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*JOURNAL OF FLUENCY DISORDERS* 8 (1983) 183–205

# Foreperiod and Stuttering Severity Effects on Acoustic Laryngeal Reaction Time

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An earlier paper presented a model of the laryngeal reaction time (LRT) paradigm that included several factors that appeared to affect LRT values. The present study assesses the effects of two of these factors: foreperiod and stuttering severity. The former was assessed by the use of 13 foreperiod durations. The latter was assessed by classifying experimental subjects as either mild or severe stutterers. Both factors significantly affected LRT values. More importantly, these factors demonstrated a composite effect on group LRT differences. Specifically, mild stutterers' LRT values approached normal values as foreperiod increased, whereas severe stutterers' LRT values remained significantly greater than normal values at all foreperiods. Results are discussed in terms of differential posturing and/or vibration initiation deficits underlying stutterers' delayed LRT values. We caution that acoustic measurements alone are insufficient to specify fully the nature of the underlying deficits.

A number of experiments (most notably Adams and Hayden, 1976; Starkweather et al., 1976; Cross and Luper, 1979; Cross et al., 1979) reported that stutterers as a group are significantly slower than normals in initiating phonation in response to reaction signals. Using a simple reaction time paradigm that allowed subjects 1 to 3 sec to prepare for a known response, we unexpectedly failed to replicate the results of these experiments (Watson and Alfonso, 1982). That is, we failed to find a significant group difference in laryngeal reaction time (LRT) between stutterers and nonstutterers, a difference we will refer to as the LRT effect. However, we did find significant within-group LRT differences between auditory and visual reaction signal conditions and between isolated vowel and phase-initial vowel response conditions. The latter results

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0094-730X/83/$03.00

suggested to us that our LRT measurements were indeed sufficiently sensitive to detect an LRT effect if one existed. Other recent investigations have also failed to demonstrate a significant LRT effect in both children and adult subjects (Cullinan and Springer, 1980; Murphy and Baumgartner, 1981; Venkatagiri, 1981, 1982). The study reported here is motivated by our original experiment, as well as other recent experiments that failed to demonstrate a significant LRT effect.

We are interested in isolating those factors that form the basis for significant LRT differences between stutterers and their controls. To this end, we have conducted experiments based on the model of the LRT paradigm developed in our original experiment. The model includes factors related to the perception of the reaction signal, production of the response, and factors specifically related to characteristics of stuttering subjects that influence LRT values. For example, we included in the model "reaction signal modality," a perceptual component, and "response type," a production component, based on our findings of significant LRT differences for both nonstutterers and stutterers as a function of reaction signal modality (visual vs auditory) and response condition (isolated vs phrase-initial vowel). The first purpose of the study reported here is to investigate further the effects of two other factors on stutterers' LRT values as well as on the LRT effect. These factors are included in the model as foreperiod and stuttering severity. We argued that our failure to find a significant LRT effect in our original experiment was related to our use of relatively long foreperiods and to the mild-to-moderate severity rating of our experimental group.

The foreperiod factor is included in the "perceptual component" of the model, although production events may also occur during this interval. In our experiments, foreperiod is defined as the interval between the presentation of the warning cue and presentation of the phonate cue. Sufficiently long foreperiods provide the subject with time to prepare for a known response (Niemi and Naatanen, 1981). Preparatory activity that may occur during the foreperiod includes perception of the warning cue, formulation and transmission of appropriate motor commands to posture the speech mechanism for the required response, and movements of the various components of the speech mechanism to achieve the required prephonatory posture. The extent of preparatory activity that actually occurs is a function of foreperiod duration. Thus, short foreperiods may restrict preparatory activity to perception of the warning cue and, perhaps, formulation and transmission of motor commands; long foreperiods may permit formulation and transmission of motor commands and posturing of the speech mechanism prior to presentation of the phonate cue.

The notion of a foreperiod effect on nonstutterers' LRT values is supported by Izdebski's (1980) observation of a U-shaped function when LRT values are plotted across a range of increasing foreperiods. That is, he found that LRT values decrease to a minimum as foreperiod increases to about 1500 msec and then increase as foreperiod increases beyond 1500 msec. These results suggest that LRT values occurring at foreperiods less than 1500 msec may reflect the subject's inability to complete preparatory activity. Increasing LRT values beyond 1500 msec may reflect the subject's inattention to the task or failure to maintain the prephonatory posture. We have argued previously that stutterers' LRT values may be particularly dependent on foreperiod duration. Specifically, we hypothesized that when certain stutterers are given sufficient time to posture the speech mechanism, they will demonstarte LRT values similar to those of normals. We concluded that the long foreperiods used in our original experiment (1 to 3 sec) provided stutterers with ample time to achieve the appropriate posture prior to the initiation of phonation and contributed to our finding of a nonsignificant LRT effect.

The studies referred to earlier that reported a significant LRT effect (and used isolated vowels as the response, a task similar to one of the response conditions in our original experiment) did not incorporate warning cues in their experimental designs (Adams and Hayden, 1976; Cross and Luper, 1979; Cross et al., 1979). Consequently, it cannot be determined if the stutterers in these experiments achieved the appropriate response posture before the presentation of the phonate cue. Thus, experiments that report significant LRT effects but do not include a warning cue may reflect stutterers' difficulty with posturing the speech mechanism prior to phonation onset as well as difficulties associated with initiating the response. It seems possible that certain stutterers' delayed LRT values may be related to posturing, that is, prephonatory events (as suggested by Freeman and Ushijima, 1978), while other stutterers' delayed LRT values may be more directly related to initiation of the response or perhaps a combination of posturing and initiation activities. If this is the case, one may suspect that certain stutterers' LRT values will approach normal values as foreperiod increases. However, other stutterers' LRT values could remain significantly greater than normal values throughout the entire range of foreperiods. The first hypothesis under test in this study states that there is a foreperiod effect on stutterers' LRT values. To test this notion, we extended the range of the foreperiods from 100 to 3000 msec. Specifically, those stutterers with deficits only in posturing the speech mechanism will demonstrate LRT values approaching normal values as foreperiod increases, whereas those stutterers with deficits in initiating the response, or in both posturing and initiation, will demonstrate LRT values significantly greater than normal values throughout the range of short to long foreperiods.

The second factor that may affect stutterers' LRT values is stuttering severity, included in the model under "subject characteristics." The results of several studies (Hayden, 1975; Lewis et al., 1979; Watson and Alfonso, 1982) suggest that mild stutterers may exhibit LRT values more similar to normals than would severe stutterers. Additional support for this notion is found in a comparison of results obtained in our original experiment and in a study by Reich et al. (1981). The average severity rating of our experimental group was mild-to-moderate. However, Reich et al. (1981), using stuttering subjects classified as moderate-to-severe, obtained a significant LRT effect. The experimental procedures were very similar in the two studies. Both included foreperiods of similar duration, for example, yet the results are clearly different. We suggest that differences between the results of these studies may, in part, be attributable to differences in the stuttering severity ratings of the experimental groups. Finally, support for a stuttering severity effect on timing is found in data reported by Borden (1982). Specifically, she observed that severe stutterers displayed significantly longer vocal and manual "execution" time values than did nonstutterers while none of the differences between mild stutterers and nonstutterers reached significance. Thus, the second hypothesis under test is that there is a stuttering severity effect on stutterers' LRT values. That is, we expect that a group of severe stutterers will demonstrate greater LRT values than will a group of mild stutterers.

The two hypotheses just described assess the independent effects of foreperiod and stuttering severity on stutterers' LRT values when compared to nonstutterers. Of interest, however, is the relationship between foreperiod and stuttering severity. Consequently, the second purpose of this study was to assess the combined effect of foreperiod and stuttering severity on stutterers' LRT values. For example, we hypothesized that certain stutterers' LRT values would approach normal values as foreperiod increases, in that these stutterers' delayed LRT values may be primarily related to difficulty posturing the speech mechanism. Alternatively, we hypothesized that other stutterers' LRT values would remain significantly different from normals' throughout the entire range of foreperiods, implying that these stutterers' delayed LRT values may be related to difficulty initiating the response or, perhaps, a combination of posturing and initiation difficulties. We wanted to ascertain if groups of stutterers, classified by severity, could be characterized according to the "posture" versus the "initiation" hypothesis. That is, is it the case that mild stutterers' primary difficulty is posturing the speech mechanism whereas severe stutterers' primary difficulty is some combination of posturing and response initiation? The third hypothesis tested this notion. Specifically, we expected that mild stutterers' LRT values will approach normal values, whereas severe stutterers' LRT values will remain significantly greater than normal values, as foreperiod increases.

In summary, the first purpose of this study was to determine the effects of two factors included in the model of the LRT paradigm (Watson and Alfonso, 1982) on the LRT effect and on stutterers' LRT values. The second purpose was to test the notion that qualitatively different deficits—posturing versus initiation—underlie mild and severe stutterers' delayed LRT values.

## Subjects

Subjects participating in this study included 10 adult stutterers and 5 adult nonstutterers. In order to test the effect of stuttering severity on stutterers' LRT values, it was necessary to classify the experimental subjects on this dimension. Stutterers were classified on the basis of three separate analyses of severity. First, a certified speech-language pathologist subjectively rated the conversational speech and speech during reading of the Rainbow Passage of the stuttering subjects. A second certified speech-language pathologist objectively rated the same speech samples using the Stuttering Severity Index (SSI) (Riley, 1972) and the Stuttering Interview (SI) (Ryan, 1974).

The results of the stuttering severity analysis, shown in Figure 1, indicate that the experimental subjects could be classified as two distinct groups: five severe stutterers and five mild stutterers. Since reaction time values may be affected by subject sex and age (Birren and Botwinick, 1955; Weiss, 1965; Izdebski, 1980), we matched the control group against the average age and sex ratio of the two stuttering groups.

### Test Stimuli

Figure 2 illustrates one sequence of the stimuli used to assess the effect of foreperiod on LRT values. Each sequence was separated by a variable interstimulus interval (ISI) of 8 to 12 sec. ISIs of this duration require that subjects breathe normally between response sequences. Consequently, subjects are not able to remain in a phonatory position

| SUBJECT | SEX | AGE | EXPERIMENTAL GROUP | SI | SSI | SUBJECTIVE |
|---|---|---|---|---|---|---|
| 1 | M | 48;4 | severe | severe | severe | severe |
| 2 | F | 36;3 | severe | severe | severe | severe |
| 3 | M | 31;8 | severe | severe | severe | severe |
| 4 | F | 30;0 | severe | severe | severe | severe |
| 5 | M | 22;5 | severe | severe | moderate | severe |
| Mean Age | | 33;8 | | | | |
| 6 | M | 44;5 | mild | mild | mild | mild/ moderate |
| 7 | M | 41;4 | mild | mild | mild | mild |
| 8 | M | 26;9 | mild | moderate | mild | mild |
| 9 | M | 22;8 | mild | mild | mild | mild |
| 10 | M | 20;11 | mild | mild | mild | mild |
| Mean Age | | 31;2 | | | | |
| 11 | M | 48;7 | normal | — | — | — |
| 12 | F | 35;8 | normal | — | — | — |
| 13 | M | 26;10 | normal | — | — | — |
| 14 | M | 26;0 | normal | — | — | — |
| 15 | M | 23;2 | normal | — | — | — |
| Mean Age | | 31;1 | | | | |

**Figure 1:** Results of the stuttering severity analysis.

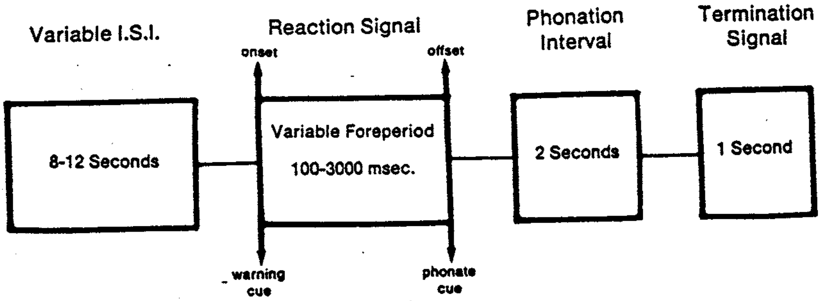

**Figure 2:** One sequence of stimuli used to assess the effect of foreperiod on LRT. The reaction signal varied from 100 to 3000 msec. Reaction signal onset served as the warning cue, offset as the phonate cue.

between responses. The reaction signal consisted of the synthetic vowel /a/. Onset of the reaction signal served as the warning cue, and the offset served as the phonate cue. Subjects were instructed to "get ready" to phonate when and only when they heard the warning cue. Duration of the reaction signal varied from 100 to 500 msec in 100-msec increments, 700 to 1500 msec in 200-ms increments, and from 2000 to 3000 msec in 500-mesc increments, a total of 13 foreperiods. A "terminate phonation" signal was presented 2 sec after the phonate cue. The terminate signal consisted of the synthetic vowel /i/. Each of the 13 sequences was replicated five times, randomized, and output onto audiotape using the Haskins Laboratories Plus Code Modulation (PCM) system.

## Procedures

Stimulus sequences were presented simultaneously to the subject, seated in a soundproof booth, and to track one of a two-track tape recorder. Subjects' responses were recorded on track two of the tape recorder. Subjects were instructed to phonate the vowel /a/ immediately at the offset of the reaction signal and to continue phonation until presentation of the terminate signal. All subjects were allowed 21 training sequences, including long and short foreperiods. Although most subjects required fewer than the maximum number of training sequences to learn the relatively simple task, all subjects were exposed to training sequences containing long and short foreperiods. Response sequences were presented in two 7-min tests separated by an optional 3- to 5-min rest interval.

### Fluency Criteria

We followed the same procedures used in our original experiment to ensure that only fluent responses were analyzed. First, subjects were instructed to identify any production that they thought was dysfluent. Second, the experimenter noted any production that he thought was dysfluent. No responses were omitted on the basis of the first two criteria. Finally, productions were excluded from the data set if the waveform showed certain irregulatirites that may be related to nonaudible stuttering, such as isolated pitch pulses before the onset of continuous phonation. As a result of the third criterion, three responses were excluded from the mild stutterers' data set, one response was excluded from the severe stutterers' data set, and no responses were excluded from the nonstutterers' data set. Thus, 322 LRT values were measured for mild stutterers, 324 values were measured for severe stutterers, and 325 values were measured for nonstutterers.

### Measurements

Data were analyzed with the aid of a computer waveform-editing system at Haskins Laboratories. Temporal resolution of the waveform analyzer is accurate to one-tenth of a millisecond (Nye et al., 1975). LRT values were defined as the interval between the offset of the phonate cue and the onset of the first regular pitch pulse of the voiced vowel /a/.

### Statistical Analyses

All data were subjected to several multiple correlation regression (MCR) analyses (Cohen & Cohen, 1975) for the following reasons. First, the procedure permits analysis of interaction effects between interval (foreperiod) and nominal (stuttering severity) level independent variables, a capability not provided by traditional multiple analysis of variance procedures. Second, MCR analysis permits experimenter selection of specific group comparisons. Finally, MCR analysis allows for the evaluation of nonlinear relationships, such as the hypothesized relationship between foreperiod and LRT. The statistical design used in this experiment was a subjects within groups (normal, mild, severe) by condition (foreperiod) repeated measures MCR. This design requires separate MCR analyses to determine (1) the significance of the between-subject (stuttering severity) main effect and (2) the within-subject (foreperiod) main effect and interaction (stuttering severity × foreperiod) effect. The first MCR analysis was conducted to determine the significance of the stuttering severity factor. For this analysis, the subject group variable was coded to permit separate comparisons between nonstutterers and mild stutterers and between mild and severe stutterers. The second MCR analysis was conducted to determine the signifiance of the foreperiod factor and the interaction betweeen stuttering severity and foreperiod. For this analysis, the subejct group variable was, once again, coded to permit comparisons between normals and mild stutterers as well as between mild and severe stutterers. The third MCR analysis was conducted to determine the magnitude of the nonlinear relationship between foreperiod and LRT for each group in order to determine whether there was an optimal foreperiod effect. Finally, comparisons between group mean LRT values at each foreperiod were conducted using the nonparametric Randomization Test for Independent Samples, since several of the criteria required by parametric analyses were not fulfilled by these data (Siegel, 1956).

## RESULTS

Figure 3 displays a summary of LRT values for the complete data set.[1] Each data point in this figure represents the average of all analyzed

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[1] The present study reports results obtained from statistical analysis of the complete data set. In so doing, it is consistent with most LRT studies comparing nonstutterers with stutterers. However, two procedures are sometimes used to eliminate the maximum and minimum LRT values prior to group comparisons. The rationale for either of these procedures is that LRT values significantly faster than the mean reflect anticipatory responses occurring before the phonate cue, whereas values significantly slower than the mean reflect the subjects' inattention to the task. As an example of one procedure, Izdebski and Shipp (1978) and Izdebski (1980) used statistical tests to eliminate only significant outliers. As an example of the second procedure, Reich et al. (1981) omitted the fastest and slowest responses of each subject before group comparisons. In a forthcoming paper, we will discuss the effects of various data-reduction procedures on the LRT effect.

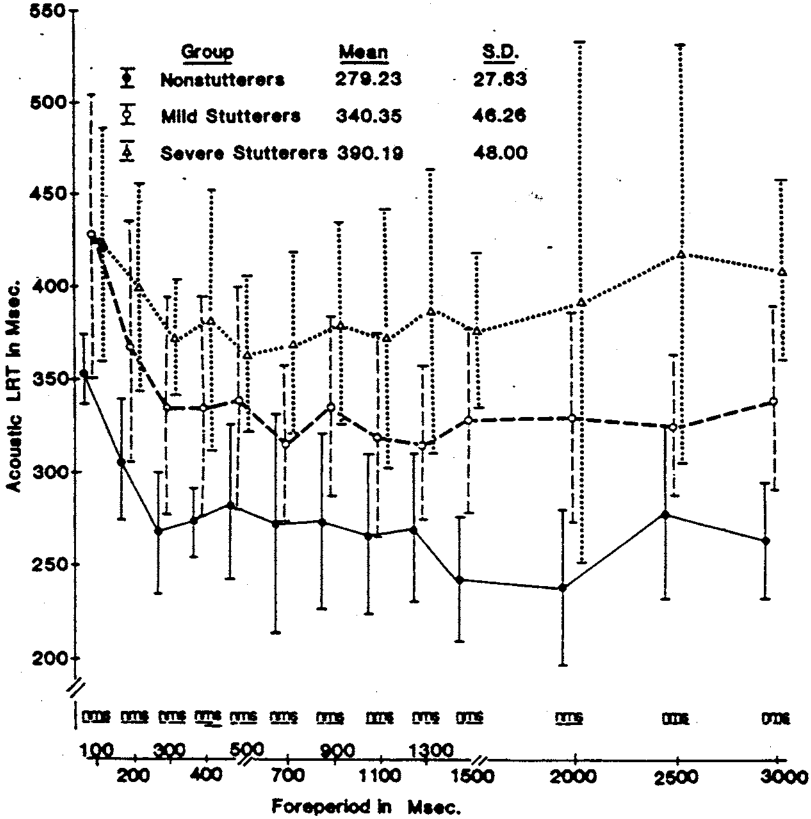

**Figure 3:** Acoustic LRT values in group means and standard deviation dispersions for the 13 foreperiod conditions. Each data point represents the individual subject averages pooled across the five subjects in each group.

responses per subject pooled across the five subjects in each group. LRT values are expressed in group means and two standard deviation dispersions for the three subject groups and 13 foreperiod conditions. Also shown are group means and standard deviations collapsed across the 13 foreperiod conditions. LRT values for nonstutterers are shown as closed circles, for mild stutterers as open circles, and for severe stutterers as open triangles. Note that this figure demonstrates that LRT varies as a function of subject group and foreperiod.

**TABLE 1**

**Summary of Main and Interaction Effects**

| Main Effects | *F* | *ti* |
|---|---|---|
| Stuttering severity | 8.88[a,b,c] | 2,12 |
| Foreperiod | 3.1[a,b,c] | 12,144 |
| **Interaction Effect** | | |
| Stuttering severity by foreperiod | 0.52 | 24.144 |

[a] $F_{.99}$ (2,12) = 6.93.
[b] $F_{.99}$ (12,144) = 2.31.
[c] $F_{.95}$ (24,144) = 1.59.

The first two hypotheses in this study predicted foreperiod and stuttering severity effects on LRT. The results of MCR analyses of these main effects as well as the stuttering severity by foreperiod interaction effect are summarized in Table 1. This table shows that both the stuttering severity and foreperiod factors are significant ($p < 0.01$).

Partial regression coefficients obtained from the between-subjects MCR are presented in Table 2. Coefficients for both the nonstutterer versus mild stutterer and mild versus severe stutterer group comparisons were significant ($p < 0.01$). These results indicate that the three groups' LRT values were significantly different when collapsed across the 13 foreperiod conditions.

Table 3 shows results of analyses of the power of the polynomial describing the relationship between foreperiod and LRT for each subject group. Second-order polynomials were found for the nonstutterers and

**TABLE 2**

**Partial Regression Coefficients for Stuttering Severity Factor**

| Comparison | *B* | *F* | *df* |
|---|---|---|---|
| Nonstutterers vs mild stutterers | −57.36 | 14.19[a] | 1,12 |
| Mild stutterers vs severe stutterers | −53.59 | 12.39[a] | 1,12 |

[a] $F_{.99}$ (1,12) = 9.33.

TABLE 3

**Summary of Power Polynomial Analysis of Foreperiod**

| | Power Term | Inc R Square | *F* | *df* |
|---|---|---|---|---|
| Nonstutterers | Linear | 0.27 | 4.17 | 1,11 |
| | Quadratic | 0.30 | 08.10[a] | 1,10 |
| | Cubic | 0.06 | 1.45 | 1,9 |
| Mild stutterers | Linear | 0.17 | 2.27 | 1,11 |
| | Quadratic | 0.33 | 11.61[b] | 1,10 |
| | Cubic | 0.16 | 4.64 | 1,9 |
| Severe stutterers | Linear | 0.11 | 1.39 | 1,11 |
| | Quadratic | 0.36 | 13.33[c] | 1,10 |
| | Cubic | 0.26 | 8.66[d] | 1,9 |

[a] *F*.95 (1,11) = 4.84.
[b] *F*.95 (1,10) = 4.96.
[c] *F*.99 (1,10) = 10.04.
[d] *F*.95 (1,9) = 5.12.

mild stutterers. That is, LRT values for these subjects decrease to a minimum and then increase as foreperiod increases. A nonlinear relationship between foreperiod and LRT was also reported by Izdebski (1980) following analysis of a reduced data set. He found, using only normal subjects, a second-order relationship between foreperiod and LRT. However, our data indicate that the relationship between LRT and foreperiod for severe stutterers is different. For these subjects, Table 3 shows that a third-order polynomial also becomes significant and approaches the second-order term in best describing the shape of the curve. This implies that LRT values for severe stutterers tend to decrease to a minimum, then increase to a maximum, and then decrease again as foreperiod increases. These results emphasize the difference between severe stutterers versus mild stutterers and nonstutterers. For example, the data shown in Figure 3 for mild stutterers and nonstutterers show single maximum and minimum values, yielding a single inflection point in the curve. A curve of predicted LRT values, representing least-squared deviations, was obtained by solving regression equations for each group. Analysis of predicted curves indicates that the inflection points for nonstutterers and mild stutterers occur at 2000 and 1500 msec, respectively. For severe stutterers, there is less difference between maximum and minimum LRT values and the curve has two inflection points, 900 and 2500 msec. Note also that the fastest LRT for nonstutterers occurred at a foreperiod of 2000 msec, consistent with the results reported by Izdebski (1980). For the severe stutterers, fastest LRT values occurred at a foreperiod of 500 msec. The foreperiod at which the fastest LRT values occurred for mild stutterers is less clear, but seems to be around 1300 msec. Thus, minimum LRT values also seem to vary as a function of group membership. Finally, it appears that foreperiod has a greater effect on the maximum and minimum LRT values of nonstutterers and mild stutterers than it does for the severe stutterers' LRT values. To summarize, the results reported thus far support the first two hypotheses of this study. That is, both the stuttering severity factor and foreperiod factor were shown to affect LRT values significantly. In addition, partial regression coefficients revealed that the stuttering severity main effect reflects significant group differences between nonstutterers and mild stutterers as well as between mild and severe stutterers when LRT values are collapsed across the 13 foreperiods. Finally, foreperiod has a greater effect on nonstutterers' and mild stutterers' LRT values than on severe stutterers' LRT values.

The third hypothesis stated that there was a difference between nonstutterers' and stutterers' (grouped by severity) LRT values as a function of foreperiod. Our original experiment revealed nonsignificant differences between nonstutterers and mild-moderate stutterers at 1-, 2-, and 3-sec foreperiods. Hence, in the present study, we expected to find significant differences between nonstutterers' and mild stutterers' LRT values only at foreperiods less than 1100 msec. Conversely, we expected to find significant differences between nonstutterers' and severe stutterers' LRT values at both short and long foreperiods. These hypotheses were tested by conducting post-hoc group comparisons by using the Randomization Test for Independent Samples. Results of these comparisons are shown below the abscissa in Figure 3. The symbol N refers to nonstutterers, and the symbols M and S refer to mild and severe stutterers, respectively. A solid line connecting groups indicates no significant difference between group means. Results of this analysis reveal that severe stutterers' LRT values are significantly greater than nonstutterers' at all 13 foreperiods ($p < 0.05$). On the other hand, mild stutterers' LRT values are significantly greater than nonstutterers' at only 5 of the first 7 foreperiods, that is, at foreperiods less than 1100 msec. However, we unexpectedly found significant LRT differences between nonstutterers and mild stutterers at 4 of 6 foreperiods equal to and greater than 1100 msec. Thus, results of group comparisons as a function of foreperiod clearly support our hypothesized differences between nonstutterers' and severe stutterers' LRT values, but only partially support our hypothesized differences between nonstutterers' and mild stutterers' LRT values. In general, these results demonstrate that mild stutterers' LRT values approach those of nonstutterers as foreperiod increases, whereas severe stutterers' LRTs remain significantly greater than nonstutterers' throughout the entire range of foreperiods.

## DISCUSSION

The first interesting finding of the present study is that of a significant stuttering severity factor. This finding is consistent with reaction time data for complex vocal and manual responses reported by Borden (1982). Using the same stuttering subjects used in the present study and a constant foreperiod equal to 1 sec, she also observed significant group differences between nonstutterers and severe stutterers for the execution of perceptually fluent counting and finger-tapping responses. Differences between nonstutterers and mild stutterers for the same tasks failed to reach significance. Thus, results of this and the Borden study indicate that stuttering severity affects group reaction time differences for both simple and complex vocal responses as well as for manual responses. Furthermore, these results suggest that the delayed LRT values demonstrated by the experimental subjects may represent an underlying deficit in general motor control in stutterers as a group. Finally, these results suggest that the magnitude of the delay, and correspondingly the magnitude of the deficit, is reflected in the stuttering severity rating. Of course, acoustic measurements alone do not permit analysis of the motor-control processes occurring before the onset of the acoustic response. Later in this discussion, we will suggest procedures that may allow analysis of motor-control processes during posturing and response onset.

Perhaps the most interesting and important finding of this study is the composite effect of the stuttering severity and foreperiod factors on the significance of group LRT differences between stutterers and nonstutterers. Specifically, we observed that mild stutterers' LRT values approach normal values as foreperiod increases, whereas severe stutterers' LRT values are significantly greater than normal values throughout the range of foreperiods. These results are in general agreement with the findings of our original LRT experiment. That study failed to show significant group LRT differences between nonstutterers and a group of mild to moderate stutterers for foreperiods equal to 1, 2, and 3 sec. Although the present study reports nonsignificant differences at only two of six foreperiods in this range, it should be pointed out that the results of the present study reflect fewer subjects per group, fewer responses per subject, and the use of nonparametric statistics. With these differences aside, the present study supports our original experiment in that the differences between mild stutterers' and nonstutterers' LRT values are significantly less than the differences between nonstutterers' and severe stutterers' LRT values.

Throughout this article, we have noted that long foreperiods permit subjects to complete activity required to posture the speech mechanism for the voiced response. Consequently, the finding that mild stutterers' LRT values approach normal values as foreperiod increases, whereas severe stutterers' LRT values do not, suggests that different deficits may contribute to delayed LRT values for the two groups of stutterers. Specifically, with regard to the comparisons between nonstutterers and mild stutterers, our results generally support the hypothesis that mild stutterers' primary difficulty is posturing the speech mechanism. However, it is also likely that our mild stutterers have some difficulty initiating vibration, since their LRT values do not become identical with those of the nonstutterers. Results of the comparisons between nonstutterers and severe stutterers as a function of foreperiod suggest that these stutterers may have both posturing and vibration-initiation deficits.

Reaction time responses have been studied with respect to their premotor and motor components (Botwinick and Thompson, 1966). Following this example, we have chosen to study the posture and initiation components of the reaction time response in an attempt to better understand the qualitative differences in the deficits underlying stutterers' delayed LRT values. These components are schematically represented in Figure 4. The posture component is represented by a series of processes related to perception of the warning and/or phonate cue, formulation and transmission of neuromotor commands to posture the speech mechanism, posturing of the speech mechanism for the required

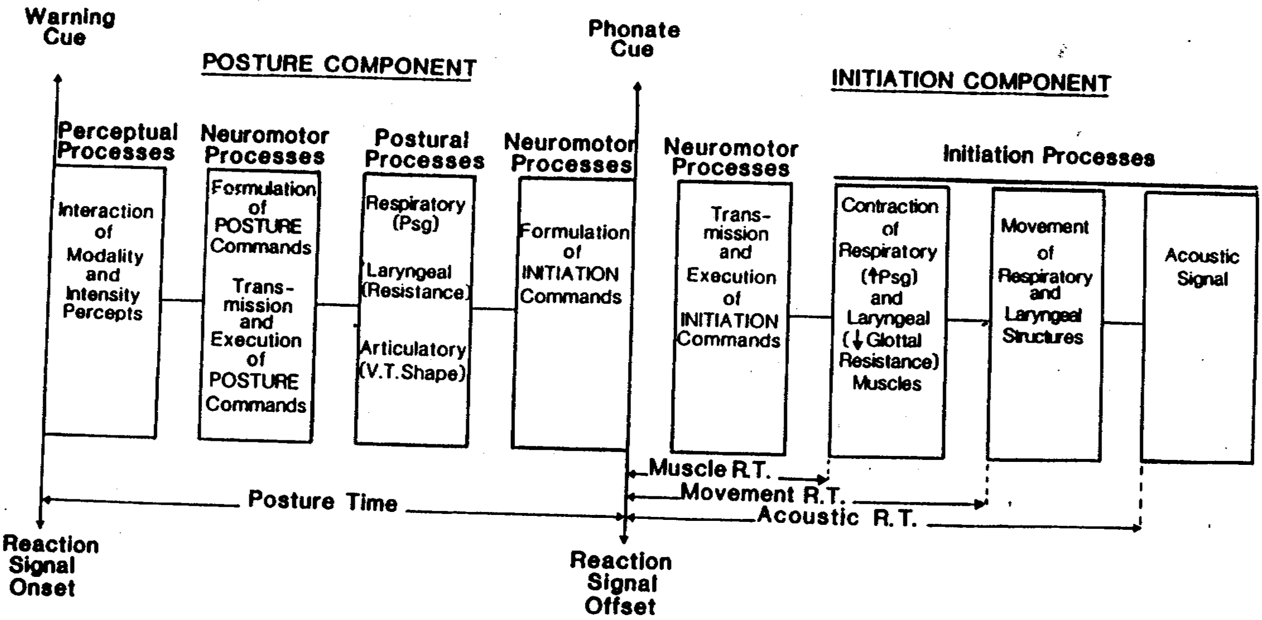

Figure 4: Posture and initiation components of the laryngeal reaction time response.

response, and formulation of neuromotor commands to initiate the response. The formulation of neuromotor commands for initiation may occur simultaneously with the formulation and transmission of neuromotor commands for posturing. Postural processes are also taken to include prephonatory gestures. The initiation component is represented by processes related to the transmission and execution of neuromotor commands for the response. The consequences of executing these commands are: (1) muscular adjustments, (2) articulator movement, and, finally, (3) acoustic output. Figure 4 demonstrates the special case in which foreperiod duration permits completion of all postural activity prior to the presentation of the phonate cue.

The interval required for perceptual processing of the warning and phonate cue will vary as a function of stimulus modality and intensity (Elliot, 1968; Murray, 1970; Watson and Alfonso, 1982). There is conflicting evidence regarding the effect of stimulus modality on the LRT effect. For example, significant group reaction time differences between stutterers and nonstutterers have been reported for auditory but not for visual stimuli by McFarlane and Prins (1978) and McFarlane and Shipley (1981). Conversely, Watson and Alfonso (1982) failed to find significant between-group LRT differences for auditory or visual stimuli. Thus, it is not conclusive whether stimulus modality influences the LRT effect. However, Kohfeld (1971) has shown that stimulus modality and intensity parameters interact in a complex manner and, more importantly, that cross modality reaction time differences may reflect the failure of experimenters to ensure that visual and auditory stimuli are presented at psychophysically equal intensity levels. In addition, cognitive and affective factors, such as instructions to the subject and the experimental setting (Murray, 1970), as well as a variable foreperiod (Niemi and Lehtonen, 1982) may interact with stimulus parameters to alter the duration of perceptual processes. Thus, the duration of the perceptual processing interval is determined by several variables. The effects of stimulus-related variables may be reduced by maintaining constant stimulus modality and intensity parameters for all subjects. Although it is not possible to measure the duration of perceptual processes in humans directly, Wall et al. (1953) provide an estimate of this interval based on physiological data obtained from anesthetized animals. Recording electrical activity in pyramidal tract neurons in the motor cortex, they observed a latency of approximately 30 msec between the onset of a visual stimulus and the onset of neural activity. These data suggest that the contribution of perceptual processing activity to overall LRT values may be relatively small. To summarize, it is not possible to measure the duration of perceptual processes directly. However, by controlling stimulus intensity and modality parameters, the duration of this interval may be held relatively constant across subjects.

The interval required for the completion of neuromotor processes (i.e., formulation and transmission of appropriate neural commands to the peripheral musculature) may also contribute minimally to overall LRT values in the simple reaction time paradigm. Estimates of formulation latencies are not available for human subjects. However, the transmission velocity of neural impulses along the recurrent laryngeal nerve is approximately 56 meters/second in nonstutterers (Flisberg and Lindholm, 1970). This value, in addition to a residual latency of 1.5 to 2.5 msec due to synaptic junctions and the decreasing diameter of peripheral nerve fibers (Basmajian, 1970), yields an estimated maximum transmission latency in nonstutterers of approximately 3.0 msec. Thus it appears that although the duration of perceptual and neuromotor processing components in the LRT paradigm cannot be directly measured, it is likely that the contribution of both these processes to group LRT differences is relatively insignificant.

Posturing the speech mechanism for the onset of an isolated, voiced vowel requires muscular adjustments in the respiratory, laryngeal, and articulatory systems. In the respiratory system, these adjustments result in the optimization of thoracic muscle tension. Optimal muscle tension levels, in turn, facilitate rapid generation of sufficient subglottal pressure for phonation initiation (Baken et al., 1979). In the laryngeal system, muscular adjustments modify vocal-fold tension and position to facilitate phonation. Articulatory adjustments result in achievement of supralaryngeal vocal-tract postures appropriate for the required response (e.g., the isolated vowel /a/). We assume that posturing activity within these systems will occur simultaneously. Furthermore, it is likely that the nature of the posturing activity within any system is, in part, a function of the qualitative interaction between systems. For example, there may be differences in respiratory and laryngeal coupling for the onset of voiced versus voiceless vowels. In addition, articulatory postures may affect laryngeal posturing (i.e., constricted open vocal-tract configurations).

In the aerodynamic domain, respiratory posturing also occurs with respect to lung volume. For example, Izdebski and Shipp (1978) have shown that a lung volume of approximately 50% vital capacity yields faster LRT values than do prephonatory lung volumes of 25 and 75% vital capacity. In addition, Hoshiko (1965) found that nonstutterers usually initiate phonation from about 50% vital capacity. Thus, this value appears to represent an optimal lung volume for the initiation of vocal-fold vibration.

It is also true that LRT values are affected by processes included in the initiation component. These include transmission and execution of initiation neuromotor commands, muscle contraction, coordinated movement of speech structures, and, finally, generation of the resultant acoustic output. Reaction time measurements of the latter three processes can be obtained and are illustrated in Figure 4.

Lastly, we should emphasize that posturing deficits in stutterers would delay initiation of the response. For example, the latency of vibration onset for stutterers may be prolonged if the vocal folds are "hyperpostured," that is, postured with excessive tension and adduction, or abnormally postured (i.e., simultaneous adduction and abduction, cf. Freeman and Ushijima, 1978). Hyperpostured vocal folds would likely result in abnormally high levels of glottal resistance and, therefore, the need for higher levels of subglottal pressure, whereas abnormally postured vocal folds would prevent the accumulation of sufficient subglottal pressure to initiate vibration. Finally, markedly constricted articulatory postures increase supraglottal pressures and, thus, may prolong vibration onset latencies. The point we wish to make is that the delayed reaction time values in these instances would reflect postural rather than initiation deficits.

We assume that the contribution of perceptual processes in this study to between-group differences was insignificant since stimulus modality and intensity parameters were held relatively constant for all subjects. In addition, it is likely that the contribution of neuromotor process to the LRT effect was insignificant. The finding that mild stutterers' LRT values approach those of nonstutterers as foreperiod increases suggests that the primary difficulty for this group of stutterers is related to posturing the speech mechanism. However, since LRT values for mild stutterers did not become identical with those of nonstutterers, it is also possible that these stutterers have some degree of difficulty initiating vibration as well. Conversely, the finding that severe stutterers' LRT values fail to approach those of nonstutterers as foreperiod increases suggests that severe stutterers may have difficulty in both posturing the speech mechanism and initiating vocal-fold vibration. What is important, is that the underlying deficit may be qualitatively different between mild and severe stutterers. Unfortunately, LRT measures obtained from acoustic analysis alone do not permit precise specification of the loci of deficits in phonation onset activity in these stutterers. For example, it is possible that mild stutterers have the same type of deficits as do severe stutterers but to a lesser degree. Thus, we feel that we have made the most of acoustic measures of LRT. That is, we need to investigate those activities that occur before the onset of voicing.

The advantage of obtaining simultaneous measures in the acoustic, movement, and EMG domains is discussed by Baer and Alfonso (in press). They suggest that simultaneous measures may be particularly informative in LRT experiments because they provide information regarding activity prior to onset of the acoustic signal corresponding to vocal-fold vibration. For example, the combined duration of perceptual and neuromotor processes may be inferred from EMG signals recorded from intrinsic laryngeal muscles. That is, the latency between the offset of the warning signal and the onset of the EMG signal in the laryngeal muscles may yield an estimate of the time required to complete perceptual and neuromotor processes. In addition, EMG measures may be useful in documenting the latency of onset, synergy, and amount of muscular activity during prephonatory posturing of the speech system as well as during generation of subglottal pressure by the respiratory system. Direct observation of chest-wall and vocal-fold movements, via Respitrace (Cohn et al., 1977) and transillumation instrumentation, respectively, may also provide information regarding the amount and coordination of respiratory and laryngeal posturing activity as well as the interaction between laryngeal posturing and respiratory-system activity during the generation of subglottal pressure.

In conclusion, the results of the present study support the results of our original experiment by demonstrating a significant stuttering severity effect. Furthermore, the present results support the notion that mild and severe stutterers' prolonged LRT values may reflect differential deficits in posturing and/or vibration initiation. We recognize, however, that acoustic analyses alone will not specifically reveal the nature of deficits contributing to stutterers' delayed LRT values. We plan future LRT experiments incorporating simultaneous measures in the acoustic, movement, and EMG domains. Only through the use of simultaneous measures can the nature of deficits underlying stutterers' often reported difficulty in initiating phonation be systematically described.

*A portion of the data reported in this paper was first presented at the annual convention of the American Speech-Language-Hearing Association, Los Angeles, California, November 1981. This research was supported by NINCDS grant NS13870 awarded to Haskins Laboratories. We gratefully acknowledge the assistance of Arlyne Russo in classifying the experimental subjects. We also wish to thank Thomas Baer for his assistance in the preparation of this manuscript.*

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