; however, the step-down analysis showed that after removing the inspiration effect, the adjusted F-value for the upper lip IEMG onset decreased, but remained significant. The Eta Squared value decreased from 30.2% to 21.6%. However, all other group effects disappeared, as could be expected on basis of the high between-variables correlations. The only variable for which both groups, but especially the control speakers, showed relatively small correlations with other variables, was the onset of abdominal compression (Table 3).

Word naming. For word naming, significant group differences were only found for the onset of upper lip IEMG and the onset of thoracic compression (Table 2). As shown in Figure 4(B), the delays for persons who stutter were smaller than in picture naming, and so were the group effects. This was also shown in the reaction time data. Results of the step-down analysis revealed that the group effects for upper lip and thoracic compression remained intact, although for the latter variable the adjusted F-value was only marginally significant ($p = .054$). The Eta Squared values for both variables increased slightly. For the onset of upper lip IEMG the (adjusted) Eta Squared value was somewhat higher in the word-naming task as compared with the picture-naming task. Pearson Product moment between-variables correlations in the word-naming task were comparable to the correlations found in the picture-naming task, except for the very low correlations found for the onset of inspiration in the data of the persons who stutter. The control speakers did not show such a striking difference, but, as in picture naming, they did show low correlations for the onset of abdominal compression.

With regard to the sequencing of motor events, both groups showed a similar pattern, with one exception: the interlip interval. In Figure 5 the means (and standard deviations) for this interval are shown, a negative value indicating that the lower lip came first. Group differences in picture naming, $F(1,22) = 4.70$, $p < .05$, $eta^2 = 17.6$, $eta^2 = 13.4$, CI = (-48.94)-(-1.08), PM = 33.0, and word naming, $F(1,20) = 5.38$, $p < .05$, $eta^2 = 19.7$, $omega^2 = 15.4$, CI = (-66.41)-(-3.71), PM = 31.9, were significant.

Discussion

In brief, it was found that during perceptually fluent speech, persons who stutter, when compared with matched control speakers, exhibited (a) longer reaction times, but this overall group effect was only significant for picture naming; (b) longer word durations, as shown by significant group effects in picture naming and word naming; (c) greater increase in word duration for longer words, as shown by a significant group-by-word complexity interaction in both naming tasks; (d) significant delays in the relative timing of specific motor events, in particular of the upper lip IEMG onset and of the onset of thoracic compression; and (e) a different order in lip onset (lower lip IEMG onset before upper lip IEMG onset).

Reaction Time Data

The primary goal of the study described here was to provide support for the claim that persons who stutter are different from persons who do not stutter in the assembly of a motor plan for a verbal response (Peters et al., 1989). The most convincing evidence for such a claim would have been a stronger group difference in speech reaction time for the polysyllabic words in comparison with the monosyllabic words. This interaction effect, however, was found neither in picture naming nor in word naming, despite a significant difference in reaction time between monosyllabic and polysyllabic words in the latter task, which replicated the effect of word size found by Peters et al. (1989), although to a smaller extent.

The overall group difference in reaction time was not as large as expected and was significant only for picture naming. The latter finding is also not in line with the "motor plan assembly" hypothesis, because in the picture-naming task subjects had more practice on a small number of verbal responses, compared to the word naming task. If the assembly of motor plans is a problem or the persons who stutter, the strongest group effect in reaction time should have occurred in the word-naming task.

The group difference in reaction time found in picture naming can have many different origins. For example, there is the possibility that it relates to the retrieval of semantic information (see also Van Lieshout, Hulstijn, & Peters, 1991), which is commonly believed to be a necessary stage in picture naming in contrast to word naming (cf. Glaser, 1992). Or, it is also possible that the group difference in picture naming relates to processes that are involved in the building and retrieval of the associations between the pictures and their verbal labels. Such a suggestion was made by Bosshardt (1993), who found impaired recall and recognition performance for persons who stutter in comparison with matched control speakers. In sum, the task effect on group differences in reaction time found in the present study may indicate subtle differences between persons who stutter and control speakers in higher order (linguistic or memory) processing of verbal stimuli (see also Rastatter & Dell, 1987). Alternatively, or perhaps in addition, there may be an influence at the level of motor processing, a possibility that will be discussed below.

The present study does not corroborate earlier findings on difficulties that persons who stutter may have in the generation of abstract motor plans (Peters et al., 1989, but see also Postma & Kolk, 1993, for a recent review on this aspect). Of course, this negative result cannot be taken as a falsification of the hypothesis in question, but it does weaken its claim. Although it is always difficult to speculate about why an effect has not occurred, some aspects can be mentioned that seem relevant in trying to explain why the data from the present study may have failed to provide evidence in favor of the motor plan assembly hypothesis.

First, there are between-study differences in the manipulation of word complexity. Peters et al. (1989) compared one-syllable words with three-to four-syllable words, whereas in the present experiment the longest word had three syllables. In picture naming, the last syllable of the three-syllable words was a suffix indicating a plural, which is a very common word ending in Dutch. Thus, it is possible that the word-size range used in the present study was too restricted to bring forward a clear group difference in reaction times for longer words. Furthermore, stimuli used by Peters et al. (1989) may have had lower word or syllable frequencies (see Levelt & Wheeldon, 1994) or may have been more difficult in their prosodic structure (see also Wingate, 1988). All these factors could influence the demands on the assembling of a motor plan. Some indication that processing demands may have been reduced in the present study may be found in the picture-naming task. In this task word size did not significantly affect reaction times. Furthermore, the fact that only a few items (4) were repeated a number of times (24) may have resulted in a working memory representation of their motor plans, assembled in the first trials of the task (see also Baddeley, 1990; Mitchell, 1989; and Monsell, 1984 for more detailed information on this matter). Practice, however, did not "destroy" all group-by-word-size interaction effects, as can be seen for word duration. Perhaps practice of a few different items had a stronger effect for the motor plan assembly stage, as compared to following stages in speech production. This may indicate that as far as group differences are concerned, the latter ones are more critical.

The main effect of word size found in word naming suggests that in this task the creation cf a motor plan was influenced by the number of syllables. The strongest difference is seen--see Figure 3(B)--between one- and two-syllable words, whereas the effect on reaction time of adding one more syllable or sound to a word seems to be of little consequence (see also Klapp & Wyatt, 1976; Sternberg et al., 1978). The larger number of different items (36) and the small number of repetitions per item (3) makes a working memory account less likely here, so it is more likely that this effect reflects a true word-size effect as was found in Peters et al. (1989). However, a possible effect of longer words on reading time (cf. Eviatar & Zaidel, 1991; Naveh-Benjamin & Ayres, 1986, but see Rossmeissl & Theios, 1982 and Hudson & Bergman, 1985) has to taken into account as well.

Second, the issue of subject selection should be considered with regard to the present study's lack of demonstrating a group-by-complexity interaction effect. Both Dembowski and Watson (1991) and Watson et al. (1992) argued that word-size effects can be quite different for individual persons who stutter. For example, "Stutterer subgroups might be distinguished by the presence, loci, and relative magnitude of cortical and/or subcortical abnormality in region(s) subserving speech production" (Watson et al., 1992, p. 560). Although Watson et al. also claim that stuttering severity is not systematically related to reaction time differences, Dembowski and Watson (1991) showed that word size affects people with severe stutters more than it affects those with mild stutters. In the present study, stuttering severity ranged from very mild to moderate. In principle, therefore, it is possible that difficulty in assembling a motor plan did not show up in the data of the persons who stutter in the present experiment simply because they formed a subgroup that does not have such problems. Of course, this would also seriously weaken the generality of the motor plan hypothesis for people who stutter. Clearly, the definition of subjects and the choice of appropriate selection criteria in stuttering research is an important issue, as is the choice of stable parameters by which group differences can be detected reliably (see also Alfonso, 1990; Borden, 1990; Schwartz & Conture, 1988). With regard to the latter issue, it is interesting that although persons who stutter showed no evidence of a problem in the assembly of abstract verbal motor plans, they were different from control speakers in the relative timing of motor events.

As regards the group differences found by Peters et al. (1989), there is one more aspect that has to be noted. In their study, Peters et al. did not check for the influence of breathing patterns on speech reaction times. In a recent paper, Winkworth, Davis, Ellis, and Adams (1994) showed that (normal) subjects tend to be very consistent in the timing of inspiration; they also showed that utterance size influences speech breathing; In the study by Peters et al. (1989) waiting periods between trials were variable and long (up to 10s), especially in the sentence condition, which may have made their subjects uncertain about the proper moment to inhale. Therefore, to reduce this uncertainty, they may have tried to time the onset of inspiration to the presentation of the stimulus. In the present study, the between-variable correlations (Table 3) for the picture-naming task showed that for both groups the timing of the onset of inspiration was related to the timing of later motor events, including the onset of phonation (see also Watson & Alfonso, 1987). In addition, the interval between inspiration onset and phonation was remarkably similar for persons who stutter (734 ms) and control speakers (754 ms). Together, these data seem to suggest that in the picture-naming task the larger group difference in reaction time, compared with word naming, had a clear origin in the onset of inspiration (but see also the alternative explanations mentioned above). A similar account might hold for at least part of the group effects found by Peters et al. (1989), thus shifting the focus from the stage of motor plan assembly to the stage of muscle command preparation.

Relative Timing Data

Persons who stutter exhibited delays in the onset of upper lip IEMG. Although the group difference in the onset of inspiration was not significant, the average delay in inspiration was very similar to the delay found for the onset of upper lip IEMG. The influence of inspiration onset on the onset of upper lip IEMG (and later events as mentioned above) was also shown in the results of the step-down analyses. This corroborates earlier findings by Watson and Alfonso (1987). In their study, short preparation intervals seemed particularly to hinder their stuttering subjects' ability to appropriately begin inhalation, leading to significant delays in the laryngeal reaction times of persons who stutter. In the present study, intertrial intervals were 500 ms shorter for picture naming than for word naming and, consistent with Watson and Alfonso (1987), the delay in the onset of inspiration was larger for picture naming, especially for the persons who stutter. It has to be noted, however, that the between-subject variability in the onset of inspiration was quite large in both tasks.

In the step-down analyses, the group effect in the onset of upper lip IEMG, although attenuated, remained significant in both tasks after removing the effect of the onset of inspiration. The onset of lower lip IEMG was also delayed, but to a lesser extent than for the upper lip, which seems to explain the group difference in the order of upper lip and lower lip IEMG onset. The order aspect itself might be less crucial, since Gracco (1988) showed that the order of synergistic muscle onsets can be variable across subjects (in his study normal speakers) and may be influenced by a number of factors, including small fluctuations in the excitability of motoneuron pools of the muscles in question. In this respect, it is important to notice the between-subject variability in the interlip interval data for both groups (see Figure 5). However, Gracco (1988) also indicated that at the same time the individual muscle onsets are adjusted in a consistent manner. This was taken as evidence that synergistic muscles are initiated by a common control signal, reflecting a functional relationship between individual articulators as part of a coordinative structure (see also Gracco, 1994; Saltzman & Munhall, 1989). In the present study, it was shown that across subjects (Table 3) there were co-variations in the onset of IEMG of synergistic articulators (upper lip and lower lip). Thus, if a given subject showed a delay in the IEMG onset of one lip, he would also show a delay in the other lip. The question remains, however, why persons who stutter would delay the onset of their muscle activity.

To answer this question, another finding of Gracco (1988) warrants attention. In his study, Gracco showed that there was a relationship between the timing of EMG onset and the use of biomechanical properties of the articulators, in particular elastic strain energy. He stated that "appropriately adjusted neural signals can interact with the release of elastic strain energy to increase movement speed, strongly influencing the "efficiency" of rhythmic speech production" (p. 4637). More generally, normal speakers, just like highly skilled performers in other motor tasks, are highly capable of exploiting built-in dynamic constraints to reduce computational Icad and sensory information processing. This will make their movements more automated and thus faster and/or more energetic (see Schmidt, 1988 for a detailed discussion of this topic). Persons who stutter, on the other hand, may have developed less efficient motor schemes or coordinative structures (e.g., Saltzman, 1991); or they may have an inherently unstable motor control system at the level of the supplementary motor area (SMA; e.g., Webster, 1990, 1993; Watson et al., 1992; see also Goldberg, 1985 for an extended discussion of the role of SMA in speech production); or they may have failed in low-level sensory-motor learning (Kalveram, 1993); or they may even have deficits in their sensory-motor integration capacities (Neilson & Neilson, 1987, 1991). Whichever hypothesis eventually proves to be valid, it seems that, in general, persons who stutter are at the low end of a verbal motor skill continuum (see also Prescott, 1988). Clearly, this might also involve the use of different motor control strategies, in which a stronger emphasis is placed on the monitoring function of proprioceptive feedback (see also De Nil, 1994; Hulstijn, Summers, Van Lieshout, & Peters, 1992; Hulstijn, Van Lieshout, & Peters, 1991; Van Lieshout et al., 1993; Van Lieshout, Alfonso, Hulstijn, & Peters, 1994). A predominantly feedback-driven mode of motor control is more time consuming and puts restrictions on the range of movement speeds that can be dealt with effectively. In line with Gracco's (1988) ideas, this might explain the group difference in lip IEMG onset, as well as the group difference in word duration (see below), as found in the present study. Furthermore, if persons who stutter have to give more attention[5] (see also Arends, Povel, & Kolk, 1988) to evaluating sensory information in order to control their speech movements, this demand on attentional resources at the level of the speech motor act could interfere with the parallel processing of other (e.g., linguistic) sources of information (see also Nudelman, Herbrich, Hoyt, & Rosenfield, 1989, 1991; Peters & Starkweather, 1990; Webster, 1990, 1993; see also Naatanen, 1992 for a more general review of parallel processing capacities in humans).

Word Duration Data

In the present study, persons who stutter had longer word durations than control speakers, in particular for longer words. Pindzola (1987) found that persons who stutter tend to spend more time than control speakers in static articulatory positions, which she explained by assuming that persons who stutter delay the initiation of co-articulatory movements. Such a delay could arise when persons who stutter first complete the execution of one motor unit (e.g., a syllabic gesture, see Levelt & Wheeldon, 1994) and, before proceeding, remain in a relatively steady articulatory state position for a variable amount of time, awaiting incoming sensory information to adjust forthcoming muscle commands. It was mentioned above that persons who stutter may use this motor control strategy to compensate for a reduced verbal motor skill. Neilson and Neilson (1991) suggested that the reduced verbal motor skill of persons who stutter is based on their problems in integrating sensory-motor information and "as a consequence of this deficiency the stutterer must do one of the following: spend longer in evaluating the sensory-motor relationships involved in speech, evaluate them less precisely, or deploy additional resources at the expense of other concurrent functions" (p. 155). The first suggestion was discussed above, that is, persons who stutter spend longer in evaluating the sensory-motor relationships. If persons who stutter depend more strongly on the integration of sensory-motor information, the almost continuous need for updating this information during speech production should be a function of word size, because longer responses need more often updating. This could explain the group-by-word-size interaction effect that was found for word duration in the study described here. Practice, on the other hand, should facilitate the integration of this kind of information (e.g., see Kalveram, 1993, Zimmermann & Hanley, 1983 and also Schmidt, 1988 and Verwey, 1994 for a general discussion of practice effects on motor control and movement execution), which might explain the stronger overall group difference in word duration for word naming (less practice per item) compared to picture naming (more practice per item). These word-duration effects might relate to the task effect on group differences for the onset of thoracic compression. Baken and his colleagues (Baken et al., 1979; Baken, McManus, & Cavallo, 1983; Cavallo & Baken, 1985) argue that the timing of chest wall adjustment is important in regulating ventilatory pressures during the act of speaking. Thus, the onset of thoracic compression may play a major part in the processing of sensory-motor information.

Recently, McClean, Levandowski, and Cord (1994), found that highly dysfluent subjects who had received intensive speech treatment tend to show longer movement durations, which was attributed to compensatory adjustments to facilitate fluent speech. In the present study it is argued that a reduced movement speed might reflect a predominantly feedback-driven mode of motor control. It is possible that in the way speech behaviors are modified in these kinds of programs (e.g., by using prolonged speech), the use of this motor control strategy is implicitly encouraged (see also Alfonso, Kalinowski, & Story, 1991). In essence, these programs are trying to help the person who stutters to learn new verbal motor skills. McClean et al. (1994) also found evidence that highly dysfluent persons who stutter but lack a history of intensive speech treatment did not show the same increase in timing durations as highly dysfluent persons who stutter but did have a treatment history. Rather, they showed a reduced variability in timing durations, which was attributed to an excessive sensory-motor coupling deficit as modeled by Kalveram (1993). Although this is quite opposite to the suggestion of the present study that persons who stutter have less well-developed motor skills and as a result may show a stronger emphasis on the use of sensory information in motor control, it clearly stresses the importance of sensory-motor integration as a major topic in future stuttering research.

To conclude, results of the present study do not support the hypothesis that persons who stutter differ from persons who do not stutter in the assembly of abstract motor plans for speech. The findings do suggest that there may be a group difference in the preferred type of motor control strategy. The reason for this difference is as yet unknown. However, there is growing evidence that the integration of sensory-motor information may be a crucial factor to consider in this respect.

Acknowledgments

This research was supported in part by the Netherlands Organization of Scientific Research (NWO), Grant 560-259-031. The authors wish to express their gratitude to Erna Lankhorst for her valuable assistance in the experiments and data analysis, as well as for her active participation throughout the research period. We also wish to thank Martin Nicolasen for his help in getting all systems running. We thank Ed Conture for his valuable comments and suggestions

on an earlier version of this manuscript. Finally, we thank Dr. Watson, Dr. Pindzola, and two anonymous reviewers whose comments and suggestions were of great help in improving this manuscript.

1. In fact, taking into account the very. small percentage of dysfluencies in the present experiment (see Method section), it was found that longer words in general induced more dysfluencies than short words in picture naming (9.2% vs. 1.4%) and word naming (3.9% vs. 1.1%).
2. There were two exceptions to this rule. The one-syllable words/o:r/and/u:r/ appeared in both naming tasks. Furthermore, since the design of the experiment was such that one-syllable words were also used as the first syllable in longer words, /o:r/and/u:r/also appeared as the first syllable in (different) longer words in both naming tasks.
3. The problem turned out to be caused by an incomplete software specification that controlled the generation of the stimuli in a so called "hidden" video mode.
4. The onset of a deflection was defined as a point in time that was followed by a (continued) minimal rise (inspiration) or decline (expiration) in the signal of 1 mm within a 100 ms (5 mm) interval.
5. The word attention is used in a general sense, not necessarily denoting a conscious mental activity (see also Webster, 1993).

TABLE 1:

Means and standard deviations (in parentheses) in ms of overall reaction time speech and word duration for persons who stutter and control speakers, separately for picture naming and word naming and within each task for word-size levels.

Legend for Chart:

A - Reaction time speech, Control speakers
B - Reaction time speech, Persons who stutter
C - Word duration, Control speakers
D - Word duration, Persons who stutter

	A	B	C	D
PICTURE NAMING				
1 syl	733	867	443	460
	(106)	(105)	(61)	(62)
2 syl/s	768	854	654	737
	(88)	(118)	(109)	(62)
2 syl/m	771	909	689	808
	(110)	(186)	(107)	(101)
3 syl	727	850	737	864
	(137)	(124)	(107)	(87)
WORD NAMING				
1 syl	539	604	418	488

	(77)	(92)	(53)	(69)
2 syl/s	563	627	618	750
	(89)	(101)	(64)	(65)
2 syl/m	582	632	660	805
	(83)	(95)	(62)	(80)
3 syl	577	632	736	895
	(87)	(103)	(67)	(89)

Note. 1 syl = monosyllabic word, 2 syl/s = bisyllabic words with single consonant at second syllable onset, 2 syl/m = bisyllabic words with multiple consonants at second syllable onset, and 3 syl = trisyllabic words.

TABLE 2:

Means (and SD) of dependent variables (7) for persons who stutter and control speakers, univariate F-values (F) for group effect, including eta^2, eta^2, the confidence intervals (CI), and the percentage of subjects misclassified (PM) values, as well as step-down F-values (F*), including step-down eta^2 values (eta^2.), separately for picture naming and word naming.

Legend for Chart:

A - Control speakers
B - Persons who stutter
C - F
D - eta^2
E - omega^2
F - CI
G - PM
H - F[a]
I - eta$^{2[a]}$

	A D G	B E H	C F I
PICTURE NAMING			
Inspiration onset	28	168	2.90
	11.7	7.3	(-30.47)-(310.39)
	36.3	--	--
	(222)	(178)	
Upper lip IEMG onset	532	674	9.50[b]
	30.3	26.2	(46.23)-(236.21)
	26.4	5.80[1]	21.6
	(92)	(129)	
Lower lip IEMG onset	547	663	6.61[a]
	23.1	18.9	(22.46)-(209.96)
	30.2	1.71	7.9

	(96)	(123)	
Initial glottal closure	661	741	3.74
	14.5	10.3	(-5.69)-(164.07)
	34.8	.06	.30
	(93)	(107)	
Abdominal compression onset	739	862	3.68
	14.4	10.1	(-9.92)-(257.06)
	34.8	.28	1.5
	(111)	(193)	
Phonation onset	782	902	6.52[a]
	22.9	18.7	(22.58)-(217.64)
	30.2	.44	2.5
	(104)	(126)	
Thoracic compression onset	931	1124	7.89[b]
	26.4	22.3	(50.42)-(334.92)
	28.4	.85	5.1
	(158)	(178)	
WORD NAMING			
Inspiration onset	-172	-109	.25
	1.1	3.2	(-194.52)-(318.90)
	46.0	--	--
	(286)	(320)	
Upper lip IEMG onset	348	435	6.43[a]
	22.6	18.5	(15.94)-(158.96)
	30.2	7.06[a]	25.2
	(74)	(93)	
Lower lip IEMG onset	370	422	2.11
	8.7	4.4	(-22.48)-(127.28)
	38.2	2.35	10.5
	(89)	(88)	
Initial glottal closure	494	571	3.40
	13.4	9.1	(-9.62)-(163.38)
	35.2	.14	.7
	(90)	(113)	

Abdominal compression onset	567	617	.71
	3.1	-1.2	(-73.25)-(174.03)
	43.3	.22	1.2
	(118)	(169)	
Phonation onset	597	654	2.59
	10.5	6.2	(-16.41)-(130.35)
	37.1	.55	3.2
	(84)	(90)	
Thoracic compression onset	693	821	5.15[a]
	19.0	14.7	(11.02)-(246.00)
	32.3	4.32[a]	21.3
	(145)	(132)	

[a] p </= .05; [b] p </= .01

TABLE 3:

Pearson product moment correlations (N = 12) for persons who stutter (above the diagonal) and control speakers (below the diagonal) for all dependent variables (7), separately for picture naming and word naming. Significant correlations ($p < .05$) are in boldface.

Legend for Chart:

A - Inspiration onset (A)
B - Upper lip IEMG onset (B)
C - Lower lip IEMG onset (C)
D - Initial glottal closure (D)
E - Abdominal compression onset (E)
F - Phonation onset (F)
G - Thoracic compression onset (G)

	A	B	C	D	E	F	G
PICTURE NAMING							
A	--	.715	.688	.658	.428	.702	.772
B	.690	--	.986	.824	.769	.988	.697
C	.657	.939	--	.850	.805	.983	.673
D	.830	.870	.901	--	.566	.807	.549
E	.544	.253	.415	.481	--	.787	.552
F	.826	.907	.884	.902	.384	--	.643
G	.585	.742	.731	.760	.170	.848	--

WORD NAMING

A	--	.483	.480	.454	.207	.259	-.428
B	.691	--	.897	.870	.784	.919	.291
C	.699	.939	--	.870	.848	.916	.263
D	.665	.960	.889	--	.737	.893	.347
E	.396	.416	.467	.494	--	.894	.390
F	.768	.919	.883	.957	.375	--	.500
G	.513	.543	.486	.598	-.111	.724	--

DIAGRAM: FIGURE 1. Schematic representation of the presentation screen for the picture naming task, showing the position of the picture frames and the part of the screen where the arrow was presented.

DIAGRAM: FIGURE 2. Examples of signals in the acoustic, phonatory, articulatory, and respiratory domain for a typical trial, showing (1) onset of speech, (2) offset of speech, (3) onset of the initial glottal closure, (4) onset of glottal oscillations (phonation), (5) onset of upper lip IEMG, (6) onset of lower lip IEMG, (7) onset of thoracic expansion, (8) onset of thoracic compression, (9) onset of abdominal expansion, and (10) onset of abdominal compression. The original pen recordings have been highlighted for clear reproduction.

GRAPHS: FIGURE 3. Data of persons who stutter and control speakers for monosyllabic words (1 syl), bisyllabic words with single consonant onset for the second syllable (2 syl/s), or multiple consonants onset for the second syllable (2 syl/m), and trisyllabic words (3 syl) for speech reaction time in the picture-naming task (A) and the word-naming task (B), as well as for word duration in the picture-naming task (C) and the word-naming task (D).

ILLUSTRATION: FIGURE 4. Group differences in the temporal sequencing and timing of the onsets of inspiration, upper lip IEMG, lower lip IEMG, the initial glottal closure, abdominal compression, phonation, and thoracic compression for the picture-naming task (A) and the word-naming task (B).

GRAPH: FIGURE 5. Mean interlip interval data for persons who stutter and control speakers in the picture naming and word-naming task. Standard deviations are given in parentheses.

References

Alfonso, P. J. (1990). Subject definition and selection criteria for stuttering research in adult subjects. In J. A. Cooper (Ed.), Research needs in stuttering: Roadblocks and future directions (ASHA Reports No. 18, pp. 15-24). Rockville, MD: American Speech-Language-Hearing Association.

Alfonso, P. J., Kalinowski, J. S., & Story, R. S. (1991). The effect of speech motor training on stutterers' speech physiology. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), Speech motor control and stuttering (pp. 513-527). Amsterdam: Elsevier Science Publishers.

Andrews, G., Craig, A., Feyer, A.-M., Hoddinott, S., Howie, P., & Neilson, M. (1983). Stuttering: A review of research findings and theories circa 1982. Journal of Speech and Hearing Research, 48, 226--246.

Arends, N., Povel, D.-J., & Kolk, H. (1988). Stuttering as an attentional phenomenon. Journal of Fluency Disorders, 13, 141151.

Baddeley, A. (1990). Human memory: Theory and practice. Hove and London: Lawrence Erlbaum Associates.

Baken, R. J. (1987). Clinical measurement of speech and voice. Boston: Allyn and Bacon.

Baken, R. J., & Cavallo, S. A. (1981). Prephonatory chest wall posturing. Folia Phoniatrica, 33, 193-203.

Baken, R. J., Cavallo, S. A., & Weissman, K. L. (1979). Chest wall movements prior to phonation. Journal of Speech and Hearing Research, 22, 862-872.

Baken, R. J., McManus, D. A., & Cavallo, S. A. (1983). Prephonatory chest wall posturing in stutterers. Journal of Speech and Heating Research, 26, 444-450.

Bochner, A. P., & Fitzpatrick, M. A. (1980). Multivariate analysis of variance: Techniques, models, and applications in communication research. In P. R. Monge & J. N. Cappella (Eds.), Multivariate techniques in human communication research (pp. 143-174). New York: Academic Press.

Borden, G. J. (1983). Initiation versus execution time during manual and oral counting by stutterers. Journal of Speech and Hearing Research, 26, 389-396.

Bordon, G. J. (1990). Subtyping adult stutterers for research purposes. In J. A. Cooper (Ed.), Research needs in stuttering: Roadblocks and future directions (ASHA Reports No. 18, pp. 58-62). Rockville, MD: American Speech-Language-Hearing Association.

Bordon, G. J., & Watson, B.C. (1987). Methodological aspects of simultaneous measurements: Limitations and possibilities. In H. F. M, Peters & W. Hulstijn (Eds.), Speech motor dynamics in stuttering (pp. 83-97). Wien: Springer-Verlag.

Bosshardt, H.,-G. (1993). Differences between stutterers' and non-stutterers' short-term recall and recognition performance. Journal of Speech and Hearing Research, 36, 286-293.

Burnage, G. (1990). CELEX--A guide for users: English linguistic guide; Appendices, glossary, and indexes. Centre for Lexical Information, University of Nijmegen.

Cavallo, S. A., & Baken, R. J. (1985). Prephonatory laryngeal and chest wall dynamics. Journal of Speech and Hearing Research, 28, 79-87.

Dembowski, J., & Watson, B.C. (1991). Preparation time and response complexity effects on stutterers' and nonstutterers' acoustic LRT. Journal of Speech and Hearing Research, 34, 45-59.

De Nil, L. F. (1994, August). The role of oral sensory feedback in the coordination of articulatory movements in adults who stutter: a hypothesis. Paper presented at the First World Congress on Fluency Disorders, Munich, Germany.

Eviatar, Z., & Zaidel, E. (1991). The effects of word length and emotionality on hemispheric contribution to lexical decision. Neuropsychologia, 29, 415-428.

Ferguson, G. A. (1984). Statistical analysis in psychology and education. Auckland, New Zealand: McGraw-Hill.

Fourcin, A. J. (1981). Laryngographic assessment of phonatory function. In C. Ludlow & M. O'Connell (Eds.), Proceedings of the conference on assessment of vocal pathology (ASHA Reports No. 11, pp. 116-125). Rockville, MD: American Speech-Language-Hearing Association.

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

Goldberg, G. (1985). Supplementary motor area structure and function: Review and hypotheses. Behavioral and Brain Sciences, 8, 567-616.

Gracco, V. L. (1988). Timing factors in the coordination of speech movements. Journal of Neuroscience, 8, 4628-4639.

Gracco, V. L. (1994). Some organizational characteristics of speech movement control. Journal of Speech and Hearing Research, 37, 4-27.

Hixon, T. J., Goldman, M. D., & Mead, J. (1973). Kinematics of the chest wall during speech production: Volume displacement of the rib cage, abdomen, and lung. Journal of Speech and Hearing Research, 16, 78-115.

Hoit, J. D., Solomon, N. P., & Hixon, T. J. (1993). Effect of long volume on voice onset time (VOT). Journal of Speech and Heating Research, 36, 516-521.

Hudson, P. T. W., & Bergman, M. W. (1985). Lexical knowledge in word recognition: Word length and word frequency in naming and lexical decision tasks. Journal of Memory and Language, 24, 46 -58.

Hulstijn, W. (1987). Programming of speech and nonspeech motor activity. In H. F. M. Peters & W. Hulstijn (Eds.), Speech motor dynamics in stuttering (pp. 41-57). Wien: Springer-Verlag.

Hulstijn, W., Van Lieshout, P. H. H. M., & Peters, H. F. M. (1991). On the measurement of coordination. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), Speech motor control and stuttering (pp. 211-231). Amsterdam:

Elsevier Science Publishers.

Hulstijn, W., Summers, J. J., Van Lieshout, P. H. M., & Peters, H. F. M. (1992), Timing in finger tapping and speech: A comparison between stutterers and fluent speakers. Human Movement Science, 11, 113-124.

Kalveram, K. Th. (1993). A neural-network model enabling sensorimotor learning: Application to the control of arm movements and some implications for speech-motor control and stuttering. Psychological Research, 55, 299-314.

Klapp, S. T. (1974). Syllable-dependent pronunciation latencies in number naming: A replication. Journal of Experimental Psychology, 102, 1138-1140.

Klapp, S. T. (1977). Response programming, as assessed by reaction time, does not establish commands for particular muscles. Journal of Motor Behavior, 9, 301-312.

Klapp, S. T., Abbott, J., Coffman, K., Greim, D., Snider, R., & Young, F. (1979). Simple and choice reaction time methods in the study of motor programming. Journal of Motor Behavior, 11, 91-101.

Klapp, S. T., Anderson, W. G., & Berrian, R. W. (1973). Implicit speech in reading, reconsidered. Journal of Experimental Psychology, 100, 368-374.

Klapp, S. T., & Wyatt, E. P. (1976). Motor programming within a sequence of responses. Journal of Motor Behavior, 8, 19-26.

Lankhorst, H. A.M., Van Lieshout, P. H. H. M., Peters, H. F. M., & Hulstijn, W. (1992). Timing en coordinatie van respiratie en fonatie bij stotteraars en niet-stotteraars [Timing and coordination of respiration and phonation in stutterers and nonstutterers]. Stem-, Spraak- en Taalpathologie, 1, 150-174.

Levelt, W. J. M. (1989). Speaking: From intention to articulation. Cambridge; MA: The MIT press.

Levelt, W. J. M., & Wheeldon, L. (1994). Do speakers have access to a mental syllabary? Cognition, 50, 239-269.

McClean, M. D. (1990). Neuromotor aspects of stuttering: Levels of impairment and disability. In J. A. Cooper (Ed.), Research needs in stuttering: Roadblocks and future directions (ASHA Reports No. 18, pp. 64-71). Rockville, MD: American Speech-Language-Hearing Association.

McClean, M.D., Levandowski, D. R., & Cord, M. T. (1994). Intersyllabic movement timing in the fluent speech of stutterers with different disfluency levels. Journal of Speech and Hearing Research, 37, 1060-1066.

McMillan, M. O., & Pindzola, R. H. (1986). Temporal disruptions in the "accurate" speech of articulatory defective speakers and stutterers. Journal of Motor Behavior, 18, 279-286.

Mitchell, D. B. (1989). How many memory systems? Evidence from aging. Journal of Experimental Psychology: Learning, Memory, and Cognition, 15, 31-49.

Monsell, S. (1984). Components of working memory underlying verbal skills: A "distributed capacities" view. A tutorial review. In H. Bouma & D.G. Bouwhuis (Eds.), Control of language processes; Proceedings of the Tenth International Symposium on Attention and Performance (pp. 327-350). London: Lawrence Erlbaum Associates.

Monsell, S. (1986). Programming of complex sequences: Evidence from the timing of rapid speech and other productions. In H. Heuer & C. Fromm (Eds.), Generation and modulation of action patterns (pp. 72-86). Berlin: Springer-Verlag.

Naatanen, R. (1992). Attention and brain function. Hillsdale, NJ: Lawrence Erlbaum Associates.

Naveh-Benjamin, M., & Ayres, T. J. (1986). Digit span, reading rate, and linguistic relativity. Quarterly Journal of Experimental Psychology, 38A, 739-751.

Neilson, M.D., & Neilson, P. D. (1987). Speech motor control and stuttering: A computational model of adaptive sensory-motor processing. Speech Communications, 6, 325-333.

Neilson, M.D., & Neilson, P. D. (1991). Adaptive theory of speech motor control and stuttering. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), Speech motor control and stuttering (pp. 149-157). Amsterdam: Elsevier Science Publishers.

Nudelman, H. B., Herbrich, K. E., Hoyt, B. D., & Rosenfield, D. B. (1989). A neuroscience model of stuttering. Journal of Fluency Disorders, 14, 399-427.

Nudelman, H. B., Herbrich, K. E., Hoyt, B. D., & Rosenfield, D. B. (1991). A neuroscience approach to stuttering. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), Speech motor control and stuttering (pp. 157-163). Amsterdam: Elsevier Science Publishers.

Peters, H. F. M., Hulstijn, W., & Starkweather, C. W. (1989). Acoustic and physiological reaction times of stutterers and non-stutterers. Journal of Speech and Hearing Research, 32, 668680.

Peters, H. F. M., & Starkweather, C. W. (1990). The interaction between speech motor coordination and language processes in the development of stuttering: Hypotheses and suggestions for research. Journal of Fluency Disorders, 15, 115-125.

Pindzola, R. H. (1987). Durational characteristics of the fluent speech of stutterers and nonstutterers. Folia Phoniatrica, 39, 90-97.

Postma, A., & Kolk, H. (1993). The covert repair hypothesis: Prearticulatory repair processes in normal and stutterered disfluencies. Journal of Speech and Hearing Research, 36, 472-487.

Postma, A., Kolk, H., & Povel, D. J. (1990). Speech planning and execution in stutterers. Journal of Fluency Disorders, 15, 49-59.

Prescott, J. (1988). Event-related potential indices of speech motor programming in stutterers and non-stutterers. Biological Psychology, 27, 259--273.

Prins, D., Hubbard, C. P., & Krause, M. (1991). Syllabic stress and the occurence of stuttering. Journal of Speech and Hearing Research, 34, 1011-1016.

Rastatter, M.P., & Dell, C. (1987). Vocal reaction times of stuttering subjects to tachistoscopically presented concrete and abstract words: A closer look at cerebral dominance and language processing. Journal of Speech and Hearing Research, 30, 306-310.

Riley, G. (1972). A stuttering severity instrument for children and adults. Journal of Speech and Hearing Disorders, 37, 314-322.

Rosenbaum, D. A., Gorden, A.M., Stillings, N. A., & Feinstein, M. H. (1987). Stimulus-response compatibility in the programming of speech. Memory & Cognition, 15, 217-224.

Rossmeissl, P. G., & Theios, J. (1982). Identification and pronunciation effects in a verbal reaction time task for words, pseudowords, and letters. Memory & Cognition, 10, 443-450.

Saltzman, E. (1991). The task dynamic model in speech production. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), Speech motor control and stuttering (pp. 37-53). Amsterdam: Elsevier Science Publishers.

Saltzman, E. L., & Munhall, K. G. (1989). A dynamical approach to gestural patterning in speech production. Ecological Psychology, 1, 333-382.

Schmidt, R. A. (1988). Motor control and learning: A behavioral emphasis. Champaign, IL: Human Kinetics.

Schwartz, H. D., & Conture, E. (1988). Subgrouping young stutterers: Preliminary behavioral perspectives. Journal of Speech and Hearing Research, 31, 62-71.

Shaffer, L. H. (1984). Motor programming in language production: A tutorial review. In H. Bouma & D. G. Bouwhuis (Eds.), Control of language processes; Proceedings of the Tenth International Symposium on Attention and Performance (pp. 17-41). London: Lawrence Erlbaum Associates.

Sheridan, M. R. (1981). Response programming and reaction time. Journal of Motor Behavior, 13, 161-176.

Shipp, T., Izdebski, K., Morrissey, Ph. (1984). Physiclogic stages of vocal reaction time. Journal of Speech and Hearing Research, 27, 173-178.

Smith, A. (1990). Factors in the etiology of stuttering. In J. A. Cooper (Ed.), Research needs in stuttering: Roadblocks and future directions (ASHA Reports No. 18, pp. 39-47). Rockville, MD: American Speech-Language-Hearing Association.

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

Soderberg, G. A. (1966). The relations of stuttering to word length and word frequency. Journal of Speech and Hearing Research, 9, 584 -589.

Starkweather, C. W. (1987). Fluency and stuttering. Englewood Cliffs, NJ: Prentice-Hall.

Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. (1978). The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In G. E. Stelmach (Ed.), Information processing in motor control and learning (pp. 117-152). New York: Academic Press.

Sternberg, S., Wright, C. E., Knoll, R. L., & Monsell, S. (1980). Motor programs in rapid speech: Additional evidence. In R. A. Cole (Ed.), The perception and production of fluent speech (pp. 507-534). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stevens, J.P. (1972). Four methods of analyzing between variation for the k-group manova problem. Multivariate Behavioral Research, 7, 499-523.

Van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. Human Movement Science, 10, 165-191.

Van Lieshout, P. H. H. M., Alfonso, P. J., Hulstijn, W., & Peters, H. F. M. (1994). Electromagnetic Midsagittal Articulography (EMMA). In F. J. Maarse, A. E. Akkerman, A. N. Brand, L. J. M. Mulder, M. J. van der Stelt (Eds.), Computers in psychology: Applications, methods, and instrumentation (pp. 62-76). Lisse, The Netherlands: Swets & Zeitlinger.

Van Lieshout, P. H. H. M., Hulstijn, W., & Peters, H. F. M.

(1991). Word size and word complexity: Differences in speech reaction time between stutterers and nonstutterers in a picture and word naming task. In H. F. M. Peters, W. Hulstijn, & C. W. Starkweather (Eds.), Speech motor control and stuttering (pp. 311-325). Amsterdam: Elsevier Science Publishers.

Van Lieshout, P. H. H. M., Peters, H. F. M., Starkweather, C. W., & Hulstijn, W. (1993). Physiological differences between stutterers and nonstutterers in perceptually fluent speech: EMG amplitude and duration. Journal of Speech and Hearing Research, 36, 55-63.

Verwey, W. B. (1994). Mechanisms of skill in sequential motor behavior. Unpublished doctoral dissertation, Free University of Amsterdam, The Netherlands.

Watson, B. C., & Alfonso, P. J. (1983). Foreperiod and stuttering severity effects on acoustic laryngeal reaction time. Journal of Fluency Disorders, 8, 183-205.

Watson, B.C., & Alfonso, P. J. (1987). Physiological bases of acoustic LRT in nonstutterers, mild stutterers, and severe stutterers. Journal of Speech and Hearing Research, 30, 434-447.

Watson, B.C., Freeman, F. J., & Dembowski, J. S. (1991). Respiratory/laryngeal coupling and complexity effects on acoustic laryngeal reaction time in normal speakers. Journal of Voice, 5, 18-28.

Watson, B.C., Pool, K. D., Devous, M.D., Sr., Freeman, F. J., & Finitzo, T. (1992). Brain blood flow related to acoustic laryngeal reaction time in adult developmental stutterers. Journal of Speech and Hearing Research, 35, 555-561.

Webster, W. G. (1990). Motor performance of stutterers: A search for mechanisms. Journal of Motor Behavior, 22, 553-571.

Webster, W. G. (1993). Hurried hands and tangled tongues: Implications of current research for the management of stuttering. In E. Boberg (Ed.), Neuropsychology of stuttering (pp. 73-111). Edmonton: University of Alberta Press.

Winer, B. J. (1962). Statistical principles in experimental design. New York: McGraw-Hill.

Wingate, M. E. (1988). The structure of stuttering: A psycholinguistic analysis. New York: Springer-Verlag.

Winkworth, A. L., Davis, P. J., Ellis, E, & Adams, R. D. (1994). Variability and consistency in speech breathing during reading: Lung volumes, speech intensity, and linguistic factors. Journal of Speech and Hearing Research, 37, 536-556.

Young, M. A. (1985). Increasing the frequency of stuttering. Journal of Speech and Hearing Research, 28, 282-293.

Young, M. A. (1994). Evaluating differences between stuttering and nonstuttering speakers: The group difference design. Journal of Speech and Hearing Research; 37, 522-534.

Zemlin, W. R. (1981). Speech and hearing science: Anatomy and physiology. Englewood Cliffs, NJ: Prentice-Hall.

Zimmermann, G. (1980). Stuttering: A disorder of movement. Journal of Speech and Hearing Research, 23, 122-136.

Zimmermann, G., & Hanley, J. M. (1983). A cinefluorographic investigation of repeated fluent productions of stutterers in an adaptation procedure. Journal of Speech and Hearing Research, 26, 35-42.