INITIATION VERSUS EXECUTION TIME DURING MANUAL AND ORAL COUNTING BY STUTTERERS

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Severe stutterers were found to be significantly slower than control subjects in performing a speech counting task that was judged to be fluent and in silently counting on their fingers. For both counting tasks the time taken to *execute* the numerical series accounted for more of the difference between severe stutterers and controls than the time taken to prepare and *initiate* the task. Mild stutterers were not significantly slower than controls on either counting task.

Recent investigations of the timing of speech motor responses of stutterers have indicated that, as a group, they may be motorically slower than nonstutterers, even during their seemingly fluent utterances. Slower speech movements have been measured from x-ray films of articulators (Zimmermann, 1980a), inferred either from slower formant changes (Starkweather & Myers, 1979) or increased phonatory reaction time (Adams & Hayden, 1976; Starkweather, Hirschman, & Tannenbaum, 1976), or observed in increased latency of muscle activity (McFarlane & Prins, 1978). It has been suggested further that stutterers may be slower than normals to perform manual as well as speech motor acts (Luper & Cross, 1978). Other studies have failed to find evidence of a significant difference in manual latency between stutterers and controls, but found stutterers to be slower in producing speech sounds (Prosek, Montgomery, Walden, & Schwartz, 1979; Reich, Till, & Goldsmith, 1981).

The investigations cited above of manual response time in stutterers used a key-press response. Such a response requires a simple ballistic movement that is not analogous to the coordination of different muscle groups necessary for speech. Counting on one's fingers, however, requires that many groups of muscles work together. Further, pressing an external object such as a button or a keyboard seems less speech-like than does counting on one's own fingers, a task in which the "targets" are intrinsic to the counter. Thus, for this study, a finger-counting procedure was chosen because it is a serially ordered, self-contained response which requires complex motor coordination analogous to speech production.

Most investigations comparing the latency of stutterers to that of controls have focused on the time between a signal to respond and the onset of the response. This interval may be considered the *initiation* time, an interval that includes premotor planning and motor initiation, in contrast to the *execution* time, which is the interval between the first and last event in a serially ordered response. This emphasis in previous studies resulted from the observation that stuttering episodes predominate at the onset of words and phrases (Bloodstein, 1975). Both initiation and execution measures, however, were included in the design of the present study to permit comparison of the two intervals.

It is possible to evaluate the importance of premovement preparation by comparing a condition in which the expected response is known by the subject before the signal to respond is given (*delayed response condition*) with a condition in which the expected response is displayed simultaneously with the signal to respond (*immediate response condition*) (Ostry, 1980). If the execution time is brief and the expected response is known 1 sec before the signal to respond is given, certain preparatory events may be presumed to have occurred before the signal, such as perceiving the expected response and priming several groups of muscles for the coming activity. The role of planning was evaluated in the present study by including an immediate response and a delayed response condition.

The main aim of the overall experiment, from which this paper is the first report, was to examine the interactions of respiratory, laryngeal, and supralaryngeal movements of stutterers and their controls during speech. The primary purpose of this particular part of the experiment was to compare the initiation and execution intervals in the seemingly fluent utterances of stutterers with the same intervals in the utterances of the controls. A second purpose was to examine finger movements in a nonspeech serially ordered task in order to determine whether differences between stutterers and controls extend beyond the speech mechanisms. To make these comparisons, the task of counting was chosen because subjects can count aloud, count silently on their fingers,

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and simultaneously count aloud and manually. The present paper deals only with results from the speech-alone and fingers-alone conditions.

METHOD

Subjects

Eight adult stutterers (7 men and 1 woman) aged 21–48 years were matched by sex, age, and general educational/occupational level with eight normal speakers aged 20–45. The mean age for the experimental group was 33 and for the control group, 32. College students, teachers, blue collar workers, and professionals were represented in both groups. Subjects were bimodally distributed in terms of the severity of their stuttering. Table 1 shows that four of the stutterers were rated as mild and four as severe, according to the *Stuttering Severity Index* (Riley, 1972), the reading and conversational parts of the *Stuttering Interview* (Ryan, 1974), and subjective judgments of two speech-language pathologists.

TABLE 1. Subject identification, sex, age, and judged severity of stuttering.

Experimental Group					Control Group			
1.	JP	M	48	severe	1.	FS	M	45
2.	DE	M	22	severe	2.	TS	M	22
3.	DA	M	31	severe	3.	SB	M	30
4.	LB	M	44	mild	4.	EG	M	43
5.	DL	F	30	severe	5.	NM	F	32
6.	MA	M	26	mild	6.	JL	M	29
7.	GV	M	41	mild	7.	AL	M	36
8.	SL	M	21	mild	8.	DR	M	20
		$\bar{X}$ = 33					$\bar{X}$ = 32	

The stutterers were recruited through the assistance of speech pathologists in the New Haven, Connecticut, area and their controls were volunteers who matched the experimental subjects in age (within 5 years), sex, and general background. All subjects reported themselves to be right handed in writing, throwing, hammering, and cutting with scissors.

Tasks

The two response tasks reported here are speech counting and finger counting. The speech-counting task involved reading aloud a digital display of 10 different sequences of the digits 2, 3, 4, and 5. Each sequence appeared twice: once simultaneously with a tonal response signal (*immediate* condition) and once 1 sec before the signal to respond (*delayed* condition). The 20 items were randomized. Any errors in counting were recorded during the experiment. Also noted was any visual evidence of stuttering, that is, signs of struggle or effort in facial or body movements, and any auditory evidence, that is, hesitations, repetitions, or prolongations.

Although this paper emphasizes an analysis of the perceptually fluent utterances of the stutterers, another purpose of the experiment was to compare fluent with stuttered utterances. Thus, for all subjects the speech counting task was followed by the finger counting task in an attempt to maximize the probability that stuttering would occur. This poses a problem for any comparison of speech with nonspeech conditions, because order could influence results, but one can still compare stutterers with controls on the manual task. A different randomization of the same 20 items was presented for the manual task, and the subjects silently counted on their fingers by contacting index finger and thumb for the number 2, middle finger and thumb for 3, ring finger and thumb for 4, and little finger and thumb for 5. All finger counting was done on the right hand. Instructions were read to each subject before a practice set of 12 sequences. Instructions included a warning to wait for the tone before responding and to count as quickly as possible without sacrificing accuracy. Practice was given on both tasks. None of the practice sequences appeared on the tests.

Instrumentation

The program presenting the test sequences was run on a microcomputer (Integrated Computer Systems). For each sequence, a visual warning signal was followed by a variable interval (300, 400, or 500 msec), after which the 4-digit display appeared. The tone signalling the subject to respond was either simultaneous with the display or delayed 1 sec after the display. Presentation of the next test sequence was experimenter controlled to allow for subject differences in response time.

An electroglottograph (F-J Electronics ApS) recorded rapid changes in impedance by high-pass filtering (25 Hz–10 kHz) the overall changes in impedance of a signal transmitted across the larynx at the level of the vocal folds. The onset of these rapid oscillations was abrupt and unambiguous and served to signal the onset of voicing during the speech task.

A special glove made of thin cotton was constructed for the right hand with circles of thin (.0015 inch, or .004 cm) brass attached to each finger pad and a larger thimble-shaped contact surface attached to the thumb. Thumb-to-finger contact produced a different voltage for each of the four fingers. These signals served to represent the onset of each digital contact during finger counting. The electroglottograph, glove, and associated speech acoustic signals were recorded on an EMI SE-7000 FM tape recorder.

Measurement of Intervals

Visicorder recordings of the physiological and acoustic signals recorded on FM tape were produced for each subject. Onset of voicing as inferred from the electroglottographic signal and onset of finger contacts were marked by the experimenter. All subject errors, including counting confusions and responses started before the signal to respond, were omitted from the measured data. These errors were categorized, however, for analysis of any speed-accuracy trade-off. Disfluencies were classified separately from fluent utterances for measurement. Disfluencies included those evident in the finger and laryngeal traces as well as any auditory or visual indications of stuttering identified during the tests. For example, the appearance of rapid fluctuations in laryngeal impedance during the silence before speech was classified as disfluent. Thus, for an utterance to be classified as "fluent," it had to satisfy three criteria:

1. no visual sign of struggle in the subject's facial or body movements
2. no auditory sign of hesitations, repetitions, or prolongations in the subject's speech
3. the subject's finger and laryngeal traces, which were examined later, had to be free from abnormal perturbations or oscillations.

Measures were made in milliseconds from the response signal to the onset of the first response in a series (*initiation* time) and from the onset of the first response to the onset of the last response of the series (*execution* time). Measurements made by the experimenter were repeated by a research assistant and any discrepancy over 10 msec was remeasured by both for consensus.

Data Analysis

For each subject, means and standard deviations were computed for initiation time in the delayed condition, initiation time in the immediate condition, execution time in the delayed condition, and execution time in the immediate condition. For the speech task, means were computed separately for the utterances of the control subjects, the perceptually fluent utterances of the stutterers, and the disfluent utterances of the stutterers. Stuttered utterances differed sufficiently from the fluent and control utterances that the need for a test of significance was precluded. The t test was used to test the significance of differences in interval times between the fluent tokens of stutterers and those of nonstutterers and between finger counting by stutterers and their controls.

RESULTS

Speech Task

The fluent utterances of the stutterers were on the average about 20% slower than the utterances of controls in the intervals measured for the speech task, while the stuttered tokens were about 178% slower, on average, than normal utterances. Table 2 summarizes the means and standard deviations of initiation and execution times for each subject in both delayed- and immediate-response conditions. Averages are based on the measures from eight controls (C), the fluent tokens of six stutterers (F), and the disfluent tokens of four stutterers (S). Two of the stutterers were disfluent on all tokens, two were fluent for part and disfluent for part, and four were judged fluent for the complete task. Fluent utterances were those in which the speaker sounded and looked fluent to the experimenter and in which there was no evidence of disfluency (abnormal perturbations or tremor) on the physiological traces as observed on the Visicorder records. Table 2 shows that when subjects knew the series of numbers 1 sec before the signal to respond (delayed condition), initiation time was reduced compared to the immediate-response condition. This advantage did not extend into the execution times for the remaining numbers in the series, however, for the control sample or for the fluent tokens of the stutterers. On the other hand, when averaged, the advantage of the delay did extend into the execution of the series in the disfluent tokens of the stutterers.

There was a more extensive overlap of stutterers with controls in the initiation time of fluent utterances than there was for execution time. The difference was significant on a t test for unequal n's between the fluent tokens of stutterers ($n = 6$) and normals ($n = 8$) in the time taken to execute the delayed series ($t = 2.28$, $p < .05$) as well as the immediate series ($t = 2.32$, $p < .025$), but there was not a significant difference in initiation time. The time difference was not due to a difference in strategy which would have resulted in different numbers of errors in the two groups. An analysis of the errors excluded from the data revealed that only three of the control subjects and three of the stutterers made errors. Most of the errors were early starts. The average number of errors among the three control subjects who made errors was 2 (of the 20 utterances), whereas the average number of errors for the three stutterers who made errors was 1.7 out of 20. Thus, accuracy was comparable in the two groups.

Two of the severe stutterers and all four of the mild stutterers produced fluent tokens on the speech counting task. When one compares each subject within each group with his or her control subject, a different picture from that of the pooled data emerges (Figure 1). The left side of Figure 1 illustrates the extent of the overlap of both initiation time and execution time when the mild stutterers (M) are compared with their controls (C). Each speaker is represented twice in this figure, once for the immediate response condition and once for the delayed response condition. None of the differences between the fluent utterances of the mild stutterers and those of their controls was found to be statistically significant. The right side of Figure 1 indicates some overlap between severe stutterers and their controls in initiation times but no overlap in execution time. Only two of the severe stutterers were judged to produce fluent utterances, but they were both slower than their controls in the execution of the number series whether the response was delayed or immediate.

TABLE 2. Means and standard deviations of speech intervals in milliseconds. Experimental subject 3 provided 6 fluent tokens and 14 disfluent tokens, and experimental subject 4 provided 10 fluent tokens, 9 disfluent tokens, and 1 discarded error.

SPEECH COUNTING

$\bar{X}$ and (SD) in msec

	Subjects	Delayed Initiation	Immediate Initiation	Delayed Execution	Immediate Execution
Disfluent Tokens	1. S	1911 (653)	2881 (624)	2094 (656)	2760 (1081)
	2. S	1294 (258)	1208 (311)	2677 (501)	2337 (436)
	*3. S	1245 (456)	1408 (267)	1150 (190)	2402 (998)
	+4. M	1070 (129)	1213 (152)	1126 (79)	1493 (399)
	Grand $\bar{X}$	1380 (318)	1678 (700)	1762 (657)	2248 (465)
Fluent Tokens	*3. S	530 (28)	804 (151)	1015 (35)	958 (36)
	+4. M	732 (94)	1033 (101)	1148 (153)	1064 (52)
	5. S	419 (48)	610 (69)	817 (49)	823 (87)
	6. M	403 (62)	552 (86)	776 (139)	812 (94)
	7. M	597 (98)	1110 (156)	714 (55)	719 (59)
	8. M	454 (95)	701 (84)	783 (120)	758 (90)
	Grand $\bar{X}$	523 (115)	802 (207)	876 (154)	856 (119)
Controls	1. C	361 (60)	587 (28)	696 (55)	700 (29)
	2. C	405 (51)	579 (142)	652 (42)	633 (45)
	3. C	470 (122)	673 (71)	608 (41)	624 (41)
	4. C	532 (114)	780 (102)	693 (64)	667 (71)
	5. C	486 (56)	586 (38)	759 (96)	712 (63)
	6. C	641 (110)	711 (92)	907 (77)	902 (75)
	7. C	469 (101)	708 (54)	634 (30)	638 (34)
	8. C	396 (53)	562 (43)	853 (70)	828 (42)
	Grand $\bar{X}$	470 (83)	648 (75)	725 (100)	713 (94)

Note: C = Control; S = Severe; M = Mild; *, + = Same subjects.

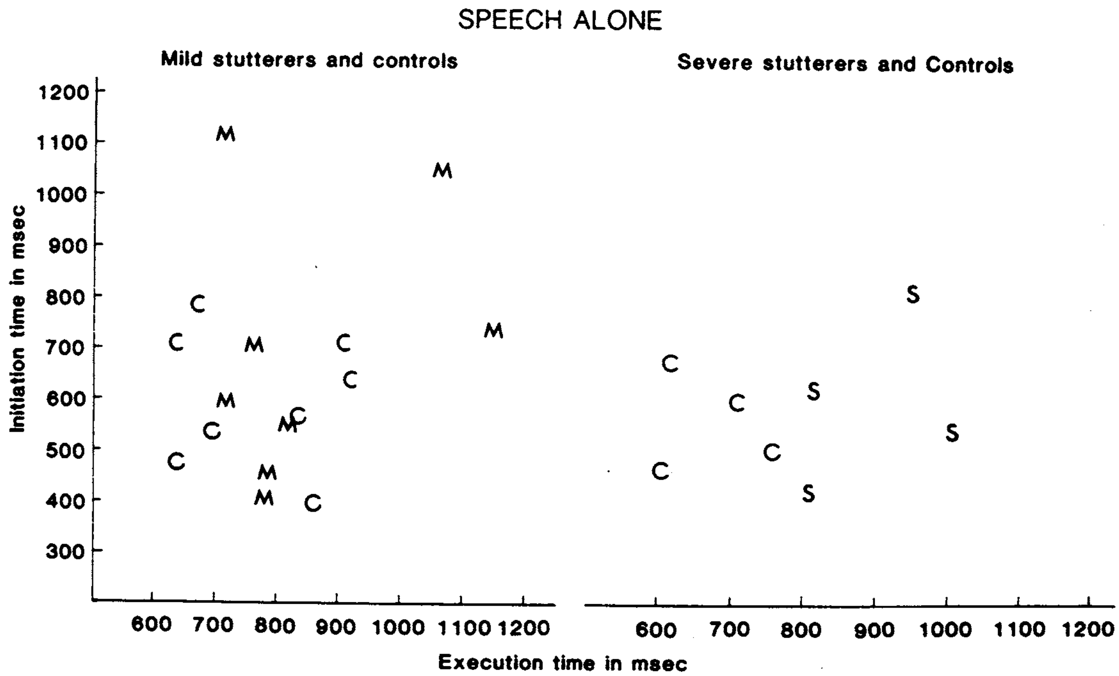

FIGURE 1. Mean initiation times plotted by mean execution times during the speech counting task for (n = 4) mild stutterers (M) with their matched controls (C) and severe stutterers (S) (n = 2) with their matched controls (C).

Finger Task

Stutterers, on the average, were found to be about 14% slower than controls in the finger task. Table 3 summarizes the means and standard deviations of measures taken for each subject. Differences between groups were not significant, however, for either the initiation times in delayed and immediate conditions or for execution times in the immediate condition. There was too much overlap; some of the stutterers were quite fast, while some of the controls were relatively slow. A significant difference was found, however, between the groups in the mean times taken to execute the series in the delayed condition [$t(14) = 1.78$, $p < .05$]. Again, when the stutterers were grouped according to severity, the severe stutterers accounted for differences found in the pooled data. Severe stutterers were significantly slower than their controls in the times taken to execute the series in both immediate [$t(6) = 2.00$, $p < .05$] and delayed [$t(6) = 3.29$, $p < .01$] conditions.

Figure 2 illustrates the extent of the overlap of mild stutterers and their controls in contrast with the separation of the data points for the severe stutterers and their controls, especially for execution time. No significant difference was found between the mild stutterers and their controls in finger counting. An analysis of the errors excluded from the data revealed that although only one of the control subjects and two of the stutterers made no errors, the errors (missed finger contacts and number reversals) averaged 3.7 for the controls and 2.7 for stutterers. A difference of one error did not seem sufficient to account for the differences in speed between the groups.

Speech and Finger Counting Compared

The manual task was about 60% slower, on the average, than the speech task for both stutterers and controls (Table 4). There was more variability in timing for the finger counting than there was for speech counting for both groups. The advantage of knowing ahead (delayed condition) was evident for both groups in the initiation time required for both tasks. This advantage was not observed in the execution of the last three digits during speech, although it was evident in the finger counting task.

TABLE 3. Means and standard deviations of finger contact intervals in milliseconds.

FINGER COUNTING

$\bar{X}$ and (SD) in msec

Subjects	Delayed Initiation	Immediate Initiation	Delayed Execution	Immediate Execution
Experimental Group				
1 S	497 (231)	1038 (138)	2014 (794)	1713 (210)
2 S	617 (105)	1134 (192)	1439 (309)	1482 (317)
3 S	1373 (588)	1624 (986)	1607 (740)	2018 (621)
4 M	948 (310)	1203 (898)	1562 (503)	1617 (1113)
5 S	1313 (431)	1566 (562)	1269 (263)	1163 (199)
6 M	476 (239)	986 (360)	1335 (430)	1324 (321)
7 M	845 (341)	1350 (287)	982 (112)	1144 (322)
8 M	452 (222)	986 (189)	815 (301)	845 (145)
Grand $\bar{X}$ (SD)	815 (347)	1236 (237)	1378 (350)	1413 (348)
Control Group				
1 C	518 (567)	931 (247)	1246 (310)	1527 (683)
2 C	335 (56)	668 (199)	830 (90)	1035 (359)
3 C	1188 (585)	1497 (364)	959 (385)	1115 (497)
4 C	1387 (618)	1852 (447)	1553 (362)	2057 (490)
5 C	381 (110)	784 (230)	729 (39)	856 (206)
6 C	385 (42)	638 (98)	1167 (183)	1175 (94)
7 C	699 (324)	1026 (192)	696 (157)	781 (206)
8 C	718 (421)	1288 (224)	1384 (442)	1480 (348)
Grand $\bar{X}$ (SD)	701 (367)	1086 (402)	1071 (295)	1253 (391)

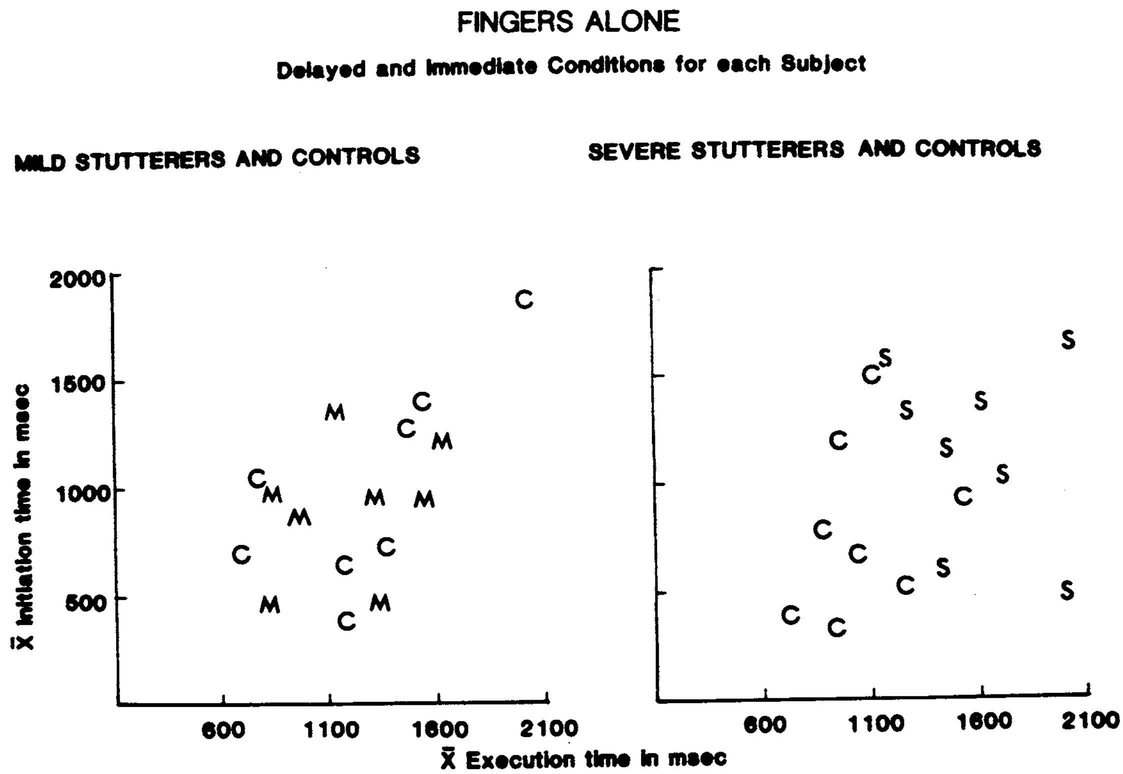

FIGURE 2. Mean initiation times plotted by mean execution times during the finger counting task for mild stutterers (M) (n = 4) with their matched controls (C) and severe stutterers (S) (n = 4) with their matched controls (C).

TABLE 4. Means and standard deviations of intervals in speech and finger tasks compared.

SPEECH AND FINGER COUNTING
$\bar{X}$ and (SD) in msec

	Delayed Initiation	Immediate Initiation	Delayed Execution	Immediate Execution
Experimental Group:				
Fingers	815 (347)	1236 (237)	1378 (350)	1413 (348)
Speech (fluent)	523 (115)	802 (207)	876 (154)	856 (119)
Control Group:				
Fingers	701 (367)	1086 (402)	1071 (295)	1253 (391)
Speech	470 (83)	648 (75)	725 (100)	713 (94)

DISCUSSION

An interesting finding of this study is the lack of significant differences between mild stutterers and their controls, in contrast with the significant differences found when severe stutterers were compared with their controls. This contrast was obscured when stutterers were pooled regardless of severity. Few studies have explored the timing of fluent utterances according to severity of stuttering. There were no stutterers in the present study who were judged moderate; they were either mild or severe. The stutterers who participated in the present study also served as subjects for another study of laryngeal reaction time (Alfonso, Watson, & Russo, 1981). Significant differences between the severe stutterers and controls were found for all of 13 different foreperiods (intervals between warning signal and cue to say "ah"), but significant differences between the mild stutterers and controls were found for only four of the intervals. Another study that classified stutterers instead of pooling them compared elementary school children who stuttered and who also exhibited other mild-to-moderate articulation or language disorders with children who simply stuttered (Cullinan & Springer, 1980). The children with additional disorders took significantly longer than nonstutterers to initiate and to terminate voicing, while children who simply stuttered were not significantly slower than the controls. These studies, along with the present study, suggest that we may be losing important information by pooling data for stutterers. Specifically, there may be stutterers who have a more generalized motor coordination problem underlying their disfluencies and other stutterers for whom this deficit is confined to speech. When fluent, mild stutterers may be more similar to normal speakers than they are to severe stutterers.

One cannot compare this study directly to most previous reaction time studies, because the tasks here involved serial ordering of speech instead of simpler phonatory responses. Previous reaction time studies, cited in the introduction, required speakers to utter a single speech sound or a known word and sometimes to press a button or key.

A comparison of this study with other studies of manual versus oral timing also is difficult due to procedural differences. Other studies have required a simple flexor response of key pressing, an anticipated response, whereas this study required a serially ordered response with coordination of many muscle groups and, in the immediate condition, the exact response could not be anticipated. Considering the initiation times alone, the present study supports those studies that found no significant difference between stutterers on the average and their controls in the manual task (Reich et al., 1981). Execution time has not been explored in other studies, but the present finding of significantly longer execution times for severe stutterers suggests that some stutterers need more time to coordinate serially ordered events, regardless of whether they involve speech or hand coordination.

Before offering possible explanations for these results, a caveat is in order. This experiment required that the subject perform the speech task first to increase the possibility that stuttering samples would be obtained in addition to the fluent tokens. It is possible that the state of excitability for the speech task carried over into the finger counting task. Thus, we must view our conclusions with caution. We are left with at least three possibilities: (a) a *radiation effect*: discoordination of fine motor control in severe stutterers that includes not only speech muscles but hand muscles, (b) a *generalized arousal effect*: carry over effects of performing the speech task before the finger task, and/or (c) a *speech mediation effect*: greater execution time for the finger task not due to difficulties in hand coordination but possibly because subjects were "speaking to themselves" as they counted on their fingers. Further research is needed to test these possibilities.

On the question of whether knowing the expected response 1 sec ahead of the response signal extends the advantage given to initiation into the execution of the rest of the series, the interesting finding was that the utterances of normal speakers and the fluent tokens of stutterers were similar, in contrast with stutterers' disfluent tokens. All subjects took less time to initiate the task, whether finger or speech counting, in the delayed-response conditions, but the fluent tokens of stutterers were like the utterances of their controls in that this advantage failed to extend through the execution of the last three digits of the spoken series. When the series was stuttered, however, the stuttering was prolonged further in both initiation and execution phases when the response signal was immediate rather than delayed. The obvious cases of "jumping the gun" in the delayed condition were removed from the analysis, but it remains possible that the measured times of delayed initiation may have been artificially shortened by some anticipation by both groups. The effect was probably spread across groups, however, since the ratios between delayed and immediate conditions of initiation were similar for both fluent stutterers (1:1.5) and controls (1:1.4), with the initiation demanded by immediate response taking about half again as long as under the delayed condition.

For the speech task, this study has gone one level further than other studies in delineating "fluent" utterances of stutterers. To qualify as fluent, the utterances had to be perceptually fluent to an observer, visually and auditorily, and, in addition, they had to be "physiologically fluent," as determined by examination of the finger and laryngeal movement indices. Any abnormal perturbation in the traces was considered evidence that the utterances fell outside the boundaries of fluency. All such utterances were discarded from the fluent sample.

Since stutterers evidence most of their disfluencies during the initiation of phrases rather than within phrases, it was interesting and surprising that initiation times for the fluent utterances were not significantly longer than those for the controls, while execution times were significantly longer. Initiation of sequential speech demanded by the present study required much more than initiation of voice. It demanded the visual perception of the series to be executed; premovement motor readiness, including excitation of the motoneuron nets to be involved; and finally, the specific neuromotor and myomotor events leading to the movements recorded. It included production of the voiceless consonant and the motor adjustments preparatory to voicing the first number of each series. Stuttering did occur on the first digit for 86% of the stuttered utterances, whereas the incidence dropped to 42% for the second, 46% for the third, and 26% for the last digit. When the tokens of stutterers were judged to be fluent, however, the times taken to initiate the response were not significantly longer even though the utterances were executed more slowly. These results lend support to the notion that it may take no more time for a stutterer to prepare for a fluent utterance than it does for a nonstutterer; it is only when the preparation is faulty that the stutterers block initiation of the speech. Faulty preparation might involve the generation of either an insufficient or an excessive degree of excitability of the appropriate neural networks. (Evidence for preparatory adjustments preceding movement and the difficulties in specifying them are reviewed by Requin, 1980.)

The principle of selective potentiation is thought to play a part in motor coordination; that is, the system increases the potential for certain neural activity while reducing the potential for activity in other neural circuits (Gallistel, 1980). In discoordinated motor acts, there may be a failure to achieve a state of arousal that is optimal for the task, and neural nets that serve a particular group of muscles may be overexcited while other groups may be underexcited (see Zimmermann, 1980b). The state of equilibrium among cooperating units and agonist-antagonist units that allows for reciprocal inhibition may not be achieved (Freeman & Ushijima, 1978). On the other hand, if stutterers achieve a balanced premovement set, they may be fluent and the set will take no more time than it would for nonstutterers. If their settings are faulty, one would expect the initiation of a coordinated act to be the most difficult part; once started it would be easier to complete.

Why, then, were the severe stutterers slower than their controls in the execution of the sequences? Was slowing the response the price that they paid for fluent performance? In order to maintain relative fluency, are there changes in the temporal organization of the mechanisms coordinating for speech? I am currently analyzing the differences in coordination among the respiratory, laryngeal, and supralaryngeal movements recorded during stuttered utterances, perceptually fluent utterances, and control utterances. Differences in coordination patterns may be found to relate to the slowing of execution, even when "fluent."

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