Objective: To determine if the tremor activity in laryngeal muscles is synchronous, which would indicate a single central source of tremor.

Design: Six persons with vocal tremor participated in this study. Laryngeal muscle activity was recorded from 2 intrinsic and 2 extrinsic laryngeal muscles during production of a sustained /ə/ sound. Correlations were computed between electromyographic activity in pairs of laryngeal muscles to measure the degree to which electromyographic activity in one muscle was synchronous with electromyographic activity in another laryngeal muscle. In addition, correlations were computed between each of the 4 laryngeal muscles and the voice signal to determine which muscle had activity that was most highly related to amplitude modulations in the voice. Multiple samples from each subject were analyzed to obtain measures of the consistency and strength of the correlations.

Results: In most subjects, the bursts of electromyographic activity in one muscle were not consistently related to tremor activity in other affected muscles. Half the subjects exhibited moderate to strong correlations between thyroarytenoid muscle activity and the amplitude of the voice signal. Although the thyroarytenoid and cricothyroid muscles were always active during sustained phonation, half of the subjects did not activate either the thyrohyoid or the sternothyroid muscle during this task.

Conclusions: The results of this study did not support the hypothesis that essential voice tremor is generated by a single central oscillator. Differences in the presence and timing of modulations in laryngeal muscle activity, as described in this study, may reflect clinically in the variable regularity and severity of vocal tremor.


TREMOR has been defined as involuntary, approximately rhythmic, and roughly sinusoidal movement. When tremor occurs in the absence of other neurological symptoms (eg, those associated with parkinsonism or with cerebellar deficit), it is called a benign essential tremor. Essential tremor is most commonly seen in elderly persons. The upper extremities are most typically affected, but essential tremor can also affect the head, the lower extremities, the trunk, and the voice. Although vocal tremor is easily identified based on the perception of fairly rhythmic changes in the pitch and intensity of phonation, little is known regarding the source of these fluctuations. In the past, investigations of the source of tremor have identified 2 major hypotheses: (1) the central oscillator hypothesis, which suggests that the source of tremor is in one or more regions of the central nervous system, and (2) the peripheral oscillator hypothesis, which suggests that neural feedback (reflexes) and/or mechanical properties of the muscle load system are the source of tremor. Evidence for a single central oscillator would include the following: (1) similar electromyographic (EMG) activity across muscles affected by tremor and (2) a stable frequency of tremor, irrespective of changes in the load placed on a muscle. Evidence of a peripheral oscillator would include the following: (1) a change in the frequency of tremor with increasing load (a property of a passive mass-spring system), (2) entrainment of the tremor frequency to the frequency of an imposed force, and (3) a reflex response to stretch. In addition to the possibility of a single central source, it is possible for tremor to originate centrally but from multiple regions of the brain. In this case, affected muscles would not necessarily share a single frequency, but they also would not be entrained by an imposed external force.

More recently, studies have suggested an additional alternative hypothesis that involves interaction between cen-
The regularity and severity of tremor were rated on 5-point scales. For regularity, 1 indicates very regular and 5 indicates very irregular. For severity, 1 indicates mild and 5 indicates severe.

<table>
<thead>
<tr>
<th>Subject No./Sex/Age, y</th>
<th>Regularity of Tremor</th>
<th>Severity of Tremor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/M/63</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2/F/51</td>
<td>3</td>
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<tr>
<td>5/F/70</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>6/F/80</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The regularity of tremor was rated on a 5-point scale, 1 indicating mild and 5 indicating severe. The severity of tremor was also rated on a 5-point scale, 1 indicating mild and 5 indicating severe.

METHODS

SUBJECTS

Six persons with vocal tremor participated in this study. As indicated in the Table, there was 1 man and 5 women. The diagnosis of voice tremor was based on a consensus between the 2 speech pathologists (E.M.F. and J.M.B.) and an otolaryngologist (H.T.H.) based on perceptual and videolaryngoscopic assessments. Subjects did not demonstrate any signs of parkinsonism or cerebellar deficit. Subjects were rated on a 5-point scale for the regularity and severity of tremor.

PROCEDURE

Simultaneous EMG and voice recordings were obtained. A small wheal (0.5 mL) of 2% lidocaine hydrochloride with 1:100000 epinephrine was injected just below the surface of the skin overlaying the cricothyroid (CT) ligament, and bipolar hooked-wire electrodes were inserted with a 25-gauge, Teflon-coated, hollow bore needle into 2 intrinsic laryngeal muscles, the thyroarytenoid (TA) and the CT muscles, and 2 extrinsic laryngeal muscles, the thyrohyoid (TH) and the sternothyroid (ST) muscles. Standard physiologic maneuvers were used to verify electrode position in the target muscles. A dynamic microphone, placed 12 cm in front of the patient, recorded the voice signal. The EMG and voice signals were amplified and recorded on a digital instrumentation tape recorder (model PC108-M; Sony Corporation of America, New York, NY). Portions of the record containing verification tasks and sustained phonation were low-pass filtered at 2500 Hz and digitized at 5000 Hz per channel by a computer system used for data analysis (CODAS; Dataq Inc, Akron, Ohio). The signals recorded during production of 2 tokens of the /\ sound at a comfortable pitch and loudness were selected from each subject’s digitized record. These signals were rectified, smoothed by taking a moving average with a 235-millisecond window, and redigitized at a lower rate of 100 samples per second (Figure 1). From each of these tokens, 2 1-second segments were systematically selected for analysis. The first 1-second segment was taken starting at 300 milliseconds after the initiation of phonation, and the second 1-second segment was taken from the portion of the record immediately following the first segment. In a few cases, the analyzed segment was shifted to avoid inclusion of movement artifact, which had been identified from visual and auditory evaluation of all the signals selected for analysis. Thus, 2 segments from each of 2 tokens resulted in 4 analyzed segments for each subject.

MEASURES

Fluctuations in the amplitude of the voice signal were characteristic of our subjects with vocal tremor, as seen in the voice...
waveform in Figure 1. Similar modulations were seen in the EMG signals, presumably due to bursts of motor unit activity in these laryngeal muscles. In this sample, the modulations in EMG activity were most obvious in the ST and TH muscles, and seemed to be highly related. Modulations of activity in the TA and CT muscles seem related as well, but this relation is less clear. We were interested in quantifying the extent of correlation between pairs of laryngeal muscles. Correlations were computed between EMG activity in pairs of laryngeal muscles to measure the degree to which EMG activity in one muscle was synchronous with EMG activity in another laryngeal muscle. In addition, correlations were computed between the EMG activity in each of the 4 laryngeal muscles and the voice signal to determine which muscle had activity that was most highly related to amplitude modulations in the voice.

Five channels of data (100 values per channel, because each token consisted of 1 second of data that had been digitized at 100 samples per second) were imported into a spreadsheet and demeaned (ie, the mean was calculated and subtracted from each data point). A correlation was computed by dividing the covariance of 2 data sets by the product of their SDs. The correlation can be used to determine the extent to which 2 data sets move together. To identify EMG activities that were correlated but phase shifted, the change in correlation as a function of lag time was plotted. To obtain each plot, the correlation was calculated between the 2 signals as they were recorded, then the bottom signal was shifted 200 milliseconds, in increments of 10 milliseconds, first to the right and then to the left. The calculation of correlations over a range of lag times made it possible to quantify phase shifts and find peak correlations. Examples of correlation plots obtained from data collected for this study are seen in Figure 2. In one example (Figure 2A), TA and CT muscle activity appear highly related and almost in phase. The cross-correlation graph (Figure 2B) shows a peak at 0.75, indicating that the correlation is strong. The peak is positive, signifying that the modulations are in phase. However, they are not entirely in phase because the peak is not at 0 seconds. In the next example (Figure 2C), the 2 signals appear strongly related, but out of phase. In this case, the peak closest to 0 seconds is negative, indicating that the signals are close to 180° out of phase (Figure 2D). The high peak indicates a strong correlation. In the third example (Figure 2E), the signals show fluctuations in activity, but there is no relationship. A correlation coefficient of less than 0.30 (Figure 2F) indicates that there was no correlation between the signals.

RESULTS

CORRELATION BETWEEN LARYNGEAL MUSCLES DURING VOCAL TREMOR

TA/CT Correlations

The composite correlation plots (and a 2-second sample of the TA and CT EMG waveforms) for each subject are provided in Figure 3. Within each subject’s correlation plot, the correlations for the 4 analyzed segments are superimposed. The results were plotted in this manner so that, in addition to providing information regarding the degree of correlation and phase relationships, the consistency of the correlation could also be assessed. Subjects varied along a continuum from highly and consistently correlated (subject 1) to not correlated (subject 6). The strength of the correlation and the phase relationship were remarkably constant in all 4 segments analyzed for subject 1, and were still strong, but slightly less consistent, for subject 2. Two subjects (subjects 3 and 4) demonstrated fairly consistent correlations, with some shifts in phase relationships (ie, during some segments, the muscle activity tended to be synchronous, and during others, it tended to be alternating) and the strength of correlation (indicated by the amplitude peaks) from one analyzed segment to the next. One subject (subject 4) was quite inconsistent in the strength of correlation and phase relationships. Finally, one subject (subject 6) showed no correlation between TA and CT muscle activity.

ST/TH Correlations

The extrinsic laryngeal muscles (ST and TH) were not activated during production of the \( \backslash a \) sound at normal pitch and loudness in 3 of the 6 subjects. One subject (subject 4) produced steady activation of the ST muscle during a comfortable \( \backslash a \) sound, but no TH muscle activity. Conversely, one subject (subject 6) produced steady activation of the TH muscle, but no ST muscle activity. Only one subject (subject 3) maintained activity in both (ST and TH) muscles during the sustained \( \backslash a \) task. This subject exhibited a consistent moderate to strong correlation in the EMG activity of these 2 muscles.

CORRELATIONS BETWEEN LARYNGEAL MUSCLE ACTIVITY AND VOCAL INTENSITY

TA Muscle Activity and Vocal Intensity Modulation

Three subjects (subjects 1, 4, and 5) exhibited a consistent relationship between TA muscle activity and the amplitude modulations in voice (Figure 4). These plots show that the signal modulations were 90° out of phase (ie, an approximately 30-40-millisecond time lag, which would be consistent with laryngeal muscle contraction time).

CT Muscle Activity and Vocal Intensity Modulation

One of the 6 subjects (subject 1) demonstrated a consistent relationship between the modulations in these 2 signals. However, this correlation between the CT muscle and the amplitude of the voice signal may have been due to the fact that this subject also had a high correlation between CT and TA muscle activity.
Figure 2. A, The thyroarytenoid (TA) and cricothyroid (CT) muscle signals appear highly correlated. B, A cross-correlation graph for part A indicates that the TA and CT muscle signals have a strong positive correlation. C, The TA and CT muscle signals appear strongly related, but are out of phase. D, A cross-correlation graph for part C indicates that the TA and CT muscle signals are close to 180° out of phase. E, The CT muscle and voice signals show fluctuations in activity, but there is no relationship. F, A cross-correlation graph for part E indicates that there is no correlation between the CT muscle signal and the voice signal. (The “Measures” subsection of the “Methods” section of the text provides a detailed explanation.)
ST and TH Muscle Activity and Vocal Intensity Modulation

As indicated previously, in addition to the one subject who activated the ST and TH muscles during the sustained task, there was one subject who activated the ST muscle only and one subject who activated the TH muscle only. The modulations in vocal intensity were related to extrinsic muscle activity only in the subject with activation of both muscles during phonation (subject 3).

COMMENT

There were 2 main findings regarding the questions posed by this study. In response to the first question, “How strong is the relationship between the EMG activity in pairs of laryngeal muscles in persons with vocal tremor?” we did not find much evidence of highly correlated activity between laryngeal muscles in persons with voice tremor. A consistent strong correlation between the TA and CT muscles was found in only one subject. In most subjects, bursts of EMG activity in one muscle were not consistently related to tremor activity in other affected muscles. The results of this study do not support the idea of a single central source of essential voice tremor.

Second, in response to the question, “Which of these 4 laryngeal muscles had modulations in EMG activity that most consistently correlated with the voice tremor?” fluctuations in the amplitude of the voice, which reflects changes in vocal intensity, were more strongly correlated with TA muscle activity than with CT, ST, or TH muscle activity across subjects.

CORRELATIONS BETWEEN LARYNGEAL MUSCLES

There was no single pattern common across subjects, indicating subjects differed in the consistency and strength of correlations between TA and CT muscle activity. The slight phase shifts may indicate that although the frequencies of the tremor in the 2 muscles are similar, they are not exactly the same. In those cases in which TA and CT muscle activity were correlated, there was typically a phase lag. Although the finding of rhythmic bursts of EMG activity in the TA muscle was usually indicative of bursts of activity in the CT muscle, this was not always the case (especially at a high pitch when activation levels in both muscles were increased).
LARYNGEAL MUSCLES AND VOICE CORRELATION

The perception of vocal tremor does not always implicate involvement of the TA muscle. In one subject (subject 6), from visual and auditory examination of the EMG recording, there were no obvious bursts of EMG activity in any of the laryngeal muscles assessed. It seems likely that the tremor in this subject was due to respiratory muscle activity. The TA and CT muscles were activated in all 6 subjects during the sustained \( \text{vowel} \) task. This was not the case with the extrinsic laryngeal muscles. Although the ST and TH muscles activated as expected during chin press and high and low pitches, it was common for EMG activity to become silent during sustained phonation at a comfortable pitch.

METHODOLOGICAL ISSUES

The presence of artifact and/or microphonics in the record can result in a spurious correlation. It was necessary to examine the records to confirm that the analysis was limited to records that were free of artifact. Although most recordings were free from artifact, artifact was more commonly present in signals that were recorded from inactive muscles. In one subject, the signals recorded from 2 muscles appeared highly correlated because of the presence of artifact on both channels, when in fact the muscles were not activated during the task.

In many subjects, a correlation computed from only one segment may not be indicative of overall muscle activity. We found that the degree of synchrony between muscle pairs varied from one analysis segment to another (ie, literally, from one second to the next).

ADDITIONAL OBSERVATIONS

Rhythmic bursts of EMG activity may be present in a muscle during production of one task but not during another (ie, at rest, but not during phonation, or at low pitch, but not at high pitch) or may be present during one portion of the task but not another (ie, near the offset of a sustained \( \text{vowel} \) sound but not at the onset).

The wide variability in the synchronicity of laryngeal muscle activity demonstrated by subjects in this study is not consistent with the concept of a single central oscillator. It could be that essential voice tremor, similar to essential tremor affecting the limbs, is caused by destabilization of the central component of physiologic tremor by a peripheral oscillator (ie, by reflex pathways to which it is connected). Further research is needed to test this hypothesis.

Differences in the presence and timing of modulations in laryngeal muscle activity, as described in this study, may reflect clinically in the variable regularity and severity of vocal tremor. They may also affect response to surgical intervention (eg, treatment with a laryngeal injection of botulinum toxin). Given that several intrinsic and extrinsic laryngeal muscles may be affected by tremor in these patients, an EMG may provide useful information regarding which laryngeal muscles to target to improve treatment outcome. In addition, because voice tremor may result from tremor affecting respiratory (and perhaps even articulatory) muscles, a clinical assessment of the pervasiveness of the tremor may provide prognostic information. Tremor primarily due to involvement of respiratory muscles might be expected to respond less favorably to a laryngeal botulinum injection than tremor primarily due to involvement of laryngeal muscles.

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