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A Comparison of LRT and VOT Values Between Stutterers and Nonstutterers*

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The experiment reported here found no significant group differences in laryngeal reaction time (LRT) and voice onset time (VOT) values. Rank-order correlations between the stutterers' LRT and VOT values were also nonsignificant. A model of the LRT paradigm is presented that (1) allows for systematic assessment of factors possibly contributing to the failure to replicate the often reported LRT group difference, and (2) is useful in examining the relationship between the LRT experimental condition and normal speaking conditions. We argue that two factors were particularly critical to our results. First, simple reaction time procedures included (1) a warning signal that preceded a response signal by a variable 1–3-sec foreperiod, and (2) a single response. We argue that foreperiod durations exceeded the stutterers' speech posture time for a known response. Second, the stuttering severity rating of our experimental group was less severe than ratings in other experiments.

INTRODUCTION

Adams and Hayden (1976) and Starkweather et al., (1976) were the first to demonstrate that stutterers require more time to initiate phonation in response to a reaction signal, such as a tone or light, than nonstutterers. This finding has been replicated several times (cf. Lewis et al., 1979; Cross et al., 1979; Cross and Luper, 1979; Reich et al., 1981). We shall refer to the paradigm used in all of these studies as laryngeal reaction time, or LRT, where the dependent variable is the elapsed time between the

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reaction signal and the initiation of phonation. Furthermore, we shall refer to the consistent group differences observed in the above LRT experiments as the LRT effect. A conclusion that can be drawn from the results of these studies, if one assumes that the LRT paradigm is sufficiently analogous to normal speaking conditions, is that the same stutterers who experience difficulty in the initation of phonation in the LRT experimental condition also experience phonation initiation difficulty in conversational speaking situations. It would be worthwhile to ascertain the relationship between the LRT experimental condition and normal speaking conditions since the LRT paradigm could be used to examine the various components of phonation, respiratory and vocal tract coupling for instance, and these data could lead to generalizations about the role of laryngeal articulation in conversational situations in which stuttering occurs.

One way to test the LRT experimental condition—normal speaking condition analogy is to test the robustness of the production and perceptual components underlying the significant LRT effect. For instance, one aspect of the production component should be phonation type.[1] Perkins et al. (1976) found that stutterers become increasingly fluent as the phonation type changes from voiced, to whispered, to "lipped," that is, silently articulated. Adams and Reis (1971), and Manning and Coufal (1976) reported that increased stuttering is more likely to occur during voiceless to voiced phonation transitions than voiced to voiced transitions. Studies such as these indicate that the occurrence of stuttering is related to the phonation type of the utterance. Accordingly, one way to test the robustness of the LRT effect is to compare group LRT values obtained using whispered responses with group LRT values obtained using voiced responses. On the basis of the above experiments, one should not expect the LRT effect to be robust with respect to phonation type, but rather one should expect to find a greater LRT effect for voiced responses than for whispered responses.

[1]We use the term "phonation type" after Ladefoged (1971, 1973) to mean the differen vocal fold behaviors that occur during laryngeal sound production. Phonation types are points on a single physiological continuum representing glottal opening; the endpoints o which are the voiced and voiceless phonation types. See Wingate (1979) for a recen discussion of the use of the term "phonation" in studies examining laryngeal behaviors ir stutterers.

Furthermore, we reasoned that since stuttering is more likely to occur in certain phonological and lexical environments, for example initial sounds in sentences and long rather than short words (see Brown, 1938; Wingate, 1977), the LRT effect should also increase as the length of the response increases from isolated vowels to phrases. To summarize, we reasoned that if the LRT effect was indeed analogous to the reported laryngeal dysfunction often observed during moments of stuttering in normal speaking conditions, we would find an increase in the LRT effect as the response proceeded from isolated whispered vowels, to isolated voiced vowels, to phrases.[2] Consequently, the first purpose of this study was to test the robustness of the production component of the LRT effect by testing the notion that stutterers require more time to initiate phonation across different phonation types and phonological environments than do normal speakers. A positive correlation between the magnitude of the LRT effect and the above sequence of responses would support the assumed analogy between the LRT paradigm and normal speaking conditions.

The second purpose of this study was to test the robustness of the perceptual component of the LRT effect. For instance, it may be that deficits in the auditory processing of the reaction signal could significantly contribute to the LRT effect (McFarlane and Prins, 1978). A comparison of LRT values obtained using visual and auditory reaction signals in the same subject would assess this assumption.

Voice onset time measures, or VOT, have also been used to compare laryngeal control mechanisms between stutterers and normal speakers. The dependent variable in VOT production experiments is the amount of time between the release of a supralaryngeal vocal tract constriction and the initiation of phonation. Thus, LRT and VOT are similar in that they represent phonation initiation times in reference to a

[2]To initiate whispered phonation, we assumed that subjects would alter glottal opening from a fully abducted nonspeech (inhalation or exhalation) position to a partially adducted whisper position, perhaps by contraction of the Lateral Cricoarytenoid muscle but not the Interarytenoid muscle (Ladefoged, 1971). In voiced phonation, we assumed that subjects would alter glottal opening from the fully abducted nonspeech position to the fully adducted voiced position. Thus, whispered phonation represents an "off-partial on" laryngeal adjustment whereas voiced phonation represents an "off–on" laryngeal adjustment (Adams and Reis, 1971).

particular event. The event is external in LRT measurements, a light or a tone, whereas the event is internal in VOT measurements, the release of a supralaryngeal occlusion. Although LRT and VOT represent estimates of a presumably similar laryngeal timing mechanism, the results of studies based on either of these two paradigms do not appear to be mutually supportive. That is, while every LRT study known to us using adult subjects has shown significant group differences, the reported VOT studies do not consistently show group differences. For example, Hillman and Gilbert (1977) reported significant group VOT differences between stutterers and normals, yet Metz et al. (1979) reported no significant group VOT differences in most of the phonetic contexts constituting their data base. Procedural differences among many of the published VOT studies—most notably the use of nonsense syllables vs meaningful words, isolated vs. continuous speech, control of speech rate and phonetic context, and subject training—make it difficult to compare their results.

Consequently, the third purpose of this study was to compare VOT values between the stuttering and normal groups, and to compare LRT values with VOT values for the same stuttering subject. Since LRT and VOT measures reflect the speaker's ability to control phonation initiation, we expected that the LRT data would positively correlate with the VOT data. Specifically, we expected to find that those stutterers who showed significantly greater LRT values than other members of the experimental group would also show significantly greater VOT values. To our knowledge, a comparison of LRT with VOT data taken from the same subjects has not previously been made.

Thus the four questions posed by this study were as follows:

1. Is there an increase in the LRT effect (significant difference between stutterers and normal speakers) as the response proceeds from whispered vowels, to voiced vowels, to phrases?
2. Is there a significant difference in the LRT effect when the reaction signal is presented visually rather than auditorily?
3. Is there a significant difference in VOT values between stutterers and normal speakers when the measurements are taken from productions of nonsense syllable phrases with speech rate and phonetic context controlled?

4. Is there a correlation between VOT and LRT values in stutterers?

METHOD

Subjects

The subjects who participated in this study included eight adult stutterers and eight adult fluent speakers. The experimental group, consisting of seven males and one female, had a mean age of 24 yr, 9 mo, and ranged in age from 18 yr, 5 mo to 37 yr, 11 mo. The control group, also seven males and one female, had a mean age of 24 yr, 10 mo and ranged in age from 19 yr, 4 mo to 38 yr, 1 mo. All subjects passed a pure tone screening at 25 dB HTL. Using the stuttering severity rating system found in Darley and Spriestersbach (1978), a mean group rating of mild-to-moderate severity was obtained for the experimental group.

Fluency Criteria

Since it is necessary to exclude dysfluent productions in order to make a valid measure of laryngeal reaction time, three procedures were used to maximize the probability that measurements were taken only from fluent productions. First, stutterers were instructed to repeat any production that they thought was dysfluent. Second, stutterers were told that they would be asked to repeat any production that the experimenter thought was dysfluent. The subjects who participated in this study had little difficulty in producing fluent speech: only one utterance was identified as dysfluent and had to be repeated. Finally, in the acoustic analysis, productions were excluded from analysis when the waveform showed certain irregularities such as isolated pitch pulses before the onset of continuous phonation. Because of this final criterion, we discarded 2.1% of the LRT data collected from stutterers and 0.82% of the data from normal speakers.

Test Stimuli

The reaction signals used in the LRT portion of this study included a 1-kHz pure tone presented binaurally and a visual signal presented by an incadescent lamp located directly in front of the subjects. The duration of the reaction signal randomly varied from 1 to 3 sec in 1-sec increments. In the isolated vowel conditions, a termination signal (light or tone) cued the subject to stop phonating. The reaction signals were channeled through a switching mechanism that permitted simultaneous presentation of a reaction signal to the subject and a tone to track one of a two-track tape recorder. Subjects' responses were recorded on track two. The onset of the reaction signal served as a warning signal. Subjects were instructed to begin phonation immediately at the offset of the reaction signal. An inter-stimulus-interval (ISI) of 4 sec was used throughout the experiment.

Procedures

The procedures used in this study are consistent with the simple reaction time paradigm described by Niemi and Naatanen (1981). In this paradigm, a warning signal is presented to prepare subjects for the forthcoming reaction signal. Presentation of the warning signal precedes presentation of the reaction signal by an interval referred to as the foreperiod. The foreperiod provides the subject time to prepare for a response. In a simple reaction time paradigm, a single response is used throughout the experiment. Consequently, the use of a single response and relatively long foreperiods provide an estimate of optimal reaction time. In the present study, the onset of the reaction signal served as the warning signai, the offset served as the phonate cue (reaction signal), and the 1-, 2-, and 3-sec reaction signal durations served as the variable foreperiods. Reaction signals were preceded by a 4-sec ISI. There were three LRT response conditions in this study and their order was systematically randomized across all subjects. In the first condition, subjects were required to produce the isolated whispered vowel /a/, and in the second condition, the isolated voiced vowel /a/. In the third condition, the subjects were required to produce a nonsense-syllable phrase beginning with a voiced schwa.

VOT values were obtained from the nonsense syllables used in the third LRT response condition. The phrases consisted of three contiguous schwa + C1−V−C2 segments where C1 was either /p,t,k/, C2 was always /t/, and V was either the high front vowel /i/, the high back vowel /u/, or the low front vowel /æ/—for example, /əputətætəkit/. Each subject produced 20 isolated voiceless vowels, 20 isolated voiced vowels, and

36 phrases (which represented all permutations of the three vowels and three consonants). All subjects were given ten training responses in each of the isolated vowel LRT conditions before data collection. In the phrase condition, all subjects were permitted to rehearse a phrase until he or she felt that they could produce the phrase correctly and fluently. The average number of training responses in the phase condition was three productions per phrase.

Measurements

Two-track tape recordings consisting of reaction signal tones on one track and subject responses on the other track were played back at half of the recording speed and analyzed on a calibrated Honeywell Visicorder at a paper speed of 102.4 mm/sec. A third visicorder channel monitored a 100-Hz pure-tone signal which served as a calibration signal for timing measurements. Figure 1(a) demonstrates an example of a LRT measurement taken from the whispered vowel condition. The onset of a whispered vowel was defined as the point of abrupt increase in acoustic amplitude.

LRT values were obtained by measuring the elapsed time between the offset of the reaction signal (point A) and the onset of phonation (point A'). Figure 1(b) shows a typical LRT measure taken from the voiced vowel condition. The onset of voiced vowels was taken to be the first regular vocal fold pulse (point A').

Traditional VOT measures were obtained from wide-band spectograms (Lisker and Abramson, 1964). Since no significant group differences were found ($p > 0.05$) in rate of articulation, absolute VOT values were used in subsequent data analysis. Of the total VOT measures taken, 2.3% of the stutterers' and 1.7% of the nonstutterers data were discarded because either the release of the stop or the onset of phonation was ambiguous.

RESULTS

LRT Measures

Figure 2 represents a summary of the LRT values expressed in group means and two standard deviation dispersions for the two reaction signals

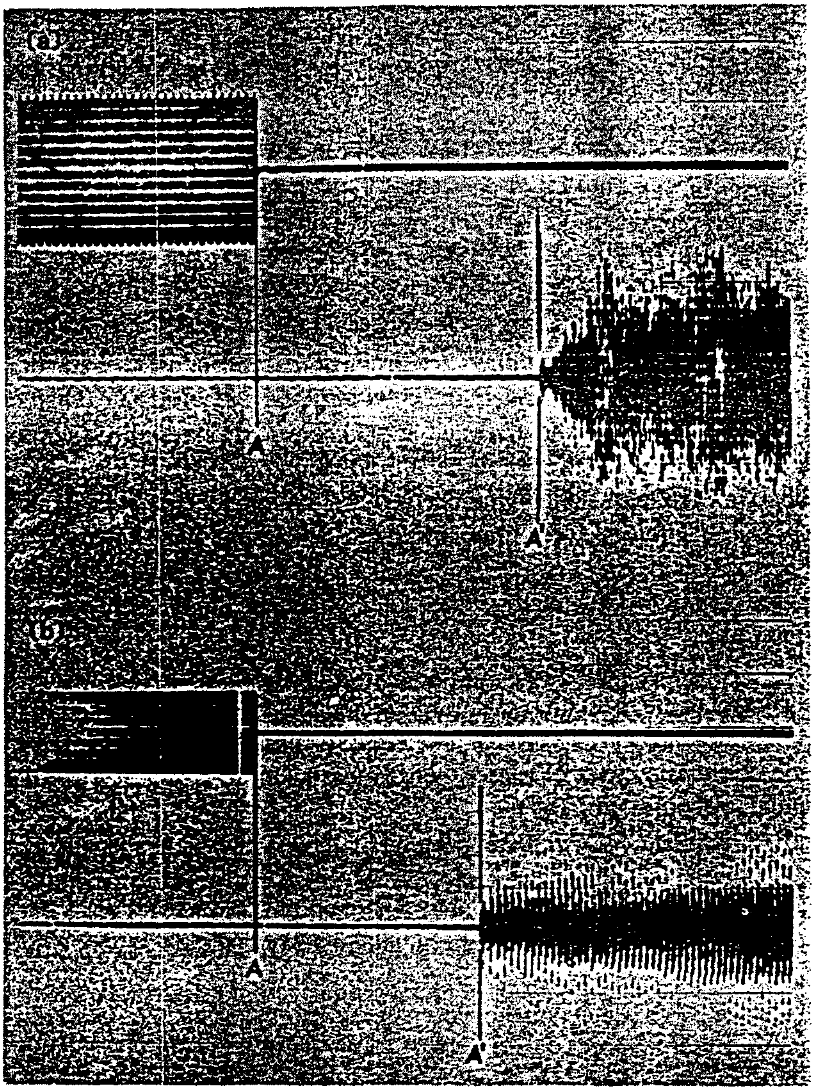

Figure 1: Waveform records of typical utterances taken from the whispered (a) and voiced (b) isolated vowel conditions. Reaction signals are shown on the upper traces; subject responses are shown on the lower traces. Timing signals have been omitted from the figure. The offset of the reaction signal is labeled as A, utterance onset as A'. LRT values were obtained by measuring the elapsed time between A and A'.

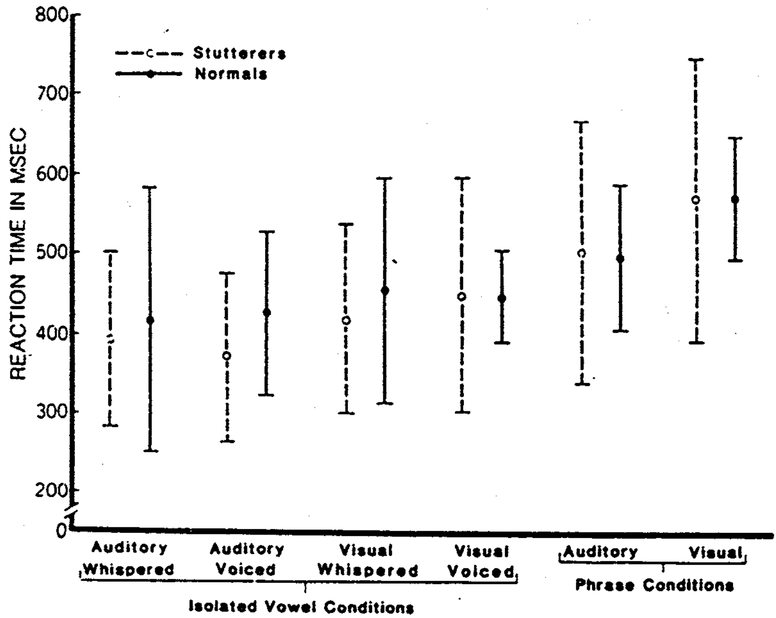

Figure 2: This figure represents a summary of the LRT values expressed in group means and two standard deviation dispersions for the two reaction signals (auditory and visual) and the three response conditions (isolated whispered and voiced vowels, and phrases) used in this experiment. Each mean value represents 80 responses in the isolated vowel conditions and 288 responses in the phrase conditions.

(auditory and visual) and the three response conditions (whispered vowel, voiced vowel, phrase) used in this experiment. Note that the mean LRT values for both groups are very similar for each response condition. Also note that there is no consistent group trend in dispersion values in the isolated vowel conditions, although the stutterers' LRT scores varied more than normals in the phrase condition.

The results of a three-way repeated measures analysis of variance on the isolated vowel conditions (groups × reaction signal × response) are shown in Table 1.

The analysis indicated that neither the group nor the response factor was significant, that is, both groups demonstrated similar reaction times

TABLE 1

ANOVA Summary for the Isolated Vowel Conditions

Source of Variation	*df*	*MS*	*F*
Between Subjects	15		
Group	1	12,929.40	0.275
Error	14	46,892.90	
Within Subjects	48		
Reaction Signal	1	27,056.96	15.27*
Group × Reaction Signal	1	2,312.65	1.30
Error	14	1,771.68	
Response	1	159.01	0.016
Group × Response	1	45.43	0.004
Error	14	9,355.60	
Reaction Signal × Response	1	1,067.55	0.507
Group × Reaction Signal × Response	1	4,367.54	2.07
Error	14	2,104.46	

*F, 0.95 (1,14)=4.60.

within and across the whispered and voiced isolated vowel conditions. This implies that stutterers were able to initiate phonation as rapidly as normal speakers regardless of the inherent differences in respiratory/laryngeal coupling and laryngeal posture associated with the two response conditions. Thus, the expected increase in stutterers' LRT values for changes in the response from whispered to voiced isolated vowels was not observed. However, the type of reaction signal was significant (F = 15.27, $p < 0.01$); both groups demonstrated greater reaction times in response to visual signals than in response to auditory signals. This difference appears to reflect the inherent perceptual disparities between the auditory and visual modalities.

The results of a two-way repeated measures analysis of variance (group × reaction signal) are shown in Table 2 for the LRT data collected in the phrase condition. Once again, no significant group effect was found but the type of reaction signal was significant ($F = 7.4$, $p < 0.01$), visual reaction signals yielding longer phrase LRT values than auditory reaction signals.

Both groups displayed significantly greater LRT values in the phrase

TABLE 2

ANOVA Summary for the Phrase Condition

Source of Variation	*df*	MS	*F*
Between Groups	15		
Group	1	60.91	0.0019
Error	14	31,320.14	
Within Subjects	16		
Reaction Signal	1	37,777.14	7.400*
Reaction Signal × Group	1	97.06	0.0190
Error	14	5,102.71	

*F, 0.95 (1,14)=4.60.

condition than in the pooled isolated vowel conditions ($t = 1.606$, $p < 0.05$). This result reflects the expected increase in LRT values as response length increased from isolated vowels to the phrase condition.

The above results suggest that the differences observed in LRT values as a function of reaction signal modality (auditory vs visual) and as a function of the increased length of the response (isolated vowel to phrase) for both groups may not be related to the LRT effect (the between-group differences in LRT observed in previous experiments). Furthermore, the data only partially support the LRT experimental condition—normal speaking condition analogy. Arguing against the analogy is the observation that stutterers' LRT values did not increase from the whispered to voiced isolated vowel condition. In support of the analogy is the observation that both groups demonstrated significantly greater LRT values in the phrase condition than in the pooled isolated vowel conditions. Finally, the most important finding of the LRT portion of this study was that of no significant group differences for any of the three response conditions. That is, we failed to replicate the frequently demonstrated LRT effect.

VOT Measures

Figure 3 displays group means and standard deviations for VOT values for each place of articulation as well as a pooled VOT value for each group. Note that, as in the LRT data, means and dispersions are very similar across both groups. As expected from Lisker and Abramson

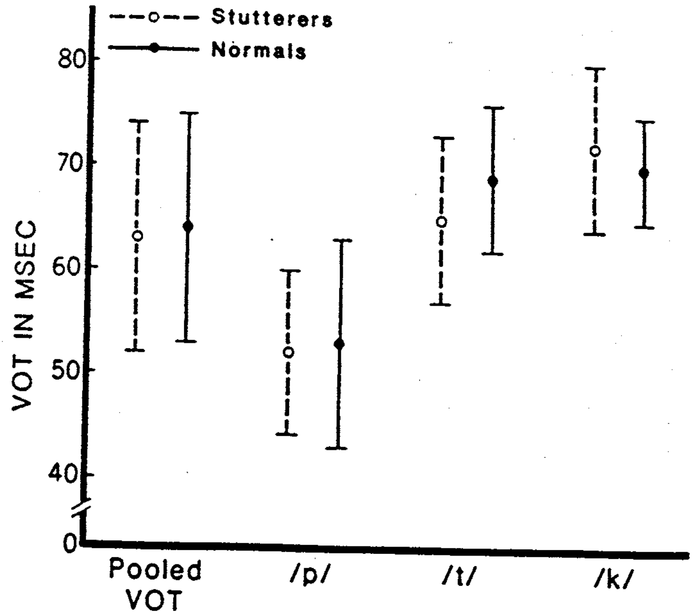

Figure 3: Shown are group means and two standard deviation dispersions for VOT values at each place of articulation. Each mean value represents approximately 288 responses. Also shown are group VOT values pooled across the three places of articulation.

(1964), VOT values increased as place of articulation progressed from labial to alveolar to velar. Once again, repeated measures of analysis of variance indicated no significant group differences for any of the three places of articulation or the pooled VOT measure. A rank-order comparison of LRT and VOT for the stuttering group revealed a nonsignificant correlation between these two measures of laryngeal timing ($r=-0.275$, $p>0.05$). We will discuss the validity of this finding below.

DISCUSSION

LRT

The most important and interesting finding of the LRT portion of this study was the failure to find a significant difference in LRT between stutterers and their controls. It would be useful to be able to identify those factors which might account for the disparity between the results of this study and the results of other LRT studies that demonstrated significant group differences. In order to assess the contribution of each of these factors systematically, we developed a model of the LRT paradigm which we believe incorporates the critical factors underlying the previously reported LRT effect. The model is presented as Figure 4.

Specifically, the model identifies factors related to the perceptual component and to the production component of the LRT paradigm as well as factors related to characteristics of the experimental group. The model may also be useful in examining the LRT experimental condition—normal speaking condition analogy. The following discussion is necessarily lengthy in order to present a detailed description of the contribution of these factors to our finding of no group LRT differences.

One purpose of this study was to define the robustness of the perceptual component underlying the LRT effect. This component is shown as the first stage in the model and consists of two factors: the perceptual mode used in the presentation of the reaction signal (either auditory or visual) and a variable foreperiod (the time between a warning and reaction signal). Our results indicate that the perceptual modality used to elicit the response is not significantly related to the LRT effect. This finding suggests, for instance, that deficits in auditory processing of the reaction signal do not significantly contribute to the LRT effect. Of more interest to us, with respect to the perceptual component, is the presentation of a warning signal as a precue. In this study, subjects were instructed to phonate at the offset of the reaction signal rather than the onset. Consequently, the onset of the reaction signal served as a warning signal. This procedure allowed subjects time to posture the speech mechanism for a known response, the amount of posturing time available to them being the duration of the reaction signal which varied from 1 to 3 sec in 1-sec increments. A plausible explanation for the results of this study is that the LRT effect is dependent upon the relationship between (1) a critical foreperiod, defined as the amount of time between the warning signal and the reaction signal, and (2) a speech posturing time, defined as the amount of time necessary to position the speech mechanism for phonation. The foreperiod used in this study may have exceeded the posturing time of the stuttering subjects. The notion of a critical

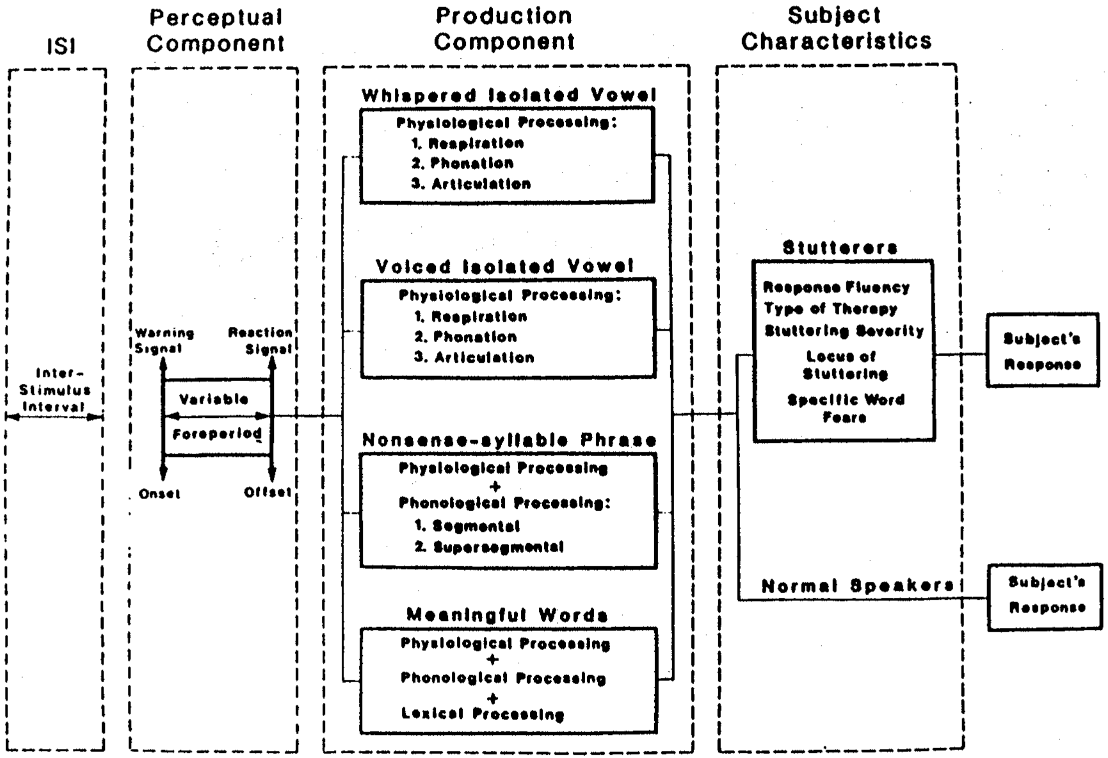

Figure 4: Model of the LRT paradigm used in the present experiment.

foreperiod is important because it implies that the LRT effect is not primarily related to difficulties in the onset of laryngeal sound production for a given phonation type, but rather is more dependent upon difficulties in the positioning, or posturing of, the speech mechanism. This view is consistent with the notion that stuttering is related to the poor coordination of motor commands to various components of the speech production mechanism, (cf. Zimmerman, 1980; Zimmerman et al., 1981). We argue here that the significant LRT effect is probably related to poor coordination of neuromotor commands in posturing the larynx for phonation. Evidence in support of the argument is provided by the results of a laryngeal EMG experiment conducted by Freeman and Ushijima (1978) who observed simultaneous contraction of antagonistic abductor and adductor laryngeal muscles during moments of stuttering.

Previous studies reporting significant group LRT effects using simple response stimuli, such as a single, isolated vowel (cf. Adams and Hayden, 1976), did not incorporate warning signals in their experimental designs. Thus, significant LRT effects are reported only in studies in which perception of the reaction signal and phonation onset occur simultaneously, that is, when the foreperiod duration is zero.[3] A plausible explanation for the disparity between the results of the present study and previous studies is our use of long duration foreperiods.

The present study demonstrates that at a foreperiod greater than the posturing time for phonation, stutterers are able to initiate phonation as rapidly as nonstutterers. This result, along with the finding of nonsignificant differences in the whispered and voiced isolated vowel conditions (which served to vary the laryngeal posture and respiratory coupling requirements) argues against the notion that the LRT effect is related to the stutterer's inability to initiate vocal fold vibration as rapidly as normal speakers. Experiments utilizing shorter foreperiods could identify the critical foreperiod in which the LRT effect emerges. Thus, the simple reaction time paradigm incorporating foreperiods shorter than those used

[3]An exception is a recent paper by Reich et al. (1981) whose experimental procedures are very similar to those incorporated in the study reported here. In the Reich et al. experiment, foreperiod duration ranged from two to four second in 0.5 second increments. Among their findings, they reported a significant LRT effect for the isolated voiced vowel /ʌ/ response.

in the present study might identify the posturing time differences between stutterers and normal speakers that underlie the LRT effect.

Another purpose of this study was to test the robustness of the production component underlying the LRT effect. The model presents this component as a series of "processing factors." A significant difference between the response conditions would have identified those physiological and/or phonological processing factors related to the LRT effect. For instance, a significant difference between the whispered and voiced isolated vowel conditions would have suggested that respiratory and phonatory factors are related to the LRT effect. Since no significant differences were found between these two conditions, our data do not allow for such conclusions. However, the use and comparison of different response conditions in future studies could prove informative. The model also demonstrates that as the response becomes longer, for instance from isolated vowels to words, the number of processes underlying the response increases. Thus, the use of relatively long responses, such as words or meaningful phrases, would make it more difficult to determine which processing factor, or perhaps combinations of factors, contribute significantly to the LRT effect. To conclude, the model demonstrates that the production component may contribute significantly to the LRT effect and that the factors underlying the production component of the LRT effect increase in number as the length of the response increases. This suggests that experimenters may be more successful in the identification of the physiological components that underlie the LRT effect by using short responses, such as isolated vowels, rather than using long responses, such as meaningful words or phrases.

Finally, the last set of factors illustrated in the model pertain to the experimental group. These factors are stuttering severity, response fluency, type of therapy, and the locus of stuttering. Any of these factors could account for the differences in the results found in this study and previous LRT studies. For example, the LRT effect may be positively correlated with stuttering severity (Hayden, 1975; Lewis et al., 1979). The average rating for the group of subjects used in the present study was mild to moderate and may have been less severe than stuttering groups used in previous studies. A case in point is Reich et al. (1981), who found a significant LRT effect. The procedures used by Reich et al. were very similar to those reported here (see footnote 3) except that their experimental subjects were classified as "moderate to very severe." The disparity in stuttering severity rating appears to be one of the few differences between Reich et al. and the study reported here; yet the results are clearly different. The implication of the stuttering severity factor is that LRT performance of any group of stutterers is dependent upon the relative severity of the disorder among the members of the experimental group. Thus, a group consisting primarily of severe stutterers may display greater phonation onset latencies than a group with a majority of mild stutterers.

The important consideration of the response fluency factor is that only natural, fluent utterances should be analyzed in the data set since the inclusion of dysfluent responses could inflate the mean performance of the experimental group. Figure 2 shows that the dispersions of LRT values about the mean were very similar for both groups and indicate that responses analyzed in the present study most likely represented fluent productions. Previous studies may not have sufficiently controlled for fluency. For example, examination of the data presented by Hayden (1975) indicates that two of the ten subjects of the experimental group exhibited greater mean reaction time values as well as larger standard deviations than the other eight members of the experimental group. It could be that data analyzed from these two subjects included dysfluent responses and thus significantly inflated the group mean.

The assumption underlying the type of therapy factor is that the nature of the fluency management program in which stuttering subjects have been enrolled could affect phonation initiation. Specifically, those management programs emphasizing the "easy onset" of phonation in order to enhance fluency may artificially increase LRT values (for example, Ryan, 1971). None of the stutterers included in the present study received therapy emphasizing the easy onset of phonation. Subjects demonstrating voluntarily prolonged phonation onsets in their conversational speech should be instructed to use a more natural phonation onset in order to attain optimal LRT performance.

The fourth factor that could influence LRT values in stutterers is identified in the model as the locus of stuttering. Implicit in this factor is the view that dysfluent speech may primarily arise as a consequence of a breakdown in motor control at a specific level of the speech production system. For instance, this breakdown may occur at the level of the larynx (laryngeal locus), within the oral cavity as a lingual fixation (lingual locus), or as lip and/or jaw tremors (labial locus).[4] It may be that a "laryngeal" stutterer would exhibit greater LRT values than a "lingual" or a "labial" stutterer. Thus, it is theoretically possible that the study reported here had fewer "laryngeal" stutterers in the experimental group than the studies reporting significant LRT effects. Although it is not clear to us whether experimenters can objectively control this factor, we offer it here to demonstrate the diversity of factors which may influence the experimental group's LRT values. We made no attempt to systematically control this factor.

There could well be factors other than those included in the model that may have contributed to the absence of the LRT effect reported in this study. For example, LRT values have been shown to vary with lung volume change (Izdebski and Shipp, 1978). They found that the shortest LRT values occurred when subjects initiated phonation while at 50% lung volumes. LRT values increased when subjects initiated phonation at 25% lung volume, and increased further at 75% lung volume. Izdebski and Shipp also found that prephonatory vocal-fold position affects LRT values, shorter LRT values occurring in the abducted than in the adducted prephonatory position. Other than instructing our subjects to initiate phonation at comfortable loudness levels, we made no attempt to control for respiratory charging levels. We also made no attempt to control for prephonatory laryngeal posture. As stated above, we assumed that our subjects achieved normal inhalation and exhalation glottal openings during the 4-sec ISI in the isolated vowel condition and after practicing each item in the phrase condition. They then moved to either the whispered or voiced phonatory position at the onset of the reaction signal.

The model makes no mention of practice effects on LRT values. Adams and Hayden (1976) reported that stutterers' LRT values approximate normalcy after nine trials, implying that practice reduces the LRT effect. Lewis et al. (1979), on the other hand, observed a consistent LRT effect throughout 30 responses and concluded that "practice had a very limited ability to improve voice reaction scores in stutterers." Furthermore, many of the studies reporting significant LRT effects included

[4]See Shapiro (1980) for a recent discussion of stuttering loci and an example of an attempt to classify stuttering on this basis.

practice trials before data collection (cf. Starkweather et al., 1976; McFarlane and Prinz, 1978; Cross et al., 1979; Cross and Luper, 1979; Reich et al., 1981).

VOT

The third purpose of this study was to compare VOT values between groups and to compare LRT with VOT values in the same stuttering subjects. As in the LRT conditions, we found no significant group VOT differences. The VOT data generally support the findings of Metz et al. (1979) who also found nonsignificant group differences between stutterers and normal speakers in most phonetic contexts. The VOT data for both groups are also in good agreement with the VOT data presented by Klatt (1975) collected from normal speakers. Rank-order correlations between VOT and LRT values for stuttering subjects were also nonsignificant. However, the correlations should be interpreted with caution. The variance of the VOT data for the stuttering group, as well as the control group, was small and nonsignificant. Thus, no stuttering subject performed significantly better or worse than any other stuttering subject. Consequently, rank-order correlations of data characterized by relatively small dispersion values probably do not represent a valid test of the underlying assumtion that stutterers who exhibit significantly greater LRT values would also exhibit significantly greater VOT values.

LRT Experimental Condition —Normal Speaking Condition Analogy

With respect to the LRT experimental condition—normal speaking condition analogy, the data from the study reported here do not conclusively support or reject the analogy assumption. Considering the perceptual component of the model presented in Figure 4, the data indicate that LRT values will vary in the expected direction with changes in the perceptual mode of presentation. Moreover, we have argued that the data suggest to us that the method of presentation, specifically foreperiod duration, will affect both absolute LRT values and the relative LRT effect. Thus, we conclude that LRT values and the LRT effect are not robust with respect to the perceptual component of the paradigm; rather, in support of the analogy, they will predictably vary as a function of perceptual component factors. Analysis of the production component is inconclusive with respect to the analogy assumption. Although LRT values increased with response length, from isolated vowels to phrases, we did not observe the expected significant difference in LRT values as a function of phonation type, that is, between isolated whispered and voiced vowels.

We have argued that foreperiods ranging from 1 to 3 sec allowed stutterers sufficient time to posture the speech mechanism and thus initiate phonation as rapidly as normal speakers. The argument can also be used to account for the nonsignificant within-group difference between isolated whispered and voiced vowels. We submit that the use of shorter foreperiods might detect differences in LRT values between these two conditions. Thus, we predict that the LRT-experimental-condition–normal-speaking-condition analogy would be supported by observing an increase in LRT values as the phonation type of the response changed from whispered to voiced. Once again, we hypothesize that the LRT effect reflects group differences in posturing-time more than it reflects the time required to establish rapid and sustained vocal-fold vibration. Consequently, at appropriate foreperiods, a significant LRT effect in both the whispered and voiced isolated vowel conditions would support the analogy. Furthermore, the LRT effect would represent the posturing time differences between groups and the posturing time differences between phonation types.

We did not attempt to control any of the factors included in the experimental group component of the model other than response fluency. It could be, however, that the LRT effect is not robust with respect to this component either, but may vary as a function of the characteristics of the experimental group. Thus, these factors could have contributed to the absence of an LRT effect reported here.

CONCLUSION

The results of this study suggest to us that the LRT effect may not be as robust as initially report but may be dependent upon certain factors similar to those presented in the model represented in Figure 4. That is, the LRT paradigm does seem to be analagous to many conditions underlying normal conversational speech. In this respect, we conclude that the nonsignificant group differences observed in all of the LRT conditions reported in this study are most probably related to the foreperiod duration and perhaps the severity rating of our experimental group.

We believe that the results of the study reported here and earlier studies reporting significant LRT effects are not contradictory. Rather, these experiments taken together support the notion of aberrant motor control in stutterers. The present study attempts to define the conditions that elicit aberrant motor control of phonation. We submit that the isolation and identification of these critical conditions can better help us to understand the significance of the LRT effect and how it relates to natural, conversational stuttering.

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