AN INVESTIGATION OF EXTRINSIC LARYNGEAL MUSCLE RESPONSES TO AUDITORY STIMULATION

DISSERTATION

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By

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The purpose of this study was to provide, through systematic investigation, empirical data to support or reject the assumption that auditory stimulation by discrete pitches evokes consistent muscle responses in the extrinsic laryngeal muscles. The study was an electromyographic investigation of specific upper and lower extrinsic laryngeal muscles as stimulated by two specific pitch stimuli. The responses were evoked by auditory stimulation, without vocalization.

Twenty-one volunteer subjects were selected from classes at Richland College, Dallas, Texas. The subjects varied from those who had no musical training to others with several years of training. The subjects ranged, in age, from nineteen to thirty-four years.

It was hypothesized that the responses from the low-pitch stimulus would produce more definitive wave forms and greater amplitudes in the lower (depressor) muscles than in the upper (elevator) muscles. Likewise, it was hypothesized that the responses from the high-pitch stimulus would produce more definitive wave forms and greater amplitudes in

the elevator muscles than in the depressor muscles.

The data were compared to determine if there were consistent responses in the male subjects, in the female subjects, and if a similarity existed among subjects.

The data were compared by amplitude (µV) and by definitive wave forms. In twenty of the twenty-one subjects, the results indicated that the low-pitch stimulus evoked greater responses in the depressor muscles than in the elevator muscles. Conversely, the results indicated that the high-pitch stimulus evoked greater responses in the elevator muscles than in the depressor muscles. The one subject who did not have similar responses possesses absolute pitch, which likely accounts for the difference.

From these findings, it was concluded that a direct relationship exists between specific pitch stimuli and specific extrinsic laryngeal muscle responses. It was concluded that these responses likely exist in the general population.

ACKNOWLEDGMENT

Sincere appreciation and gratitude is expressed to Texas Neurological Institute for the use of their laboratory, equipment, and advice during the course of this investigation. Particular gratitude is expressed to Dr. Allen Rupert, staff member of TNI and faculty member of University of Texas at Dallas, for his assistance in the design, planning, and execution of this research project.

J. D. W.

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INTRODUCTION

Students wishing to pursue the study of music in a college, university, or conservatory have, for the past ten decades, been required to study a core of subjects that is intended to improve their basic musicianship as well as increase their knowledge of music as a field of study. The core subjects that have been required lie in the area of music history, music theory, and applied music. In the area of music theory, the content of study includes knowledge of harmony as exemplified in the common practice period, counterpoint, sight-singing, and some basic understanding of the piano keyboard.

Teachers of music theory generally agree that they have their greatest success in teaching the understanding of the harmonic functions and the formal structures in music. They consider their efforts to teach the technique of singing music at sight to be rather lacking in success. James Middleton (4, p.29) has stated: "empirical evidence indicates a certain inadequacy in sight reading skills.

Individual reading abilities often demonstrate a hesitant, inaccurate, and faltering capacity. Many students have participated from elementary through high school (in sight reading activities) yet, as college freshmen they still lack the ability to sing rather simple music."

Two rather dichotomous presuppositions, thus, confront the music educator. First, it is generally accepted that aural and sight-singing skills are essential to the study of music and they will continue to be taught as an integral part of the music curriculum. Second, a general agreement exists among educators and in the evaluative literature that current methods have been less than successful. In an attempt to solve the dilemma, music educators have turned to interdisciplinary knowledge, research, and techniques to increase the effectiveness of pedagogical methods.

The principle of this particular study evolved from the author's work with college age students enrolled in music theory courses. It was noted that the playing of single pitches at the keyboard elicited specific and consistent neck muscle responses. It seemed prudent to investigate further this muscle response as a possible supplement to the existing sight-singing and ear-training methods.

For a more thorough exploration, a small sample of students (two male and two female) was selected and tested individually. After lengthy and systematic testing, the students agreed that they did, in fact, sense the muscle responses in approximately the same areas. Thus, there appeared to be preliminary, if only crude, evidence that throat muscle responses might exist in relation to discrete pitches. Inasmuch as there was no supportable evidence in either existing music theory literature, or through discussion with neurologists and audiologists and searching their literature, the task was to determine if the muscle responses did actually exist and to examine whether the responses would be consistent enough to be applied to a teaching technique.

A pilot study was developed to test the concept as a teaching technique. If the pilot study proved to be a viable tool for teaching, then a more thorough investigation could scientifically verify or reject the consistency and existence of the responses.

In the pilot study, a pre-test was given to twenty volunteer students (freshmen and sophomores). The test included recognition of fifty random pitches and vocalization of fifty randomly notated pitches within their ranges. The piano was used as a stimulus for pitch recognition by playing fifty random pitches twice each and having the students write each pitch of staff paper. The range of correct scores in the pre-test was from 0% to 25%. The mean score, however, was only 5% accuracy which could obviously be attributed to chance factors. The muscle response as a teaching technique was introduced and repeated in each session. During the tests the students were not allowed to vocalize the pitches. During the training sessions, however, the students were told what each pitch was, asked to sing the pitch, and attempted to "feel" the muscle responses in the various laryngeal areas from the mastoid to the sternum. Finally, a pitch was identified and played on the piano, the student then sang the pitch, and then the pitch would be replayed several times while the students attemped to feel a muscle response or movement in the approximate designated laryngeal areas. During the early training sessions, it was found that the students could be more aware of the muscle responses if they closed their eyes. The instructional time involvement was approximately twenty minutes per day, four days per week, for five weeks. The final test produced a correct score test range from 87% to 100% with a mean score slightly over 90%.

The observations and results from the pilot study warranted pursuit of the investigation. Although the study was admittedly rough and unsophisticated in design, it did exhibit promise that use of the knowledge regarding muscle responses could implement and improve the effectiveness of present ear-training and sight-singing methods. The absence of any previous studies on this particular subject implied that no guidelines would be found for the pursuit and design of the investigation. The lack of guidelines and parameters obviously meant that the investigation would involve much trial and error experimentation.

Dr. Ralph Greenlee, neurologist, of Texas Neurological Institute; Dr. Allen Rupert, neuro-anatomist, of Callier Institute of Audiology (University of Texas At Dallas); and Jeanne Moore, Lab technician, also of TNI, first met with the investigator in the summer of 1982. By that time, the pilot study mentioned above had been repeated for the second time. Sharing the general background of the proposed investigation and the results of the pilot study aroused the interest and curiosity of this group. Neither the neurologists of TNI, nor the audiologists of Callier knew of the existence of the muscle responses or of any literature, studies, or investigations related to this discovery. The investigator's personal library search, three computer searches and several conferences produced no direct references to the concept. The information produced by the pilot studies, however, indicated that a muscle-auditory response was probable and the TNI group offered their equipment and personal aid to investigate further the phenomenon. It was concluded by the group that the investigation would have to be designed and constructed from a totally original design base.

The investigation with which this dissertation was concerned was based on the premise that the hearing of specific pitches elicits consistent responses in specific extrinsic laryngeal muscles which can be located and identified. The purpose of the study was to provide empirical data to support or reject the assumption that auditory stimulation by discrete pitches elicits such responses. It should be noted that the specific role of these muscles being investigated has not been fully determined (1, p. 86). The task, following the pilot study, was to develop a protocol that could be used effectively in the testing of multiple subjects in order to verify or reject the premise.

Purpose of the Present Study

The purpose of this study was to provide, through systematic investigation, empirical data to support or reject the assumption that auditory stimulation by discrete pitches elicits consistent muscle responses in the extrinsic laryngeal muscles.

Problems of the Study

The problems of the study were as follows:

1. To investigate the relationship of specific pitch stimuli to specific extrinsic laryngeal muscle responses in males;

2. To investigate the relationship of specific pitch stimuli to specific extrinsic laryngeal muscle responses in females;

3. To determine if consistencies in responses to stimuli exist among subjects.

Definition of Terms

The term electromyography (EMG), which will be used in this investigation, is the recording of electrical energy generated by muscle activity.

The term extrinsic laryngeal muscles refers to the external or surface muscles that elevate or depress the larynx.

The term amplitude is defined as the magnitude of energy measurement of a muscle response (measured in microvolts, which is one one-millionth of a volt). The amplitude is easily recognized in EMG plots as the peaks of the wave forms.

The term latency (measured in milliseconds) refers to the point in time from delivery of the signal to the muscle activity peak.

The term electrode in this study refers to gold-plated, surface electrodes applied to each subject and connected to the EMG analyzer.

Limitations of the Study

1. The study examined only students attending Richland College (freshmen and sophomores) and the sample may, therefore, not be representative of the population.

2. This study was limited to the investigation of only certain extrinsic laryngeal muscles responses to specific pitch frequencies.

3. This study specifically investigated only the relationship of the specific high muscles (the elevator muscles being the posterior digastric muscle as it attaches to the mastoid process and its overlapping muscle, the stylohyoid as it attaches to the styloid process) to a specific high pitch (F 349 hz for males and 698 hz for females) and specific low muscles (the depressor muscles being the the sternothyroid and the sternohyoid muscles at the point they overlap and attach to the sternum) to a specific low pitch (D flat 138.5 hz for males and 277 hz for females).

4. The study was limited to the capabilities of the equipment.

A General Survey of the Laryngeal Structure

Both the intrinsic and extrinsic laryngeal muscles play a major role in the control of various aspects of speech, singing, intonation, aspiration and other functions. The purpose of this section is to provide the uninformed reader with a brief overview of pertinent anatomical information related to this dissertation (2).

As mentioned previously, the specific role of the individual muscles in the larynx has not been fully determined (1, p. 86). Many of the muscles function as groups, and often the groups do not function in precisely the same manner even within an individual. In this investigation, some of the subjects were tested more than once and, though the results were generally similar, the wave forms were, more often than not, quite different in both amplitude and latency. It is generally accepted that in order for one muscle group (or muscle fiber) to contract, there has to be a corresponding muscle or nearby fiber that relaxes. Thus, there may be multiple actions responding to variable changes within a muscle or between two related groups as with the extrinsic and intrinsic muscles of the laryngeal structure.

There are only two general groups of muscles in the laryngeal structure (2, Zemlin, 1968, p. 140). The intrinsic laryngeal muscles, those having both attachments in or on the larynx (2, Zemlin, 1981, p. 151), are used to adjust the relative positions of the laryngeal cartilages and may effect the tension and mass of the vocal folds and the walls of the laryngeal airway. The muscles referred to as the extrinsic laryngeal muscles may serve to move the larynx in the neck or, as this author believes, lower and raise the larynx as related to high or low pitch production.

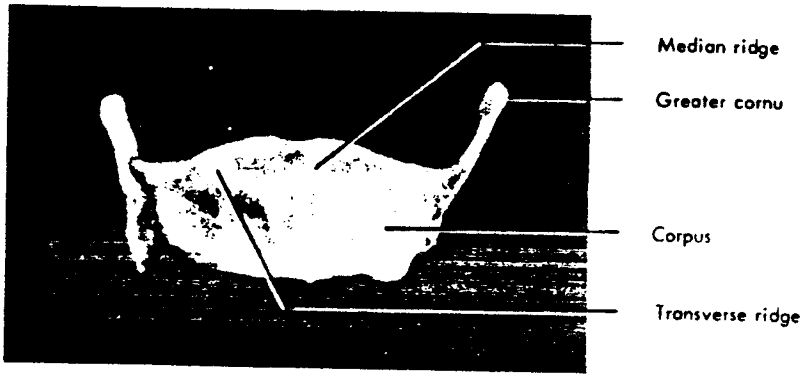
The three biological functions of the larynx are to act as a valve preventing air from escaping from the lungs, preventing foreign substances from entering the larynx, and forcefully expelling foreign substances which threaten to enter the trachea (2, Zemlin, 1981, p. 126). According to Zemlin (2, 1968, p. 115) sound production is considered to be a non-biological function of the larynx.

The human larynx is well equipped for sound production (2, Zemlin, 1968, p.126). The vocal folds are long, smoothly rounded bands of muscle and connective tissue, which may be lengthened and shortened, tensed and relaxed, as well as abducted and adducted. In addition, there is evidence that the tension may be varied segmentally as well as grossly. The system of cartilages, ligaments, extrinsic and intrinsic muscles is quite involved and complicated. Although this investigation deals more directly with the extrinsic laryngeal muscles, it is judicious to discuss all the structures that are assumed to be important to the vocal production of sound.

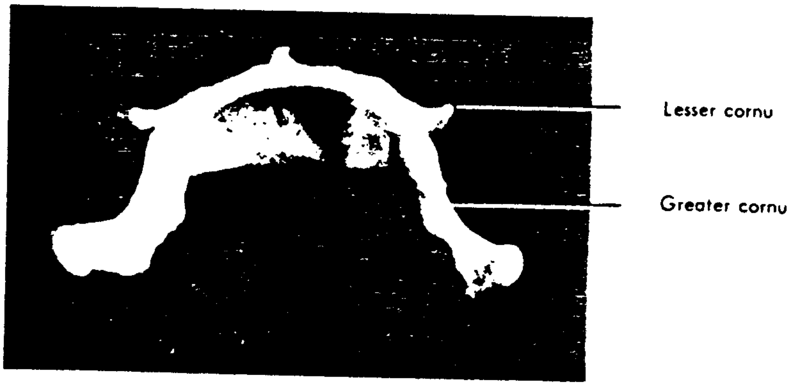
The supportive framework for the larynx begins with the hyoid bone. This bone is actually a supportive structure for the root of the tongue rather than being an integral part of the laryngeal framework (2, Zemlin, 1968, p.116). The larynx, nevertheless, is suspended from the hyoid bone, which also serves as the superior attachment for some extrinsic laryngeal muscles. In all, there are some thirty muscles which either take their origin from or insert into the hyoid bone (2, Zemlin, 1968, p. 116). Furthermore, most of these muscles are essential to speech and singing. The hyoid bone is unique within the skeletal structure because it is not directly attached to any other bone in the skeleton. Rather, it is bound in position by a very complex system of muscles and ligaments, thereby rendering it highly mobile and flexible. Three isolated views (Figure 1.1) of the hyoid reveal its prominent characteristics. Extrinsic muscles from the larynx approach from below, as do the muscles from the sternum and clavicle. The muscles which attach to the hyoid bone and suspend it in position are sometimes called the hyoid "sling" muscles. These muscles include the following:

1. Stylohyoid
2. Digastricus posterior
3. Digastricus anterior
4. Geniohyoid
5. Thyrohyoid
6. Sternohyoid
7 Sternothyroid
8. Omohyoid

The last five of this muscle group are known as the "strap muscles" of the neck and are shown schematically in Figure 1.2. (These strap muscles served as general guidelines for proper placement of electrodes in this study). Note that the hyoid bone, to which the strap muscles attach is



As seen from the front



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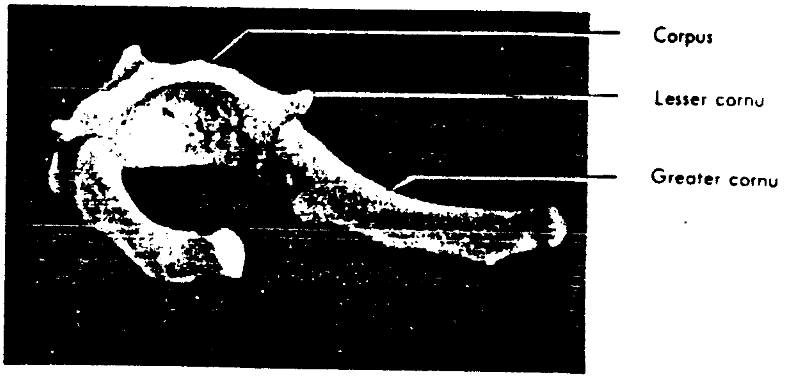


As seen in perspective

Figure 1.1 Photographs of the hyoid bone from various angles. (2, Zemlin, 1968, p. 118).

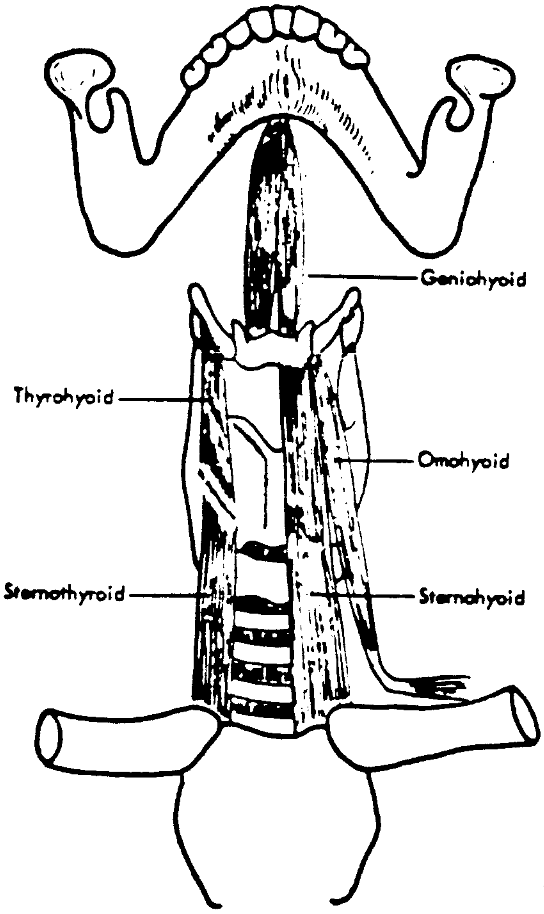


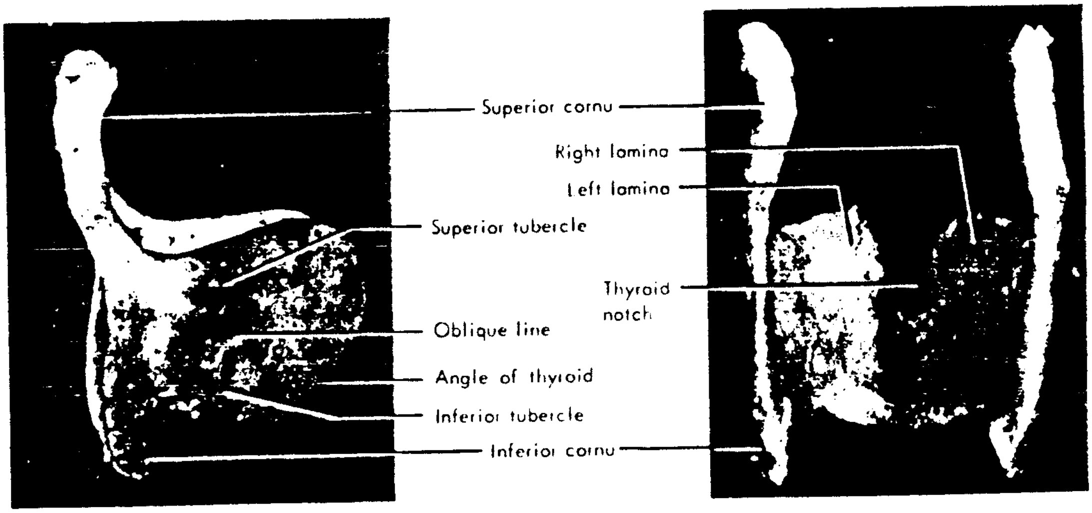
Figure 1.2 Schematic of the strap muscles and hyoid bone. (2, Zemlin, 1968, p. 117).

somewhat horseshoe shaped. It is located in the neck, horizontally, with the limbs of the U directed backward and slightly upward.

The next section of the larynx is the cartilaginous framework. There are nine cartilages and their connecting membranes in the structural framework of the larynx. Of the nine, three are unpaired, large cartilages; and three are paired, smaller cartilages. They include the following:

1 Thyroid
1 Cricoid
1 Epiglottis
2 Arytenoid
2 Corniculate
2 Cuneiform

The thyroid (Figure 1.3) is the largest cartilage of the larynx.

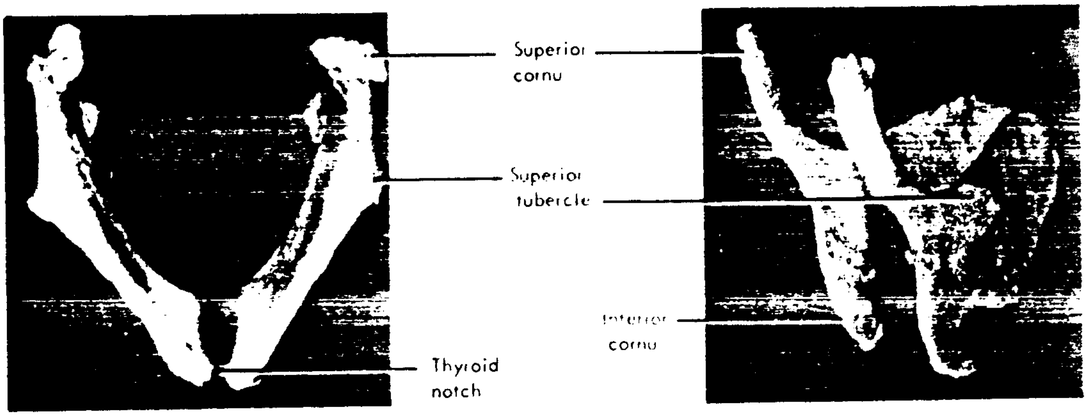


A. As seen from the side

B. As seen from behind

Figure 1.3. Four views of the Thyroid cartilage. (2, Zemlin, p. 119).

Figure 1.3 (Continued)

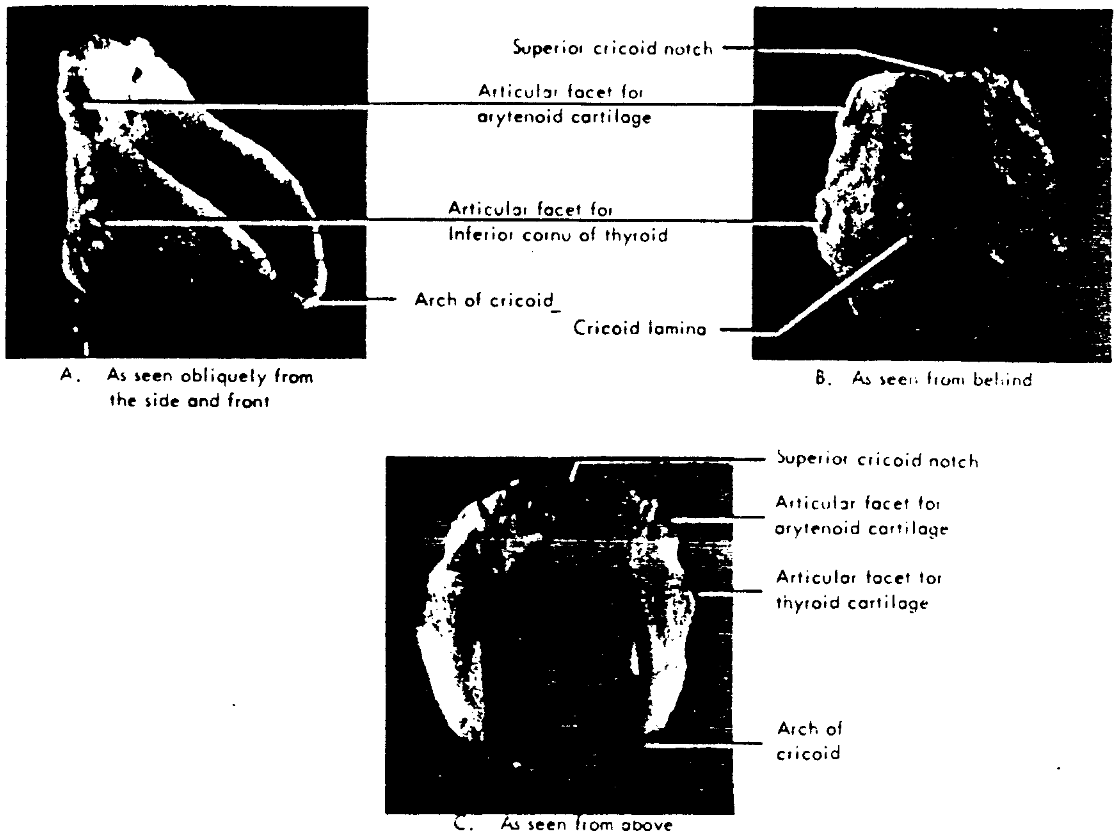


C. As seen from above

D. As seen in perspective

It forms most of the anterior and lateral walls of the larynx. One of the landmarks of the thyroid cartilage is the oblique line, shown in Figure 1.3A which runs down and forward from the superior to the inferior thyroid tubercle. This line forms the point of attachment for some important extrinsic laryngeal musculature.

The cricoid cartilage is located immediately superior to the uppermost tracheal ring. It is smaller than the thyroid and forms the lower portion of the laryngeal framework. The cricoid cartilage consists of two parts: an anterior arch and a posterior quadrate lamina. As shown in figure 1.4, the cricoid lamina is a hexagonal plate. It extends upward to occupy the space between the posterior borders of the thyroid cartilage. The ridge and the adjacent



A. As seen obliquely from the side and front

B. As seen from behind

C. As seen from above

Figure 1.4. Various views of the cricoid cartilage. (2, Zemlin, 1968, p. 121).

depressions of the lamina are sites for muscle attachment. Laterally, on either side, the arch of the cricoid presents small oval articular facets for articulation with the inferior cornu of the thyroid. The result is a pivot joint, which permits either the thyroid or the cricoid to rotate about an axis through the joint, as indicated by the dotted line in Figure 1.5. This rotational movement is an important part of the pitch-changing mechanism in the lifting and lowering process of the larynx (2, Zemlin, 1968, p. 120).

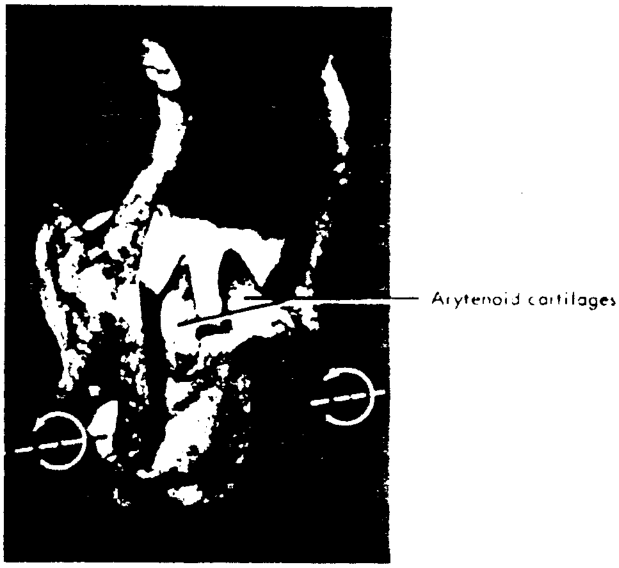
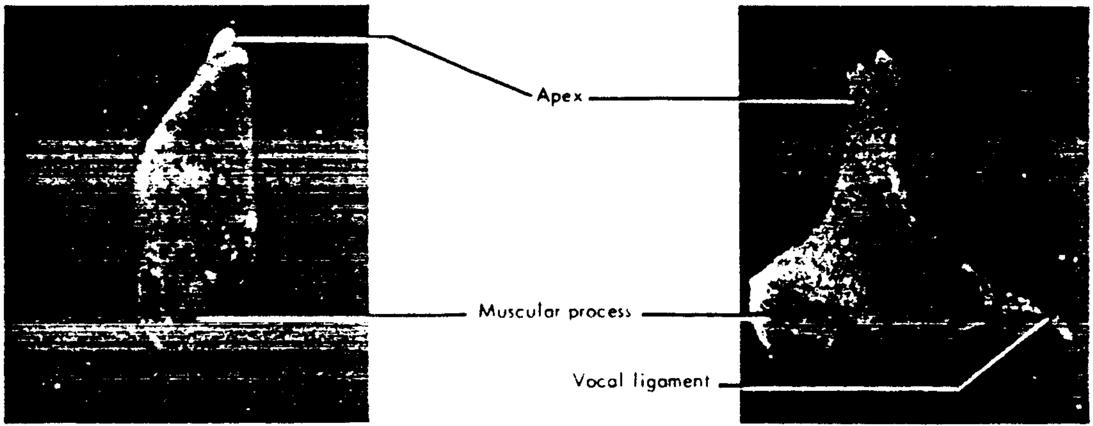


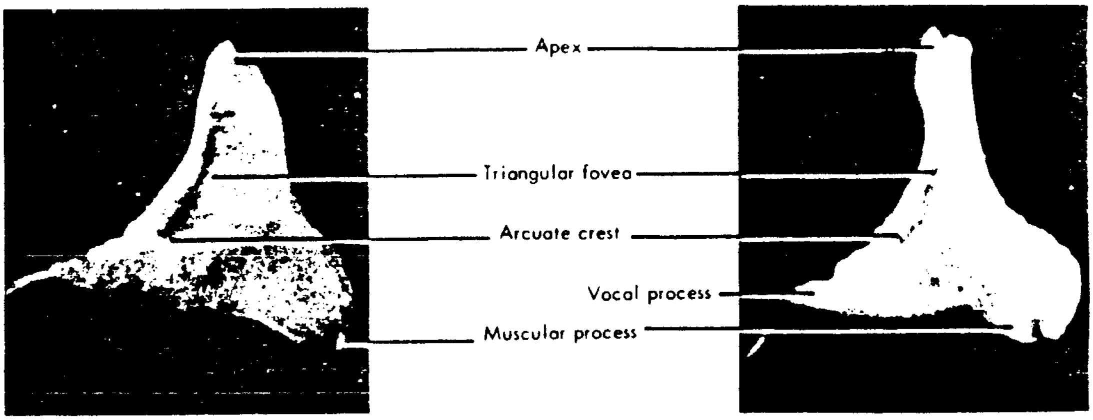
Figure 1.5. Rotation of the cricothyroid joint (2, Zemlin, 1968, p. 121).

The arytenoid cartilages are located on the sloping superior border of the cricoid lamina. (Figure 1.5, 1.6). The two muscles that attach to the arytenoid cartilage are the vocalis muscle and the cricoarytenoid muscle (attaching to the muscular process). The cricoarytenoid joint (Figure 1.7) allows multi-directional movement of the arytenoid cartilages. For example, the arytenoids may rock forward, thus approximating the vocal processes, and at the same time they may slide medially.



Posterior surface

Medial surface



Antero-lateral surface

Lateral surface

Figure 1.6. Four views of the left arytenoid cartilage (2, Zemlin, 1968, p. 122).

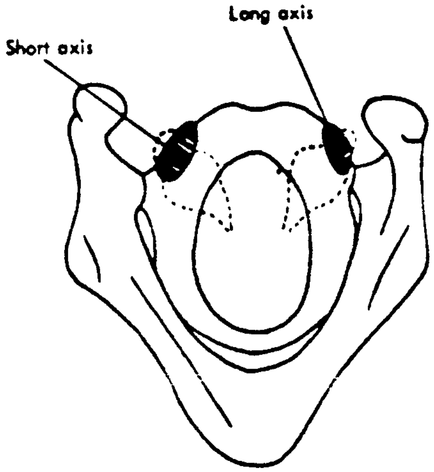


Figure 1.7 Schematic of thyroid and cricoid cartilages as seen from above illustrating the axes of the cricoarytenoid joint (2, Zemlin, 1968, p. 123).

The epiglottis (Figure 1.8) is a leaf-like structure originating from the thyroid notch and attaching to the thyroid cartilage by means of a ligament. The theories concerning its function are many and varied. A safe agreement among all the anatomy texts is that the epiglottis contributes very little to the production of speech (2, Dickson, p. 90, and Zemlin, 1968, pp. 125-126). It may modify laryngeal tone, however, by producing changes in the size and shape of the laryngeal cavity. Some singers claim that the epiglottis is capable of modifying tone quality by partially covering the laryngeal opening during tone production and thus, producing various timbres as well as the muted tone (2, Zemlin, 1968, p. 126).

Figure 1.8 The epiglottis as seen from the front the front and from the side (2, Zemlin, 1968, p.124).

Lastly, the cuneiform cartilages are found near the entrance of the larynx inbedded within the folds called the arypiglottic folds on either side of the connecting stalk-like structure of the epiglottis. These cartilages are even absent in some specimens, however, because they are vestigial structures. Their location can be seen in the schematic of laryngeal cartilages and associated structures (Figure 1.9).

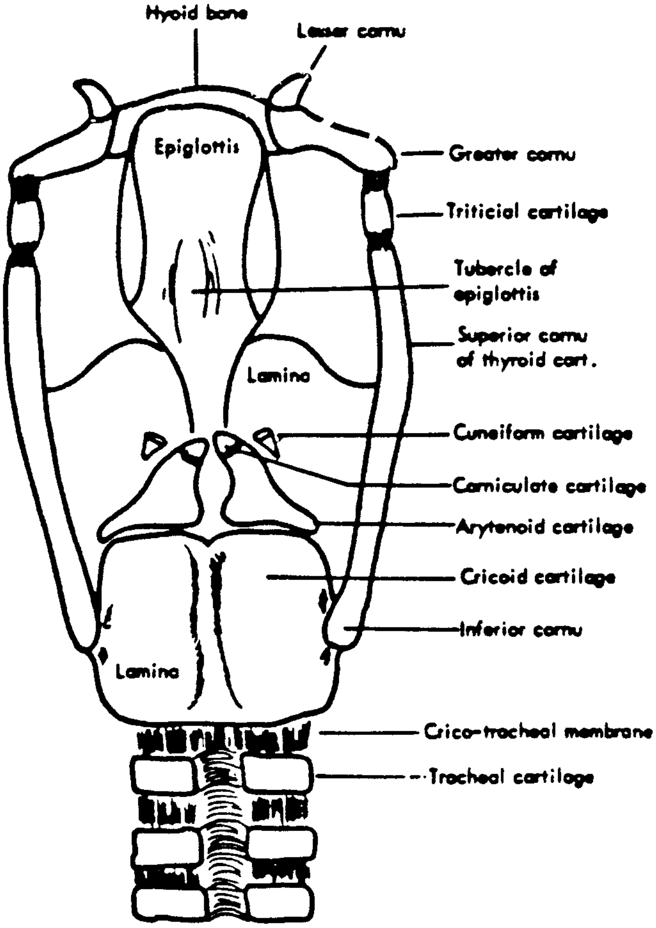


Figure 1.9 Schematic of laryngeal cartilages and associated structures (2, Zemlin, 1968, p. 128).

A group of ligamentous membranes connects the laryngeal cartilages with their adjacent structures. This group is called the extrinsic laryngeal membranes and includes the hyothyroid membrane, the paired lateral hyothyroid ligaments, the hyoepiglottic ligament, and the cricotracheal membrane (Figure 1.10).

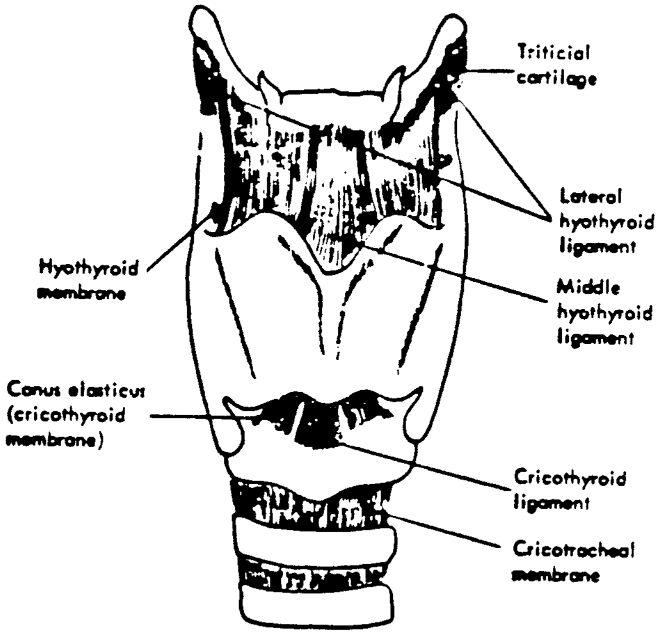


Figure 1.10. Ligaments and membranes of the larynx as seen from the front (2, Zemlin, 1968, p.129).

Another group of membranes interconnects the various laryngeal cartilages and helps regulate the extent and direction of their movements. They are the intrinsic laryngeal membranes, one of which (the conus elasticus) actually contributes to the composition of the vibrating portion of the vocal folds (Figure 1.11).

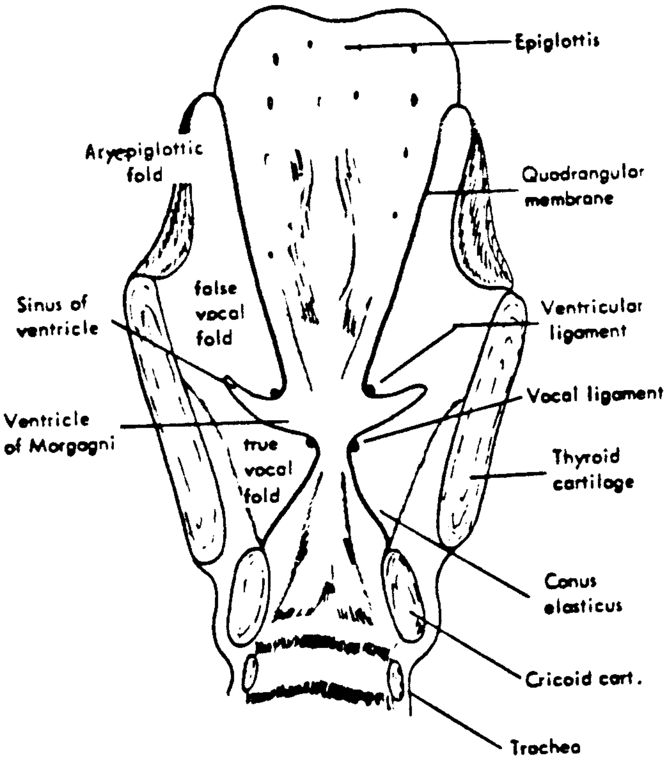


Figure 1.11 A frontal section of the larynx illustrating the relationship of quadrangular membrane with conus elasticus (2, Zemlin, 1968, p. 131).

The actual cavity of the larynx extends from the laryngeal entrance to the inferior border of the cricoid cartilage beneath. It is divided into supraglottal and infraglottal portions by the medial projection of the true vocal folds. The portion above the vocal folds is known as the vestibule or aditus laryngis. The cavity of the vestibule is wide above, becoming narrower toward the vocal folds. This is shown in Figure 1.12.

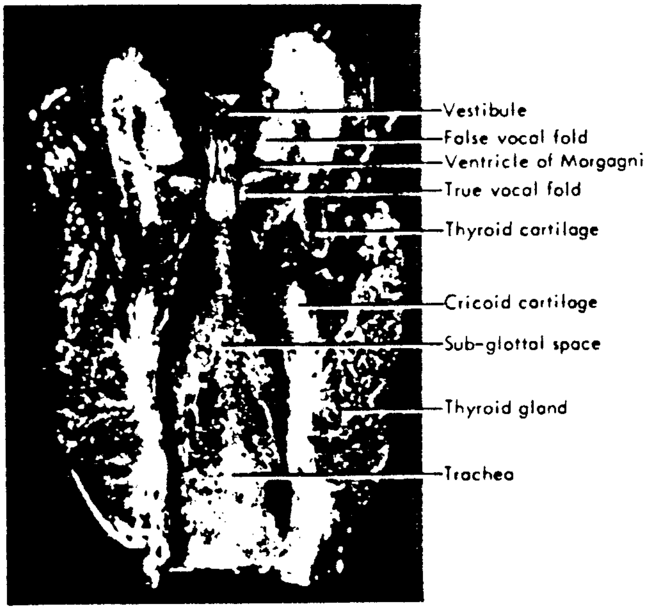


Figure 1.12 Frontal section showing division of the larynx (2, Zemlin, 1968, p. 133).

A deep depression, lateral to the aditus, is known as the pyriform sinus. As depicted in Figure 1.13, it is bounded laterally by the thyroid cartilage and medially by the aryepiglottic fold.

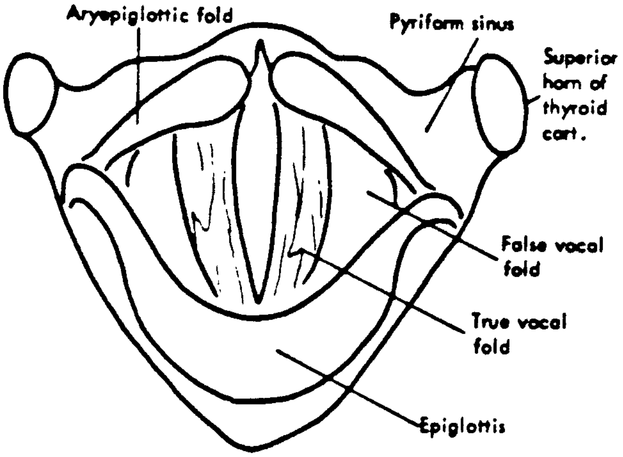


Figure 1.13. Schematic of larynx as viewed from above showing relationship of pyriform sinus to thyroid cartilage and aryepiglottic fold (2, Zemlin, 1968, p. 134).

The rima glottis, or simply the glottis, is a variable opening between the vocal folds anteriorly and the vocal processes and bases of the arytenoids behind (Figure 1.14).

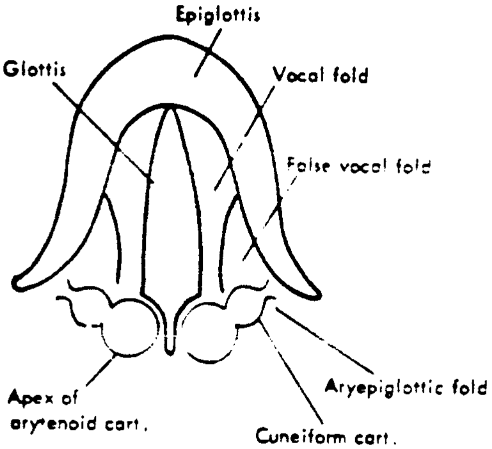


Figure 1.14. Schematic of the larynx as viewed from above (2, Zemlin, 1968, p. 137).

As shown in Figure 1.15, the dimensions and configurations of the glottis are highly variable, depending upon laryngeal activity and the adjustment of the controlling cartilages. The configurations of the glottis during a single cycle of vocal-fold vibration are shown in Figure 1.16. These motion pictures were taken at an exposure rate of 4,000 frames per second, and the entire cycle represents glottal activity during 1/140 seconds. It is evident that the length, width, and shape of the glottis is subject to extreme variability, not only from individual to individual, but also within a given individual. The shape and size of the glottis can be altered by the abduction or adduction, rotation or tilting of the arytenoid cartilages, by the air stream directed against the vocal folds, and by contraction of the laryngeal muscles.

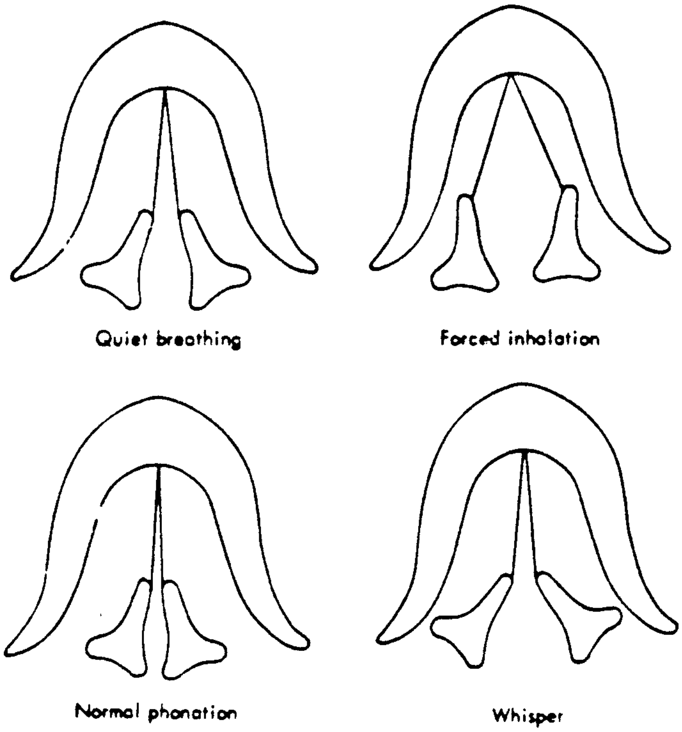


Figure 1.15 Schematic of various glottal configurations (2, Zemlin, 1968, p. 138).

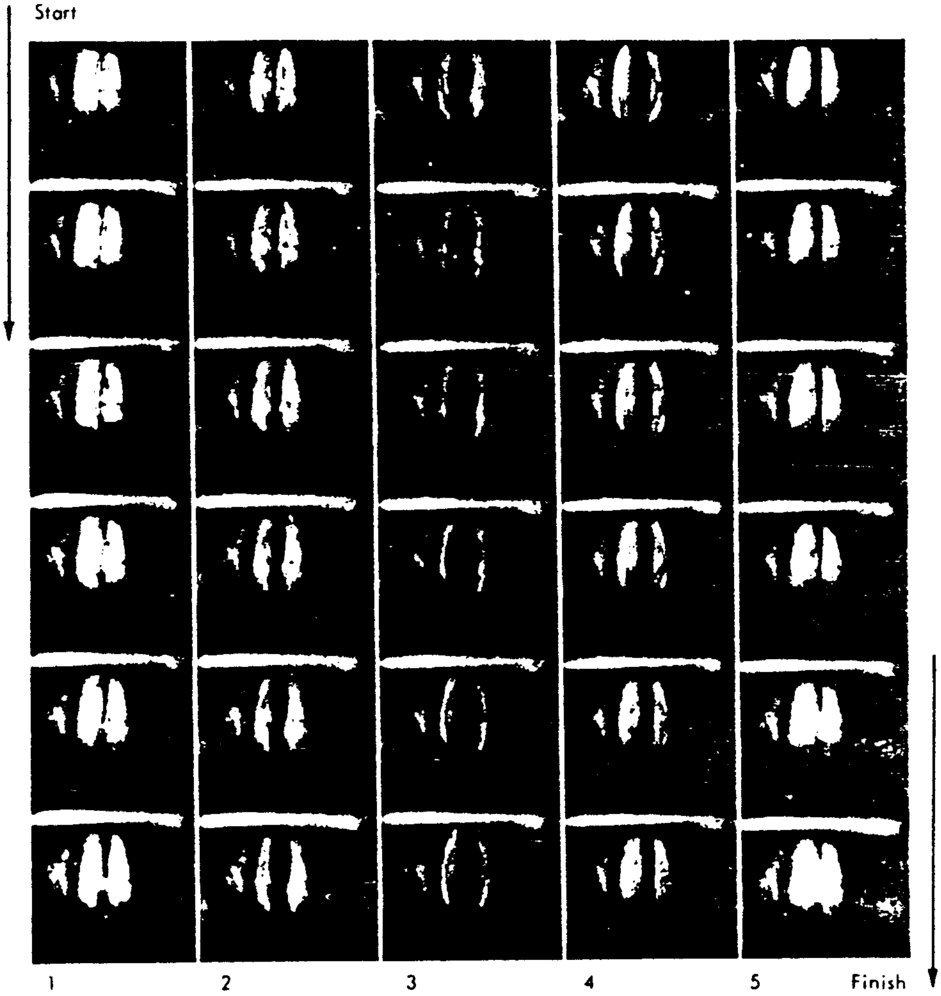


Figure 1.16 A single cycle of vocal fold vibration taken from a high-speed film (2, Zemlin, p. 139)

Finally, the two muscle groups will be discussed. As mentioned previously, the extrinsic muscles are those which have at least one attachment to structures outside the larynx, while the intrinsic are those which have both attachments within the larynx. Although both the extrinsic and intrinsic muscles may influence laryngeal function, the intrinsic muscles are largely responsible for the direct control of sound and pitch production. The extrinsic muscles are largely responsible for support of the larynx and for fixing it in position. They elevate and depress the larynx. The extrinsic set of muscles is divided into two groups, the suprahyoid (laryngeal elevators) and the infrahyoid (laryngeal depressors). It is suggested in this study that these muscles, by nature of their function, are acting as elevators and depressors in response to pitch as a heretofore unexplored facet of muscular activity required to control pitch production.

There are four suprahyoid muscles: the digastric, the stylohyoid, the mylohyoid, and the geniohyoid muscles. First, the digastric muscle is a paired muscle, rather complex in structure. This muscle, as the name implies, consists of two distinct muscles, but they are always considered as one in anatomy texts. There are two fleshy bellies as shown in Figure 1.17. The anterior section takes its origin from the inside surface of the lower border of the mandible. The posterior belly takes its origin from the mastoid process of the temporal bone. The fibers course down and forward. The two bellies meet and are joined at an intermediate tendon. This connecting tendon perforates the

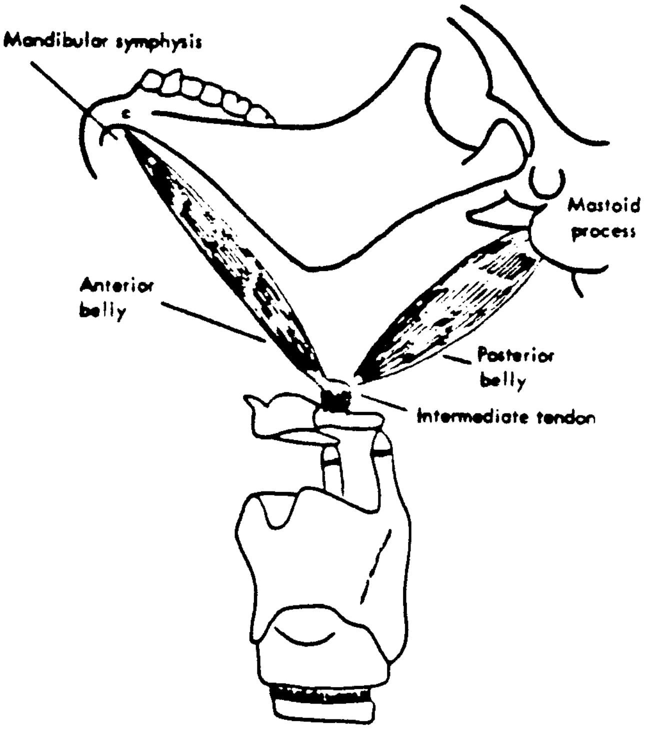


Figure 1.17 Schematic of the digastric (2, Zemlin, 1968, p. 141).

stylohyoid muscle and is attached to the junction of the corpus and greater cornu of the hyoid bone by a fibrous loop, which is part of a more extensive suprahyoid aponeurosis (2, Zemlin, 1981, p. 638), aponeurosis meaning a broad sheet of connective tissue that forms the attachment of muscle to bone. As might be supposed, contraction of the digrastric muscle raises the hyoid bone up and forward (anterior), up and backward (posterior) or directly upward (both muscles simultaneously), all of which contribute to deglutition (swallowing) as a biological function and as a non-biological function as related to pitch production. Further credibility is given to the non-biological theory in studies being presently conducted by Dr. Larry Dunn (3).

The stylohyoid muscle, shown in Figure 1.18, is a long, slender muscle placed superficially to the posterior belly of the digastric muscle and roughly parallel to it. It

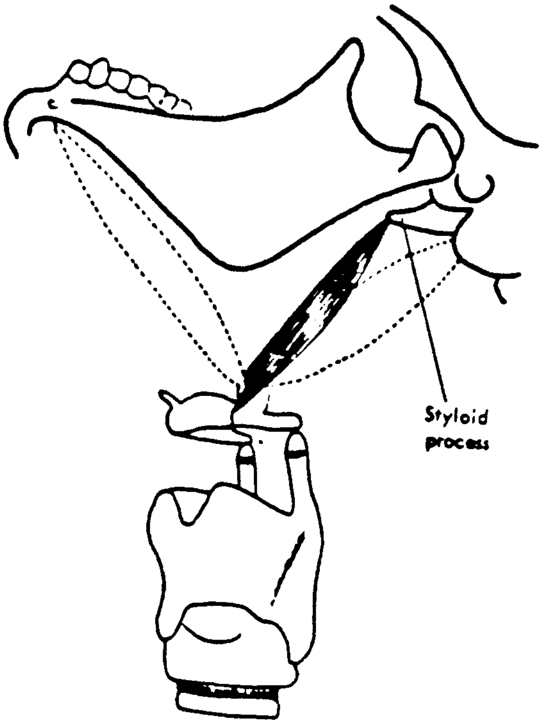


Figure 1.18 Schematic of the stylohyoid muscle (2, Zemlin, 1968, p. 142).

takes its origin from the styloid process of the temporal bone. It then splits into two slips which pass, one on either side of the intermediate tendon of the digastric, to insert into the body of the hyoid at its junction with the greater cornu. Contraction of this muscle also draws the hyoid bone upward and backward which this investigator feels is partially responsible for matching the high pitch being used in this study as a high note stimulus.

The mylohyoid muscle is a thin, unpaired, trough-like sheet of muscle fibers which form the floor of the mouth. These fibers take their origin along the mylohyoid line and connect at the inner surface of the mandible bone. The mylohyoid (Figure 1.19) also elevates the hyoid bone, the floor of the mouth, and the tongue. The geniohyoid is a paired cylindrical muscle, located above the superior surface of the mylohyoid muscle (Figure 1.20). These muscles pull the hyoid bone up and forward.

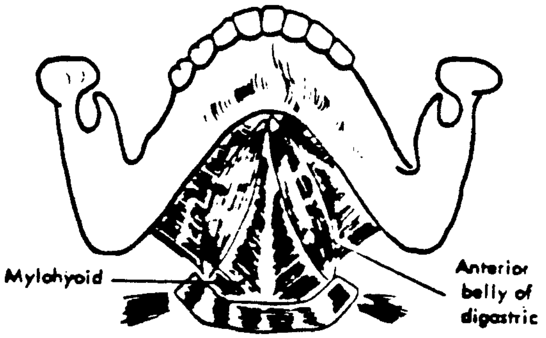


Figure 1.19 Schematic of the mylohyoid muscle (2, Zemlin, 1968, p. 142).

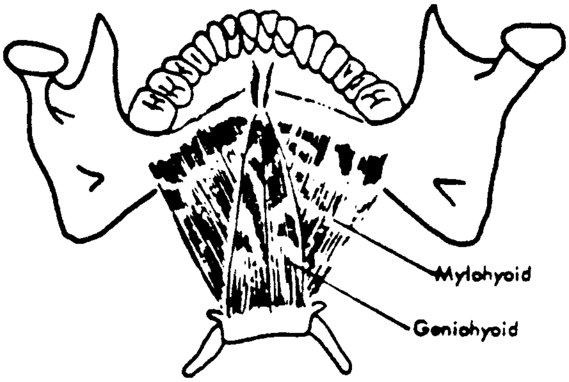


Figure 1.20 Schematic of the geniohyoid muscle (2, Zemlin, 1968, p. 142).

Two other muscles that are usually considered to be a part of the extrinsic tongue muscle group and may influence the position of the larynx are the hyoglossus muscle and the genioglossus muscle (Figure 1.21). The hyoglossus muscle may draw the hyoid directly upward while the genioglossus muscle may draw the hyoid up and forward. Both muscles insert into the tongue and connect to the hyoid bone. Dickson (1, p. 133-134) considers the function of the hyoglossus and genioglossus muscles to be for tongue control only during the speech articulation process even though he suspects the two muscles "may" raise and lower the larynx.

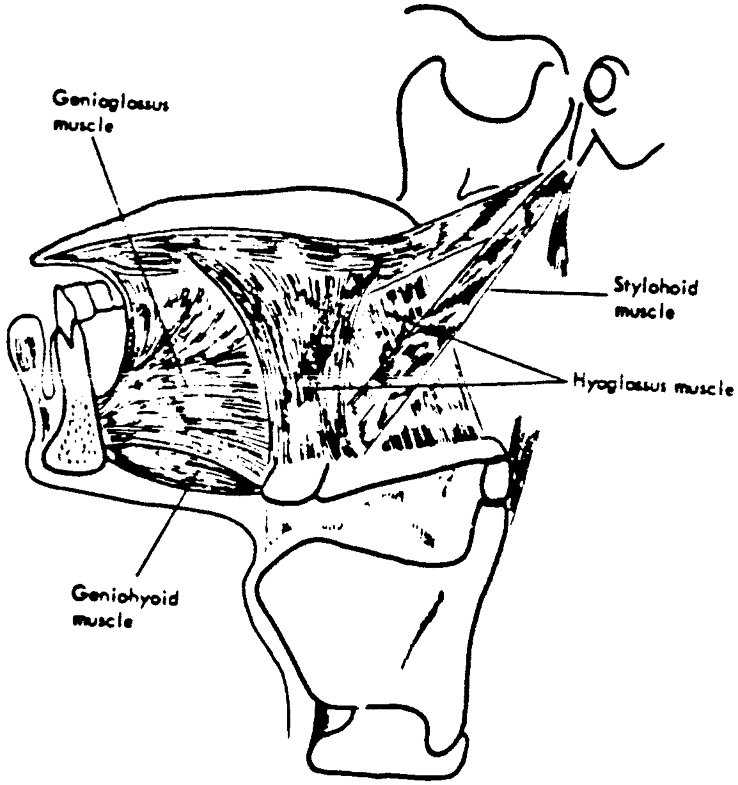


Figure 1.21 Schematic of extrinsic tongue muscles showing their relation to the laryngeal structures (2, Zemlin, 1968, p. 143).

There are two paired extrinsic laryngeal muscles which serve as infrahyoid muscles (depressors). They are the sternohyoid and the omohyoid muscles, both of which are "strap" muscles of the neck. First, the sternohyoid, a flat muscle, (Figure 1.22) lies on the anterior surface of the neck. Its origin is the posterior surface of the sternum. The fibers connect vertically to the lower border of the hyoid bone. With the sternum in a fixed position, the sternohyoid muscles draw the hyoid bone downward.

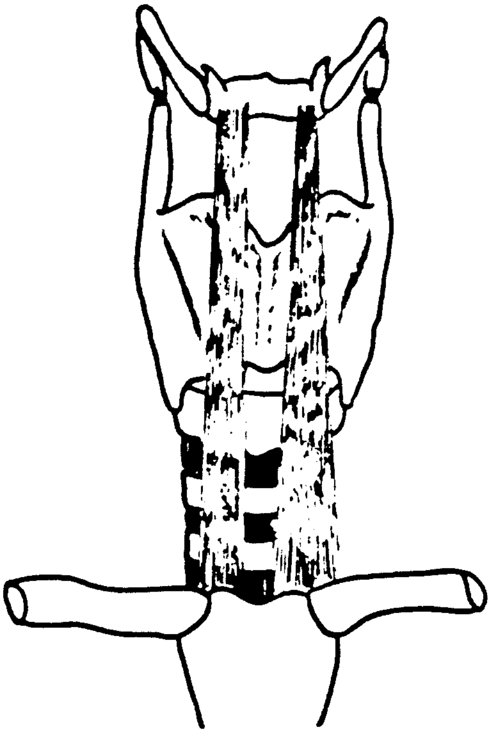


Figure 1.22 Sternohyoid muscles (2, Dickson, p. 103).

The omohyoid muscles (Figure 1.23) are long, narrow, two-bellied muscles situated on the antero-lateral surface of the neck. These muscles originate from the scapula (inferior belly) to the hyoid (superior belly). The contraction of the omohyoid muscles depresses the hyoid bone and moves it somewhat posteriorly.

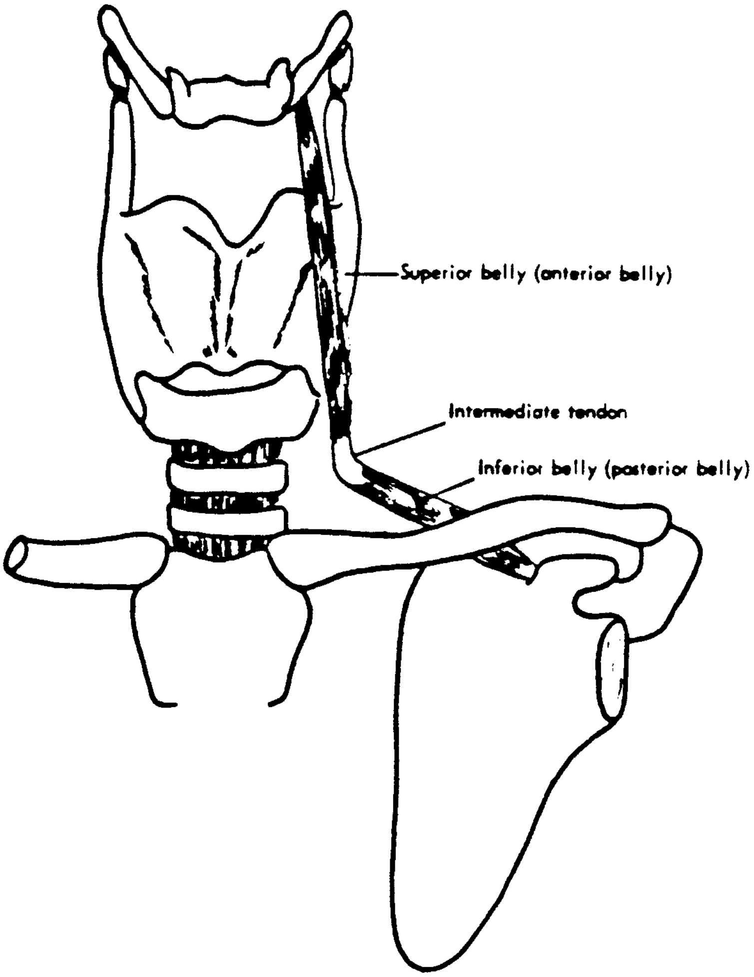


Figure 1.23 Schematic of the omohyoid muscles (2, Zemlin, 1968, p. 145).

In addition to the muscles just described, there are two other extrinsic laryngeal muscles which support the larynx. They are the thyrohyoid (identified as hyothyroid in some texts) and the sternothyroid. The thyrohyoid supports the larynx from above and is, thus, a laryngeal elevator, while the sternothyroid is below and serves as a depressor. Figure 1.24 shows the two muscles.

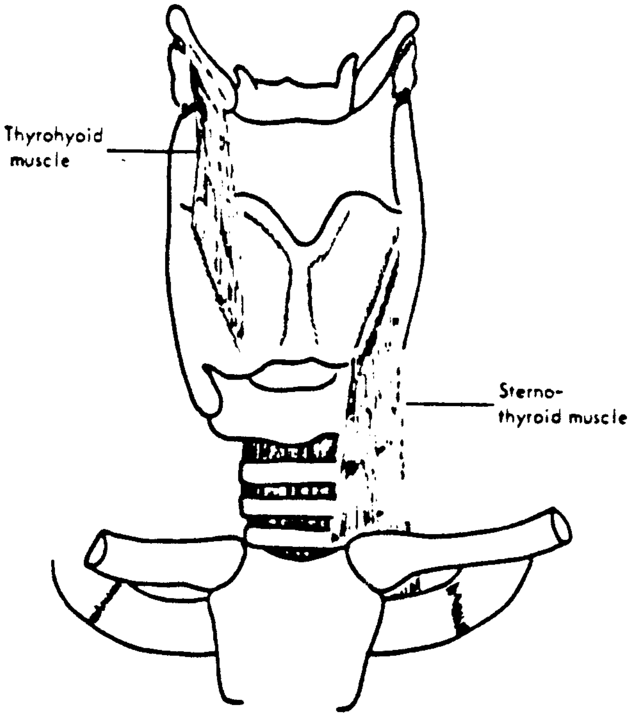


Figure 1.24 Schematic of the sternothyroid muscle and the thyrohyoid muscle (2, Zemlin, 1968, p. 147).

There are, in all, eight extrinsic laryngeal muscles. Five of these are laryngeal elevators, and three are laryngeal depressors. Their specific action, as related to larynx movement, is depicted in Figure 1.25. The arrows indicate the direction of their movements and placement of the larynx. These muscles are the structures with which this investigation is concerned. The specific extrinsic laryngeal muscles to be investigated were identified earlier in the problem statement.

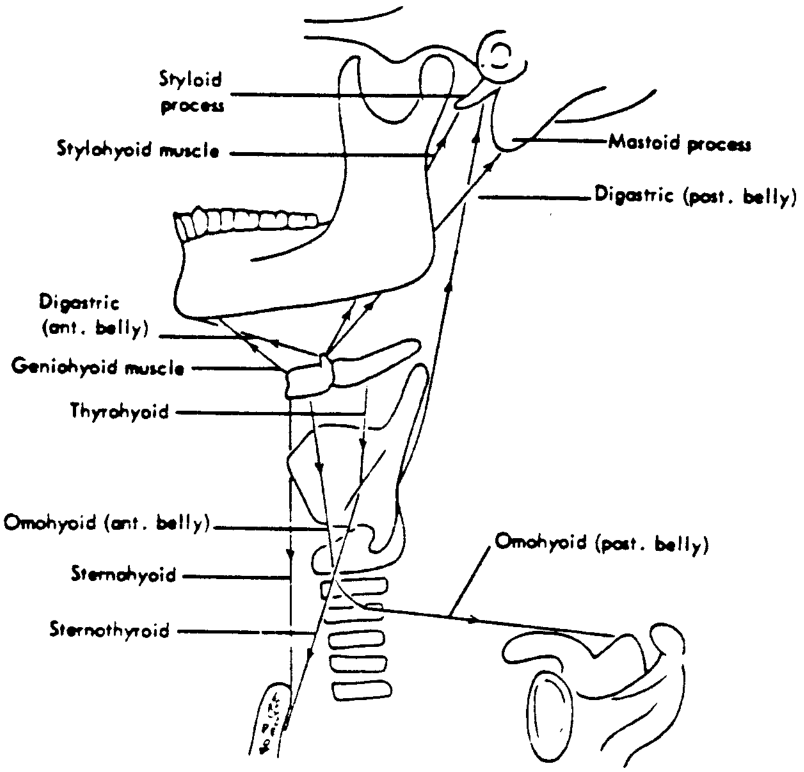


Figure 1.25 A schematic of the actions of the extrinsic laryngeal muscles (2, Zemlin, 1968, p. 146).

Although the extrinsic laryngeal muscles are the primary focus of this document, a brief discussion of the intrinsic muscles of the larynx will complete the basic structural survey.

A very intricate system of intrinsic muscles contributes to the complexity of the larynx. These muscles have a unique structure and are able to accomplish the many and varied rapid changes that are required for speech or singing. Intrinsic laryngeal muscles are categorized according to their effects on the shape of the glottis or on the vibratory behavior of the vocal folds. The larynx contains abductor, adductor, tensor, and relaxer muscles. The abductor muscles, which separate the arytenoids and vocal folds for respiratory actions are opposed by the adductors, which approximate the arytenoids and vocal folds for phonation. There are glottal tensors which elongate and tighten the vocal folds. They are opposed by relaxers, which shorten the folds.

The main mass of the vibrating vocal folds is composed of the thyrovocalis (or vocalis) muscles. They form the medial portion of the more extensive thyroarytenoid muscles. The thyroarytenoid muscle is very complex and is composed of two primary bundles referred to as the thyromuscularis and the thyrovocalis portions as shown in Figure 1.26.

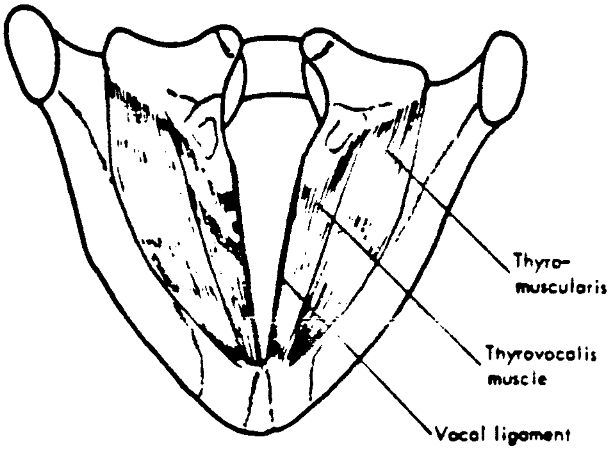


Figure 1.26 Schematic of the thyroarytenoid muscles (2, Zemlin, 1968, p. 149).

There is just one abductor muscle in the larynx, the posterior cricoarytenoid (Figure 1.27). Two muscles act as antagonists to the posterior cricoarytenoid muscle, being the lateral cricoarytenoid and the interarytenoid (arytenoid muscle). During contraction they will close the glottis (Figure 1.28). Additionally, according to Dickson (1, p. 106), they may lengthen the vocal folds while assisting in the lift of the cricoid cartilage. They abduct the vocal folds by moving the arytenoid cartilage posterolaterally over the rim of the cricoid cartilage.

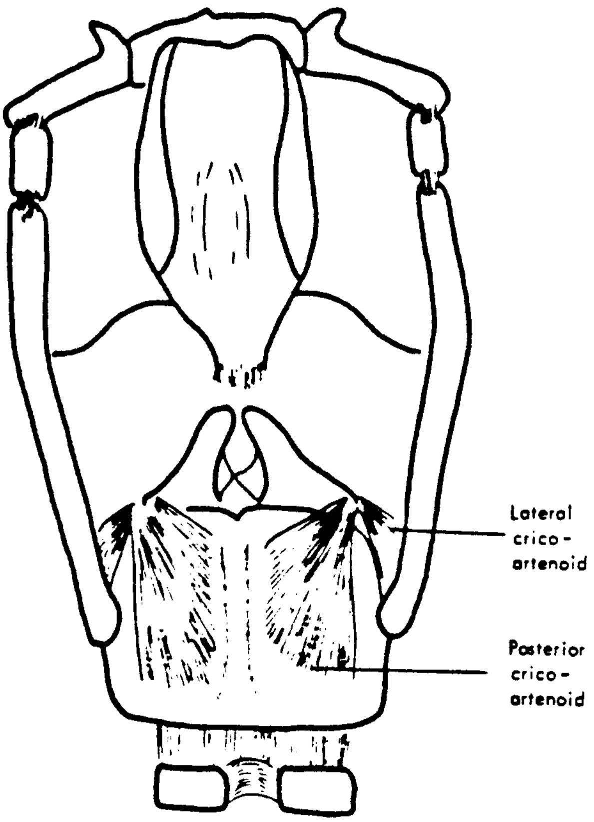


Figure 1.27 Schematic of posterior cricoarytenoid muscle (2, Zemlin 1968, p. 151).

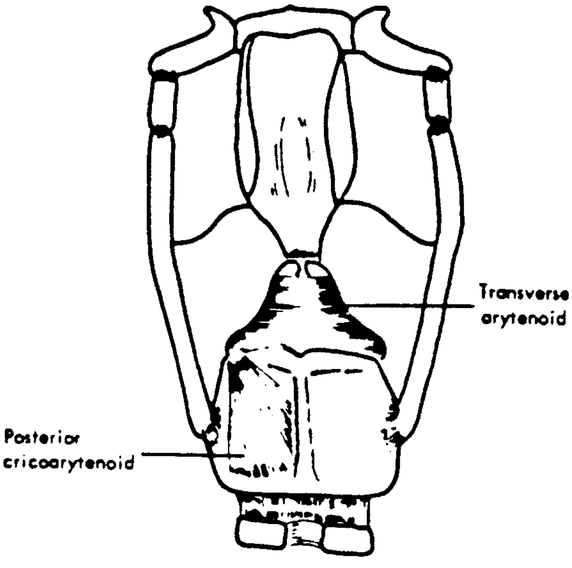


Figure 1.28 Cricoarytenoid and arytenoid muscles (2, Zemlin, 1968, p. 154).

The transverse arytenoid and the oblique arytenoid muscles control the epiglottis. This "X" shaped muscle and its adjacent vertical structure can be seen in Figure 1.29.

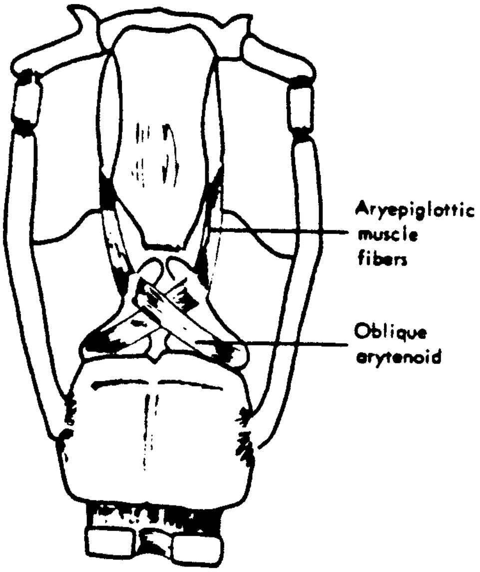


Figure 1.29. A schematic of oblique and aryepiglottic fibers of the interarytenoid muscle structure (2, Zemlin, 1968, p. 154).

The cricothyroid (Figure 1.30) is fan-shaped muscle, broader at the upper section. From the viewpoint of the mechanics of phonation and singing, this muscle is extremely important and has therefore received a great deal of attention in research on laryngeal physiology. If the thyroid cartilage is fixed in position (by extrinsic laryngeal muscles), contraction of the cricothyroid muscle raises the cricoid. If the cricoid is fixed, the thyroid tilts downward. Either action provides the modifications in tension and length of the vocal folds to control pitch changes. All the texts agree that these muscles are directly responsible for the tensing or relaxation of the vocal folds as a preliminary function of pitch control. These two actions can be seen in Figure 1.31.

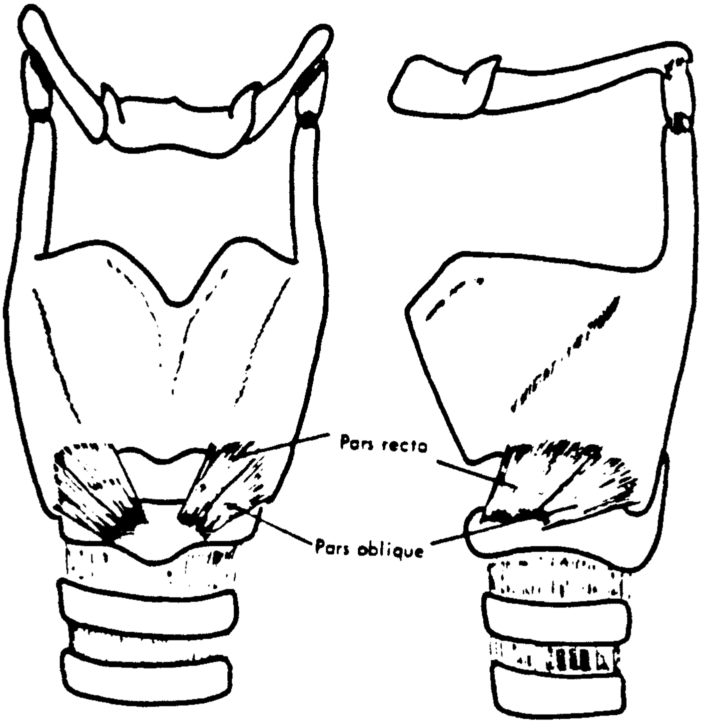
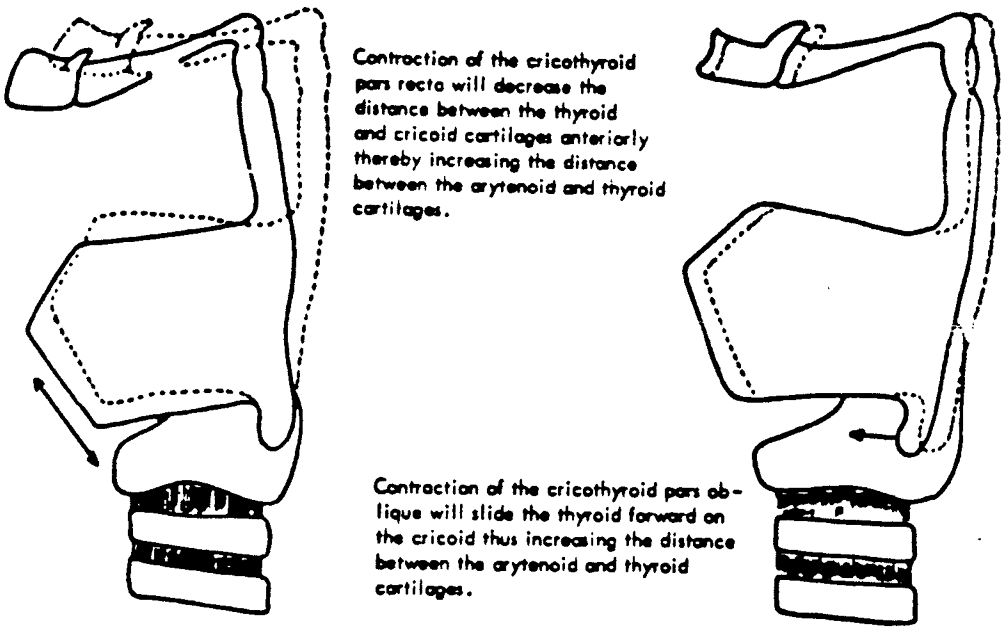


Figure 1.30 Schematic of the cricothyroid muscle (2, Zemlin, 1968, p. 156).



Contraction of the cricothyroid pars recta will decrease the distance between the thyroid and cricoid cartilages anteriorly thereby increasing the distance between the arytenoid and thyroid cartilages.

Contraction of the cricothyroid pars oblique will slide the thyroid forward on the cricoid thus increasing the distance between the arytenoid and thyroid cartilages.

Figure 1.31 Means by which the cricothyroid may function to tense the vocal folds (2, Zemlin, 1968, p. 157).

The intricate structure of the larynx is far more complex than is outlined in this brief survey. Researchers have been actively investigating the laryngeal mechanisms for over a century and a half. Speculation, however, has been recorded as early as 200 A.D. by a famous physician and writer of that time (2, Zemlin, 1981, p. 170). Because function and structure are so inextricably bound to one another within the phonation process, much of what has been learned remains conjecture. "In spite of the number of significant technical advances in recent years, differing opinions exist today on some very fundamental concepts of laryngeal physiology" (2, Zemlin, 1981, p. 170). It is the intent of this document to provide additional information to the physiological aspects of laryngeal function as well as providing an additional pedagogical instrument for the music educator.

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3. Dunn, Larry A., interview, Dallas Texas, June, 1984 regarding findings in his studies and practice as related to this dissertation. Dr. Dunn is a prominent oral surgeon who specializes in temporomandibular joint disorders. His research has shown that hearing impairment or loss can be caused by constriction of the upper extrinsic laryungeal elevators resulting from abnormal TMJ.

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CHAPTER II

RELATED LITERATURE

Recent developments in psychology and neurology have presented endless possibilities for heretofore unexplored research in sound recognition and sound production. Interdisciplinary studies and interaction between scholars and researchers have begun to filter into texts and methodologies. The primary focus of this dissertation was to examine and verify an observation which related to sound production and recognition. Literature involving the non-biological function of the extrinsic laryngeal muscles was found to be almost non-existent. There were, however, numerous studies that provided essential information toward the completion of this investigation.

All musical activity depends upon auditory perception. As stated by James Sherbon, "an individual must be able to hear tonal stimuli in order to exhibit any form of musical behavior"(18). To hear with greater accuracy and discernment will obviously enhance one's musical ability, whether as performer or listener. Psychologists refer to the general nature of pitch discrimination as being either the process known as inherited frequency analyzers--absolute pitch; or prior learning experiences--the process of relative pitch (19). This dissertation explores the probability of a physiological middle ground where those two possibilities meet.

Although numerous studies have been conducted to measure the success of present teaching methods, from programmed and computer-assisted instruction to special teaching machines, none of the studies address the physiological or psychological nature of pitch recognition and production. Even as late as 1965, a study reported by Schneider and Cady (17) produced a total of twelve competent studies (there were likely more than this number, but their document listed only twelve) on music reading and pitch discrimination. In the ensuing time period, music educators, using interdisciplinary research began to explore the psychology and physiology of learning processes with far more frequency. The essential element of strategy soon differentiated the merit of some methods over others. For example, James J. Canelos concluded:

> By supplying learners with a well organized instructional presentation via a particular instructional strategy, they have a better opportunity to acquire relavent academic content information. Self-paced, self-tutoring programs lack that strategy (2).

Various studies regarding experimental methods from the sixties, such as Hammer (8), Wiley (24), Mortenson (15), and Gregory (7), all conclude that the experimental methods or devices were no more effective than traditional instructional methods. Therefore, it seemed prudent to explore a concept more basic to the physical science of hearing and speech rather than revised pedagogical techniques from the past.

Scientific literature abounds with reports and studies on control mechanisms of vocal pitch and intensity. Although this study is a psycho-physical study, combining two simultaneous functions of the mind and neural responses, some previous studies of peripheral pertinence do exist.

Vogelsanger (23), Van den Berg (22), Ladefoged and McKinney (13), Isshiki (11) and lists of others have studied, in great depth, the relationship between vocal intensity, sub-glottic pressure and airflow rate. The conclusions of these studies give much information concerning dynamic control and air flow without pitch change. These studies do not, however, give any specific insights into laryngeal muscle activity and especially extrinsic laryngeal muscle activity. Faaborg-Anderson (5, 3), Katsuki (12), Zenker and Zenker (27), and many other scientists and researchers have accumulated, through electromyography, valuable information on the activities of laryngeal muscles associated with changes in pitch. Faaborg-Anderson (6), for example, investigated specifically the activity of the cricothyroid muscle during voice production. The conclusion of this study, as with other similar studies, was that there was increased electrical activity in the cricothyroid muscle from normal respiration as compared to the electrical activity during phonation. Of greater significance in that study was the conclusion that voice intensity had no effect on the cricothyroid muscle and, thus, no effect on pitch change. This relatively early study was one of the first to suggest that pitch change was a purely muscle activity. Tokashi (21) and others in a later study concluded that pitch regulation was a result of muscle activity varying the vibrating mass. Very little information was presented on how the vibrating mass was altered.

A rather involved study by Hirano, Vennard, and J. Ohala (10) in 1970 dealt with electromyographic investigation of intrinsic laryngeal muscles. This study employed hooked-wire electrodes. Although the hooked-wire electrodes worked better than standard needle electrodes, the authors of the article admitted that the vigorous movements of the larynx caused slippage of the electrodes and much of their data was, in fact, invalidated by reason of extreme motion and so contaminated with microphonics that it was impossible to evaluate. The conclusions of this study were many, yet constantly vague. For example, they concluded that (10) "register, pitch, and intensity are not independent parameters in the living human beings. There is, however, dominancy of particular muscles in regulating these parameters." Additionally, their conclusions stated that although the vocalis muscle primarily regulated pitch and register, other muscles cooperated in the fine adjustments. The study neither identified the specific cooperative muscle group or groups nor made any speculations concerning their functions. In defense of their study, however, it must be noted that they used only very limited electrodes to avoid interference with the normal singing process and were primarily concerned with only two particular muscles. They acknowledged, for example, that the entire larynx was probably lifted and lowered, that the vocalis muscles were being abducted and adducted, and that the muscles responsible for those actions were probably constant. However, the study did not conclude, as neuro-anatomists now know (26) and as this investigator suggests, that the extrinsic muscles play a very important part in these adjustments.

All of the studies mentioned to this point have dealt strictly with intrinsic laryngeal muscle activity as a pitch control. In 1980, a study by Harvey and Howell suggested that the extrinsic laryngeal musculature "_may_ contribute to the control of frequency by altering the position of the thyroid cartilage and thereby changing the length (and hence the anterior-posterior tension) or vertical tension of the vocalis muscles" (9). There are very few studies dealing with extrinsic laryngeal muscles in a non-biological context and therefore very few conclusions regarding their precise place in the complex nature of sound production.

In another study by Faaborg-Anderson (4), it was concluded that there is less activity of the vocalis muscle in falsetto than in chest voice. This study attributed the control mechanism to the cooperative status of the extrinsic laryngeal muscles. In essence, Faaborg-Anderson was stating that there was an increase in activity of muscles outside the vocal folds themselves directly associated with register shifts. This dissertation speculates that these outside muscles must be the extrinsic muscle group even though their contribution is in a second-stage relationship, the intrinsic being affected first.

In many of the electromyographic studies in humans, the responses of the extrinsic and intrinsic muscles are often controversial. One study finds no significant change in activity while the next study finds increased activity. This, in part, could possibly be due to the lack of stability in electrode placement. Furthermore, no documentation was found concerning the possible effect that pitch might have on any particular muscle. In the scientific journals, these discrepancies are often dismissed and attributed to experimental differences.

To demonstrate the ambiguity that still exists today concerning the functions of the extrinsic muscles, a study recently by Charles Painter concluded that genioglossus, digastric, and sternothyroid muscles function as pitch control muscles but that "it is not clear why raising of the larynx should accompany an increase in pitch" (16).

In a bulletin researched and written by Frank Wilson, (25) he suggests that any thought process evokes a chemical/electrical activity. This assumption is further supported by an article of 1983 from a NIMH bulletin which states that thinking, reading symbols, or simple memory sets into action a chain of electrical and chemical processes (1, p.41). If the process of vocalizing different pitches is a muscle function of some consistency, then the auditory stimulation by different pitches must, where memory is involved--as it is in music--create a muscle response that is conditioned by prior learning experiences or by encoded inheritance factors.

All memories begin with electricity (1, p. 42). Memories are stored in neurons. Neuroscientists have determined that the electrical impulses for long-term memory differ from the impulses for short-term memory (1, p.44). Repeating or drilling seems to place sensations into the long-term memory. This is the specific process, mentioned previously, known as prior-learning experiences as it relates to the acquisition of relative pitch. One such catalyst in the long-term memory process between experience and long-term storage is a structure in the limbic system called the amygdala (1). Thus, the neuron, serving as a relay station to the brain, and the amygdala, which may help in establishing permanently altered changes in the cortex, stores the information for instant recall.

The other structure in the limbic system that is essential for forming new and enduring memories is the hippocampus (1), a small structure in the center of the brain. Although neither the amygdala nor the hippocampus are used to store information, they are the controllers that determine what becomes long-term or short-term memories. All long term memory is assumed to be stored in the cortex after the two limbic structures determine the importance of the stimuli and impressions (1, p. 44).

It would be easy to speak of the brain as if it were only composed of neurons, but there are many other kinds of cells. What they do is by no means understood though some recent research suggests they are involved in some mental activities (20, p. 96). More accurately, there are some 15,000 million neurons and more than ten times that number of other cells. Nevertheless, the neurons provide the essential wiring for thinking processes and muscle responses. Furthermore, the neurons react with a relative rapidity.

The brain is constantly being compared to the computer as an analogy to the conduction process in thinking (20, p.97). With regard to speed, Smith has noted that (20, p. 97-99) the brain bears scant relation to the computer. Electricity travels near the speed of light (186,000 miles per second) in computers. Human neurons, which are exceptionally leaky in their conductivity, and far more resistant than copper wire, travel about 225 miles per hour by contrast. Further, all neurons do not conduct at the same rate. On the average, though, the longest transmission from head to toe would only take twenty milliseconds (ms). Then allowing for processing, turn-around and signal, only five hundred ms would be required to process an entire cycle

(20, p. 97). This time frame--one half second or 500 milliseconds--is the general guideline for neurological research in electromyography normally used as a high analysis time (14, p. 301). The short term latency can be as low as one millisecond (ms). Long term latencies can range to a high of five hundred milliseconds. The forty millisecond analysis time employed in this study was simply the result of scores of adjustments in both directions ranging from 6 ms to 300 ms. Neuro-physiologists and physiologists have determined that from the moment a sound wave hits the ear to that later moment when the relevant impulse reaches the auditory cortex is about twenty milliseconds (20, p. 183). The task for this research project was to determine a reasonable mean time for the extrinsic laryngeal muscles to respond to that stimulus.

A tone (defined by cycles per second) is, simply stated, a series of impulses that is picked up by the auditory system of the inner ear. It might be expected that the impulses would be mirrored by the impulses traveling along the auditory nerve. This, however, is not true because the fastest impulse the auditory nerve can manage is three hundred or so cycles per second, regardless of the frequency of the tone (20, p. 183-185). How, then, the brain interprets all this information, with one nerve firing at one impulse rate while another interprets the same tone at a different rate, and still recognizes the frequency of the tone (or perhaps a third, totally unrelated impulse frequency), is--to quote the scientific phrase for such circumstances--not entirely clear. What is clear, however, is that the brain receives the information and decides how to process it. It is thus the brain and not the ear that contains the skill. Therein lies the connection between the stimulus and the response.

It is instantly apparent that there was a relative dearth of existing materials directly related to this dissertation and that all the studies and literature mentioned here are merely indirectly related to the premises presented in this document. In fact, a general statement can be made that no literature exists directly related to this study. Neither the author's research, nor interviews with neurologists, audiologists, neuro-anatomists or electromyographic diagnosticians produced any sources. Neither the physicians nor the audiologists could recall any previous studies connecting auditory stimulation to throat muscle responses. After personal searches, three of the major computer searches were conducted with the same results--no references.

Several conferences were held with the neurologists and technicians of TNI. They suggested extensive background reading in general anatomy, vocal anatomy, speech and hearing science, and principles of EMG procedures and interpretation. A rather lengthy period of backgound training took place concurrently with the suggested reading lists from the TNI neurologists and technicians. Additionally, much supervised time was spent observing and assisting in the EMG lab in order to become familiar with procedures and techniques. The related literature and the conferences produced much pertinent information relevant to the background and procedures of this investigation.

It should be noted that the texts and articles which were read in preparation for the investigation, as well as those who assisted in the design, warned of the inconsistencies of all muscle responses. The objective and problem, therefore, was to develop a protocol that could be replicated for a rather unpredictable medium--muscle activity. Although the capabilities of EMG have been greatly improved and expanded through interfacing with computers, they are still not totally reliable. In dealing with muscle group actibity, the EMG cannot ignore nearby muscle responses. Electrode placement is, therefore, of utmost importance in determing the point of greatest amplitude. Thus, within the limitations of the available equipment, the development of the protocol for the investigation proceeded.

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CHAPTER III

METHODOLOGY

Background of the Protocol Design

During the time from the early experiments to the final testing, the design format underwent countless changes. The rather loose structure of the classroom experiment was of little value in the science laboratory. The first trials at the TNI lab, although somewhat successful, were not consistent to the point of scientific realiability. The initial difficulty was the author's lack of knowledge and understanding of the EMG analyzer and its possibilities. Therefore, as much time as possible was spent in the lab observing and assisting the technicians in order to learn the processes and controls. Even after learning the basics of the computer, analyzer and plotter, the problem of reading the EMG results proved to be an even more complex challenge. Most of that training took place in the laboratory under the supervision of the technicians.

Learning and knowing all the capabilities of the equipment and electrode preparation procedures was essential to the development of the design parameters. In all, it took more than a year to become independent of the technicians and neurologists and to become competent in controlling the total experiment.

The first trials of the program consisted of a rather crude design with trial and error parameters. As noted previously, no guidelines existed for this type of experiment and, thus, no way of projecting the results. The initial tests were run with the following design shown in Figure 3.1:

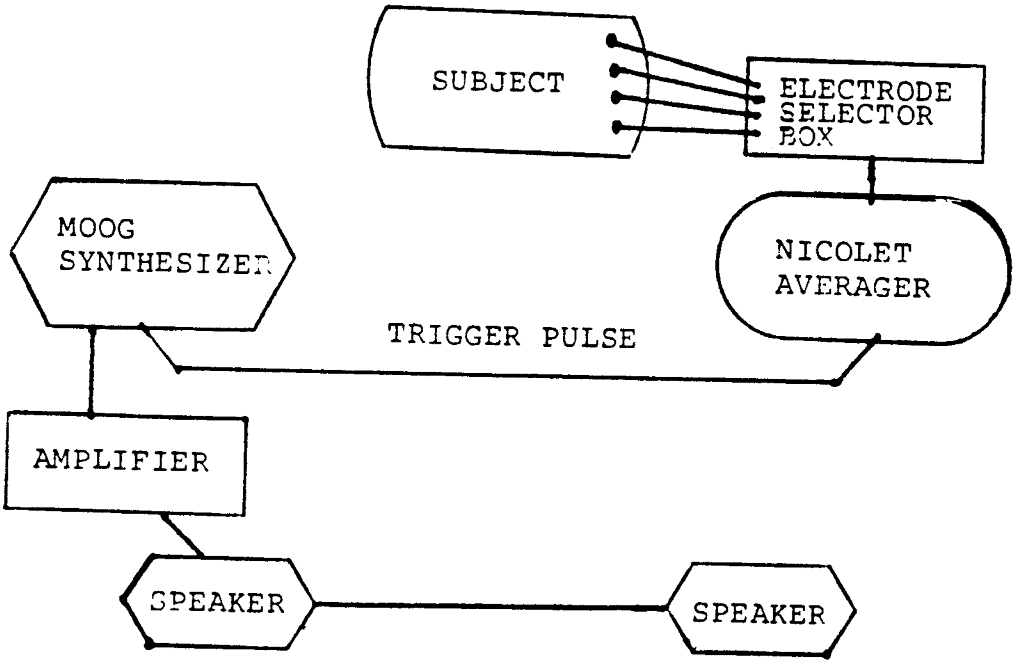


Figure 3.1 Preliminary Design

As the design developed and better results were obtained, the design was refined until the methodology was workable and produced reliable results. Often, one parameter change such as an increase or decrease in total sweep time would produce totally different EMG results. Likewise, any change in band pass filters or any of the other fine tuning adjustments would alter the results in numerous ways.

In essence, muscle responses were located and recorded by trial and error. After the electrodes were placed on the subject, a series of pitches were played on the keyboard of the synthesizer until one of the four electrodes on the throat registered a response. The information from this early experiment, though crude and inconclusive, led to the general procedure concerning the measurement of auditory stimulus and muscle responses for the final design. From the outset, the tests revealed a consistent range of pitches between the upper and lower muscles being measured. That area included the muscles found between the sternum and mastoid process. The information obtained in these early experiments proved to be the normal range in all subjects, both male and female. Furthermore, the precise pitches employed proved to be consistent in both male and female subjects.

One problem with this early design was the latency measurement. Inasmuch as this study dealt with time frames in milliseconds, any loss of time produced invalid data. The problem at this point of the design development was the time loss from speaker to ear. The difference in time between sound traveling through air to the ear and the speed of the trigger pulse going to the analyzer gave a false reading for this muscle latency response even if the speaker were only a few feet away from the subject. (10 feet requires about 10 ms for the sound to reach the subject.)

Another unknown in the early trials was the number of stimuli required for a good, predictable response and how many stimuli should occur within a given time frame. These early trials included a range from 10 stimuli to 400 stimuli occurring at a frequency ranging from one per second minimum to twenty per second maximum. Latencies were measured from 5 ms to 500 ms. Further trials were made with amplitudes ranging from threshold of hearing (which would obviously be individual) to 100 decibels which could not be used because of its startle effect as well as discomfort. Although this phase of the study yielded very enlightening support for the basic premise of the study, the scientific verification was far from conclusive.

After the initial phase was completed, the decision was made to change from open field (speakers) to contained field (head phones). The headphones would eliminate the time discrepancy between trigger pulse and ear-response. One parameter was changed at a time until the responses began to be more and more consistent. As the design proceeded, it became apparent that the major response would occur very quickly--somewhere less than 100 ms.

As the time factors of the latency response were narrowed, it seemed prudent to change from keyboard to digital cassette tape for the stimuli. Thus, there would be total control of the amplitude, exact time between stimuli, exact frequencies, and simultaneous trigger/stimulation by placing stimulus on one channel and trigger pulse on the other. The computer within the analyzer could, therefore, register the time lapse from stimulus to response within 1/100th of one millisecond.

The digital tape underwent approximately twenty revisions before reaching its final form. In the same method as in the earlier experiments, the parameters were changed one at a time, then tried in the lab. As the desired result was achieved, the digital tape gradually reached a workable format. With the assistance of Callier Institute (University of Texas), a highly controlled digital tape was prepared utilizing exact frequencies, decibels and wave forms. The pitches were derived from a computer program written by this researcher (Appendix Three). The wave form was taken from a Moog synthesizer. A saw-tooth wave form, which sounds very similar to a harpsichord tone, was used. Several wave forms were tried in the early stages of the design, but it was found that subjects responded more noticeably to the harpsichord-like tone than to any other. Many experiments employ sine waves, but the use of sine waves as a stimulus was rejected because those tones are not realistic representations of normal musical tones. In its final form the tape contained the following parameters as decided by the researcher and those assisting in the study:

1. 5 stimuli on each pitch would be used.
2. Each pitch would be 100 ms in length.
3. A space of 1 second would be placed between each stimulus to allow the muscle to relax.
4. Three tests (5 each) would be run consecutively.
5. The three sets would then be averaged into a fourth channel.

Each pitch would be tested through four trials for each of the four electrodes to assure consistency and thus validity. It should be noted that the EMG analyzer averages the five responses each time so that the data actually reveals an average of the five stimuli into one channel of the scope, repeats that process on trials two and three, then averages the three "averages" together for a final conclusion.

The purpose for the digital tape was to maintain a constant control on all the stimulus parameters in order to determine whether the responses would be consistent or different among the subjects.

The general function of laryngeal structures was discussed in chapter one. A brief discussion of electromyography at this point will afford a better understanding of the methodology and the related basic electromyographic principles employed in this study.

Electromyography

When a nerve stimulus is adequate and causes a muscle to contract, the rapid chemical change that takes place (ion exchange) results in a small electrical current flow. This flow can be detected by an EMG analyzer over the surface of a muscle. If muscle activity is adequate and enough muscle fibers become active, the electric activity and energy can be detected on the surface of the skin (6, p. 81). The sensitivity of the Nicolet analyzer used in this study was capable of detecting the electrical activity on the skin surface, thus justifying the choice of the surface electrodes as opposed to the complex processes required (sterilizing, needles, etc.) by the use of bipolar types.

EMG measures the relative activity of a particular muscle during a particular motor task. The generated voltage may vary from .1-200 µV, each extreme being very rare (5, p. 304). The duration of each peak may last from 2-10 ms, and each wave form may have as many as four phases (5, p. 316). Figure 3.2 represents an EMG response from this investigation. The µV range that is noted above is for the major muscles of the body and does not apply to the smaller muscles that control laryngeal movements where µV readings would be much less.

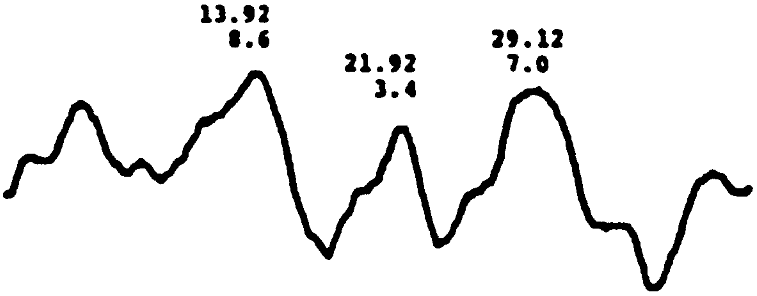


Figure 3.2 Sample Wave Form

The upper numbers in this response represent latencies measured in millisesonds. The lower numbers represent the amplitude of the response measured in microvolts.

Generally, an isoelectric line, meaning complete rest, is almost impossible to obtain during test trials. In fact, the subject who registers complete rest is most likely to be in a state of mortality. Therefore, a muscle will not begin at an absolute "0" µV point but, rather some point below -.5 and +.5 (5, p. 318). Even that estimate is subject to variance due to the inconsistency of all muscle activity (5, p. 319). Thus, in viewing a peak, the µV measurement at the point of the peak may not represent a large µV reading even though the peak appears very prominent. The activity may have begun at a negative point and thus moved a great distance in scale if not in microvoltage.

In normal muscles, fibers never contract individually. Instead, several contract at almost the same time in a quasi-wave form, all being supplied by branches of the axon of one spinal motor neuron (1, p. 104). Figure 3.3 is a diagram of a motor neuron showing how the axon controls several dendrites which are connected to the muscle fibers.

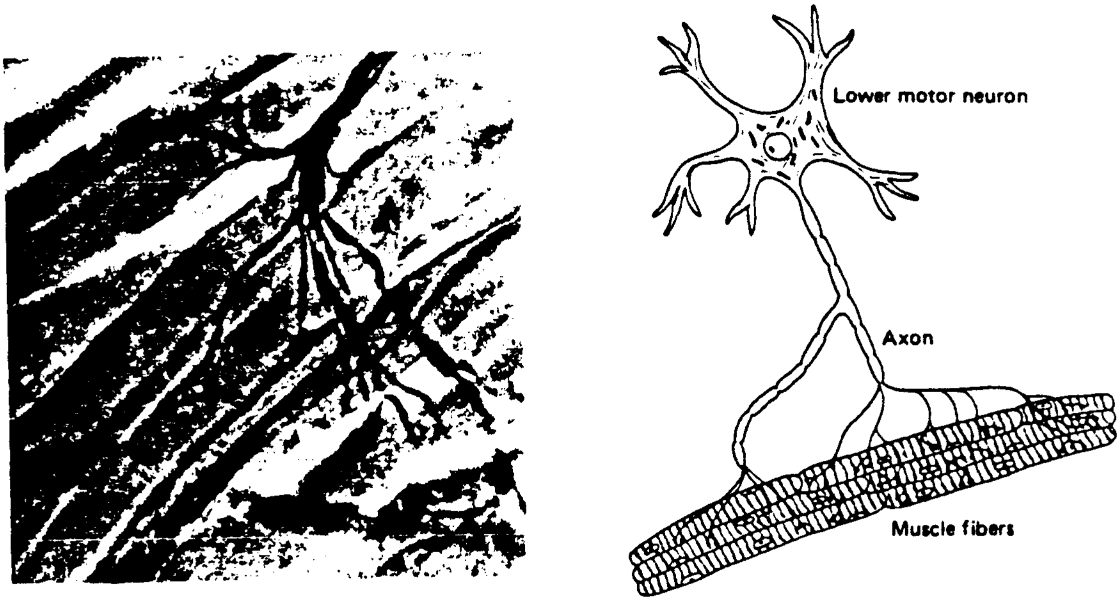


Figure 3.3 Motor Neuron

The number of striated muscles fibers that are served by one axon, i.e., the number in a motor unit, varies widely. The eyes have ten or less, while the laryngeal muscles only two or three. For coarse-acting muscles there can be 2000 or more per motor unit. The electrical result of a single motor unit twitch is a charge having an amplitude of about .5 µV (1, p. 106).

Basically, the procedure for EMG measurement in this investigation was to place one eletrode over the muscle to be tested and place the reference (not to be confused with the ground) electrode over some neutral point. Sidney Licht (5, p. 300-301) suggests a bony prominence with little or no underlying tissue such as the mastoid or forehead. In the early experiments of this study, the mastoid was employed for the reference electrode. However, inasmuch as most of the extrinsic laryngeal muscles function bilaterilly (that is in pairs, each functioning simultaneously), the electrode being measured was too close to the elevator muscles and caused some degree of interference. Thus, in the final design of the study, the reference electrode was placed on the forehead opposite the ground electrode. For this study four electrodes were employed. The two measurements electrodes were placed over the two pre-determined points of the elevator and depressor muscles, the reference electrode was placed on the forehead, and the ground electrode was placed on the forehead opposite the reference.

A major concern in any EMG study is artifacts which means any voltage registration not originating in the skeletal muscles being measured. Artifacts can originate from a number of sources ranging from swallowing to a strong cardio-vascular response. There are three methods for controlling artifacts. The first one, an artifact reject, built into the Nicolet analyzer, was not satisfactory for this type of study because of the co-ordination of pre-recorded tape and responses. It is effective in a situation in which large numbers of responses (100 or more are required as in neural studies.) The artifact reject mode on the analyzer will refuse any response outside of the controlled µV parameters. Thus, while waiting for a series of five acceptable responses for averaging purposes, the analyzer might reject as many as fifty or more responses because of extraneous activity.

The second method was simply to control the filters just above cardio-vascular (EKG) responses and just below excessive responses such as coughing and swallowing. According to Sidney Licht and other neurologists, that range is from +/-5 to +/-250 µV (5, p. 319). EKG response is normally less than the smaller number while swallowing and coughing are far greater than the larger response.

The third method was to prepare the subjects themselves with instructions not to swallow or breathe heavily during the short time for each trial. By controlling the band pass filters and by using the brief instruction session for each subject the data was relatively easy to obtain. If one of the subjects did cough, swallow or move excessively, the data for that trial was not recorded because of the false readings that were produced. Thus, with five pre-recorded stimuli, one can expect five reasonable responses. Should coughing occur, it would not be registered. The sensitivity filter was set at +/- 25 µV, and the best latency (total analysis time) was eventually determined to be 40 ms.

The contacts must be securely attached to the skin surface. Should the contact be loose, the result would be an interference wave or artifact. Therefore, after attaching the surface electrodes, each electrode had to be checked for resistance with special instruments to verify proper preparation and connection with the skin surface. Additionally, the electrodes had to be checked periodically within the Nicolet averager by a reference switch. The resistance was frequently checked during this study between each phase of the investigation trials.

Preparation of subjects

To assure proper electrode contact, each subject was prepared in the following manner:

(1) Cleaned skin surface with alcohol.

(2) Cleaned area to be used for electrode placement with Omni Preparation Solution which is a cleaning agent

and is electrically conductive.

(3) Electrode cream (paste) was placed on the prepared area.

(4) Electrode was placed in the paste and covered with a strip of gauze.

(5) A strip of surgical tape was then placed over the electrode and gauze to prevent any loosening of the electrode.

(6) Each electrode was then checked for resistance. A reading of "3" or more on the scale is considered to be a poor placement connection.

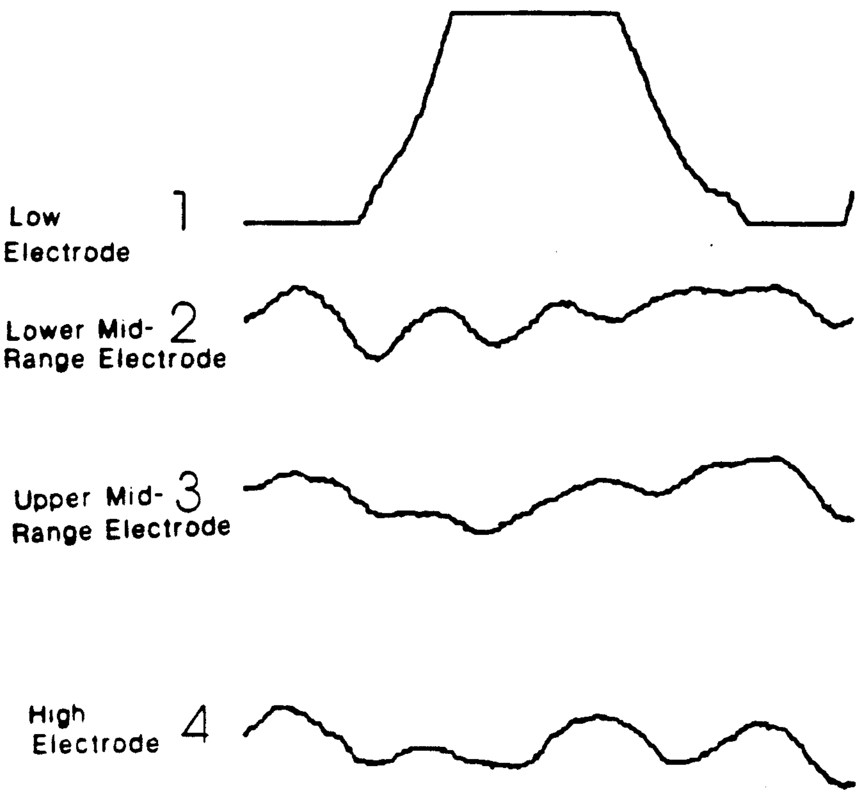
Often for a variety of reasons, the electrodes had to be re-applied to achieve an acceptable level of resistance. Of course, the re-application meant that all six steps had to be repeated.

The Nicolet Model CA 1000 Clinical Averager

The analyzer in this investigation was the Nicolet CA 1000 Clinical Averager which can measure EMG activity. The Nicolet is a differential averager that utilizes a differential amplifier to measure the difference between two electrodes--in this case the reference and the reading electrodes. The EMG analyzer is controlled by a disk controller, DC2000 Nicolet biomedical storage and analyzer computer. The computer was also interfaced with an oscilloscope for immediate viewing and analysis, and a plot scanner which then transferred the stored medical data to hard-copy EMG graph plots. The computer allowed for either internal or external trigger for calculating stimulus and response latency time. External trigger had to be employed in this investigation because the pitch stimulus which was built into the Nicolet was only one octave in range, and this study utilized pitches over a range of seventeen notes.

There are almost infinite control factors built into the Nicolet averager so as to make the instrument multi-funtional. The unit can measure muscle responses, neural responses, brain-stem function, and other uses. In this investigation, the problem was narrowing the possibilities so as to achieve the best and most consistent results for a number of subjects.

In the early experiments, the parameters were adjusted and fine-tuned until responses became consistent. The method which was employed for locating the general tessitura of the extrinsic laryngeal muscles was to place four electrodes in a general line from just below the mastoid process to just above the sternum, then, use the Moog synthesizer to play a series of pitches while observing the oscilloscope. When a muscle responded to a specific pitch, the measurement would appear on the oscilloscope and store the response. Almost fifty trials were run using this simple method in order to determine the appropriate pitch range. It was during this phase of the study that the pitches to be employed in the final design were determined. Figure 3.4 is an example of the four channels being plotted from the four electrodes.



Muscle responds to low pitch (D) and peaks off the scope.

Figure 3.4 EMG Plots for Pitch Stimulus Determination

In this plot three of the electrodes are registering a relatively flat or isoelectric-like response while the electrode over the muscle which coincided with the particular stimulus shows a great increase in amplitude (seen by the size of the peak response).

The procedure as described above was repeated numerous times until definite patterns of responses to auditory stimulation were documented and compared. With those determinations made, the "electrode placement" phase of the protocol was complete. The methodology as related to the problems was then developed.

Subjects

There were over forty volunteer subjects who participated in the design and completion of this study. Twenty-one of those subjects, ten male and eleven female, participated in the final phase of the investigation. Some of the subjects were musicians, some had limited experience, and some were non-musicians. This document is concerned with the data of the final twenty-one subjects, and that information is reported. The subjects reported were all young adults ranging from 19 to 34 years old. All the subjects were students at Richland College, Dallas, Texas. All of the subjects were normal and free of any speech, hearing or medical problems.

Muscles Being Tested

The lower electrode was placed just above the sternum at the point where the lower segment of the sternohyoid muscles adjoin with the sternothyroid at their attachment to the sternum. (See Appendix Two, page 196 for a detail of these structures). These muscles are laryngeal depressors and, thus, should respond to the lower pitch stimulus. The electrode placement was just above the sternum and slightly to the right.

The upper electrode was placed at a point where the posterior digastric muscle connects to the mastoid process and overlaps with the stylohyoid muscle as it attaches to the styloid process. (For a detail of these structures, see Appendix Two, page 197). These muscles are laryngeal elevators and should, thus, respond to the high pitch stimulus.

As noted in Chapter One, there are six laryngeal elevators and three laryngeal depressors. Their combined action is very complex and has not been totally understood or determined. A Zenker and Zenker study (9, pp. 1-36) concluded,in general, that the elevator/depressor action regulates vocal-fold tension in that the extrinsic muscles moved the mechanisms of the larynx, but offered no explanation as to why the movement exists.

Final Design of the Investigation

The final design of the study is shown in Figure 3.5. The Nicolet has been fully described. The remainder of the equipment was a Kenwood Amplifier, a Fisher stereo cassette tape deck, shielded headphones, and a recliner chair.

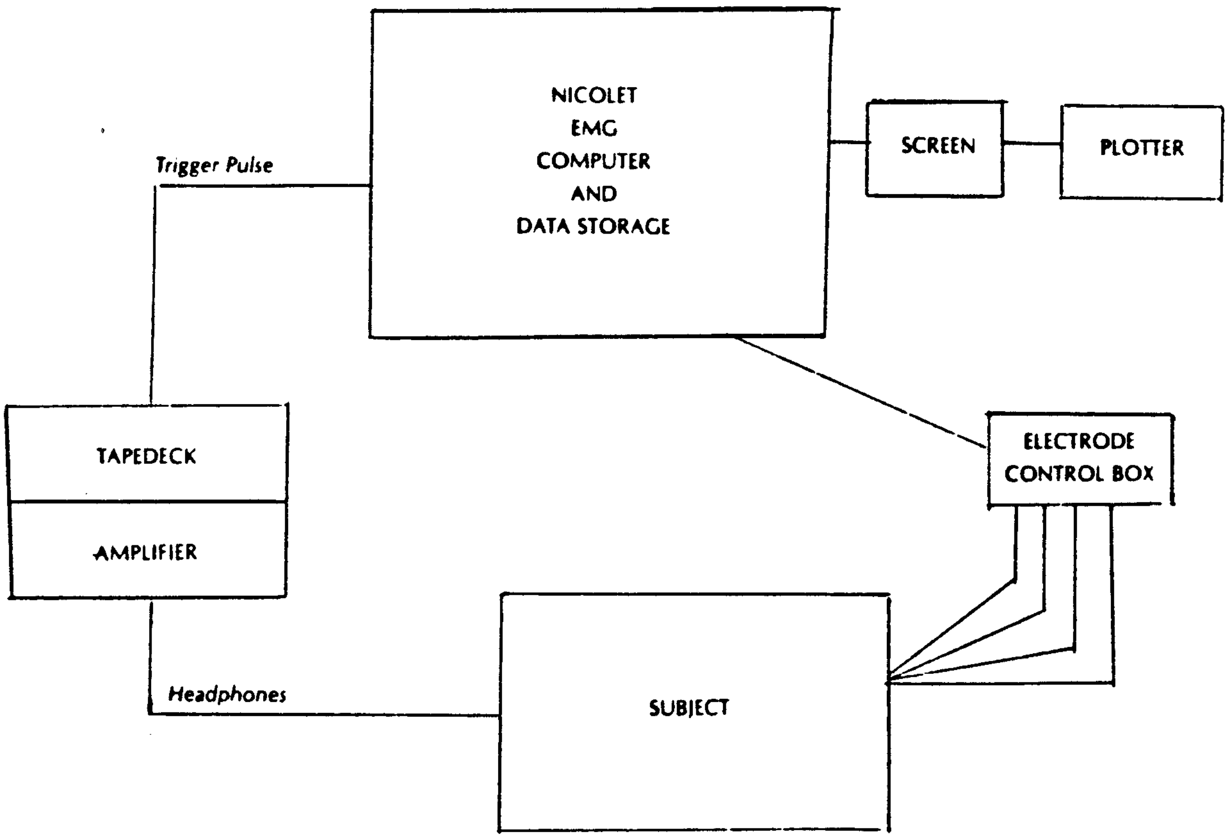


Figure 3.5 Final Design of the Investigation

Procedure for Data Collection and Analysis

The primary objective of this investigation was to collect empirical data to support or reject the assumption that auditory stimulation by discrete pitches elicits consistently evoked muscle responses in specific extrinsic laryngeal muscles in the absence of voicing. The problems of this investigation were as follows:

1. To determine if discrete pitch stimuli will evoke specific extrinsic laryngeal muscle responses in males.

2. To determine if discrete pitch stimuli will evoke specific extrinsic laryngeal muscle responses in females.

3. To determine if consistencies and similarities in responses to the stimuli exist among subjects.

All the tests were run at TNI using their equipment and facilities. Normally, the run time per subject was 1.5 hours. Another one to two hours were required for plotting of the data. Analysis of EMG's was done at a later time. The complete procedure of data acquisition was as follows:

The subjects (N=21) met with the author at the lab and were given a brief explanation of the procedures and the purpose of the study. The only instructions to the subjects were to concentrate on each pitch as the stimuli was presented and to think of duplicating the pitch. No actual phonation took place in any of the tests. The preparation (cleaning) for electrode placement took place after a total explanation of the process. A normal amount of tension and apprehension is expected in any situation of this type because of the unfamiliar process, placement of electrodes and the psychology of the environment. Thus, a short trial run was usually given to familiarize each subject with the EMG process and demonstrate the simplicity of the subject's responsibility. All the subject had to do was relax and "think" each pitch as he heard it. After the trial run, the subject was allowed to view the screen and watch the EMG recording and averaging. This small amount of explanation and relaxation time was invaluable in lowering tension and assuring accurate muscle responses.

The subject was seated in a recliner chair (in reclined position) with headphones. The tone was generated by the amplifier to the subject through the headphones and the trigger pulse sent to the Nicolet analyzer simultaneously. The tone, a saw-tooth wave form, was digitalized at 100 ms in length with a one-second pause between stimuli. The tone was presented at 80 decibels for all subjects for design consistency.

Two specific pitches were used for the male group. The low-pitch stimulus was "D flat" (138.5 Hz). The high-pitch stimulus was "F" (349 Hz). Two specific pitches were used for the female group, exactly one octave above the stimuli used in the male group. The low-pitch stimulus for the female group was "D flat" (277 Hz). The high-pitch stimulus for the female group was "F" (698 Hz).

As stated previously, the digital tape was arranged in three groups of five stimuli for each specific pitch. The low tone was used for the first stimulus trial. The tone was 100 ms long with a one second pause between each stimulus. The tone was synchronized with a trigger pulse to inform the computer that the stimulus had been sent to the headphones. The EMG analyzer registered the response and analyzed the time lapse from stimulus to response. The five tones were averaged into a single EMG plot that was viewed and stored on the first channel of the oscilloscope. Then there was a ten-second pause to allow the subject time to breathe or swallow. The second group of five stimuli on the same tone was then run, averaged, and stored on the second channel of the EMG analyzer. Finally, the third series on the same tone were run and stored on the third channel of the analyzer. Those three trials of forty-five stimuli were then averaged into the fourth channel of the EMG analyzer and stored. Then the entire process was repeated for three more complete cycles. The computer was then employed to recall the fourth channel of each series, which represented the forty-five averaged stimuli, and plot them for analysis and comparison. The four plots of the averages represent, therefore, 180 total responses to the low-pitch stimulus. Figure 3.6 is a sample of the data taken from the plots. LpLe refers to low pitch as it affects the low electrode.

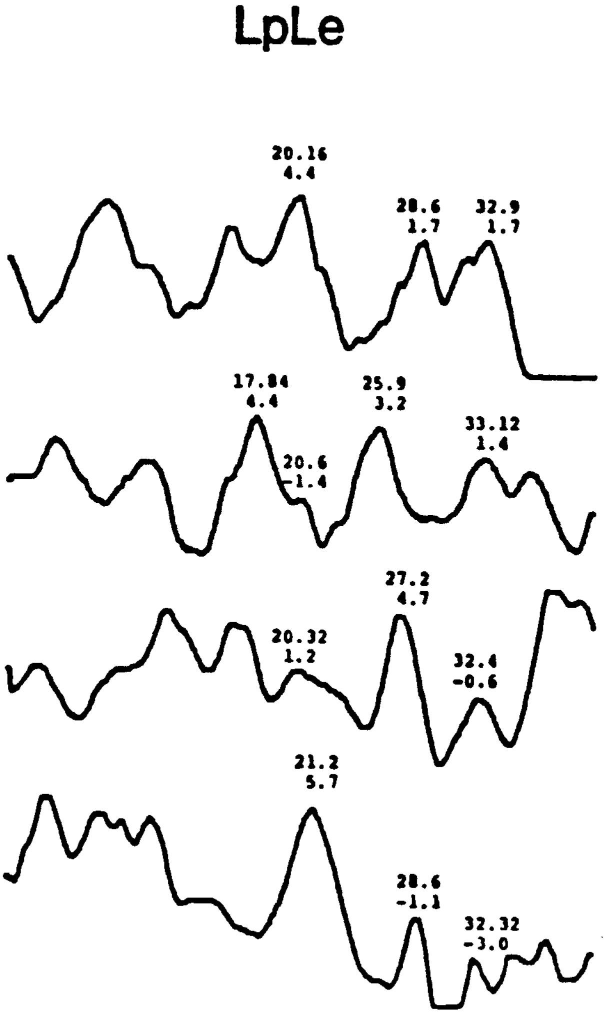


Figure 3.6 Sample Data Plot For LpLe Responses

The first plot represents the average of the first trial (forty-five stimuli). The second plot represents the second trial etc., through the fourth trial. The four plots represent the evoked response of the lower extrinsic laryngeal muscles, previously described, as stimulated by the low pitch. This process is labeled as LpLe (low pitch-low electrode) for all ensuing data reported in this investigation.

By switching the electrode controller to register the high electrode, the entire process could then be repeated to determine the effect of the low stimulus on the high extrinsic laryngeal muscle structure as described earlier. This segment of the data collection is labeled as LpHe (low pitch to high electrode) for the ensuing data reported in this investigation.

The method for analyzing the data was to compare the magnitude of the responses from the LpLe to the responses of the LpHe. Although the data could be compared by several methods, the one chosen for this study was to average the highest responses for each LpLe plot and compare those averages to the averages of the highest responses for the successive LpHe plots. The two other methods for measuring the amplitude of the responses were (1) to take the averages of all the peaks of each sample and compare them or (2) measure the millimeter of change in each response. One centimeter of change in vertical peak represents 5 µV of muscle activity. The centimeter change would likely show the greatest difference between data groups, but the difference in all three was relatively negligible. Figure 3.7 represents the collected data from LpHe.

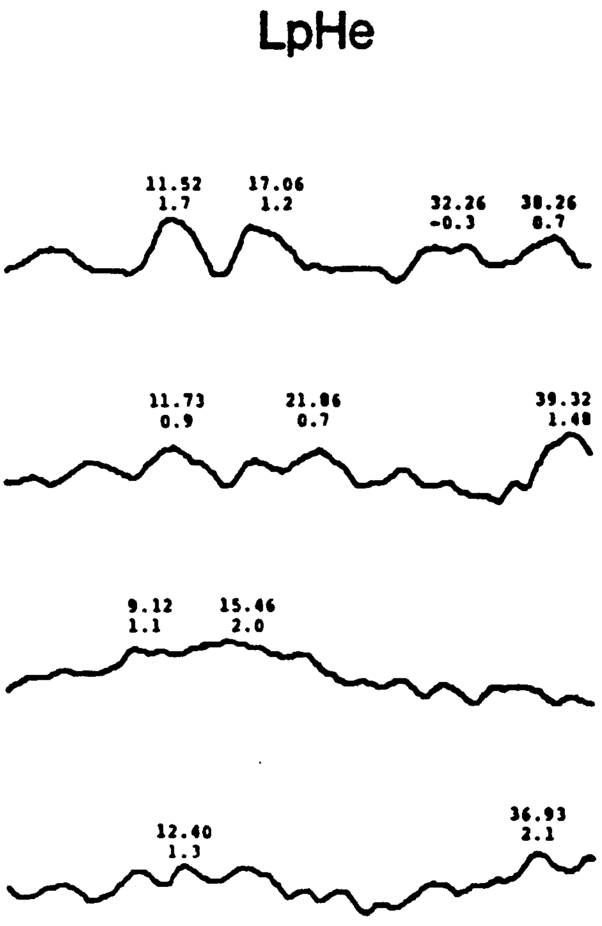


Figure 3.7 LpHe Responses

The difference in µV amplitude was the most obvious indicator of greater or lesser activity. A second and very valid indicator was the general shape of the wave form. Each plot was examined and analyzed further to determine regular peaks, which meant a substantial response, or a generally flat or gently undulating plot, which indicated no definitive muscle activity and, thus, a lesser response. As stated earlier, there will always be some activity in the muscles, even at rest. The difference in amplitude or in the general wave form were the determining factors for analyzing the results.

After completing the eight trial cycles employing the low-pitch stimulus, the same procedure was followed in testing the responses of the two electrodes from the high pitch stimulus. Exactly the same procedure was followed in gathering the data for the high-pitch stimulus as was employed in gathering the data for the low-pitch stimulus.

For the male subjects the high pitch was "F" (349 Hz). First the high pitch was used to measure its effect on the low electrode using the same procedure as described for the low pitch. Then the high pitch was used to measure its effect on the high electrode.

After the data was gathered and plotted, the same comparisons were employed to analyze the data. Figure 3.8 is a sample of the data gathered from the male group showing the results of HpLe (high pitch to low electrode).

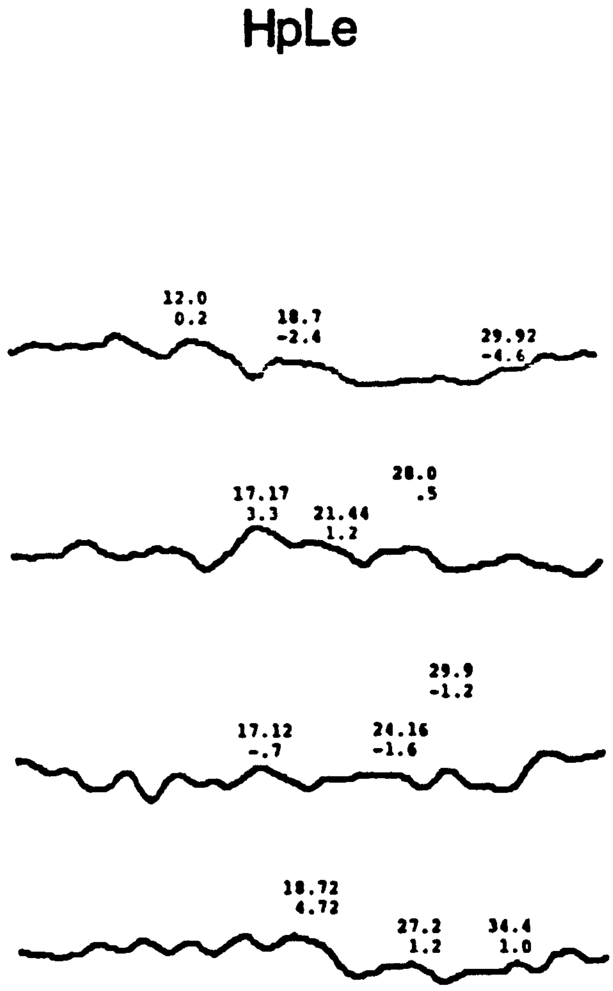


Figure 3.8 HpLe Data Sample

Figure 3.9 is a sample of the data taken from the high-pitch to the high-electrode series of trials. Once again, the data was compared from these two high-pitch groups and analyzed.

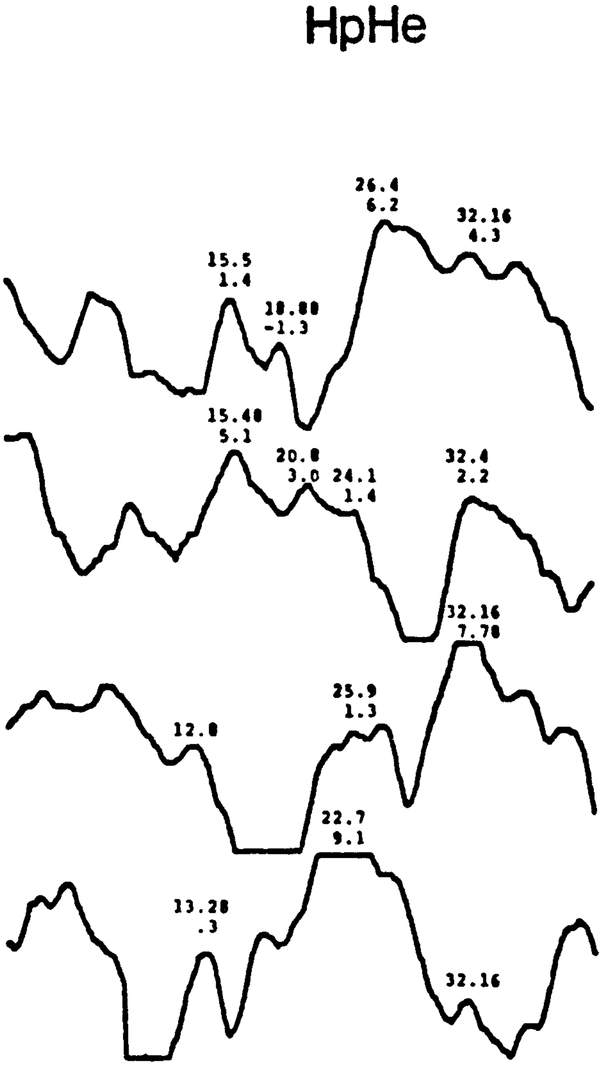


Figure 3.9 HpHe sample

After the data from all subjects (N=21) were gathered and recorded, the results were compared in answer to Problem One. Did the low pitch affect the muscles being measured by the low electrode more than it affected the muscles being measured by the high electrode? Conversely, did the high pitch affect the muscles being measured by the high electrode more than the muscles being measured by the low electrode?

Finally, the data were compared to determine if the responses were consistent in all the male subjects (N=10) and determine what similarities, if any, existed among the male group. The raw data for all the male subjects are contained in Appendix One (subjects 1-10) and will be summarized in tables. (See pages 122-124)

The same procedures were employed in gathering the data and analyzing the results for the female group (N=11) in answer to Problem Two. Did the low pitch affect the muscles being measured by the low electrode more than it affected the muscles being measured by the high electrode? Conversely, did the high pitch affect the muscles being measured by the high electrode more than it affected the muscles being measured by the low electrode? The data were compared to determine if the responses were also consistent in all the female subjects (N=11) and determine what similarities, if any, existed among the female group. The raw data for all the female subjects is contained in Appendix one (subjects 11-21) and will be summarized in tables. (See pages 124-126)

The final comparison of the study will be to compare the results of the compiled data of all the subjects (N=21) to determine what similarities, if any, exist among all the subjects in answer to problem three.

Verification of Electrode Placement

Although many discussions took place with the TNI technicians and neurologists concerning electrode placement, merely knowing the general location of these muscles was not always easy to apply to live situations. Before beginning this study, several anatomy texts were read concerning head and neck anatomy, speech and hearing science, and basic electromyographic principles. Those studies were beneficial to the basic understanding of the hearing process and provided a general clarification of the muscle structure and function.

Through special permission of the University of Texas at Dallas, Texas, the researcher was allowed to attend head and throat anatomy classes. This particular summer session included cadaver dissection. The result of attending this class was that it enabled the researcher and the physicians to determine the precise segment of each muscle that was activated by the stimuli. The knowledged gained was indispensible in that it made the final stages of this study easier and certainly more confident from a medical and scientific viewpoint. The photographs in Appendix Two are examples of the documentation of the dissection class. These two photographs identify the muscles being investigated in this study.

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CHAPTER IV

RESULTS

The purpose of the present study was to provide empirical data to support or reject the assumption that auditory stimulation by discrete pitch frequencies would elicit consistent evoked muscle responses in specific extinsic laryngeal muscles. The problems of the study were as follows:

1. To investigate the relationship of specific pitch frequency stimuli to specific extrinsic laryngeal muscle responses in males.
2. To investigate the relationship of specific pitch frequency stimuli to specific extrinsic laryngeal muscle responses in females.
3. To determine if consistencies in responses to the stimuli exist among subjects.

Twenty-one subjects were tested individually, and all data were stored and plotted by the Nicolet 1000 EMG clinical analyzer. The primary measurement of the muscle responses in this study was amplitude, measured in micro-volts (µV).

This measurement, as explained in Chapter III, represents the change in muscle activity from a point of rest to a point of greatest contraction. Thus, amplitude of muscle response will indicate how much activity takes place in one muscle as compared to another muscle (measured by the recording electrode). A further consideration in the analysis of the data of this study was the shape of the EMG wave form. This aspect meant determining whether or not the wave form had consistent peaks and shape as opposed to a lack of activity characterized by no definitive peaks or shape.

Problem One

To investigate the relationship of specific pitch stimuli to specific extrinsic laryngeal muscle responses in males.

To investigate the first problem, ten male college students volunteered to participate in the study. The skills of the volunteers ranged from sophomore level music majors to non-musicians. Some of the students had limited musical background but were not skilled musicians. The age range was from nineteen to thirty-four years. All the students were normal and free of any speech, hearing or medical problems. All the students attended Richland College in Dallas, Texas.

Each volunteer subject was prepared as discussed in Chapter III, and the electrodes were attached to the proper muscles for investigation. The electrodes were connected to an electrode switch box which, in turn, was connected to the EMG analyzer. The electrode switch box enables the investigator to choose which of the mesurement electrodes will be used for analyzing and recording the data. The switch box encodes the four electrodes and, by manipulating its settings, tells the computer which electrode to measure and analyze.

Four electrodes were used for each subject. The two measurement electrodes were attached to the two muscle areas being investigated. A reference electrode was placed on one side of the forehead as a reference to the measurement electrodes. The fourth electrode was the ground electrode and also was placed on the forehead opposite the reference electrode.

The pre-recorded digital tape was a two-channel stereo recording. One channel was used for the pitch frequency stimuli and the other contained a synchronized trigger pulse. The trigger pulse activated the computer at the same time the sound stimuli was sent to the subject through shielded headphones. The EMG analyzer could, therefore, measure the time lapse from the advent of the stimulus to the peak or peaks of the evoked muscle responses from the stimulus. The data were displayed on an oscilliscope, analyzed, and stored by the computer. Each series of responses was then plotted and analyzed for amplitudes and latencies--by means of dot cursor--for comparison of the data among subjects. The plots found in the raw data of this research (Appendix One) represent four complete trials--a total of sixty stimuli per pitch frequency. Each trial, five stimuli and responses, was averaged, repeated a second and third time, and then averaged into a fourth channel. This process was repeated until four complete trial cycles (the sixty stimuli) were completed and stored. Each pitch stimulus, one high and one low, was used to test each electrode/muscle.

The pitch D flat (138.5 Hz) was employed as the low stimulus for the male subjects. The pitch D flat (277 Hz) was employed as the low stimulus for the female subjects. The pitch F (349 Hz) was employed as the high stimulus for the male subjects. The pitch F (698 Hz) was employed as the high pitch for the female subjects. These pitches were chosen because the pilot study, mentioned in Chapter I, indicated that those pitches were consistent extreme ranges of both male and female auditory responses. In both the pilot study and the preliminary EMG experiments, this premise proved to be consistent.

The specific muscles being investigated were the primary depressor muscles, which lower the larynx and hold it in place for the matching or phonation of low pitches, and the primary elevator muscles, which lift the larynx and hold it in place for the matching and phonation of higher pitches. The depressor muscles are the sternothyroid and the sternohyoid muscles. These muscles are being investigated at the point where they overlap and attach to the sternum. The elevator muscles are the posterior digastric and the stylohyoid muscles. These muscles are being investigated at the point which they overlap and attach to the mastoid process and the styloid process, respectively. Appendix Two shows details of the exact muscles being investigated and the electrode placement.

The electrode investigating the depressor group was placed just above the sternum and to the inside of the sternocleidomastoid muscle. The electrode investigating the elevator group was placed in the depression just below the ear and next to the mastoid bone.

The basic premise was that a low pitch would evoke a definite response from the lower extrinsic laryngeal muscles (depressor muscles) while having little or no effect on the high extrinsic laryngeal muscles (elevator muscles).

Conversely, a high-pitch stimulus would evoke a high extrinsic laryngeal muscle response (elevator muscles) while having little or no effect on the lower extrinsic laryngeal muscles (depressor muscles).

The investigation trials were run in the following sequence for all twenty-one subjects:

1. The low-pitch stimulus (Lp) was used to investigate its effect on the low electrode (Le), hereafter designated as LpLe.

2. The low-pitch stimulus (Lp) was used to investigate its effect on the high electrode (He), hereafter designated as LpHe.

3. The high-pitch stimulus (Hp) was used to investigate its effect on the low electrode (Le), hereafter designated as HpLe.

4. The high-pitch stimulus (Hp) was used to investigate its effect on the high electrode (He), hereafter designated as HpHe.

It was hypothesized that the responses from the low pitch stimulus would show more definitive wave forms and greater amplitudes in the depressor muscles than in the elevator muscles. Likewise, it was hypothesized that the responses from the high-pitch stimulus would show more definitive wave forms and greater amplitudes in the elevator muscles than in the depressor muscles. As noted earlier, definitive wave forms (peaks) and greater amplitudes would be indicators of a higher degree of muscle response.

A true and recognizable response is marked by extreme and contrasting peaks as opposed to a series of regular, equal peaks or, as sometimes occurred in this investigation, no peaks at all. Figures 4.1 through 4.4 are examples of the plotted data from subject one (male) according to pitch and electrode placement.

Subject 1

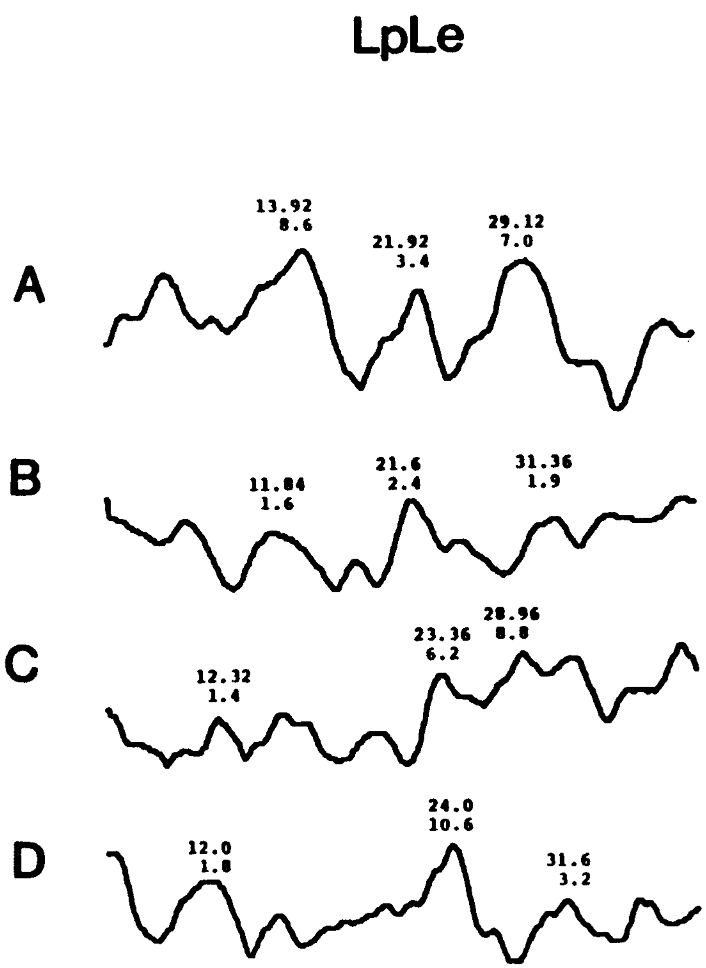

Figure 4.1

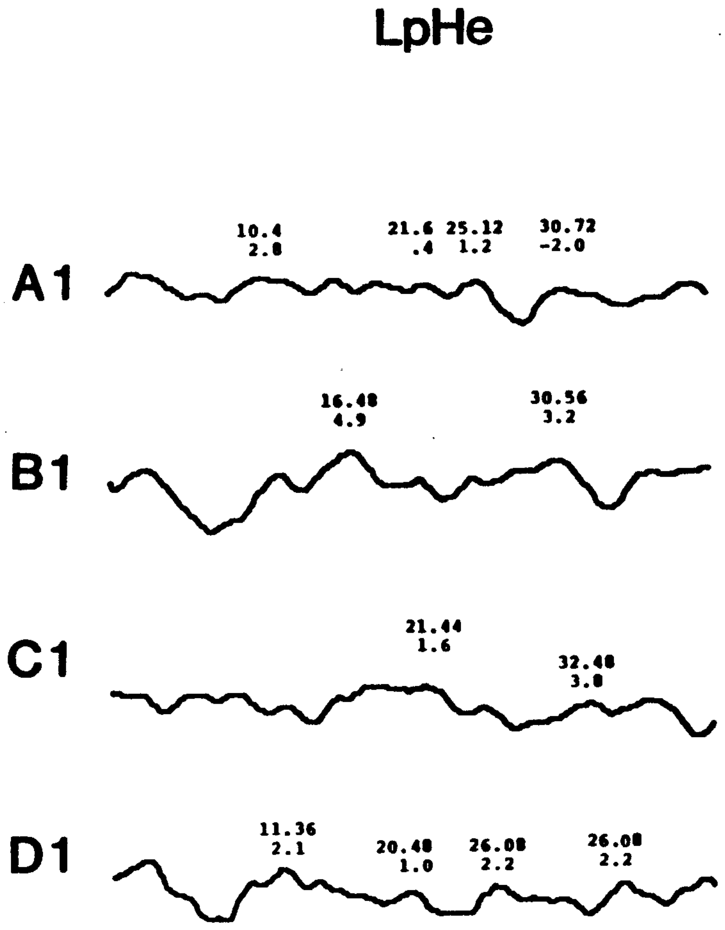

Figure 4.2

Subject 1

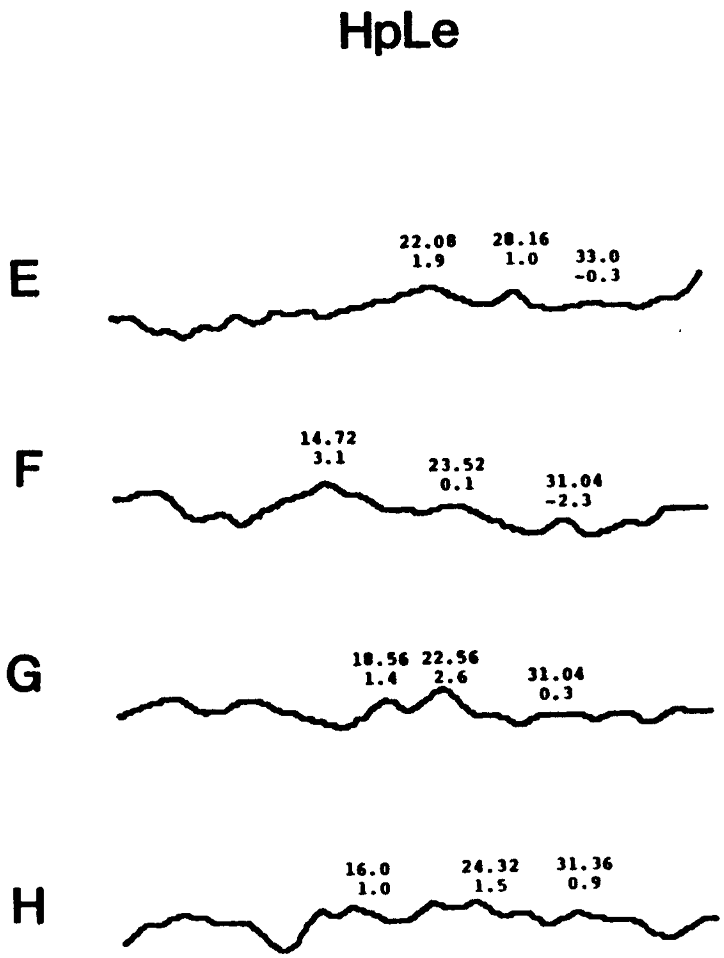

Figure 4.3

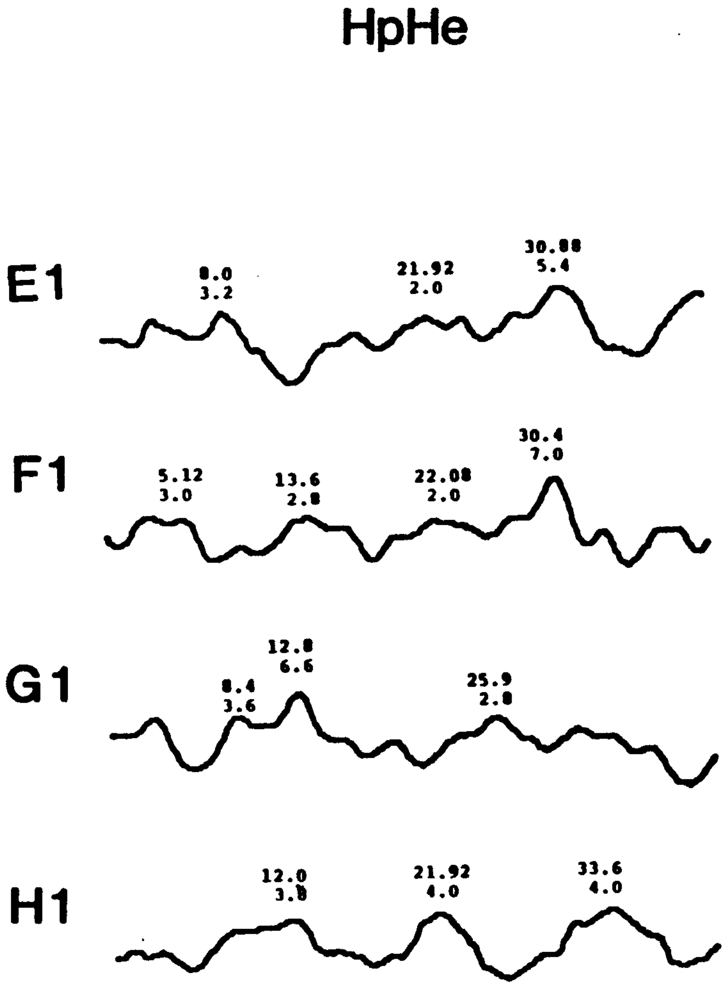

Figure 4.4

In Figure 4.1, the EMG data provide a great deal of information. The first of the four EMG plot indicates that the low-pitch stimulus produced a series of peaks ranging from 1.4 µV to 10.6 µV in the low electrode (LpLe). The micro-volt readings registered the activity or µV change as related to the muscle activity at the inception of the EMG plot (the beginning is seldom 0.0 µV). Each vertical millimeter of change on the EMG plot represents approximately .5 µV of electrical activity. Thus, measuring from valley to peak, the µV change in the first peak (occurring at 13.92 ms) represented a muscle change of 8.6 µV from the beginning of the plot while registering only 1.4 µV on the cursor scale. The third peak, however, if measured in mm, indicated a change of 10 µV from valley to peak while registering a µV reading of 10.6 on the cursor scale. Therefore, either method of observation represented a picture of the activity of the muscle even though the two sets of numbers were not the same.

In the second EMG plot of Figure 4.1, one can observe the second peak (occurring at a latency of 21.6 ms) and note a 2.4 µV reading from the beginning of the plotted graph. The amount of change, however, is 1.6 cm. If one cm equals five µV of change (one mm change equals .5 µV), one can then multiply the 16 millimeters by .5 µV to indicate an 8.0 µV change in activity of the muscle for that peak. This calculation is offered to inform the reader that a µV reading taken from within the analyzer may not be indicative of the gross change in muscle activity. Although the two methods differ in final µV analysis, the change can be noted far more quickly and more accurately from within the computer.

Therefore, in this investigation, the data was derived from µV readings obtained from the cursor scale within the Nicolet analyzer rather than by the millimeter of change method. Once again, each EMG plot represents an average of fifteen stimuli/responses. Thus, the entire column represents four trials or sixty stimuli/responses for the low-pitch/low-electrode (LpLe) series.

Visually, the magnitude of all the peaks in Figure 4.1 indicated a great amount of activity and definitive peaks while testing the low-pitch signal to the low electrode. By comparing the plots of Figure 4.1 with the EMG plots in the second column (Figure 4.2) which represents the low pitch as it affected the high electrode, one can readily observe the difference in response levels. The high electrode was measuring the elevator muscles.

In the second trial of Figure 4.2 there was a seemingly high degree of muscle activity. That activity would be a valid response if the μV reading were the only point of consideration. However, the 4.9 μV reading which occurred in that particular peak (16.48 ms latency) was the only distinguishable peak in the entire series and can thus be considered a chance response in the activity cycle or an artifact from conjunctive muscle activity. Conjunctive muscle activity means that other nearby muscles, either respiratory, intrinsic laryngeal, or other muscles involved in biological activities such as swallowing caused the unusually high degree of activity.

Excluding the one high response, the remaining μV ranges of the responses were from -2.0 μV to 3.2 μV in the upper electrode. When this response is compared to the 1.4 μV to 10.6 μV range of the responses of the low-pitch to the low-electrode series, the differences in the levels of responses are obvious. The lower electrode produced an over-all average of 7.6 μV from all the peaks while the upper electrode produced an average of only 3.53 (including the 4.9 μV artifact).

Figure 4.3 represents the EMG plot of the low-electrode responses to the high-pitch stimulus. Once again, the lack of definitive peak activity indicates a very low muscle response. The range of responses in this series was from

-3.3 µV to 3.1 µV with most of the responses falling in the 1.9 or less range. The most striking feature of these plots was the lack of definitive activity, i.e., the graph appears to be relatively flat as compared to the graphs in the corresponding results of the upper electrode (Figure 4.4).

Figure 4.4 represents the high-electrode responses as stimulated by the high-pitch stimulus. In this series (HpHe), the range of responses was from .2 µV to 7.0 µV. Compare that range to the response range of Figure 4.3 (-3.3 to 3.1 µV). The average µV readings from all the peaks of Figure 4.3 (HpLe series) was 1.81 µV while the average of all peaks in Figure 4.4 (HpHe series) was 3.39 µV--almost double in activity.

Inasmuch as a high amplitude (higher µV response) was the primary measurement of muscle activity, the high response of one electrode to the other while employing the same stimulus indicated the level of the muscle's response or lack of response to the stimulus. Each plot on the series represents an average of fifteen stimuli and responses. Each trial was run four times (sixty stimuli on each frequency) with each of the twenty-one subjects to assure accuracy of the procedure and to eliminate chance factors as much as possible.

Table I is a summarization of the μV ranges as derived from the data of subject one. The abbreviations used in the tables are as follows:

Lp = low pitch; Le = low electrode; Hp = high pitch; He = high electrode. For example, LpLe represents the low pitch stimulus as testing the response from the low electrode. LpHe represents the low pitch stimulus as testing the response from the high electrode. HpLe represents the high pitch stimulus as testing the response from the low electrode. HpHe represents the high pitch stimulus testing the response from the high electrode.

Table I

Summary of data from subject one (male)

Range of LpLe peaks	Range of LpHe peaks
1.4 to 10.6 μV	-2.0 to 4.9 μV
Range of HpLe peaks	Range of HpHe peaks
-2.3 to 3.1 μV	2.0 to 7.0 μV

Table II is a presentation of the LpLe and LpHe data which summarizes the information of the EMG plots from Figures 4.1 and 4.2. This table lists the peak activity by trials one through four. The peaks are listed horizontally as they occur in the EMG plots. In some of the trials there were only two peaks while some had as many as four. The inconsistencies usually occurred in the LpHe and HpLe series. The peaks are read in μV of muscle activity.

Table II

Summary of the individual trial data for subject one

LpLe

	Peak 1	Peak 2	Peak 3
Trial 1:	8.6	3.4	7.0
Trial 2:	1.6	2.4	1.9
Trial 3:	1.4	6.2	8.8
Trial 4:	1.8	10.6	3.2

The average μV response for all the peaks in the LpLe series was 4.74 μV.

LpHe

	Peak 1	Peak 2	Peak 3	Peak 4
Trial 1:	2.8	0.4	1.2	-2.0
Trial 2:	4.9	3.2		
Trial 3:	1.6	3.8		
Trial 4:	1.8	1.0	2.2	2.6

The average μV response for all the peaks in the LpHe series was 1.98 μV.

Table III indicates the result of change in muscle activity as measured by millimeter differences. This table summarizes the change in activity from the beginning of each peak to its apex. The results of this table should be compared to Table II to observe the differences that occur in measuring mm change as compared to μV readings.

Although the end result will be the same as regards more muscle activity to less activity, the mm measurement will indicate a higher degree of difference. It should be noted, however, that the mm chart is less accurate in that the measurements are approximate, whereas, the µV measurements are taken from within the EMG computer and are precise. Although both methods are reliable and accurate, the data are much easier to obtain from within the computer. This table is offered solely for the purpose of documenting the fact that the mm change could offer another viewpoint in verifying the data.

Table III

Summary of data µV ranges as derived from mm change

LpLe

	Peak 1	Peak 2	Peak 3
Trial 1:	8.0	3.4	7.0
Trial 2:	5.0	7.5	6.0
Trial 3:	4.5	8.0	10.5
Trial 4:	5.5	9.5	6.0

Average µV activity as measured by mm of change for this series was 7.46 µV.

LpHe

	Peak 1	Peak 2	Peak 3	Peak 4
Trial 1:	2.0	1.0	1.5	3.0
Trial 2:	3.5	3.5		
Trial 3:	3.0	2.5		
Trial 4:	4.5	2.5	3.0	3.5

Average µV activity as measured by mm of change for this series was 2.79 µV.

The average μV readings from Table II on the LpLe series was 4.74 μV while the mm of change from Table III indicated a 7.46 μV average. The LpHe series indicated a μV average of 1.98 from Table II while the average from Table III was 2.79. The mm method indicated a reading that was 2.72 μV higher on the LpLe series and a reading that was .90 μV higher on the LpHe series. Thus, the mm method increased the reading by approximately 57% on the LpLe series and 47.6% on LpHe series. Although the differences are obvious, the results are not altered; and, as stated, the μV readings from within the Nicolet averager are far more accurate. Thus, the ensuing data will reflect only the μV readings from the computer.

Table IV summarizes the results of the EMG plots where the high-pitch stimulus was used. The first trials (HpLe) indicate the responses as measured in the low electrode (depressor muscles). The second trials indicate the effect of the high-pitch stimulus as measured in the high electrode (elevator muscles). The average μV response from the HpLe series was 0.95 μV. The average μV response from the peaks of the HpHe series was 3.86 μV. Again, one should consider both the μV readings and the definitive peaks of Figures 4.3 and 4.4.

Table IV

Summary of responses to the high pitch stimulus for subject one (male)

HpLe

	Peak 1	Peak 2	Peak 3
Trial 1	1.9	1.0	-0.3
Trial 2	3.1	0.1	-2.3
Trial 3	1.6	1.5	0.9
Trial 4	1.0	1.5	0.9

The average µV response for all the peaks in the HpLe series was 0.95 µV.

Summary of responses to the high-pitch stimulus for subject one (male)

HpHe

	Peak 1	Peak 2	Peak 3	Peak 4
Trial 1	3.2	2.0	5.4	
Trial 2	3.0	2.8	2.0	7.0
Trial 3	3.6	6.6	2.8	
Trial 4	3.8	4.0	4.0	

The average µV response for all the peaks in the HpHe series was 3.86 µV.

The average of the total µV readings for the HpLe series was 0.95 which should be compared to the average µV readings for the HpHe series which was 3.86 µV. The uV reading for the HpHe series indicated a µV increase that was quadruple the HpLe series.

Problem Two

To investigate the relationship of specific pitch stimuli to specific extrinsic laryngeal muscle responses in females.

In answer to Problem Two the following results are presented.

Figures 4.5 through 4.8 are the plotted EMG responses for subject one, female group according to pitch and electrode placement. These data were treated exactly the same as with the male subject. The plots are arranged by low-pitch stimulus (Figures 4.5 and 4.6) for comparison and high-pitch stimulus (Figures 4.7 and 4.8).

In trial one of Figure 4.5 (LpLe series), for example, the three peaks indicated µV readings of 6.5 µV, 3.5 µV, and 3.0 µV respectively. In the first trial of Figure 4.6 (LpHe series), there are no definitive peaks, and the highest µV response was 0.02 µV.

Figures 4.7 and 4.8 are the EMG plots resulting from the responses of the high-pitch stimulus to each of the two electrodes. In Figure 4.7 (HpLe series), the highest µV response was 2.0 µV. In this series there was an absence of definitive wave forms and peaks. The activity of the wave forms in Figure 4.8 (HpHe series) is visually perceptible. Furthermore, the range of responses was from 1.75 μV to 5.2 μV, an obvious increase in activity. The information derived from these four EMG series is summarized in the tables following the plots.

Subject 11

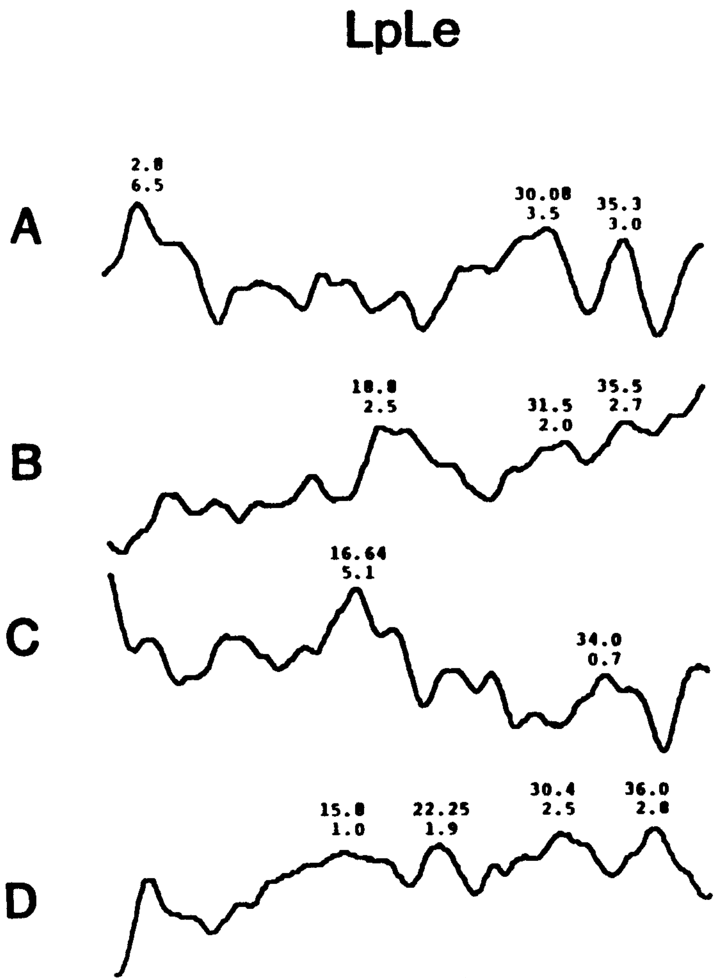

Figure 4.5

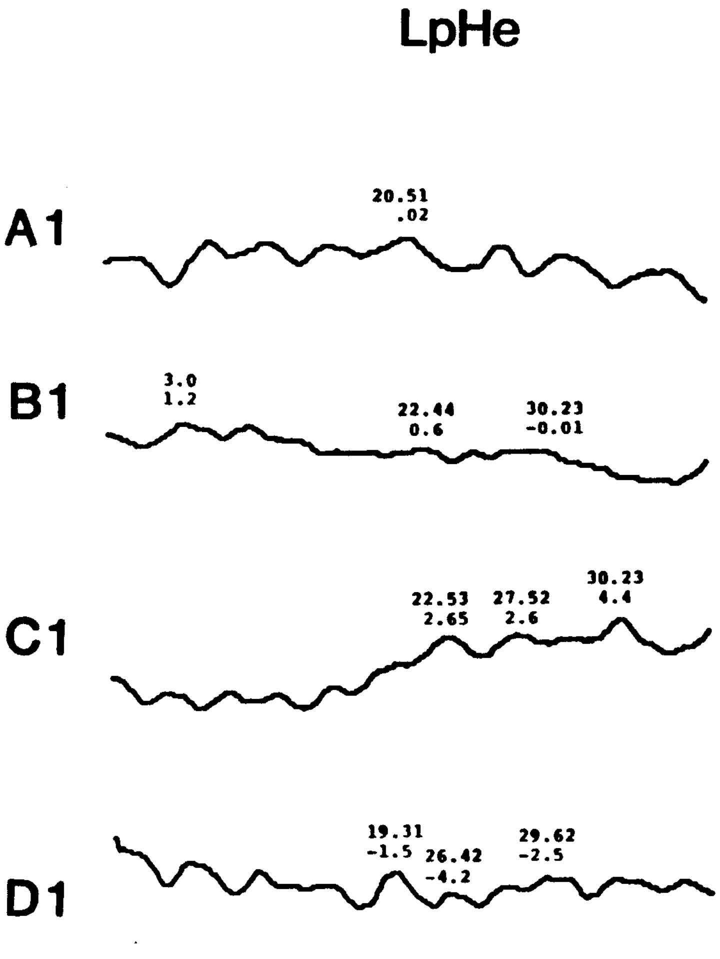

Figure 4.6

Subject 11

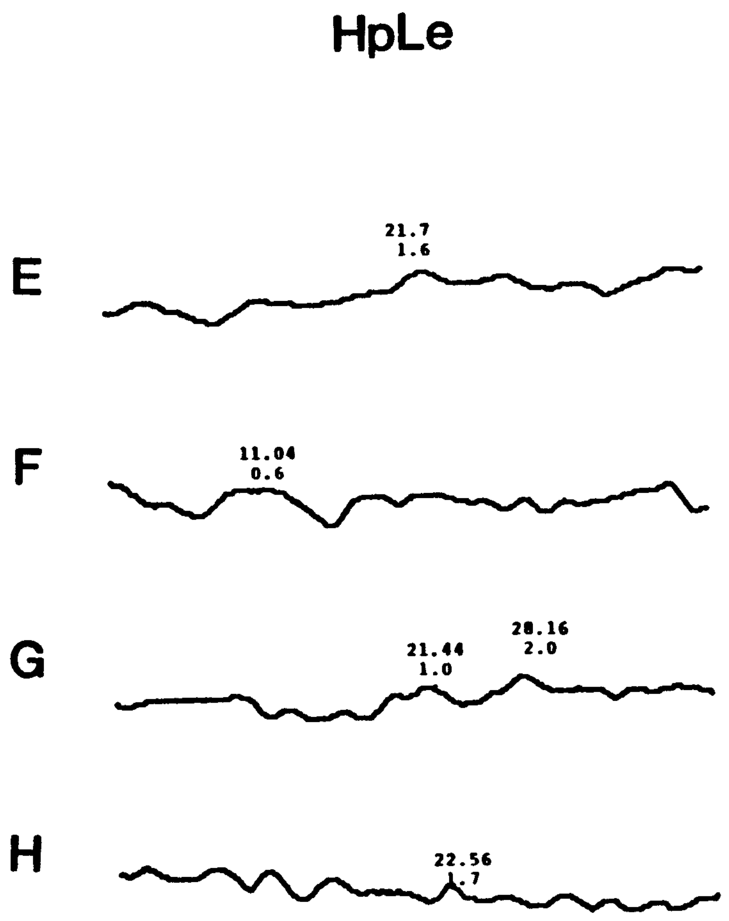

Figure 4.7

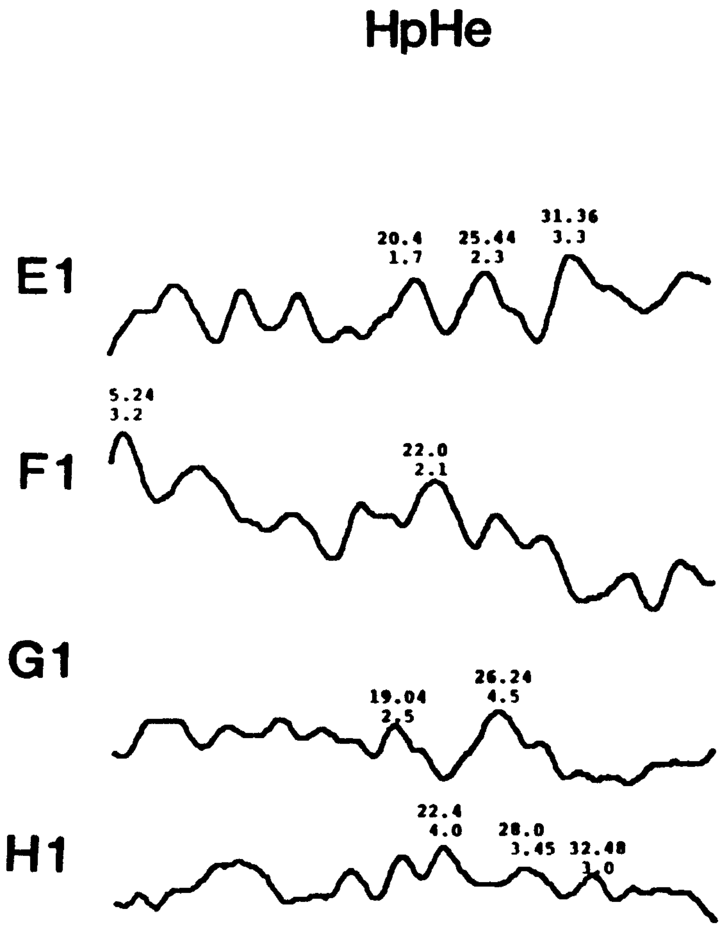

Figure 4.8

Table V

Summary of the peak ranges for subject one, female.

This table indicates the extreme ranges of peak μV activity for all the trials in each category.

Range or LpLe Peaks	Range of LpHe Peaks
0.7 to 6.5 μV	-4.2 to 4.4 μV
Range of HpLe Peaks	Range of HpHe Peaks
0.6 to 2.0 μV	1.75 to 5.2 μV

Table VI summarizes the LpLe and LpHe data derived from the EMG plots for Subject one, female group. The data are recorded in μV as derived from the Nicolet averager.

Table VI

Summary of data from EMG plots for subject one, female

LpLe

	Peak 1	Peak 2	Peak 3
Trial 1	6.5	3.5	3.0
Trial 2	2.5	2.0	2.7
Trial 3	5.1	0.7	
Trial 4	1.9	2.5	2.8

The average µV response for all the peaks in the LpLe series was 3.02 µV.

LpHe

	Peak 1	Peak 2	Peak 3
Trial 1	0.02		
Trial 2	1.2	0.6	-0.01
Trial 3	2.6	2.6	4.4
Trial 4	-1.5	-4.2	-2.5

The average µV response for all the peaks in the LpHe series was 0.30 µV.

Table VII is a summary of the data derived from the EMG plots of Figures 4.7 and 4.8, derived from the high-pitch stimulus to the two measurement electrodes (HpLe and HpHe). In the EMG plot of Figure 4.7, it was immediately clear that scarcely any discernible peak activity was present in the trials. The first trials indicate the data derived from the recording electrode measuring the depressor muscles, and the second trials indicate the data derived from the electrode measuring the elevator muscles.

Table VII

Summary of data from subject one, female

HpLe

	Peak 1	Peak 2
Trial 1	1.6	
Trial 2	0.6	
Trial 3	1.0	2.0
Trial 4	1.7	

The average µV response for all the peaks in the HpLe series was 1.38 µV.

HpHe

	Peak 1	Peak 2	Peak 3
Trial 1	1.75	2.3	3.3
Trial 2	5.2	2.1	
Trial 3	2.5	4.5	
Trial 4	4.0	3.45	3.0

The average µV response for all the peaks in the HpHe series was 3.21 µV.

All the EMG data for each of the twenty-one subjects were plotted and analyzed employing the same procedures as with subject one.

In response to Problem Three,

Problem Three

To determine if consistencies in responses to the stimuli exist among subjects.

the following procedures were used. First, the EMG data for all subjects (N=21) were examined and analyzed. It was found that whether calculating the responses by mm of change or μV reading, the results were essentially the same. It was further noted that by using only the highest μV peak for each separate trial, the ratios remained close enough to have no appreciable effect on the over-all results. Thus, the summary tables which follow are averages of the high peaks taken from each individual trial. The 7.60 from column one, subject one, for example, is the average of the four highest μV peaks of the LpLe series. Therefore, the numbers in these tables are averages of the maximum μV responses from the four trials of each category--LpLe, LpHe, HpLe, and HpHe. Table VIII is a summary of the male subjects (N=10), and Table IX is a summary of the female subjects (N=11). Each column represents a stimulus to a specific electrode as indicated. The data of each pitch stimulus should be compared to its corresponding electrode. In subject one, male, the low-pitch stimulus produced an average maximum μV response of 7.60 from the low electrode while producing a maximum μV response of 3.53 μV from the high electrode.

Table VIII

Summary of data by average μV peak activity

Male Subjects

Low-pitch stimulus

Subject	LpLe	LpHe
1	7.60	3.53
2	4.33	0.45
3	7.08	2.28
4	3.64	1.88
5	5.08	3.10
6	2.94	0.87
7	4.88	2.45
8	4.88	2.05
9	4.50	3.78
10	5.90	3.78

High-pitch stimulus

Subject	HpLe	HpHe
1	2.28	5.75
2	2.08	3.40
3	2.30	4.88
4	5.90	7.05
5	5.05	5.23
6	0.29	2.80
7	4.23	9.70
8	3.13	3.48
9	2.28	3.53
10	3.90	6.53

Table IX

Summary of data by average μV peak activity

Female Subjects

Low-pitch Stimulus

Subject	LpLe	LpHe
1	4.28	1.08
2	6.43	3.95
3	9.20	6.10
4	4.80	1.82
5	6.03	2.65
6	6.09	1.58
7	6.70	3.24
8	4.80	3.55
9	4.45	2.18
10	4.58	2.37
11	5.08	3.25

High-pitch Stimulus

Subject	HpLe	HpHe
1	1.48	4.25
2	2.30	4.45
3	1.30	11.80
4	0.97	5.41
5	3.30	10.75
6	1.23	5.30
7	4.50	9.10
8	0.85	5.90
9	1.13	5.25
10	1.94	3.75
11	5.45	5.88

The purpose of this study was to provide empirical data to support or reject the assumption that auditory stimulation by discrete pitches will evoke consistent responses in specific extrinsic laryngeal muscles. In order to address that premise, a summation of the results follows. Each category of stimulus and response is presented by gender. In response to the first question:

Did the low frequency stimulus evoke a consistent and measurable response from the low electrode in males?

Table X

LpLe

Subject	Response
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
6	Yes
7	Yes
8	Yes
9	Yes
10	Yes

In response to the second question:

Did the low frequency stimulus evoke a consistent and measurable response from the high electrode in males?

Table XI

LpHe

Subject	Response
1	No
2	No
3	No
4	No
5	No
6	No
7	No
8	No
9	No
10	No

In answer to the third question:

Did the high-pitch stimulus evoke a consistent and measurable response from the low electrode in males?

Table XII

HpLe

Subject	Response
1	No
2	No
3	No
4	No
5	No
6	No
7	No
8	No
9	No
10	No

In response to the fourth question:

Did the high-pitch stimulus evoke a consistent and measurable response in the high electrode in males?

Table XIII

HpHe

Subject	Response
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
6	Yes
7	Yes
8	Yes
9	Yes
10	Yes

For the female subjects the same questions must be addressed. In response to question one for the female group:

Did the low-pitch stimulus evoke a consistent and measurable response from the low electrode?

Table XIV

LpLe

Subject	Response
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
6	Yes
7	Yes
8	Yes
9	Yes
10	Yes
11	No

In answer to the second question for the female group:

Did the low-pitch stimulus evoke a consistent and measurable response from the high electrode?

Table XV

LpHe

Subject	Response
1	No
2	No
3	No
4	No
5	No
6	No
7	No
8	No
9	No
10	No
11	Yes

In response to question three for the female group:

Did the high-pitch stimulus evoke a consistent and measurable response from the low electrode?

Table XVI

HpLe

Subject	Response
1	No
2	No
3	No
4	No
5	No
6	No
7	No
8	No
9	No
10	No
11	Yes

In response to question four for the female group:

Did the high-pitch stimulus evoke a consistent and measurable from the high electrode?

Table XVII

HpHe

Subject	Response
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
6	Yes
7	Yes
8	Yes
9	Yes
10	Yes
11	No

Twenty of the twenty-one subjects responded as expected. Only one of the subjects did not have responses as expected. One male subject (number eight) was border-line in his responses. There is an apparent relationship between auditory stimulation and muscle response. The two subjects who did not conform to the normal patterns will be discussed further in Chapter V.

CHAPTER V

SUMMARY, CONCLUSIONS, GENERALIZATIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

The primary concern of the present study was to provide empirical data to support or reject the assumption that auditory stimulation by specific discrete pitches would elicit consistent evoked muscle responses in specific extrinsic laryngeal muscles. The problems of this study were as follows:

1. To determine if specific pitch stimuli evoke specific extrinsic laryngeal muscle responses in males.
2. To determine if specific pitch stimuli evoke specific extrinsic laryngeal muscles responses in females.
3. To determine if consistencies in evoked responses to stimuli exist among subjects.

The study was limited to two specific pitches for all subjects (N=21). The low pitch for the males was D flat

(138.5 Hz). The low pitch for the females was D flat (277 Hz). The high pitch for the males was F (349 Hz). The high pitch for the females was F (698 Hz). The stimuli were presented fifteen times per trial and averaged by the Nicolet 1000 clinical averager.

The specific muscles being tested or investigated by the low pitch for all subjects were assumed to be the depressor muscles of the extrinsic laryngeal muscles. The specific muscles being investigated by the high-pitch stimulus were assumed to be the elevator muscles of the extrinsic laryngeal muscles. The depressor muscles are the sternothyroid and the sternohyoid muscles at the point they overlap and attach to the sternum. The elevator muscles being studied are the posterior digrastic muscle as it attaches to the mastoid process and its overlapping muscle, the stylohyoid as it attaches to the styloid process. Surface electrodes were attached to each subject at the points of each identified muscle.

Amplitude is the primary measurement of muscle activity in evoked responses. A high amplitude response from an electrode indicates a greater amount of muscle activity than a low amplitude response. A second method of denoting muscle activity is regular and spaced peaks in the responses. By contrast, a lack of activity will produce irregular wave forms or much flatter wave forms, also indicating a lack of activity.

In the male subjects (N=10), the results indicated that when the low pitch was sounded, that pitch evoked a high µV response from the low electrode. The low pitch did not evoke a high µV response in the high electrode. The high pitch stimulus did evoke a high µV response in the high electrode. The high-pitch stimulus did not evoke a high µV response in the low electrode. The results for this segment of the study indicated a 100% rate of success.

In the female subjects (N=11), the results indicated that when the low pitch was sounded, that pitch evoked a high µV response from the low electrode. The low pitch did not evoke a high µV response in the high electrode. The high-pitch stimulus did not evoke a high µV response in the low electrode. The high-pitch stimulus did evoke a high µV response in the high electrode. The summary of those results indicated a 91% rate of success. Ten of the eleven subjects elicited consistent responses. The only exception was a subject who possessed absolute pitch. A plausible explanation for this discrepency will be discussed later.

For all subjects (N=21) the results of success were 95.2%. Twenty of twenty-one subjects exhibited similar responses. The execption was the female subject who had absolute pitch. The low-pitch stimulus evoked a greater µV response from the low electrode than from the high electrode. Likewise, the high-pitch stimulus evoked a greater µV response from the high electrode than from the low electrode.

Conclusions

The data from the investigation suggest that specific auditory pitch stimuli evoke consistent laryngeal muscle responses. In all the subjects except one (N=21), the depressor muscles were clearly affected by the low stimulus. The low stimulus, however, had little or no effect on the elevator muscles. In most subjects, the amplitude difference was doubled or more than doubled. Conversely, the high stimulus evoked consistent responses from the elevator muscles while producing little or no response from the depressor muscles. Again, the amplitudes were consistently double or more in amplitude response. Furthermore, the wave forms were clearly more distinct when plotting the low stimulus to depressor muscles than in plotting low stimulus to elevator muscles. Conversely, the EMG plots of the high-pitch stimulus to the depressor muscles were not distinct in peak and wave form while the peaks were very obvious in the high stimulus to elevator muscles plots. The facts that (1) the evoked responses were dependent upon specific pitches and (2) repetitive stimuli produced consistent similar evoked responses were conclusive proof that the responses were not simple startle responses.

The muscle response produced by the stimuli was very likely a psychological one intended to match one of the two pitch stimuli which had been presented. The attempt at matching the pitch sets the larynx in place through extrinsic laryngeal muscle movement in preparation for producing the pitch vocally. This conclusion was further evidenced by the researcher's observation of diminishing amplitudes in the five successive stimuli that are averaged during each trial. With each successive tone, while the latencies remained generally fixed, invariably the amplitudes grew less with each succeeding tone. Logically, the muscles would be expected to respond with less change following each stimulus because, as the brain signaled that the pitch would likely be repeated, there would not be a total relaxation of the muscle. Thus, the response would dimimish proportionally as the repetitions continued. In other words, the muscles tended to remain in a fixed position after the first stimulus. Thus, after the fifth stimulus the muscle would often register a negligible change.

A direct relationship did exist between specific pitches and specific extrinsic laryngeal muscles (elevators and depressors). Specific low-pitch stimuli would elicit a constant and measurable muscle response from the low extrinsic laryngeal depressor muscles. Low-pitch stimuli would have little or no effect on the high extrinsic laryngeal elevator muscles. Specific high-pitch stimuli would elicit a strong response from the high extrinsic laryngeal elevator muscles. High-pitch stimuli had little or no effect on the low extrinsic laryngeal depressor muscles.

The results of the data in the male subjects (N=10) indicated a success rate of 100%. Therefore, the responses were consistent in all the male subjects tested. It could be concluded that the responses would be true for the general population since the sample included both musicians and non-musicians. This conclusion applies only to normal males in the age bracket as stated earlier (twenty to thirty-two years). Thus, it could be concluded that specific discrete pitch stimuli would evoke a response in specific extrinsic laryngeal muscles in all males in this category. While the sample was not a random sample, it seems highly probable that the results could be replicated.

The results of the data in the female subjects (N=11) indicated a success rate of 91%. The responses were consistent in all female subjects except one and can be generalized as true for the general population since the sample included both musicians and non-musicians (the one exception, as noted, has absolute pitch). This conclusion applies only to the age bracket stated earlier (19 to 34 years). It might be noted at this point that an additional subject was tested who was literally unable to match pitches. Although the data were not reported in this study, the results were much the same as the subject who has absolute pitch. The only difference was that the subject who was unable to match pitch elicited responses of such low amplitudes that the EMG was practically an isoelectric line (flat line). Therefore, it could be concluded that specific discrete pitch stimuli would evoke a response in specific extrinsic laryngeal muscles in females within the stated age bracket.

Twenty of the twenty-one subjects tested produced the expected results yielding a success rate of 95.24%. These results could be extrapolated as true for the general population. It was believed that the percentage would have been higher if a larger sample had been used. The reason for this conclusion was that studies by Siegel (8), Hartman (3), and Jeffers (4) indicated that less than one percent of the general population possess absolute pitch; and, therefore, the results contained a slight bias by means of sample.

Furthermore, the similarities of wave forms were consistent. All but one of the subjects showed clear, definitive responses. Therefore, this study suggests that specific discrete pitch stimuli would evoke similar responses in specific extrinsic laryngeal muscles in the general population.

In general, there was an inter-subject and intra-subject variability in both amplitude and latency. It is generally accepted that muscle responses are not consistent in humans in either amplitude or latency. However, with all the subjects tested, the peaks in wave forms occurred within a 40 ms time frame. Although some subjects showed peak responses very early or very late, in general, the peak responses occurred within the 12 to 30 ms time range. There was, in this study, a variability in latencies within each subject from trial to trial, as well as variability between subjects.

It could be expected that the amplitude measurement and comparison would offer a large variability. Again, in muscle responses, it is accepted that the responses will be variable. In this investigation there were greater differences in amplitudes than in latencies between subjects.

There was a variability in µV amplitude within each subject as well as between subjects. In general, however, those subjects who evoked higher amplitude in one trial registered high responses in all the trials. The subjects whose responses were of low amplitude remained at a low amplitude throughout all the trials. The low pitch to low electrode range in the male subjects was from 2.94 µV to

7.60 µV. The subject who registered the 2.94 µV for this trial average registered only a 0.87 µV in the corresponding electrode (low pitch to high electrode). The subject who registered the 7.6 µV response had a 3.53 µV response in the corresponding electrode (low pitch to high electrode). Thus, the data supports the original assumption, although the variability, as was predicted, exists. Therefore, the variability is not an issue inasmuch as amplitude is individual and often changes within each subject as a result of attention, exhaustion, or other factors.

Specifically, the results of the study indicated that discrete low pitches did, with consistency, evoke muscle responses in specific depressor muscles of the extrinsic laryngeal muscles. The same low pitch being used as a stimulus did not evoke a like response in the elevator muscles of the extrinsic laryngeal muscles. Specific high-pitch stimuli did evoke a consistent response in the elevator muscles of the extrinsic laryngeal muscles. That same high pitch did not evoke a like response from the depressor muscles of the extrinsic laryngeal muscles.

All the subjects responded to the pitch D flat as a low stimulus and the pitch F for the high pitch. Thus, all subjects respond to approximately the same range. It is apparent, therefore, that the extrinsic laryngeal muscles control a general tessitura of approximately a tenth, the female range being exactly one octave higher than the male. This general range was proven to be consistent in numerous subjects tested outside the scope of this investigation. During the formulation of the design of this study, approximately one hundred trials were run, and all of those trials supported the pitch range consistency.

Therefore, the assumptions proved correct for all the stated problems of the study. Examination of the data results revealed that there was a high degree of similarity between pitch stimuli and the resulting muscle activity. Since very little was known concerning the functions and properties of auditory-laryngeal muscle responses in humans and their relevance to phonatory control during speech and singing, these findings should be quite useful in future studies in numerous areas of science, speech pathology, and music education.

A final conclusion of the investigation concerns the remarkable similarity in the EMG wave forms among subjects. Figure 5.1 is a comparison of wave forms produced between a male and a female subject. The upper graph is the male subject. The Nicolet is capable of overlaying wave forms as needed for comparisons. In this EMG plot the subject's responses were taken from low-pitch stimulus to low electrode. There was a slight variation in peaks (amplitude, seen as a vertical difference) and a very slight variation in latency (seen as a horizontal difference). The peaks have the same general shape (rise and fall) and also very close latencies. The dotted lines indicate the similarities of the general shape of the form where almost simultaneous peaks occurred. The comparisons of these graphs are from subjects seven and twelve of Appendix One.

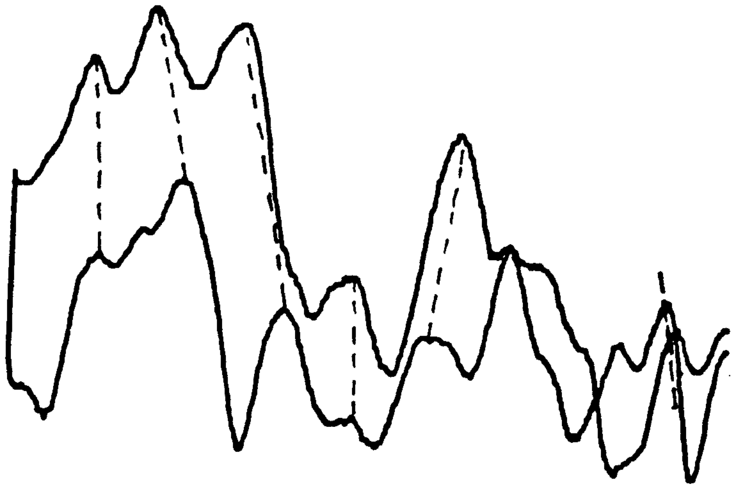

Figure 5.1 LpLe

Figure 5.2 is a display of the same two subjects' responses of low pitch to the high electrode. In both graphs the responses were very small so the display gain was raised to display the peaks more clearly and to emphasize the similarities.

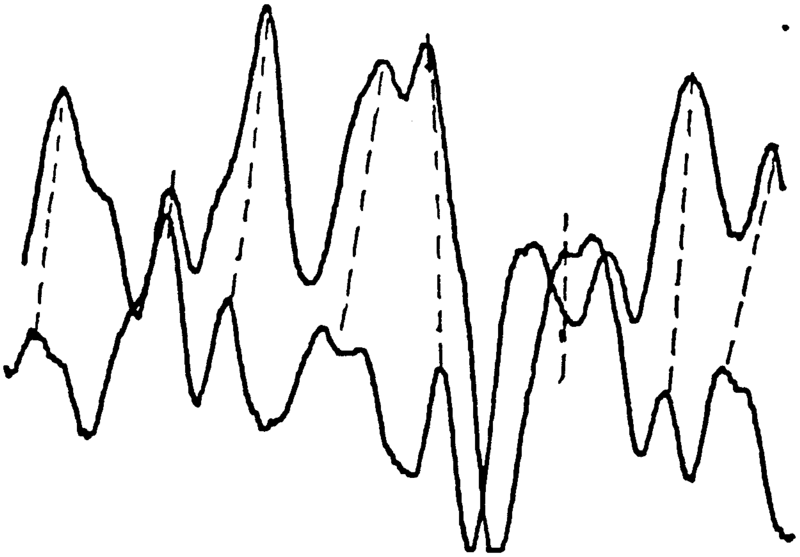

Figure 5.2 LpHe

Figure 5.3 is a comparison of two different responses to the high-pitch, high-electrode series. The similarities of these two EMG responses are obvious. In this particular sample, the data reveal both similar wave forms and amplitudes.

Figure 5.3 HpHe

Figure 5.4 is the plot of the same two subjects as they responded to high pitch and low electrode. Again, for this plot, the display gain was raised to enhance and emphasize the similarities.

Figure 5.4 HpLe

The one subject who did not register the same response results as the others was the one female who possessed absolute pitch (subject twenty-one in the Appendix). In all the trials, this subject produced only EMGs which the assisting neurologist classified as "noise"--that is, no apparent or recognizable change in muscle activity or muscle peaks. Through the researcher's own knowledge and in discussions with the neurologists, speculation concerning the reason for the difference in this one subject might have been from two possibile causes. First, no muscle activity was produced toward "pitch matching" by the cortex inasmuch as the neurological pathways for reproducing pitches were inherently pre-established (genetically encoded). Therefore, there was no need for the preparatory contractions to control the pitch production after hearing a stimulus. Second, the EMG analyzer, which only recognizes changes in muscle activity, could not receive any muscle activity change because the subject, knowing the pitches to be tested, may have had the muscle structure set before the stimulus was presented. Thus, when the stimulus was presented, the muscle activity would already have taken place and therefore, no change could have been registered.

The final conclusion concerning consistencies among subjects was the grouping of subjects by background. In examining the raw EMG data, it was found that subjects who were trained vocalists elicited the highest range of stimulus/response amplitudes. Trained musicians who were non-vocalists exhibited the next highest stimulus/response amplitudes. The lowest stimulus/response amplitudes were from non-musicians. Thus, the extensive use of the pitch matching process and the cognizance of the need for pitch accuracy may increase the µV amplitude of the responses.

Generalizations

The complete data of all twenty-one subjects are found in Appendix One. After a thorough examination and analysis of the data, the following generalizations can be made:

(1) The range and muscle responses were consistent without respect to voice ranges in both males and females. In the male subjects, for example, the author tested the general range/vocal quality of the subjects and found that whether bass, baritone, or tenor, the results were the same.

(2) It was noted that through trial and error electrode placement, a mid-range pitch such as "A" (440 Hz) would stimulate the mid-line muscle structure in the extrinsic laryngeal muscle group. Those findings were outside the original scope of this study and have not been reported in the data but are worthy of future investigation.

(3) It was found that all high pitches, the designated F and above, tend to stimulate the muscles around the mastoid process. Pitches which were lower than the designated D flat, by contrast, tended to move away from the laryngeal depressors (just above the sternum) and into the chest cavity. Since the human body responds to a much wider pitch range than a tenth, it was noted that surface electrodes would be impractical, if not totally ineffective, in measuring these responses.

(4) Although the results were generally consistent in all the subjects, the amplitudes and latencies varied somewhat. The differences in amplitudes formed the most consistent pattern among the subjects. In examining the data against subject background, the following generalizations were made:

(a) Trained musicians who were singers had the greatest amplitudes.

(b) Trained musicians who were non-vocal majors produced the next greatest amplitudes.

(c) Subjects who were non-musicians produced the least amplitudes.

(d) The one subject (male: subject eight) who produced the least contrast in amplitudes was a musician who had a highly developed relative pitch to the point that he bordered on absolute pitch, thus, the similarity to the subject with absolute pitch.

These generalizations can be considered as true for the general population since the sample included both musicians and non-musicians.

(5) Latencies, as far as known, had never been determined for extrinsic laryngeal muscles for this stimulus paradigm. The results of this investigation show that:

(a) in all trials, the muscles peaked two to four times within the 40 ms time frame.

(b) all subjects had major peaks within the 12 to 18 ms time range.

(c) in all subjects, the early peak occurred within 3 to 10 ms making these groups of muscles second only to the eye muscles (saccadic, involuntary reflexes) in speed of response time (6, p. 37). This short-term latency was not expected by the neither the investigator nor the neurologists assisting in the study.

(6) The speculation of the neural pathways concerning the phenomena of hearing and pitch matching have never been determined. The results of this investigation suggest--due to the short-term latencies-- the possibility that many of the functions of auditory and phonation phenomena share the same neural network but with selective tuning of its parts. In other words, the neural pathways that interpret an auditory signal may be the same pathways that reproduce the

pitch in singing. This premise is evidenced by the fact that all the subjects had consistent muscle responses to auditory stimulation without phonation. The speed of the responses is the factor that questions the concept of two separate network channels. Thus, a singer can be free to hear another pitch while producing one, merely fine tune the adjustments from short-term memory storage, and then move on to the next pitch with uninterrupted flow.

There has been some evidence in neuroanatomical and neurophysiological data from animals that there are two divisions within the auditory system at the level of the brain stem. Studies by Evans (1), Knudsen and Konishi (4), and Lawicka (6) conclude that these two divisions involve localization and sound generation while the other division is for pattern recognition of the auditory signal. The results of this study (short-term latencies) suggest the possibility that, in humans, the division for signal recognition, localization, and reproduction are related pathways. Therefore, in comparisons such as this one, the neurophysiology of animals may not be applicable to human responses.

In humans, while one signal is traveling along the pathway, the reproduction may be on the same pathway. The supportive evidence is that the auditory stimulation can, with no attempt at singing, evoke the muscle responses related to the pitch stimulus. This further explains why the subject with absolute pitch produced different EMG responses from the other twenty subjects. However, when the subject with absolute pitch was asked to think the pitch being used for testing, a response was evoked in the expected muscle structure--without the auditory stimulation! Studies of this nature concerning fiber optics are now being conducted by Barbara Thomas (8) in which vocal chord activity is observed while the subjects are silently reading music scores and merely thinking pitches. Both these studies also offer the possibility that the psychological process that Edwin Gordon (2, p. 2-13) refers to as "audiation" may really be a muscle response rather than a mental process.

(7) Although all the above observations suggest that the responses to auditory stimulation were due to activity of only the extrinsic laryngeal muscles, one should not exclude the possibility that these responses were induced by conjunctive responses with the respiratory and/or intrinsic laryngeal muscles. The respiratory muscles prepare the multi-systems that control phonation or singing by accumulating air in the lungs. The intrinsic laryngeal muscles control the length of the vocal chords to fine tune the pitch they will produce. Thus, the three muscle groups are inseparable in reproducing a pitch for singing. In all probability, all three sets of muscles are activated

simultaneously under cortex command; and an extremely complex set of muscle adjustments takes place in a very short time to set the larynx, vocal chords and respiratory control into place. The exact contribution of the intrinsic laryngeal muscles or the respiratory muscles cannot be assessed at this point inasmuch as their EMG activity or other physiological measurements related to the activities of those muscles were not recorded in this investigation.

(8) During this investigation the same decibel setting was employed for all twenty-one subjects. Periodically, however, for the sake of verifying knowledge, non-recorded tests were run at both high decibel (90 or over) and threshold of levels of hearing. The responses elicited from those new settings were essentially unchanged, and peaks were still constant. The fact that the magnitude of the responses (amplitude) could not be changed by the magnitude of the stimulus further proves that these responses were not simply startle or reflex responses but, rather, voluntary motor responses.

Recommendations For Further Study

The present investigation was designed to determine whether or not auditory stimulation by discrete pitches would evoke muscle responses in specific extrinsic laryngeal muscles. The study proved to be effective in recording evoked responses from those muscles. There were some methodological difficulties that made the acquisition of the data difficult to obtain. A major problem was electrode placement which often had to be adjusted and reset because of interference from adjacent muscle fibers. Had the author not had the privilege of attending a dissection class (Head and Neck Anatomy) under the supervision of Allen Rupert, proper placement would have been even more difficult. Actually seeing the muscles simplified the protocol design of the study. Even with that experience, occasionally an electrode would have to be moved and reset in order to get the most effective response. Perhaps bi-polar injected electrodes would have been more effective and might provide even more supportive evidence.

Another problem was that the Nicolet averager could only measure four channels at one time. To measure relative muscle activity, the ideal laboratory equipment would have been capable of measuring eight to ten electrodes, thereby producing a more comprehensive pitch-to-evoked-muscle response relationship. Therefore, a more advanced technology is required to improve and advance this study.

Another problem was using the same pitch in the digital tape for five successive stimuli. This allowed the muscles to be prepared after the first signal and, therefore, diminish the ensuing four responses. Ideally, the stimuli would have been a series of random pitches with the EMG analyzer only recording the one specific pitch response being sought. The Nicolet was incapable of handling a program of this complexity. The only option would have been to include a series of random pitches that were predetermined and have the operator of the Nicolet be ready to trigger the computer. Obviously, this would have prevented the subject from preparing the muscle structure ahead of time, but it also would have increased the time required to test each subject so drastically that exhaustion would have become a negative factor in the design.

From a theoretical point of view, it may be argued that the type of auditory stimulus could change the results of the investigation. Several wave forms were tried during the early stages of the investigation before the final protocol was developed and completed. The approximate saw-tooth wave (the wave closely assimilates a harpsichord sound) was finally chosen by the author because of the relative number of overtones present. The wave form is a relative "middle of the road" tone that gives a more general response than either a sine wave or an extremely complex wave. In future studies, it would be desirable to use auditory stimuli that encompass a wide range of wave forms and assess the effect of these stimuli on the same muscles.

This study, although employing a much larger sample than the usual study of this type (six to ten is a normal sample), still represents a rather narrow segment of the general population. There are many applications of the study that would require the testing of other subjects such as hearing impaired, vocally impaired, mentally handicapped, and a broader age group (including children).

The most common problem in training the deaf to speak is that they speak in a range that is extremely high. At the present time, an oscilloscope is used to try to show them how to change that speaking range. By applying this study, they would merely need to locate the lower muscles by feel (which all the subjects tested in this study were able to do) and speak at that range--a far more concrete method than trying to make the adjustments by watching an extraneous and abstract measurement which might take weeks to master while the muscle responses could be felt in a few minutes.

There are definite applications of this study to other areas of clinical speech disorders such as with spastic dysphonic patients, a speech problem that evolves from abnormal laryngeal reflexes. The same applications will, of course, apply to the victims of aphasia in their therapy to recover speech patterns and control.

Using an experimental design somewhat similar to the one used in this investigation, the potential studies range from use in the music theory classroom, to vocal pedagogy, to speech therapy. Therefore, the study should be of use to future studies employing different modes of phonatory control whether singing, speaking, or hearing.

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6. Lass, Norman J., et al, Speech, Language, and Hearing, Volume 1, Philadelphia, W. B. Sanders, Co. 1982, p. 370. Saccadic refers to the eye-movement such as fixing the eye on a moving target and making constant adjustments ahead and back to the object. Lass lists this as the fastest motor response in the human body. This type of response is more closely related to involuntary than voluntary responses, however. The short-term latencies found in this dissertation were surprising to both the neurophysiologists and the neuroanatomists.

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9. Thomas, Barbara, unpublished studies now in progress at North Texas State University, Denton, Texas, 1985.

APPENDIX ONE

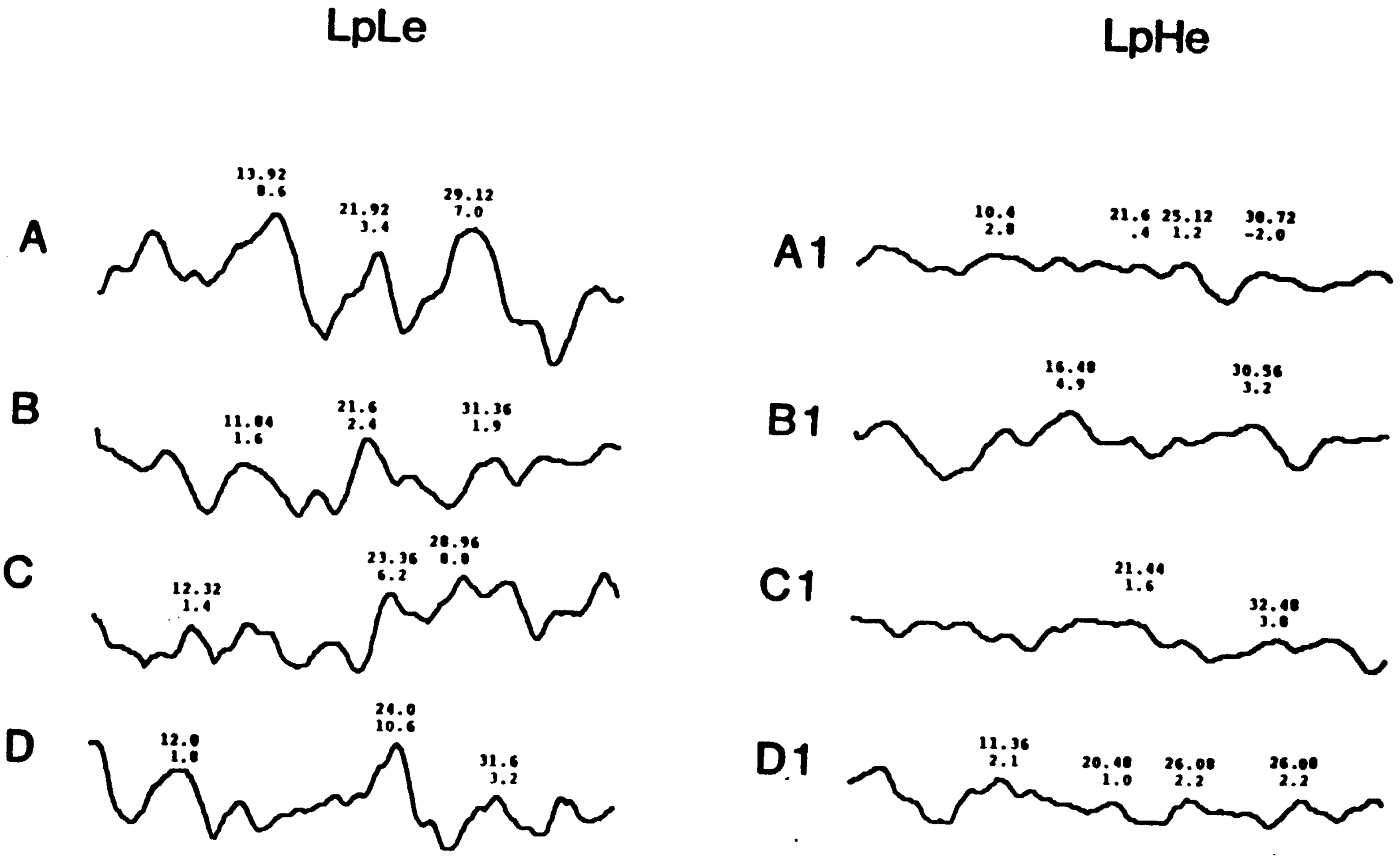
PLOTTED DATA FOR MALE SUBJECTS

(1-10)

PLOTTED DATA FOR FEMALE SUBJECTS

(11-21)

Subject 1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C
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D
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1.8
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3.2
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10.4
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C1
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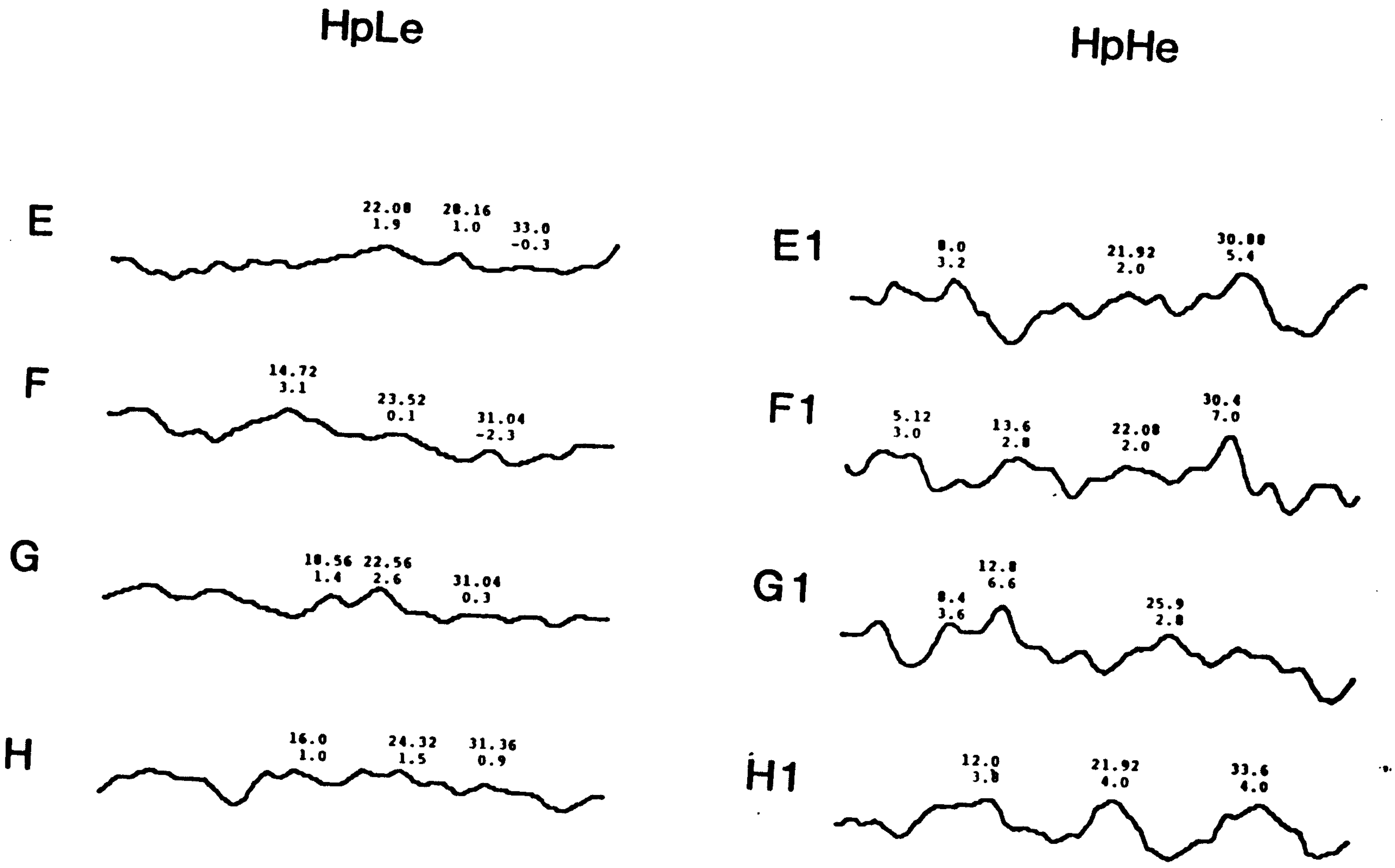
2.2

Subject 1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F1
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7.0
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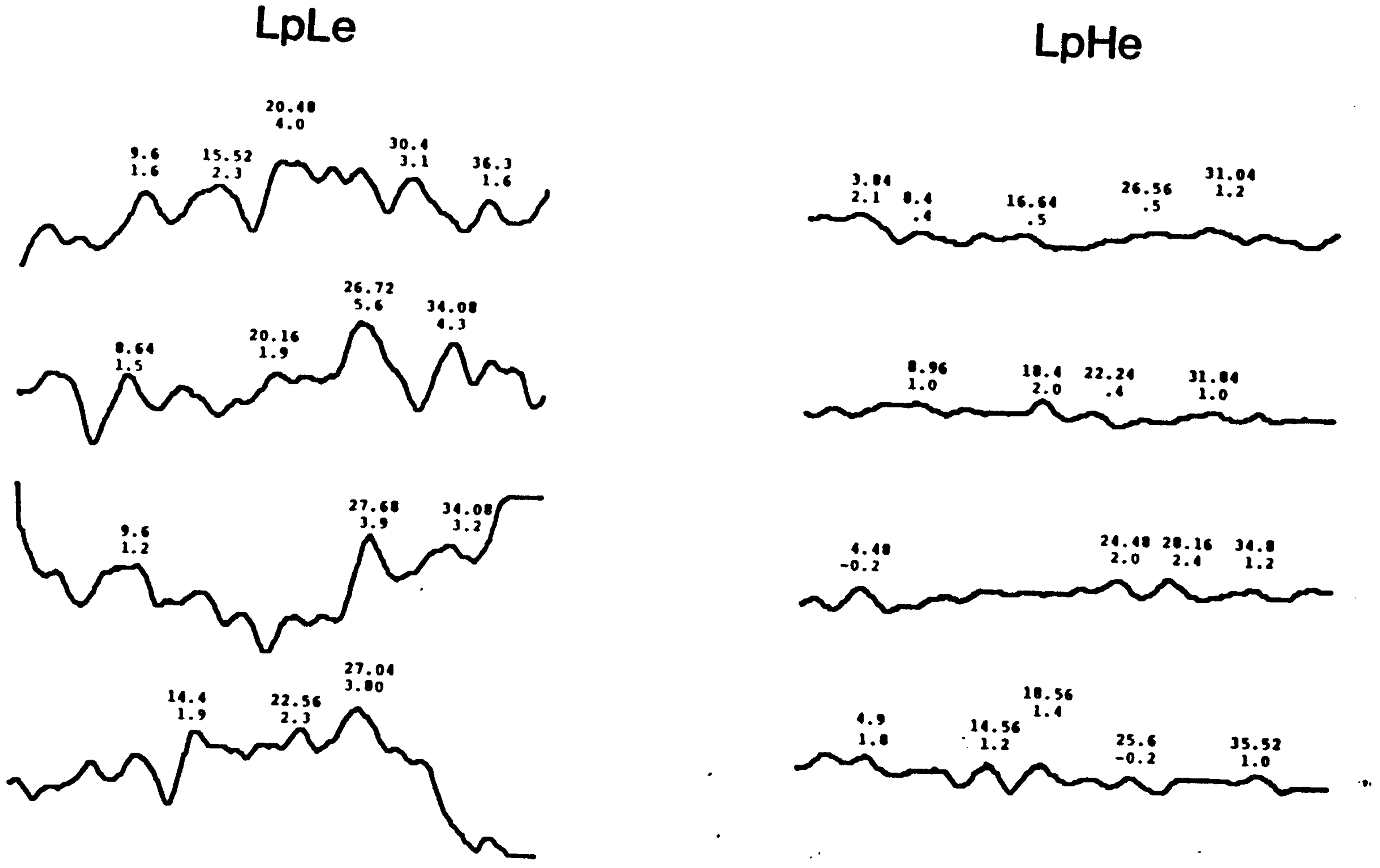
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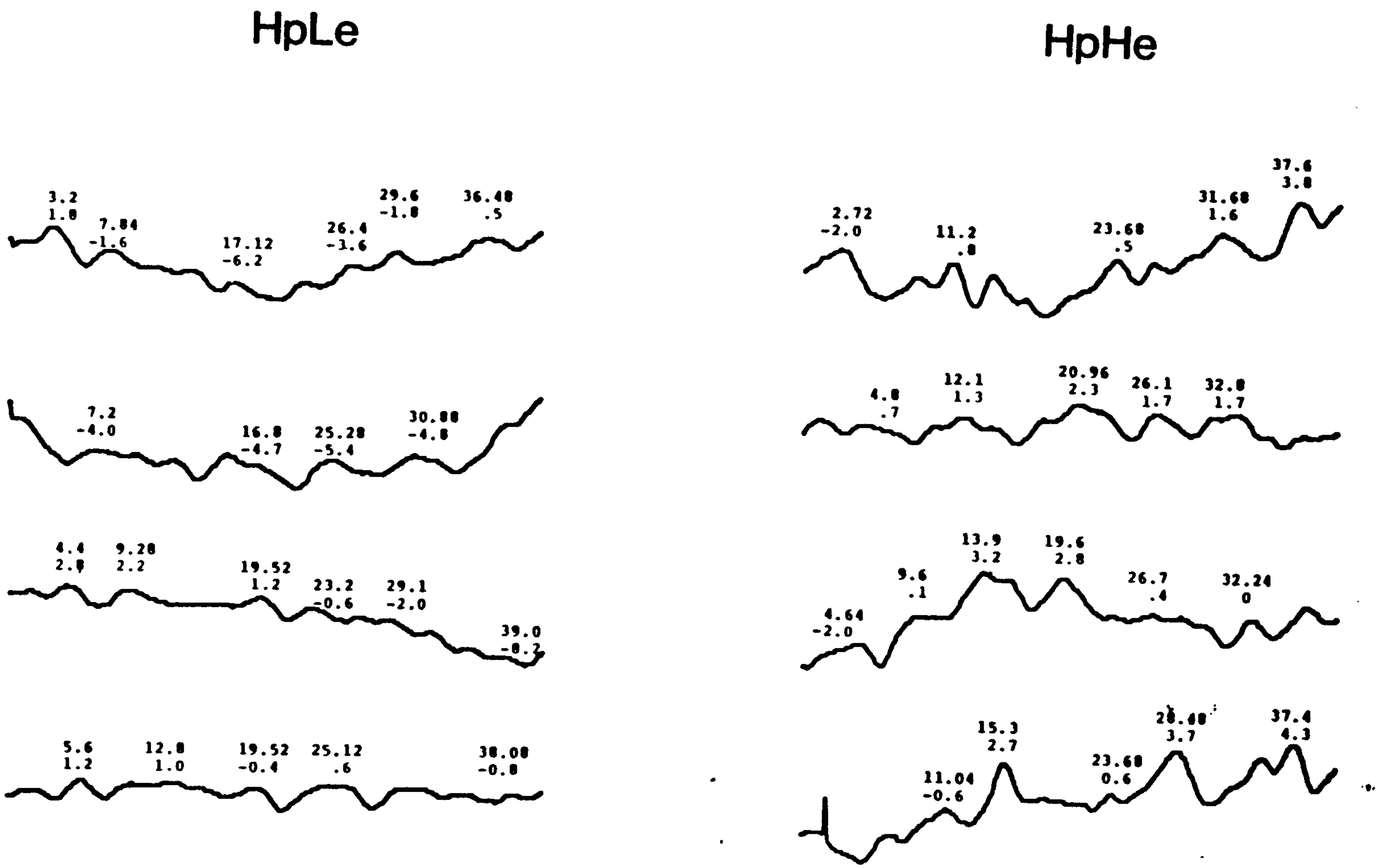
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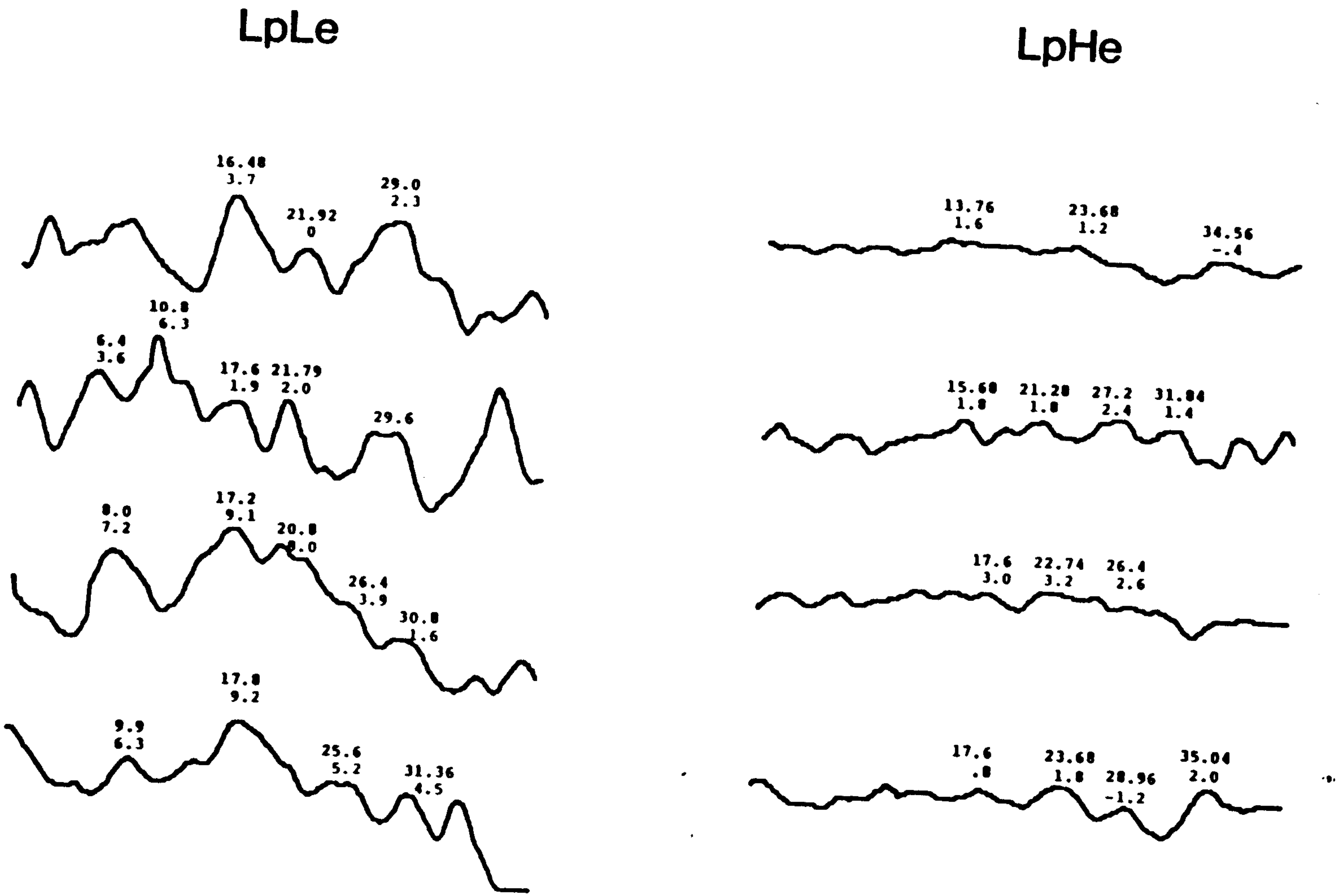
Subject 3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1.8
28.96
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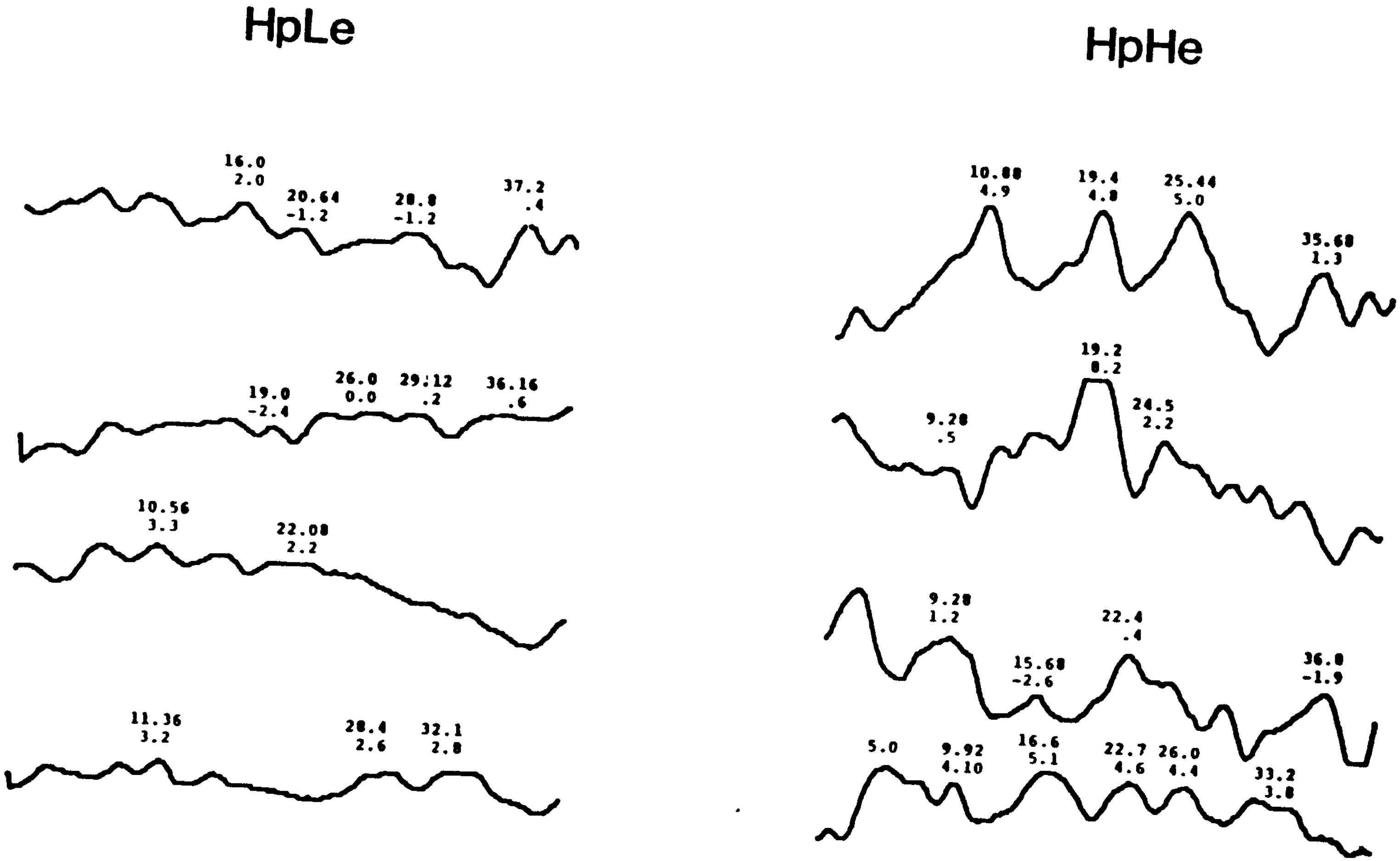
2.0

Subject 3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HpHe
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-1.2
28.8
-1.2
37.2
.4
19.0
-2.4
26.0
0.0
29:12
.2
36.16
.6
10.56
3.3
22.08
2.2
11.36
3.2
28.4
2.6
32.1
2.8
10.88
4.9
19.4
4.8
25.44
5.0
35.68
1.3
9.28
.5
19.2
8.2
24.5
2.2
9.28
1.2
15.68
-2.6
22.4
.4
36.8
-1.9
5.0
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4.10
16.6
5.1
22.7
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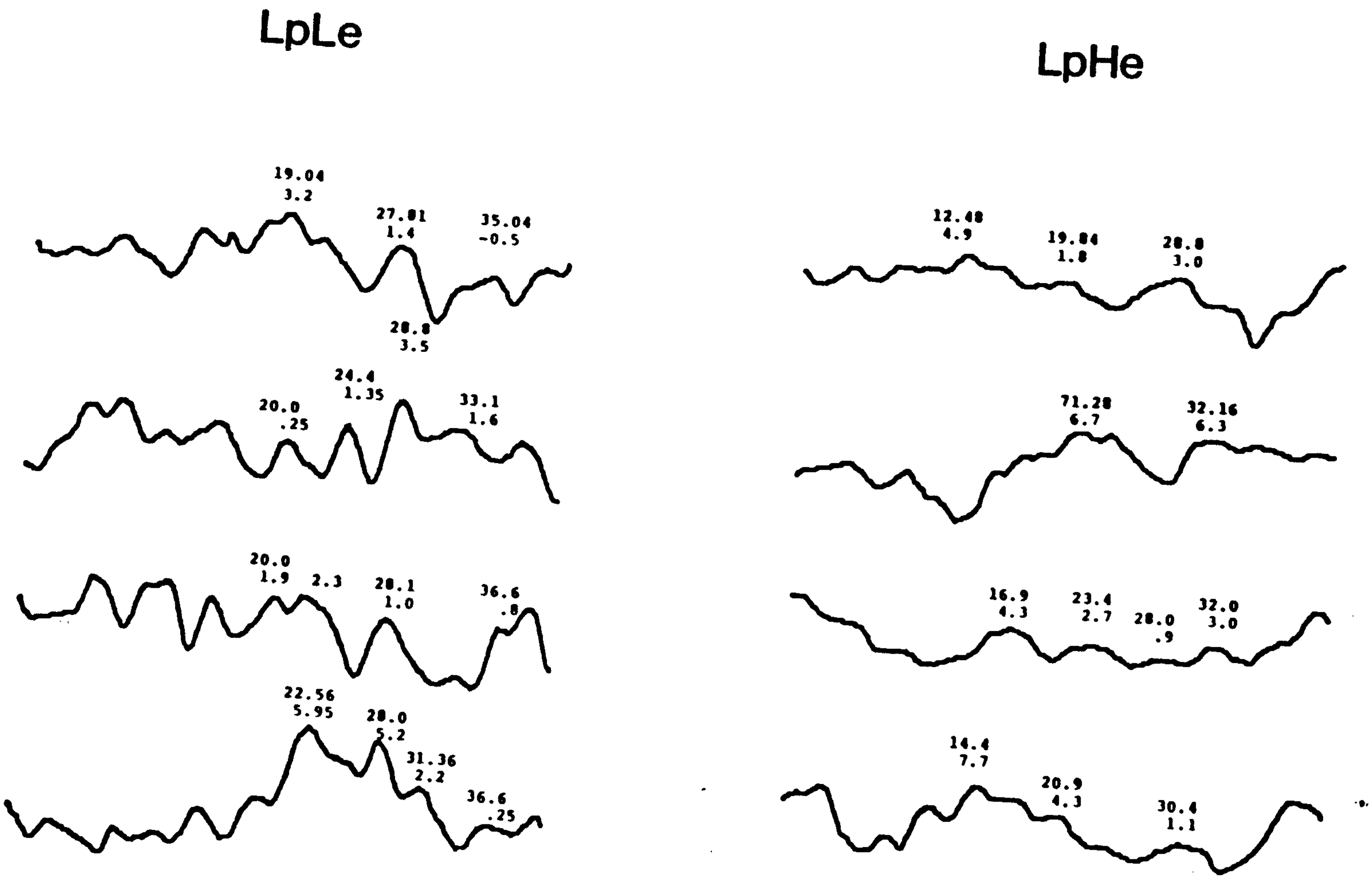
26.0
4.4
33.2
3.8

Subject 4


LpLe
19.04
3.2
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1.4
35.04
-0.5
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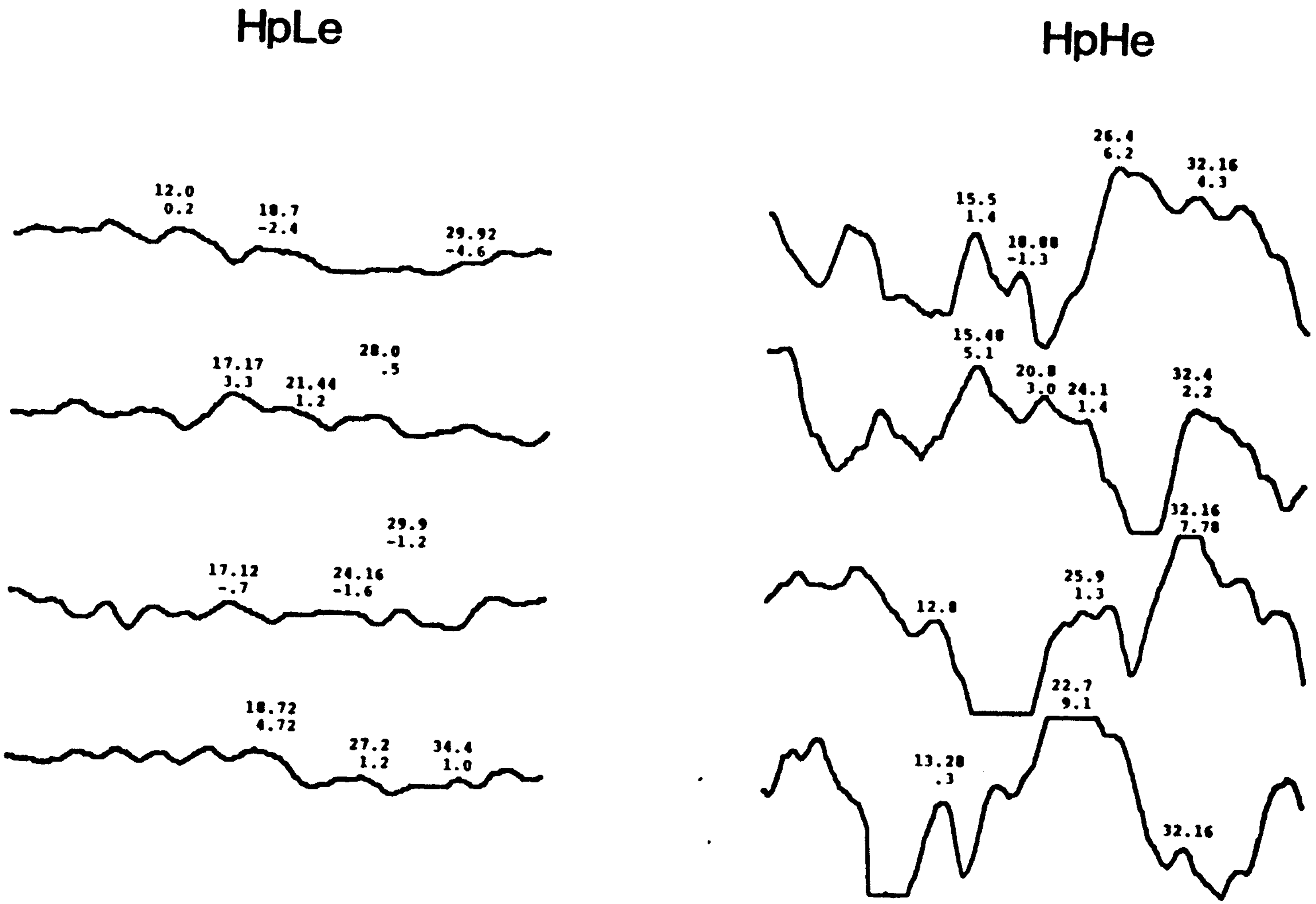
3.5
24.4
1.35
20.0
.25
33.1
1.6
20.0
1.9
2.3
28.1
1.0
36.6
.8
22.56
5.95
28.0
5.2
31.36
2.2
36.6
.25
LpHe
12.48
4.9
19.84
1.8
28.8
3.0
71.28
6.7
32.16
6.3
16.9
4.3
23.4
2.7
28.0
.9
32.0
3.0
14.4
7.7
20.9
4.3
30.4
1.1

Subject 4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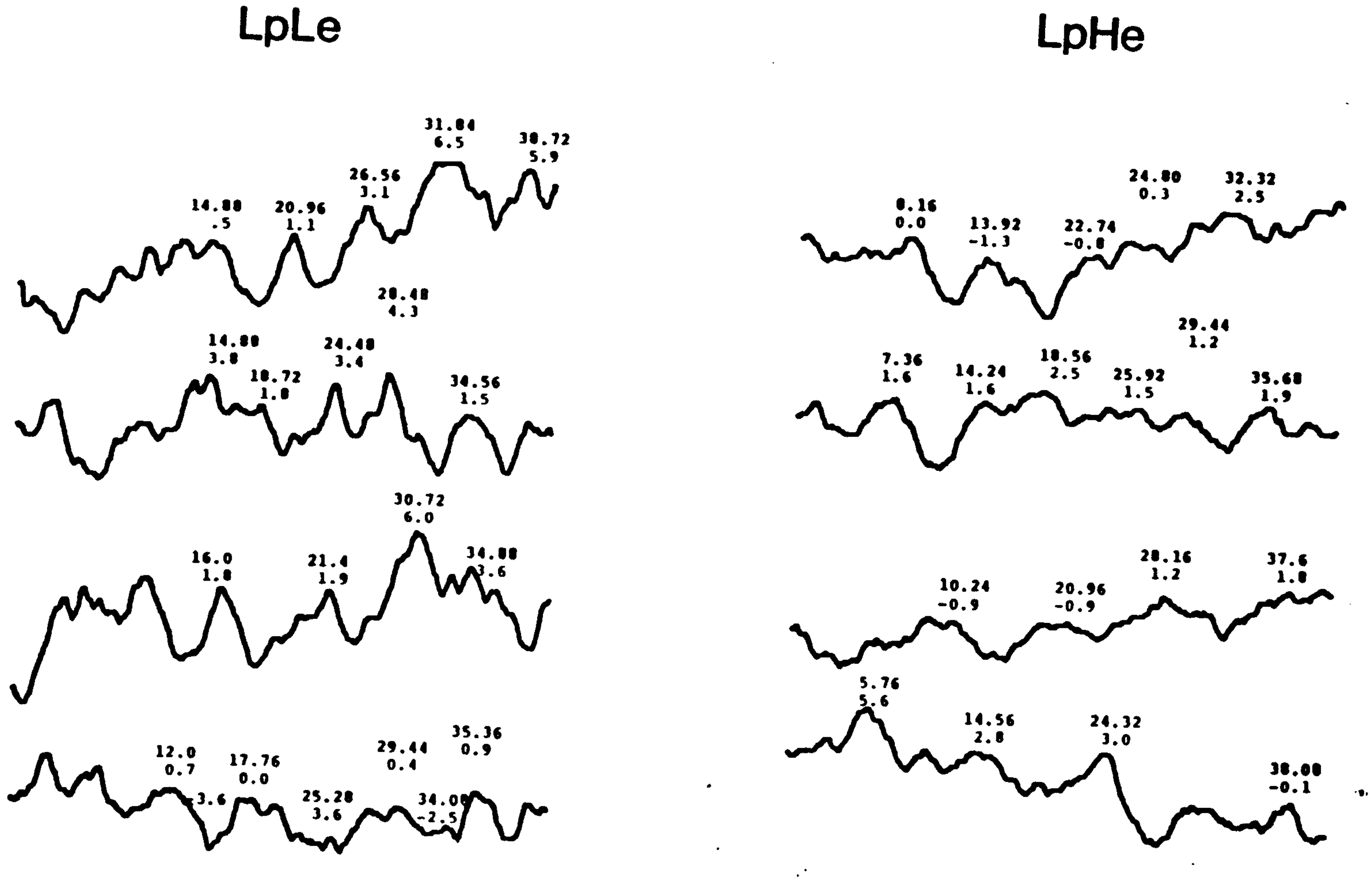
-4.6
17.17
3.3
21.44
1.2
28.0
.5
29.9
-1.2
17.12
-.7
24.16
-1.6
18.72
4.72
27.2
1.2
34.4
1.0
26.4
6.2
32.16
4.3
15.5
1.4
18.88
-1.3
15.48
5.1
20.8
3.0
24.1
1.4
32.4
2.2
32.16
7.78
12.8
25.9
1.3
22.7
9.1
13.28
.3
32.16

Subject 5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14.88
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26.56
3.1
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38.72
5.9
28.48
4.3
14.88
3.8
18.72
1.8
24.48
3.4
34.56
1.5
30.72
6.0
16.0
1.8
21.4
1.9
34.88
3.6
12.0
0.7
3.6
17.76
0.0
25.28
3.6
29.44
0.4
35.36
0.9
34.00
-2.5
LpHe
8.16
0.0
13.92
-1.3
22.74
-0.8
24.80
0.3
32.32
2.5
29.44
1.2
7.36
1.6
14.24
1.6
18.56
2.5
25.92
1.5
35.68
1.9
10.24
-0.9
20.96
-0.9
28.16
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5.76
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2.8
24.32
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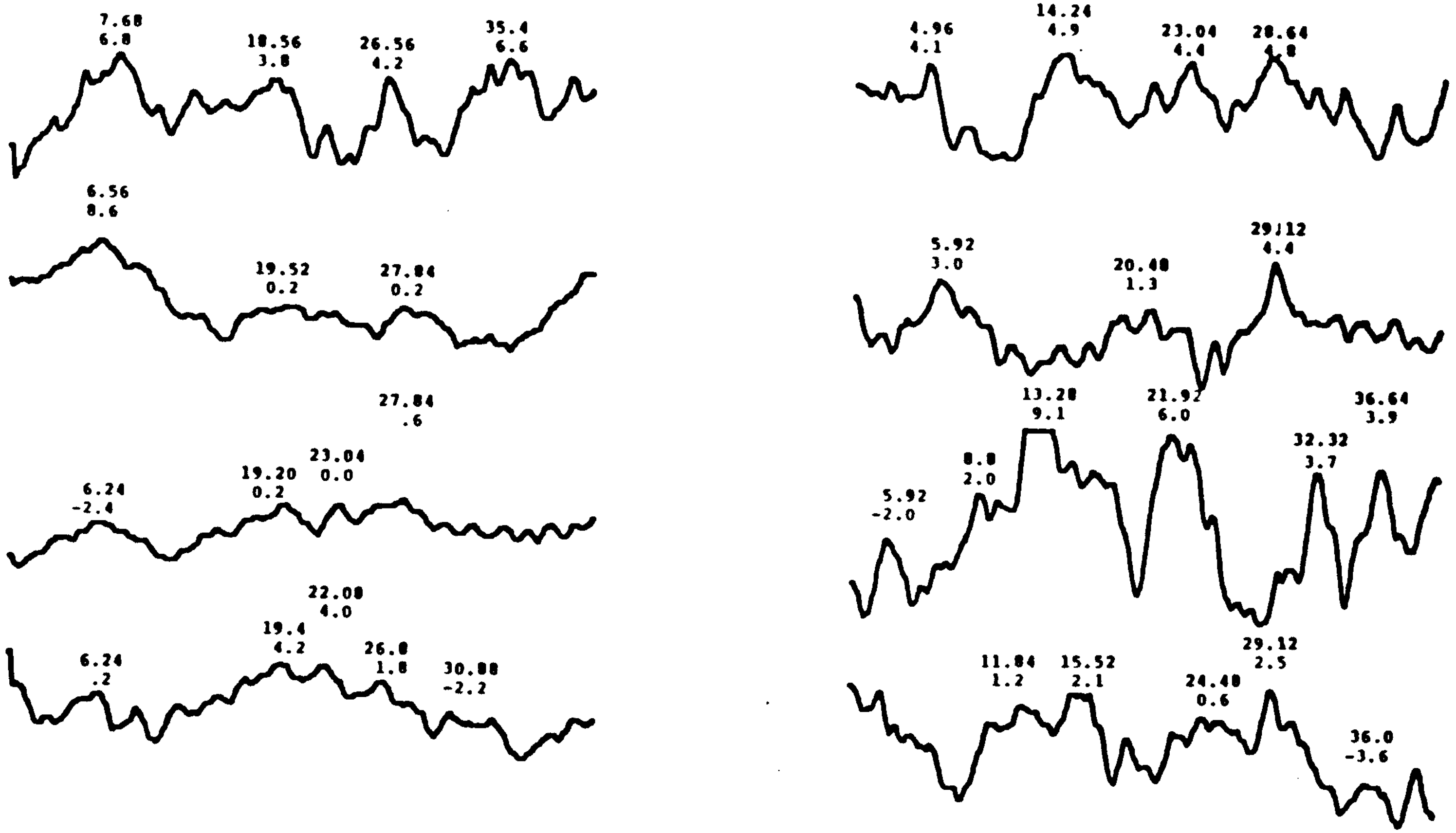
38.00
-0.1

Subject 5

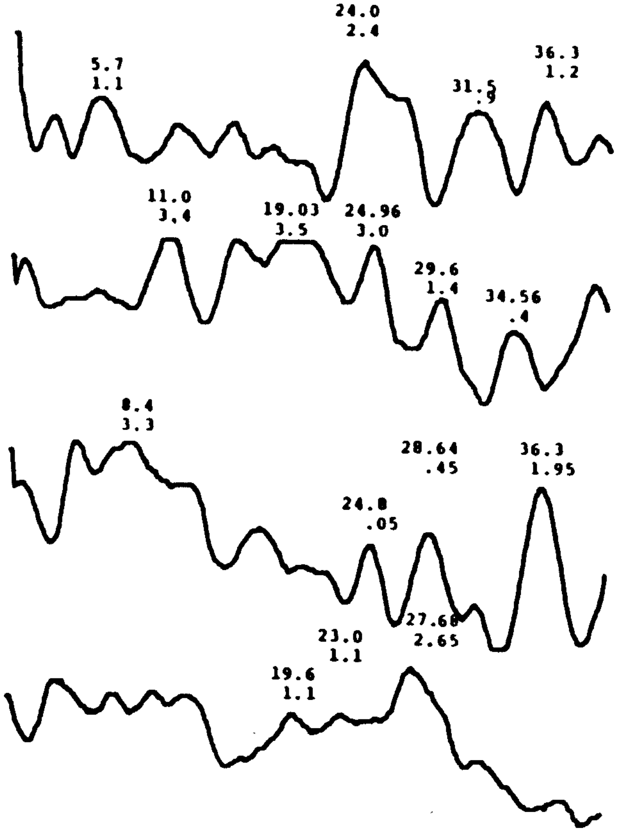


HpLe

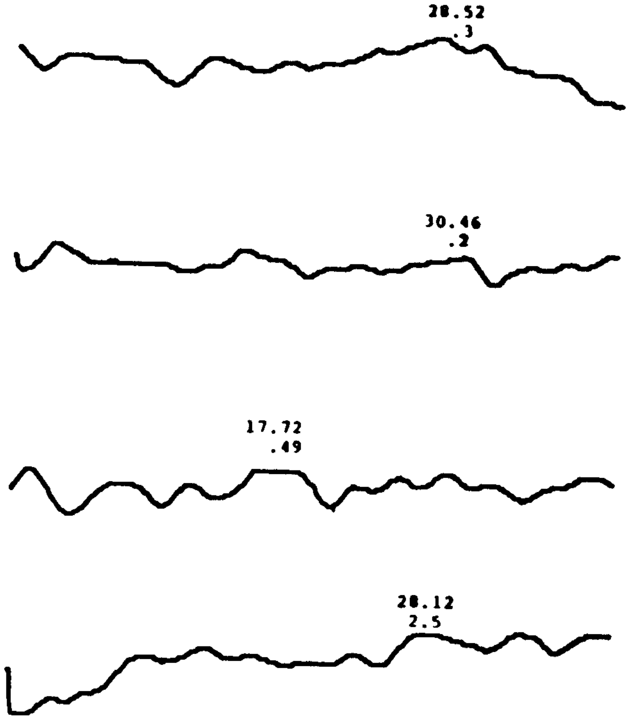
HpHe

Subject 6

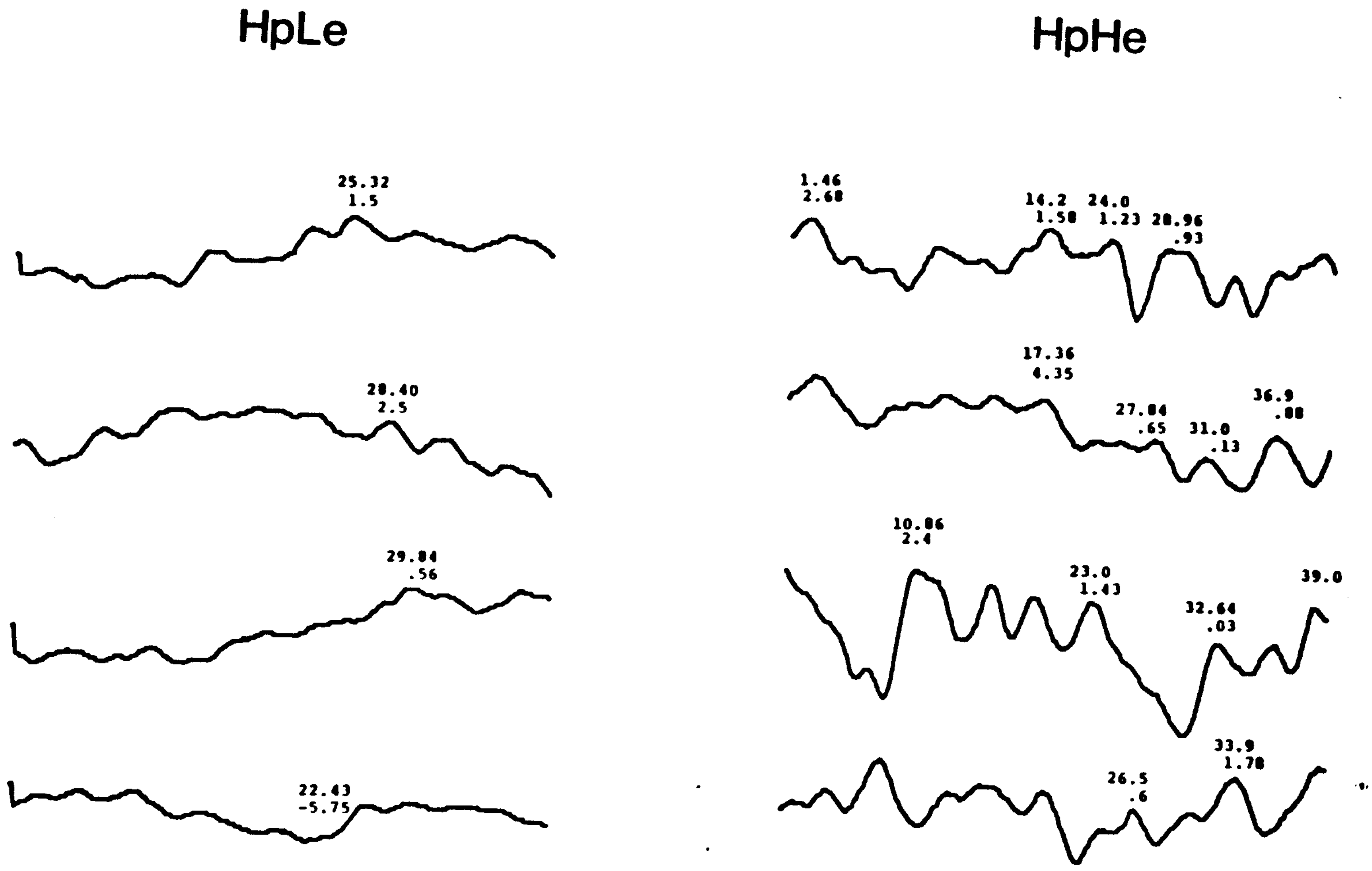
LpLe



LpHe



Subject 6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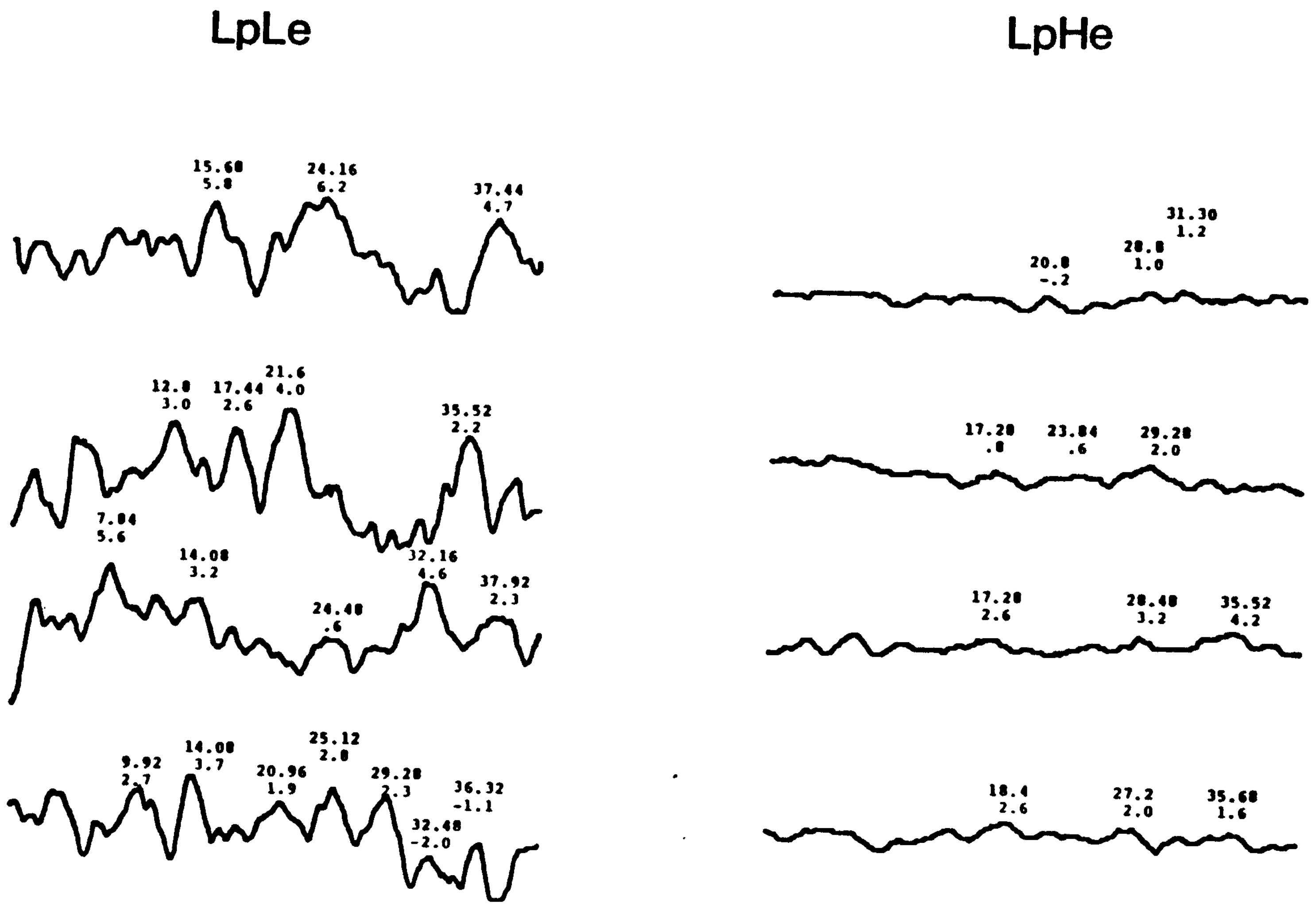
1.5
28.40
2.5
29.84
.56
22.43
-5.75
1.46
2.68
14.2
1.58
24.0
1.23
28.96
.93
17.36
4.35
27.84
.65
31.0
.13
36.9
.88
10.86
2.4
23.0
1.43
32.64
.03
39.0
26.5
.6
33.9
1.78

Subject 7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LpHe
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24.16
6.2
37.44
4.7
20.8
-.2
28.8
1.0
31.30
1.2
12.8
3.0
17.44
2.6
21.6
4.0
35.52
2.2
17.28
.8
23.84
.6
29.28
2.0
7.84
5.6
14.08
3.2
24.48
.6
32.16
4.6
37.92
2.3
17.28
2.6
28.48
3.2
35.52
4.2
9.92
2.7
14.08
3.7
20.96
1.9
25.12
2.8
29.28
2.3
32.48
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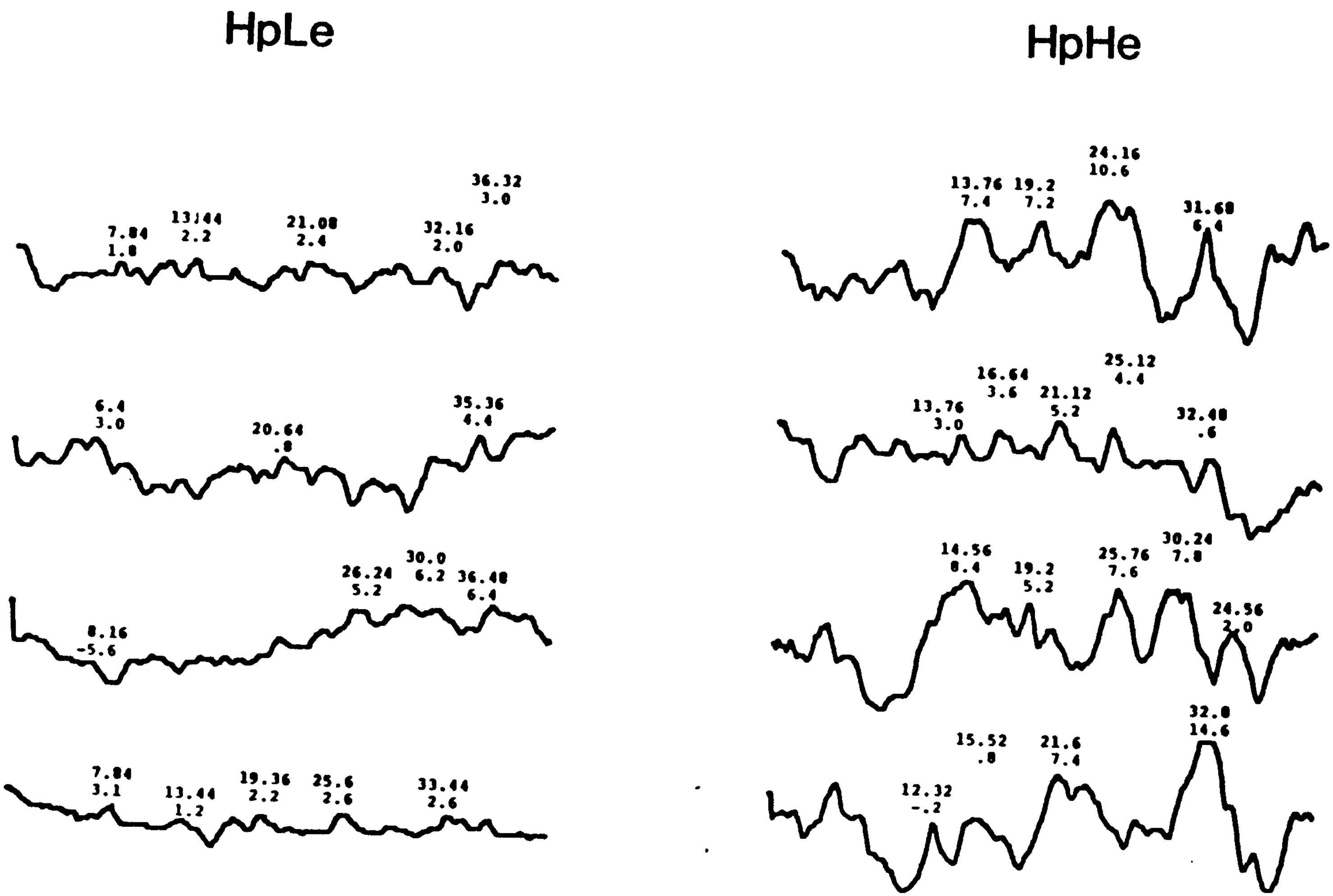
36.32
-1.1
18.4
2.6
27.2
2.0
35.68
1.6

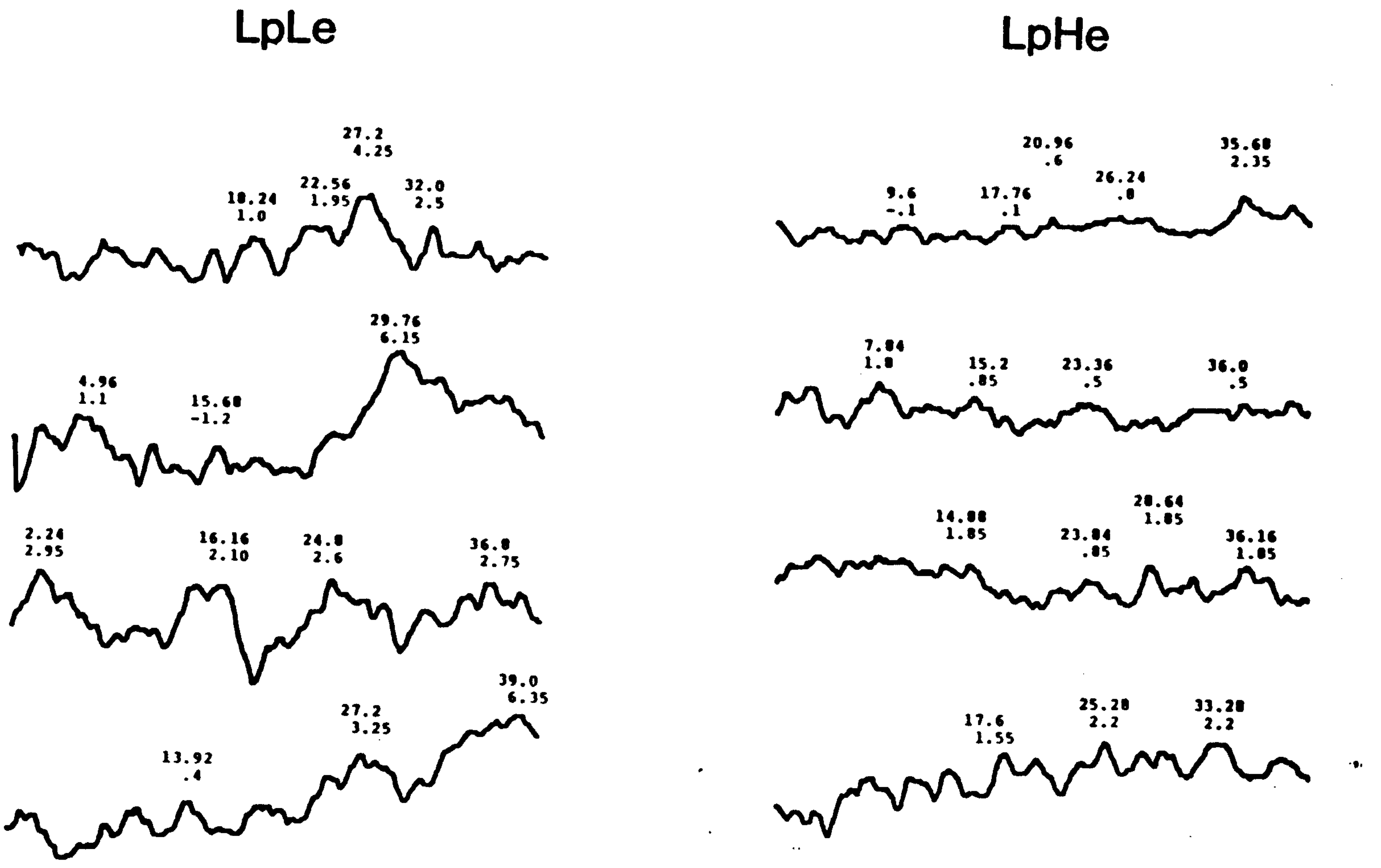
Subject 7



HpLe

HpHe

Subject 8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LpHe
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1.0
22.56
1.95
32.0
2.5
29.76
6.15
4.96
1.1
15.68
-1.2
2.24
2.95
16.16
2.10
24.8
2.6
36.8
2.75
39.0
6.35
27.2
3.25
13.92
.4
20.96
.6
35.68
2.35
26.24
.8
9.6
-.1
17.76
.1
7.84
1.8
15.2
.85
23.36
.5
36.0
.5
28.64
1.85
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1.85
23.84
.85
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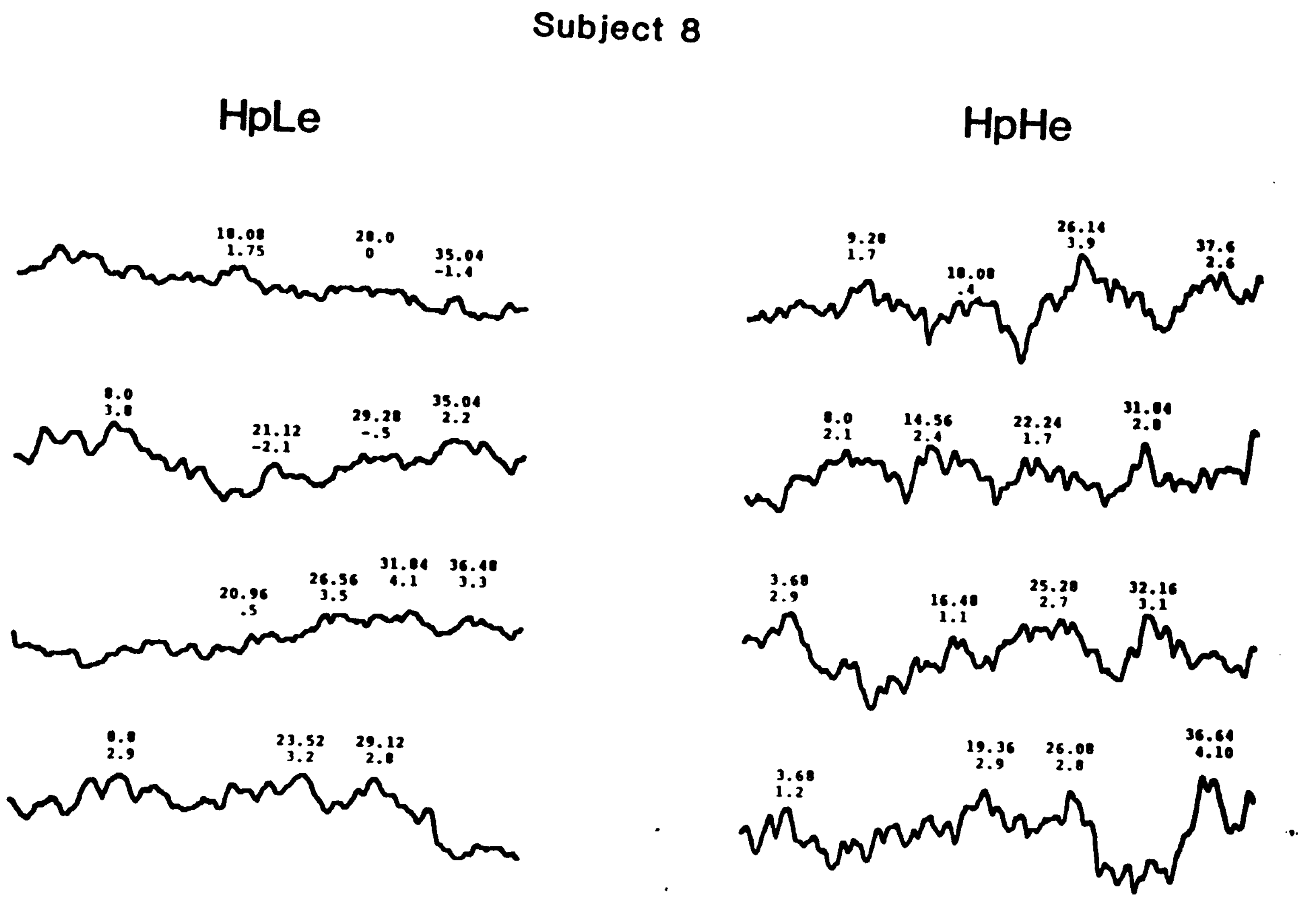
25.28
2.2
33.28
2.2
17.6
1.55


Subject 8
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1.75
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0
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3.8
21.12
-2.1
29.28
-.5
35.04
2.2
20.96
.5
26.56
3.5
31.84
4.1
36.48
3.3
8.8
2.9
23.52
3.2
29.12
2.8
9.28
1.7
18.08
.4
26.14
3.9
37.6
2.6
8.0
2.1
14.56
2.4
22.24
1.7
31.84
2.8
3.68
2.9
16.48
1.1
25.28
2.7
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3.1
3.68
1.2
19.36
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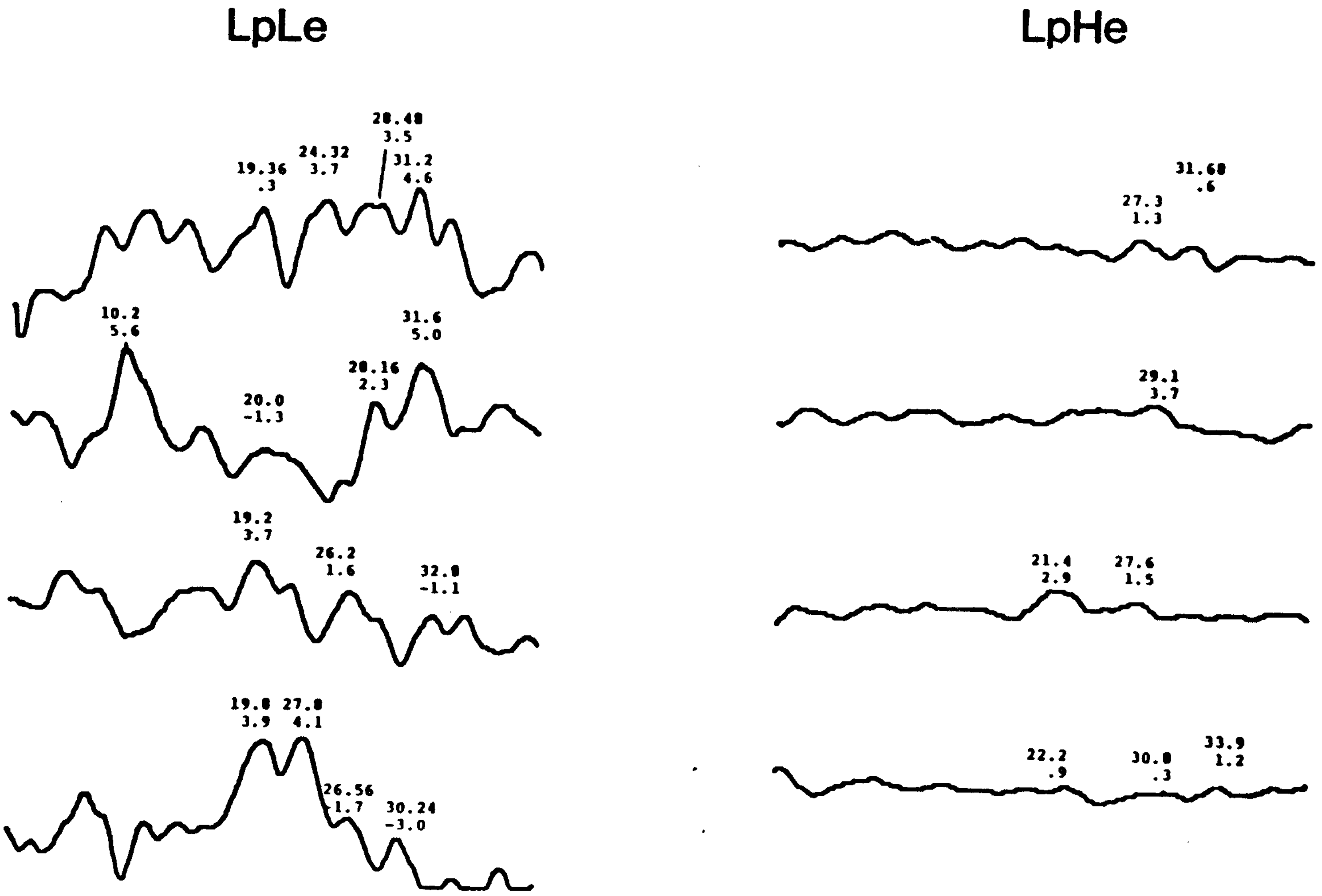
26.08
2.8
36.64
4.10

Subject 9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3.7
28.40
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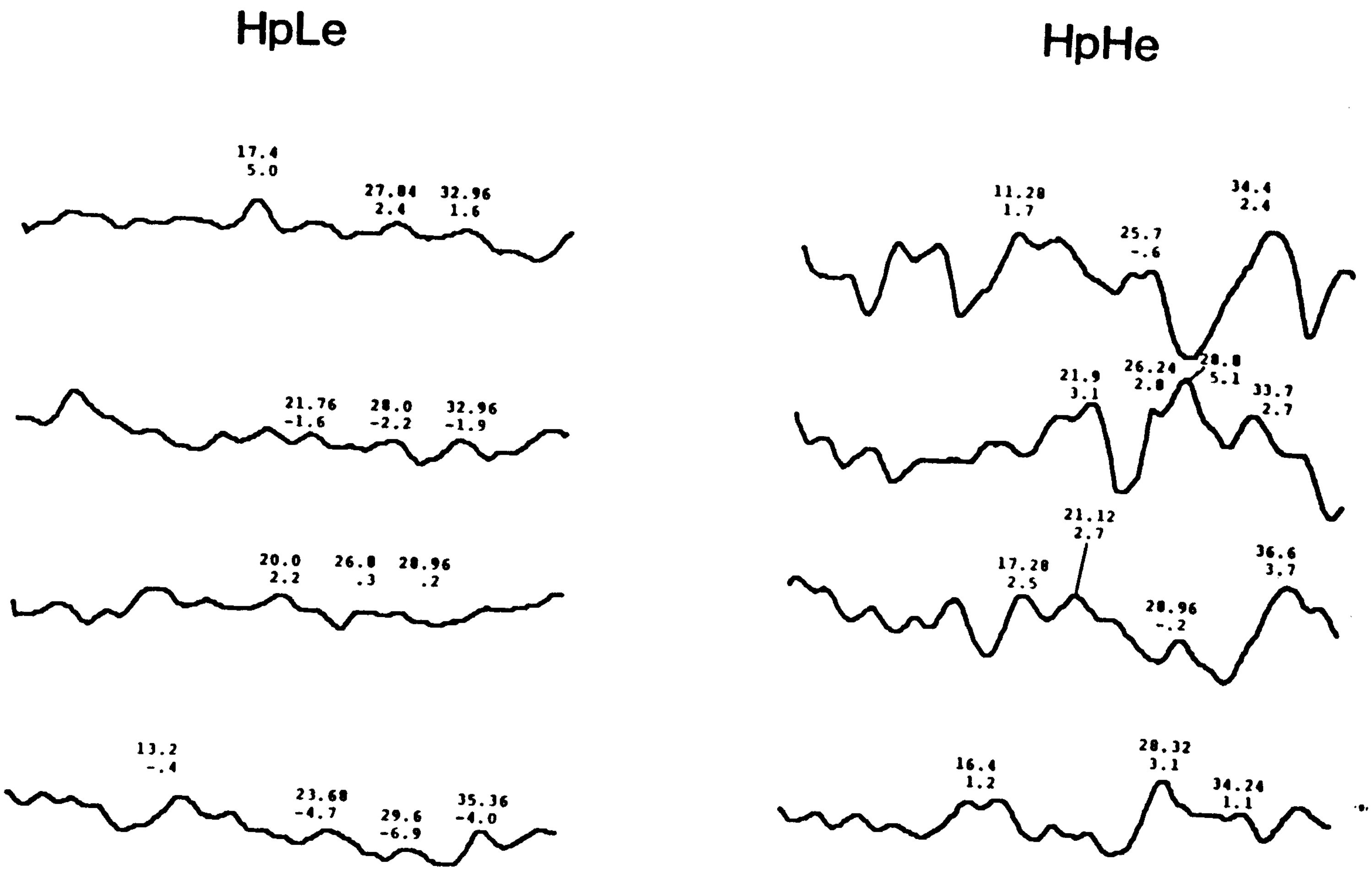
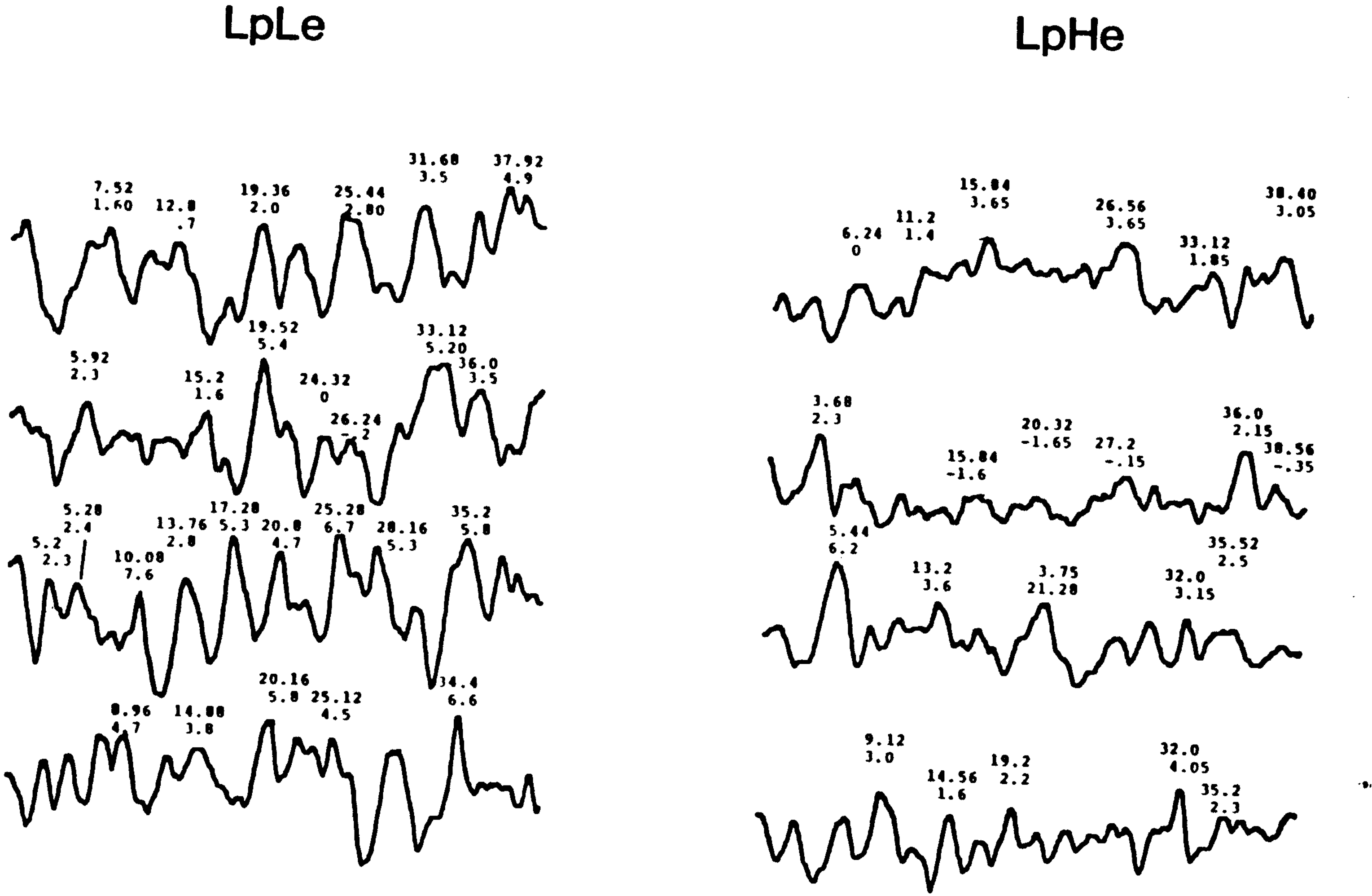
31.2
4.6
10.2
5.6
20.0
-1.3
28.16
2.3
31.6
5.0
19.2
3.7
26.2
1.6
32.0
-1.1
19.0
3.9
27.0
4.1
26.56
-1.7
30.24
-3.0
27.3
1.3
31.60
.6
29.1
3.7
21.4
2.9
27.6
1.5
22.2
.9
30.0
.3
33.9
1.2

Subject 9


HpLe

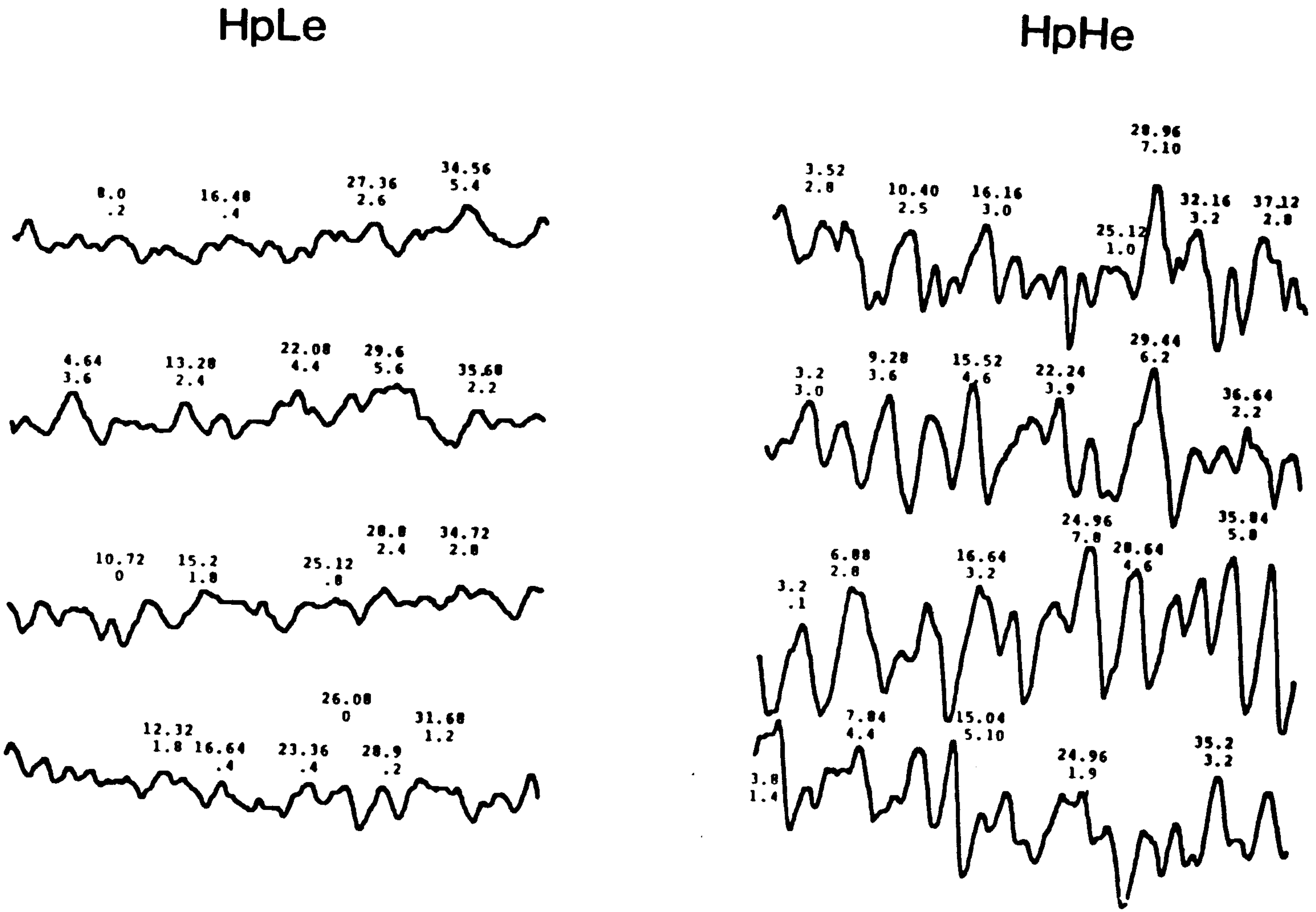
HpHe

Subject 10


LpLe

LpHe

Subject 10


HpLe
8.0
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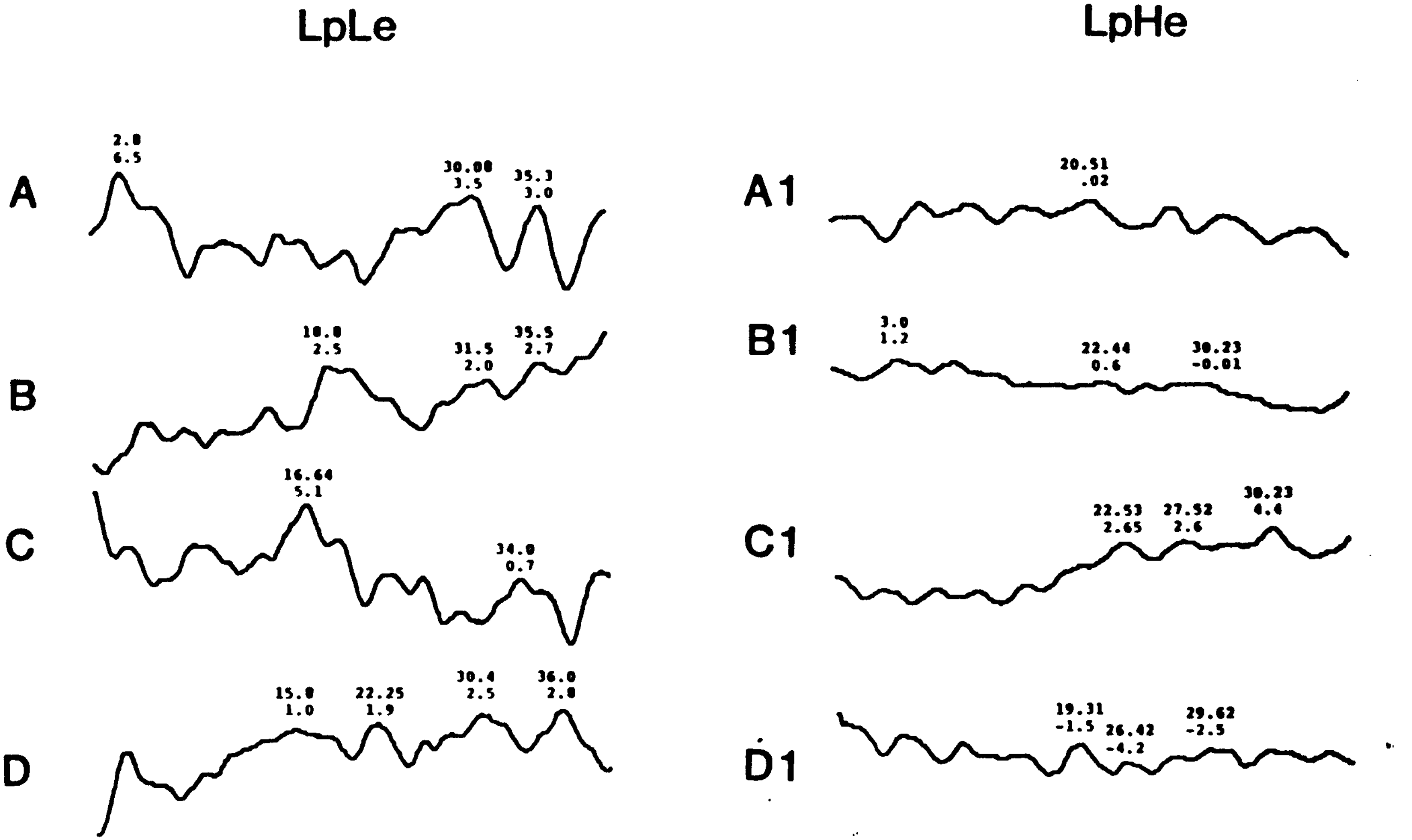
16.48
.4
27.36
2.6
34.56
5.4
4.64
3.6
13.28
2.4
22.08
4.4
29.6
5.6
35.68
2.2
10.72
0
15.2
1.8
25.12
.8
28.8
2.4
34.72
2.8
12.32
1.8
16.64
.4
23.36
.4
26.08
0
28.9
.2
31.68
1.2
HpHe
3.52
2.8
10.40
2.5
16.16
3.0
25.12
1.0
28.96
7.10
32.16
3.2
37.12
2.8
3.2
3.0
9.28
3.6
15.52
4.6
22.24
3.9
29.44
6.2
36.64
2.2
3.2
.1
6.88
2.8
16.64
3.2
24.96
7.8
28.64
4.6
35.84
5.8
3.8
1.4
7.84
4.4
15.04
5.10
24.96
1.9
35.2
3.2

Subject 11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LpHe
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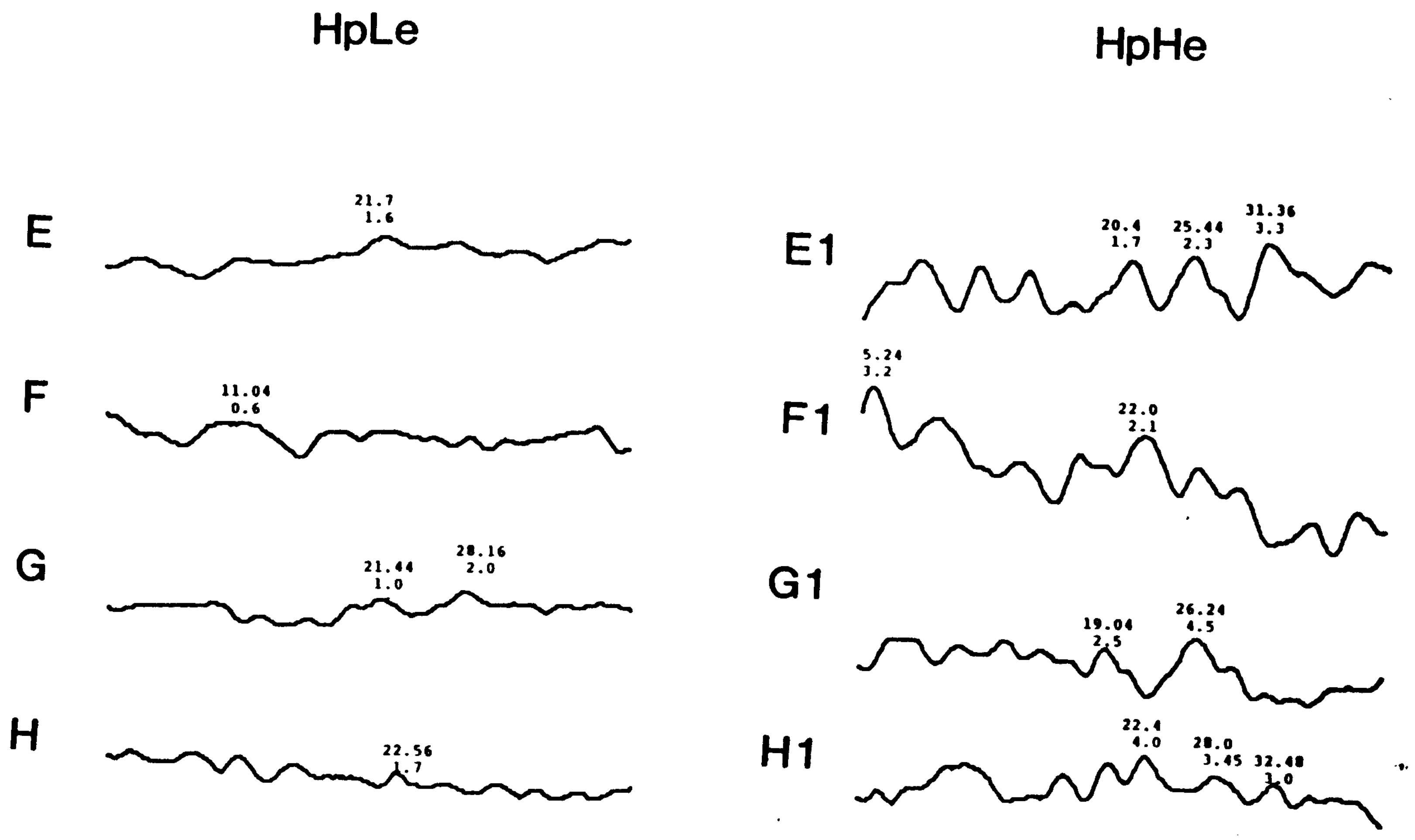
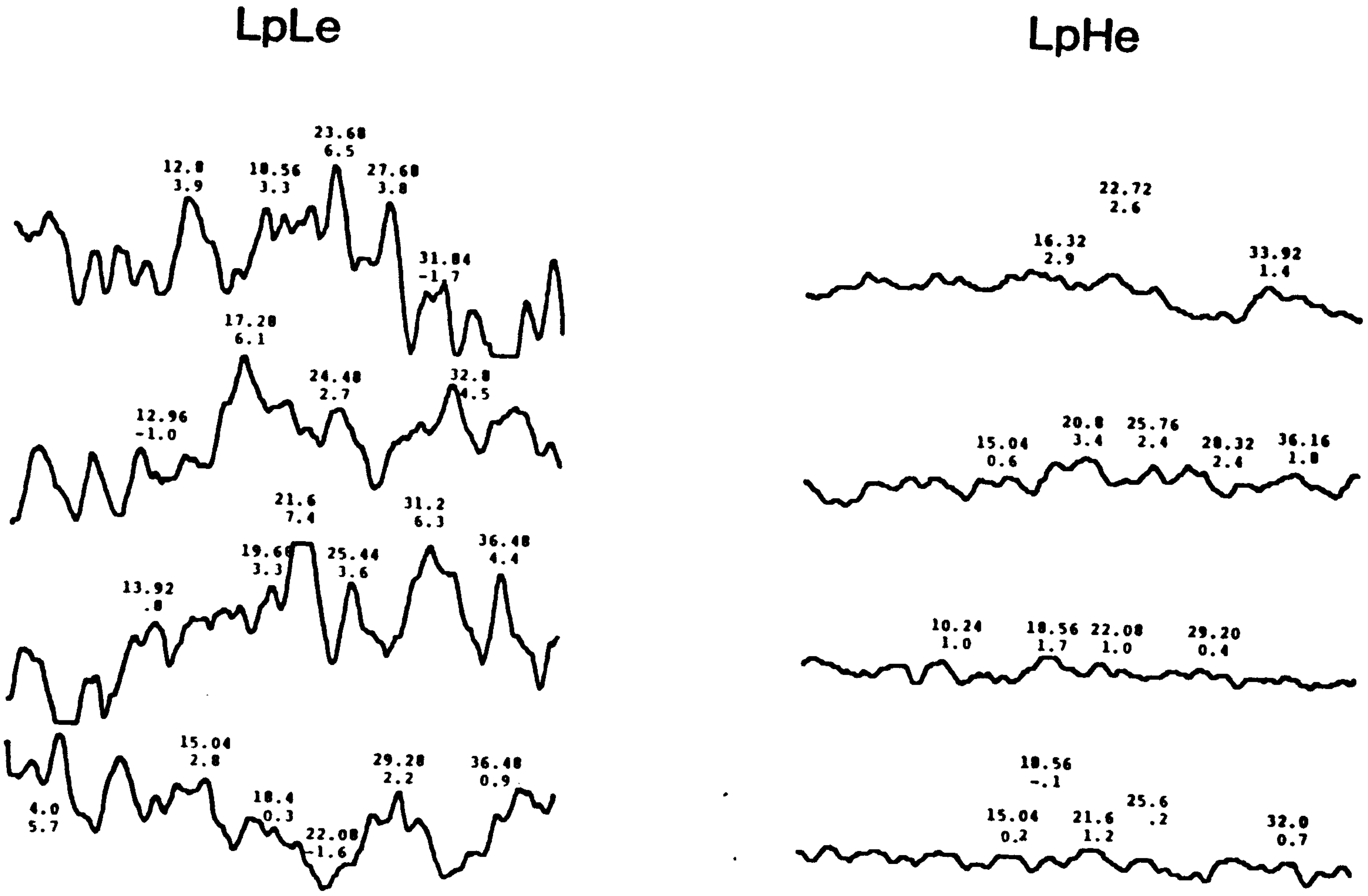
3.5
35.3
3.0
A1
20.51
.02
B
10.0
2.5
31.5
2.0
35.5
2.7
B1
3.0
1.2
22.44
0.6
30.23
-0.01
C
16.64
5.1
34.0
0.7
C1
22.53
2.65
27.52
2.6
30.23
4.4
D
15.0
1.0
22.25
1.9
30.4
2.5
36.0
2.0
D1
19.31
-1.5
26.42
-4.2
29.62
-2.5

Subject 11

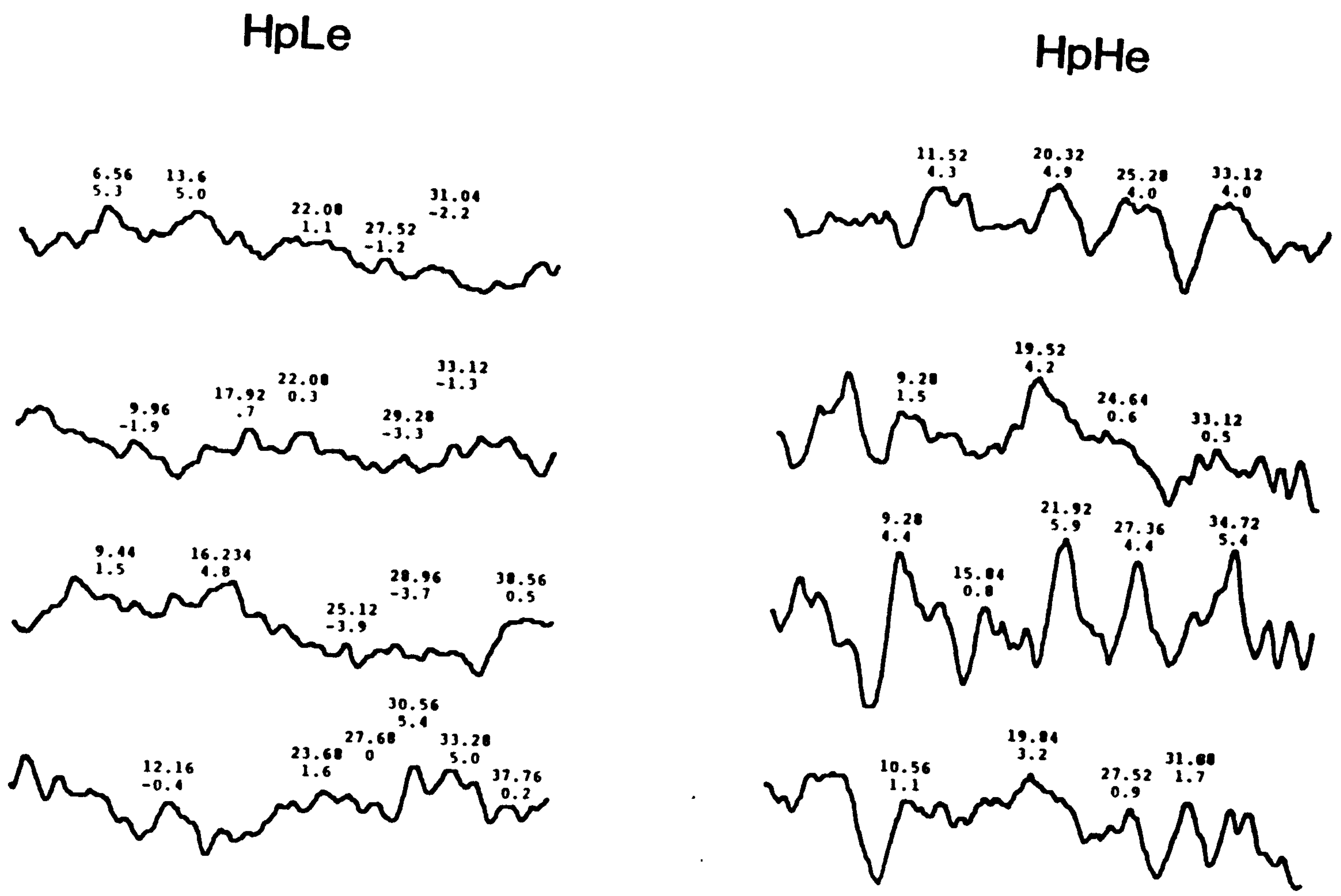

HpLe
HpHe
E
21.7
1.6
E1
20.4
1.7
25.44
2.3
31.36
3.3
F
11.04
0.6
F1
5.24
3.2
22.0
2.1
G
21.44
1.0
28.16
2.0
G1
19.04
2.5
26.24
4.5
H
22.56
1.7
H1
22.4
4.0
28.0
3.45
32.48
3.0

Subject 12


LpLe

LpHe

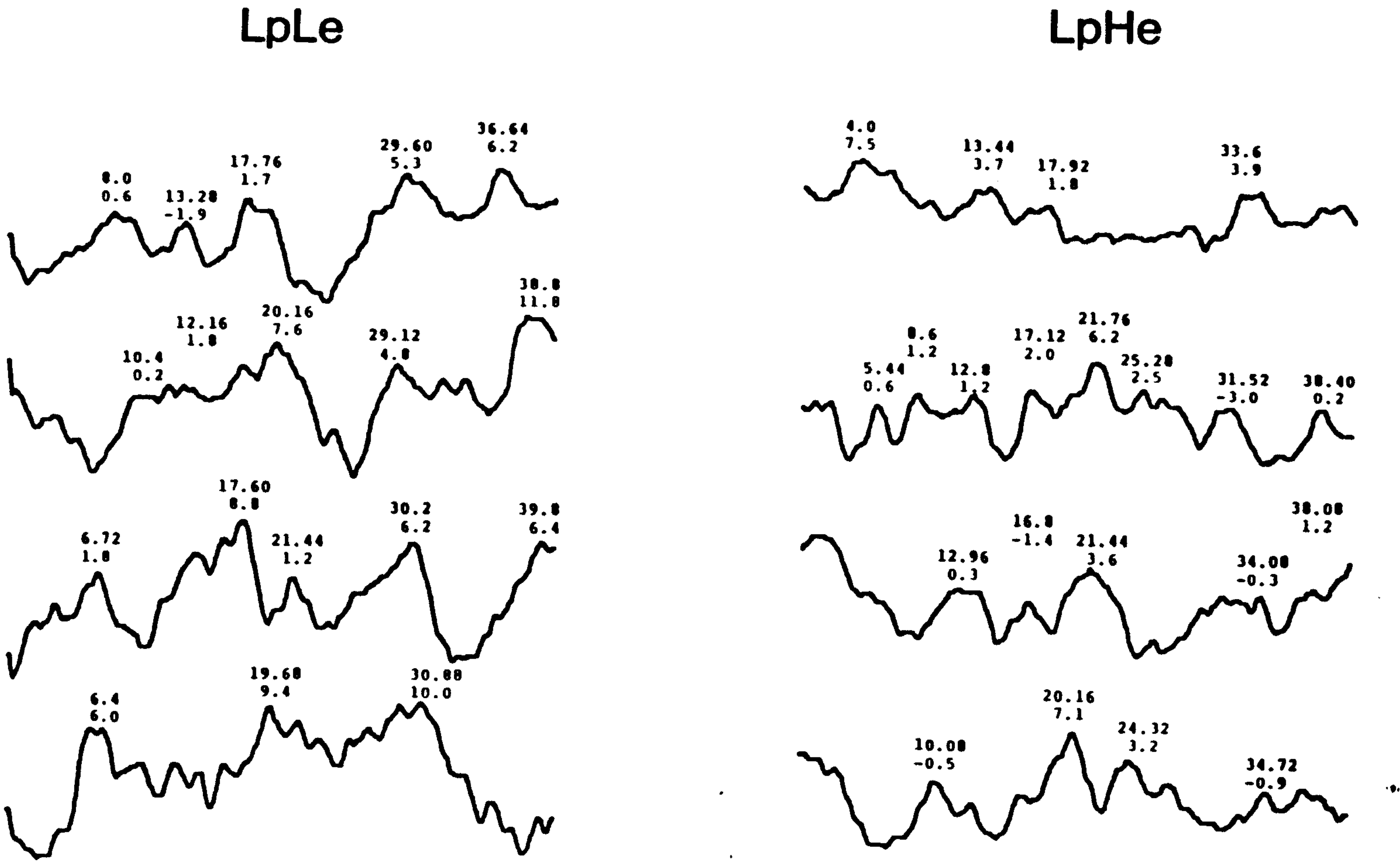
Subject 12



HpLe

HpHe

Subject 13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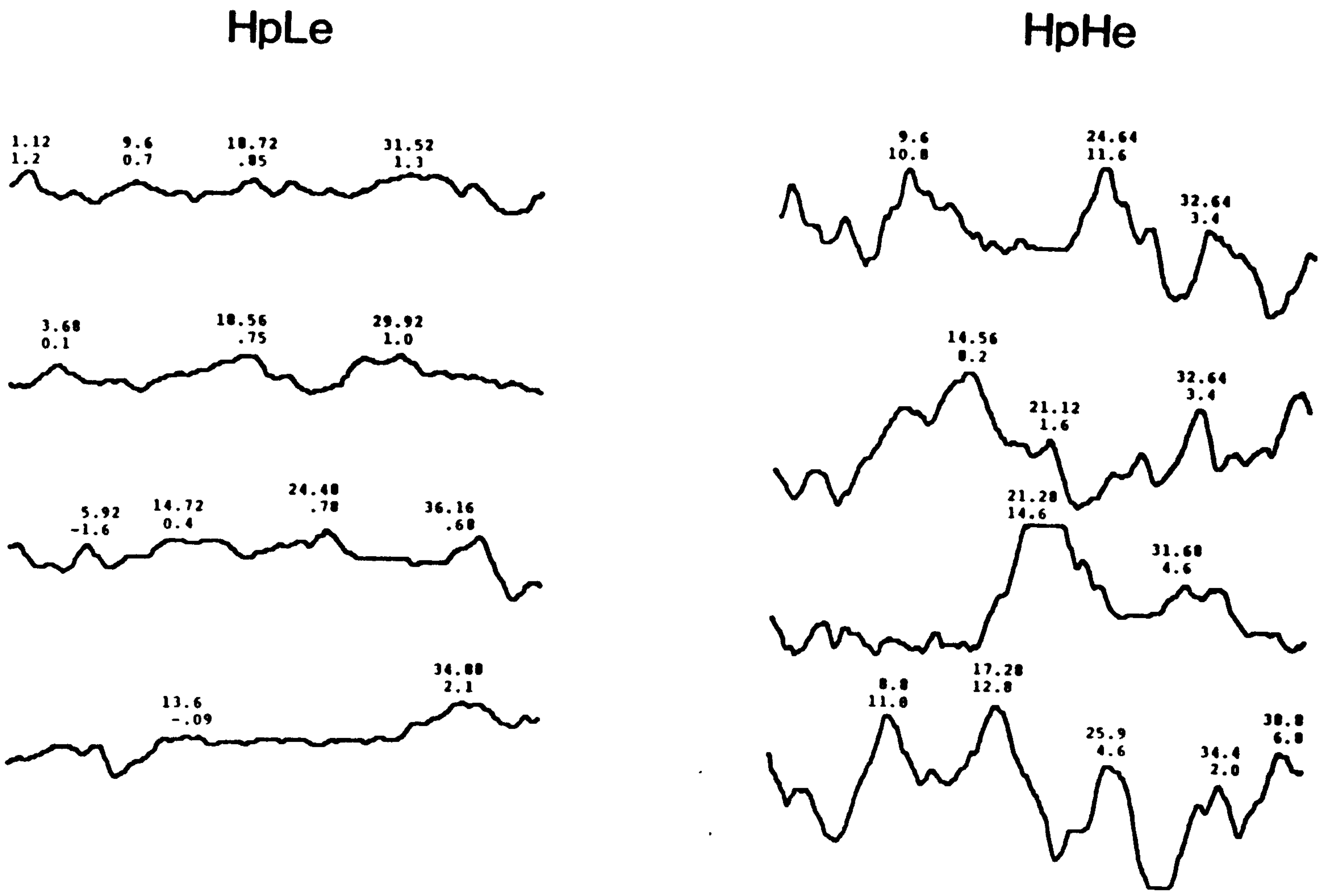
-1.9
17.76
1.7
29.60
5.3
36.64
6.2
10.4
0.2
12.16
1.8
20.16
7.6
29.12
4.8
38.8
11.8
6.72
1.8
17.60
8.8
21.44
1.2
30.2
6.2
39.8
6.4
6.4
6.0
19.68
9.4
30.88
10.0
4.0
7.5
13.44
3.7
17.92
1.8
33.6
3.9
5.44
0.6
8.6
1.2
12.8
1.2
17.12
2.0
21.76
6.2
25.28
2.5
31.52
-3.0
38.40
0.2
12.96
0.3
16.8
-1.4
21.44
3.6
34.08
-0.3
38.08
1.2
10.08
-0.5
20.16
7.1
24.32
3.2
34.72
-0.9

Subject 13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HpHe
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9.6
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1.3
3.68
0.1
18.56
.75
29.92
1.0
5.92
-1.6
14.72
0.4
24.48
.78
36.16
.68
13.6
-.09
34.88
2.1
9.6
10.8
24.64
11.6
32.64
3.4
14.56
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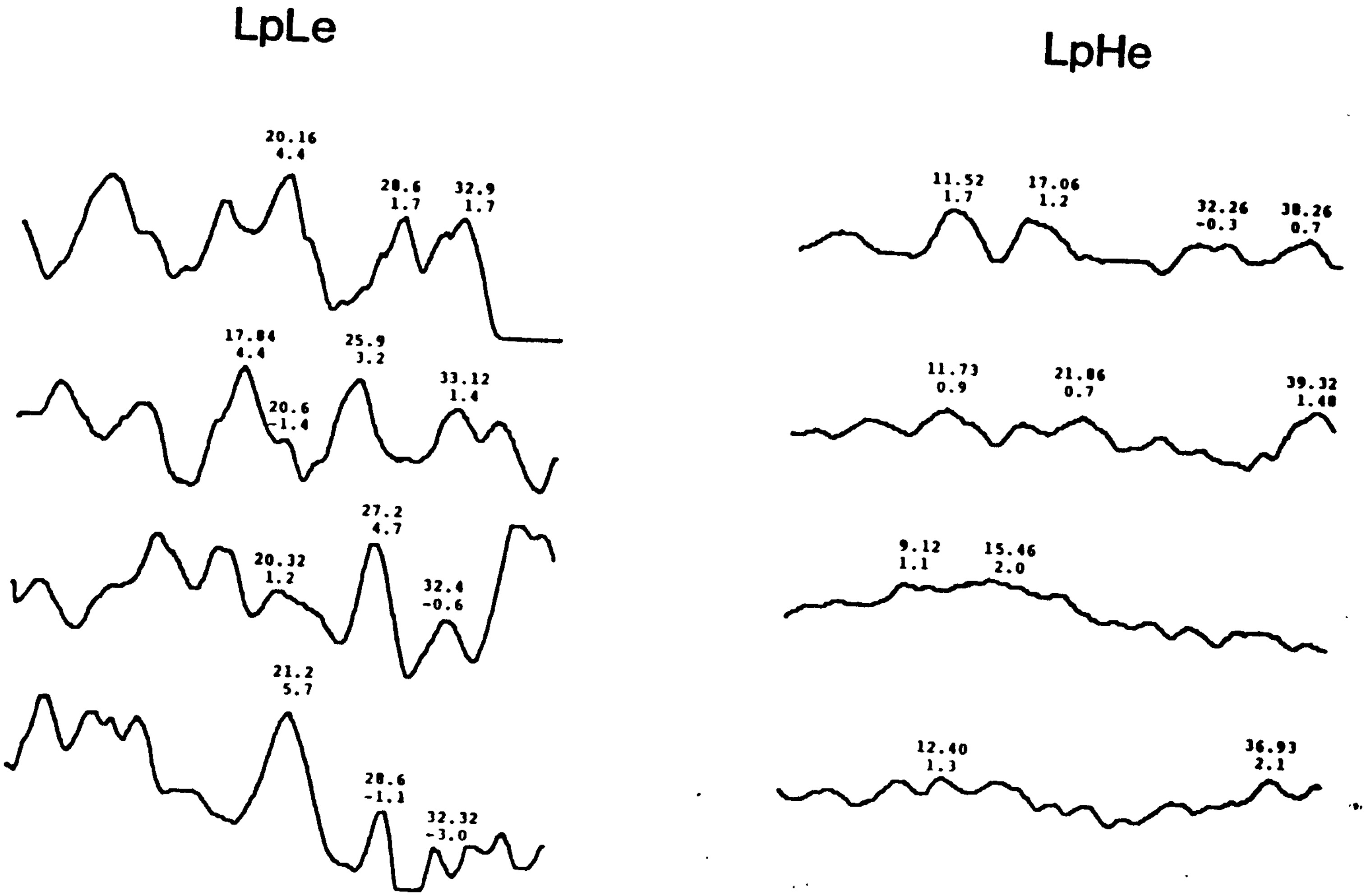
3.4
21.28
14.6
31.68
4.6
8.8
11.8
17.28
12.8
25.9
4.6
34.4
2.0
38.8
6.8

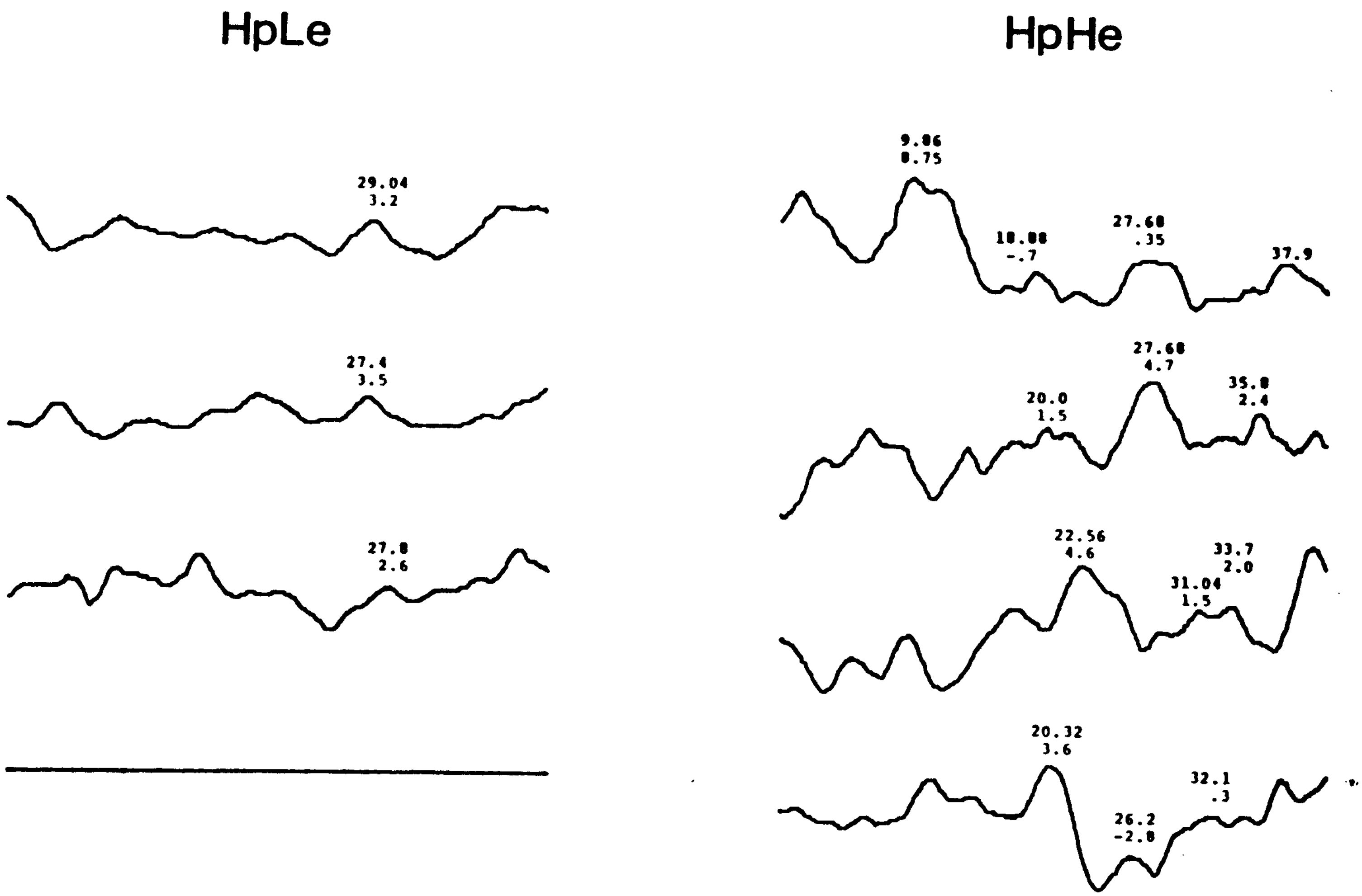
Subject 14



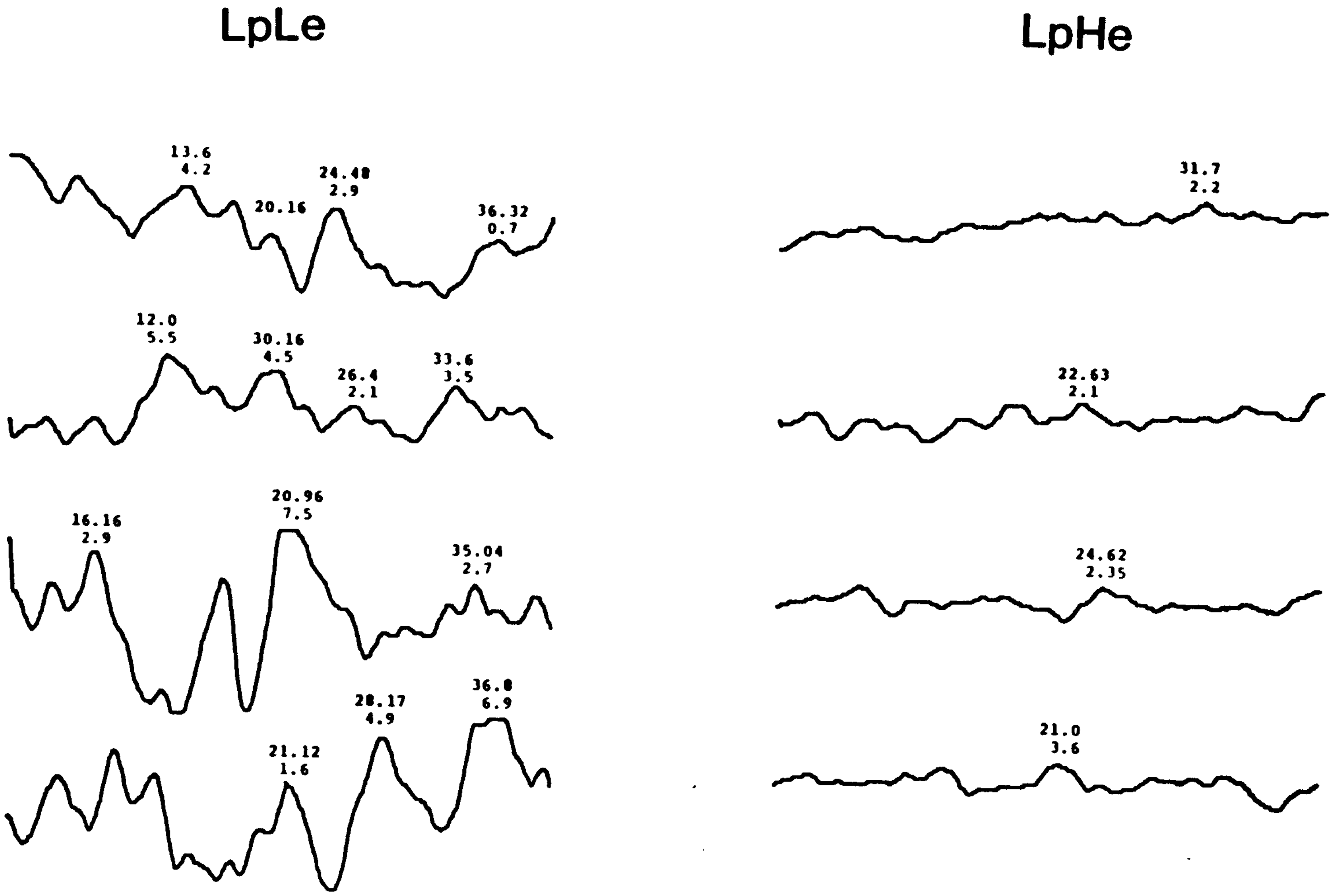
LpLe

LpHe

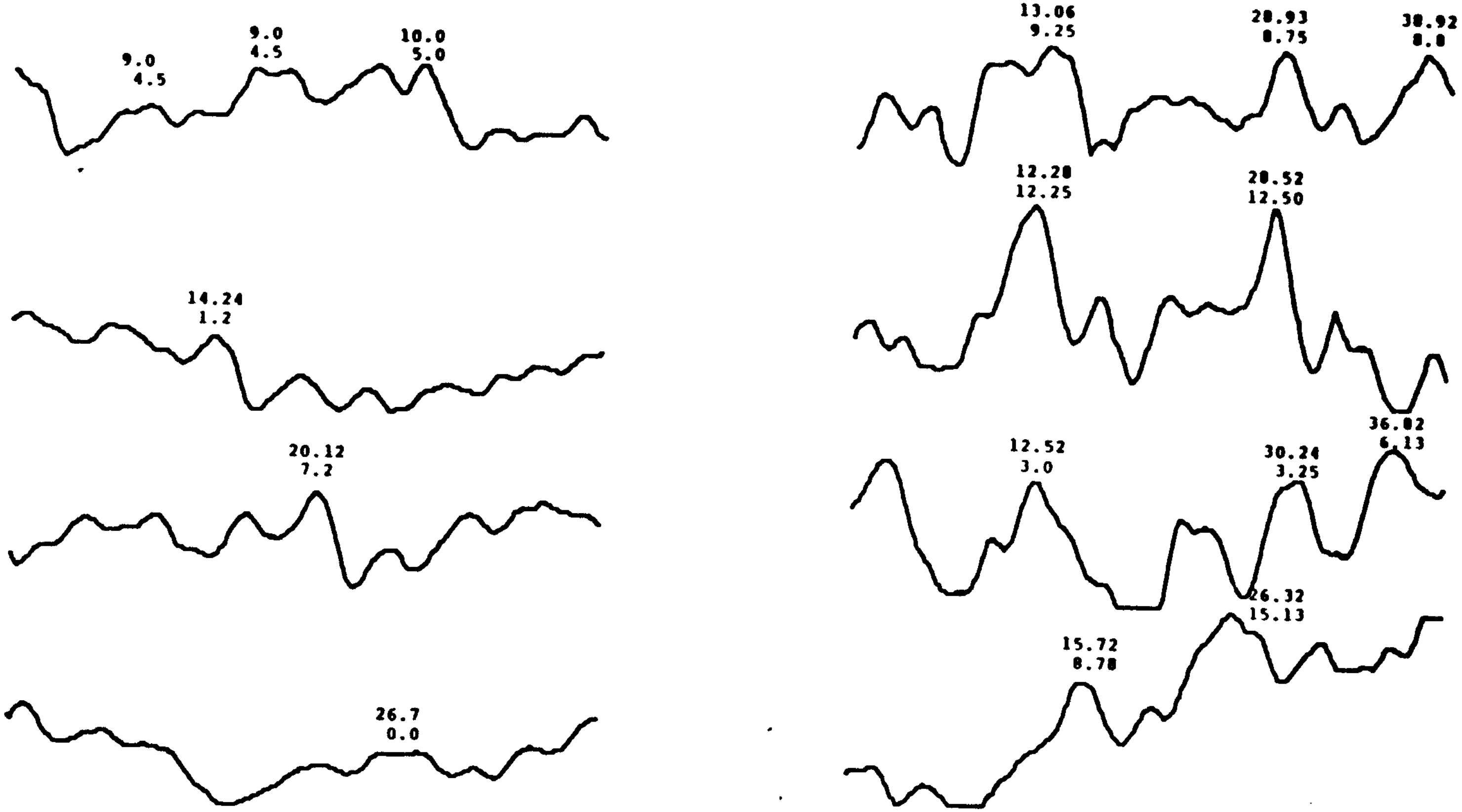
Subject 14


HpLe
HpHe
29.04
3.2
27.4
3.5
27.8
2.6
9.86
8.75
18.88
-.7
27.68
.35
37.9
27.68
4.7
20.0
1.5
35.8
2.4
22.56
4.6
33.7
2.0
31.04
1.5
20.32
3.6
32.1
.3
26.2
-2.8

Subject 15


LpLe
13.6
4.2
20.16
24.48
2.9
36.32
0.7
12.0
5.5
30.16
4.5
26.4
2.1
33.6
3.5
16.16
2.9
20.96
7.5
35.04
2.7
21.12
1.6
28.17
4.9
36.8
6.9
LpHe
31.7
2.2
22.63
2.1
24.62
2.35
21.0
3.6

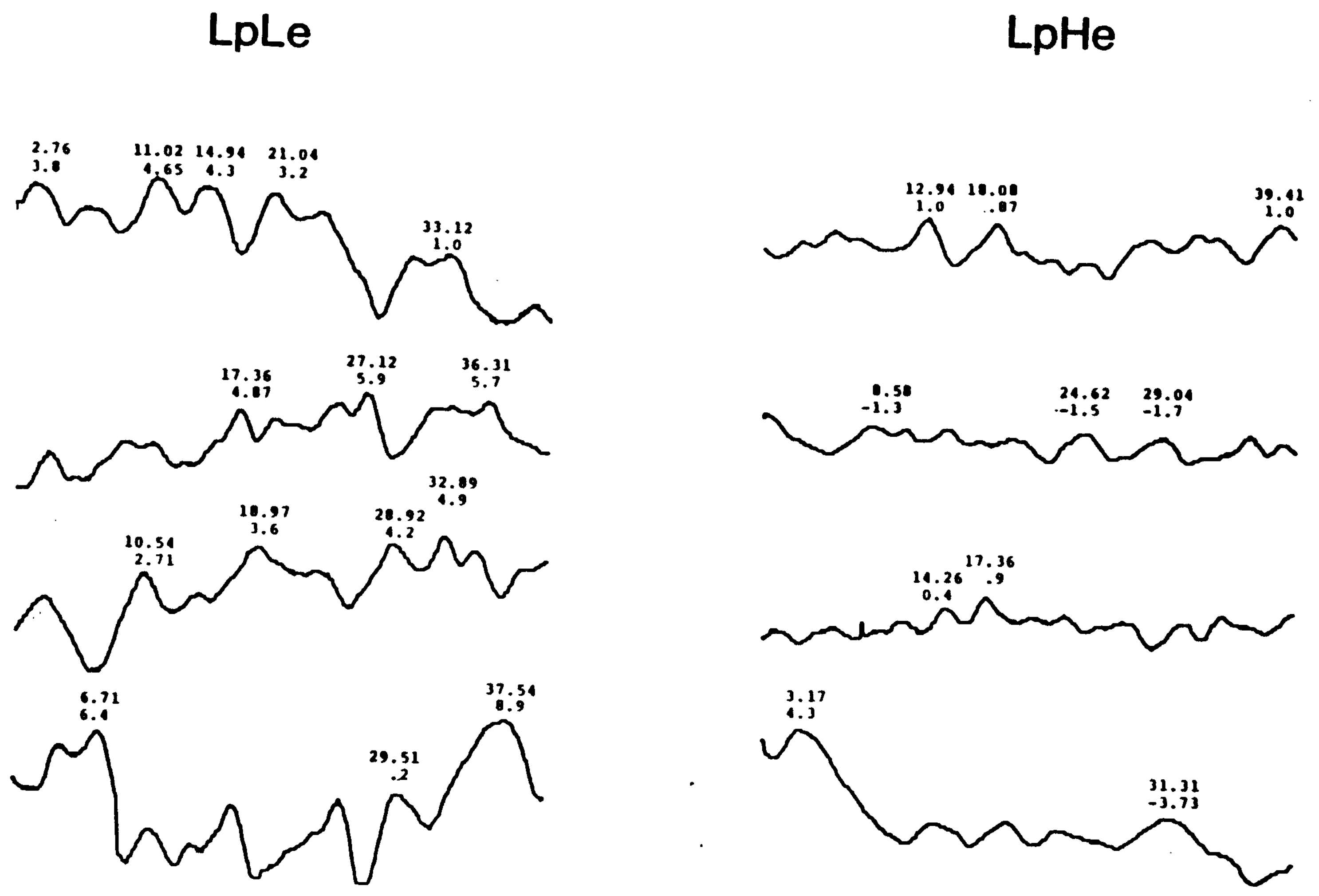
Subject 15



HpLe

HpHe

Subject 16


LpLe
2.76
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11.02
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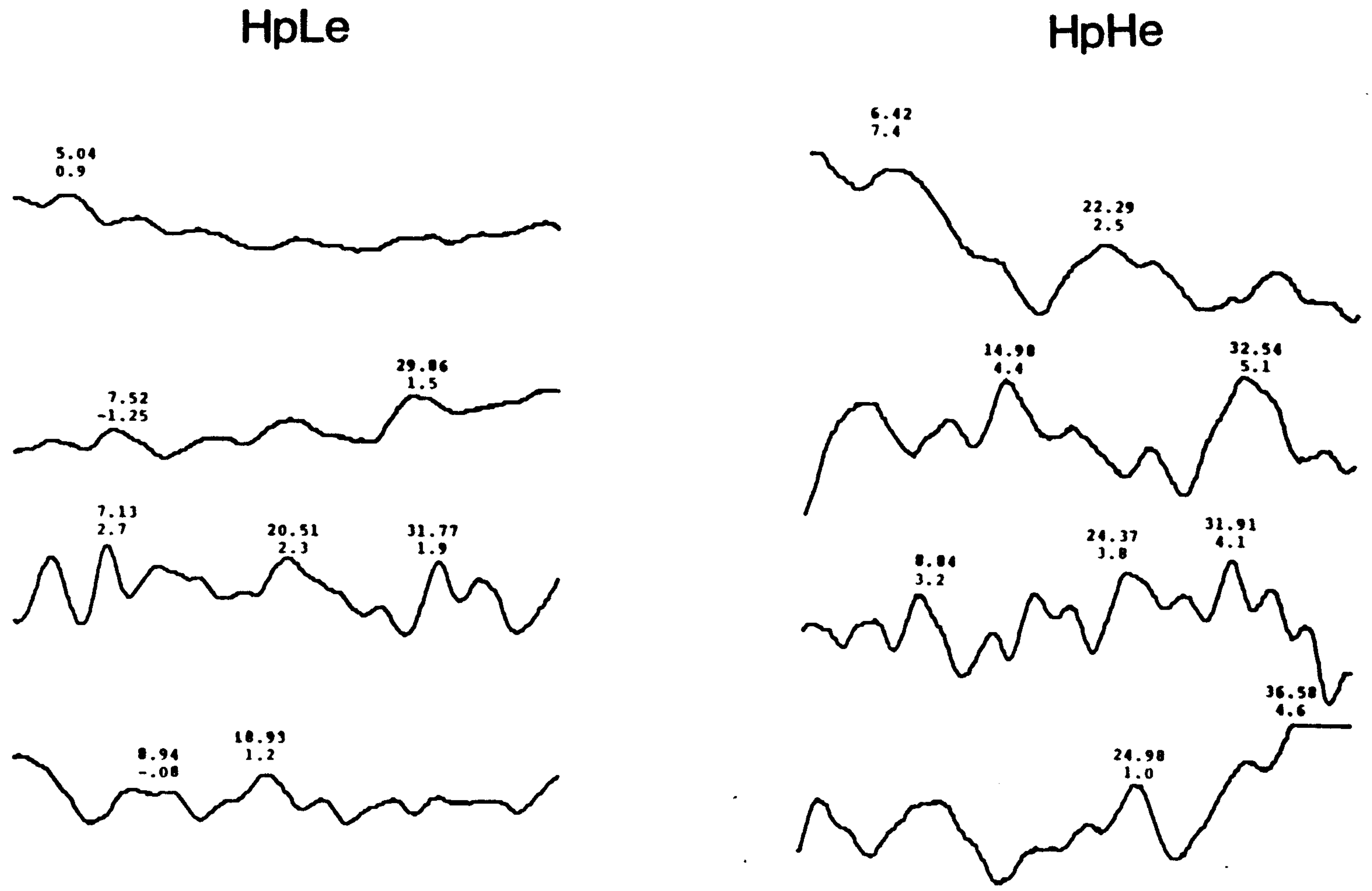
14.94
4.3
21.04
3.2
33.12
1.0
17.36
4.87
27.12
5.9
36.31
5.7
10.54
2.71
18.97
3.6
28.92
4.2
32.89
4.9
6.71
6.4
29.51
.2
37.54
8.9
LpHe
12.94
1.0
18.08
.87
39.41
1.0
8.58
-1.3
24.62
-1.5
29.04
-1.7
14.26
0.4
17.36
.9
3.17
4.3
31.31
-3.73

Subject 16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HpHe
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2.5
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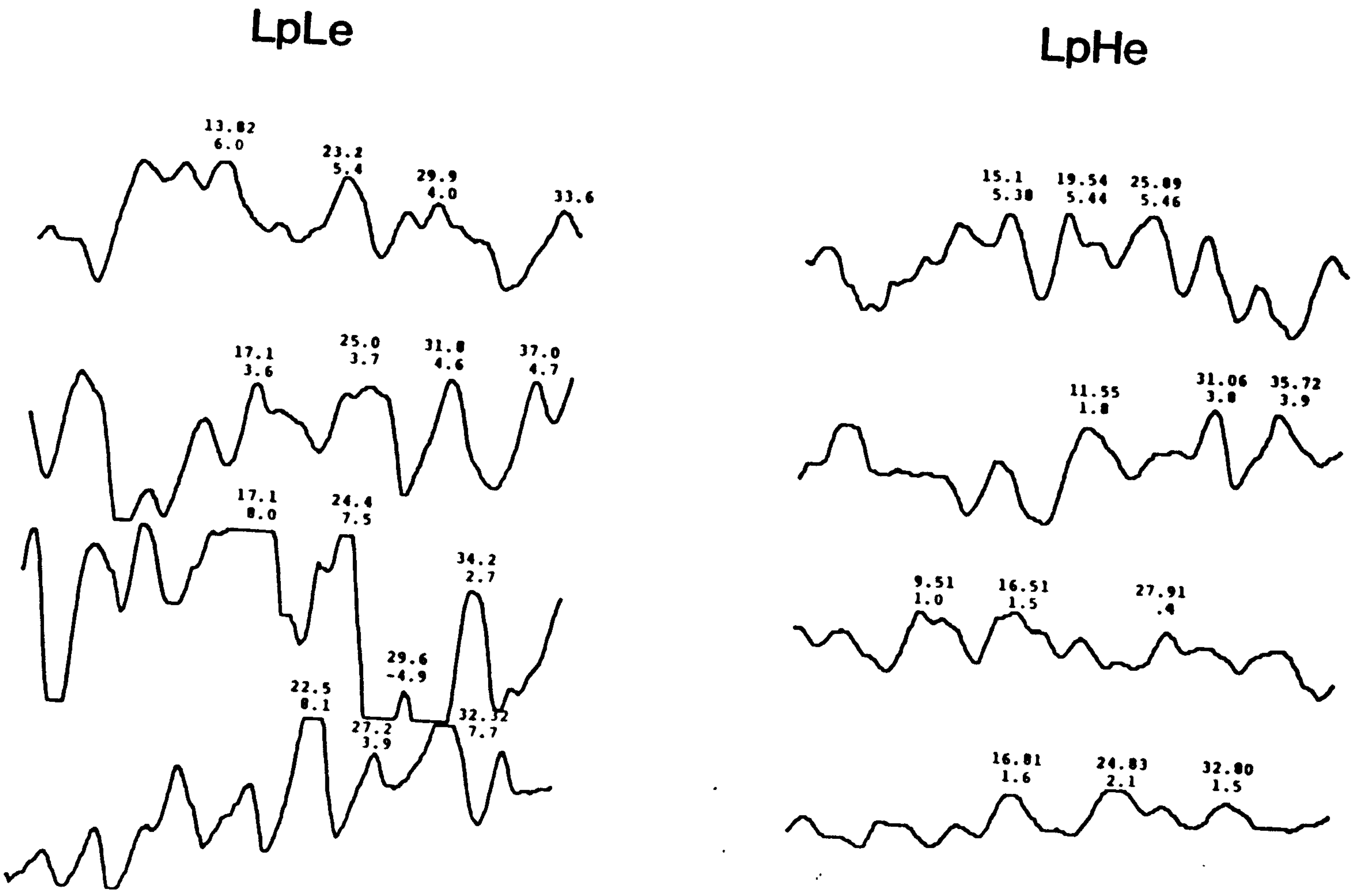
-1.25
29.86
1.5
14.98
4.4
32.54
5.1
7.13
2.7
20.51
2.3
31.77
1.9
8.84
3.2
24.37
3.8
31.91
4.1
8.94
-.08
18.93
1.2
24.98
1.0
36.58
4.6

Subject 17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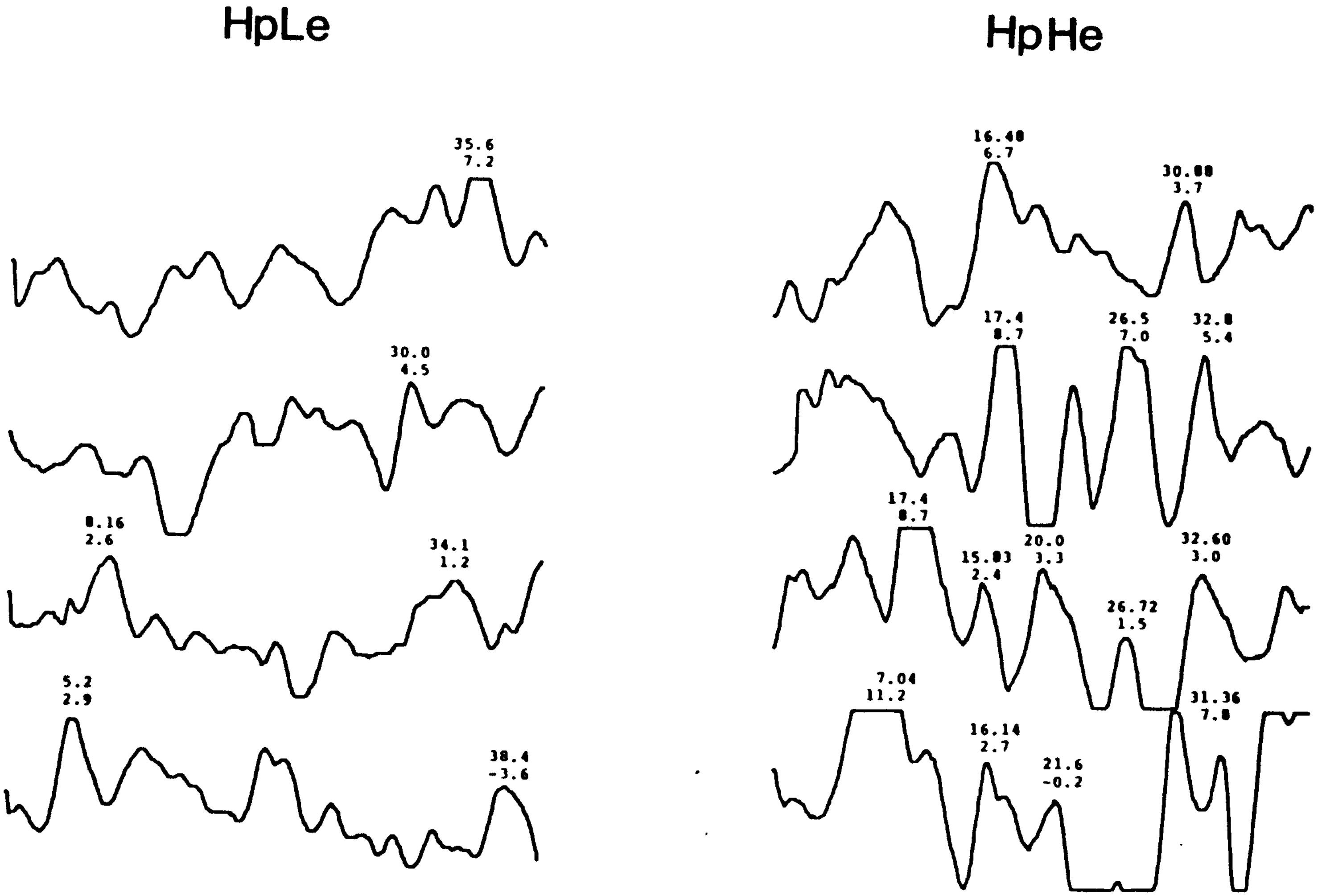
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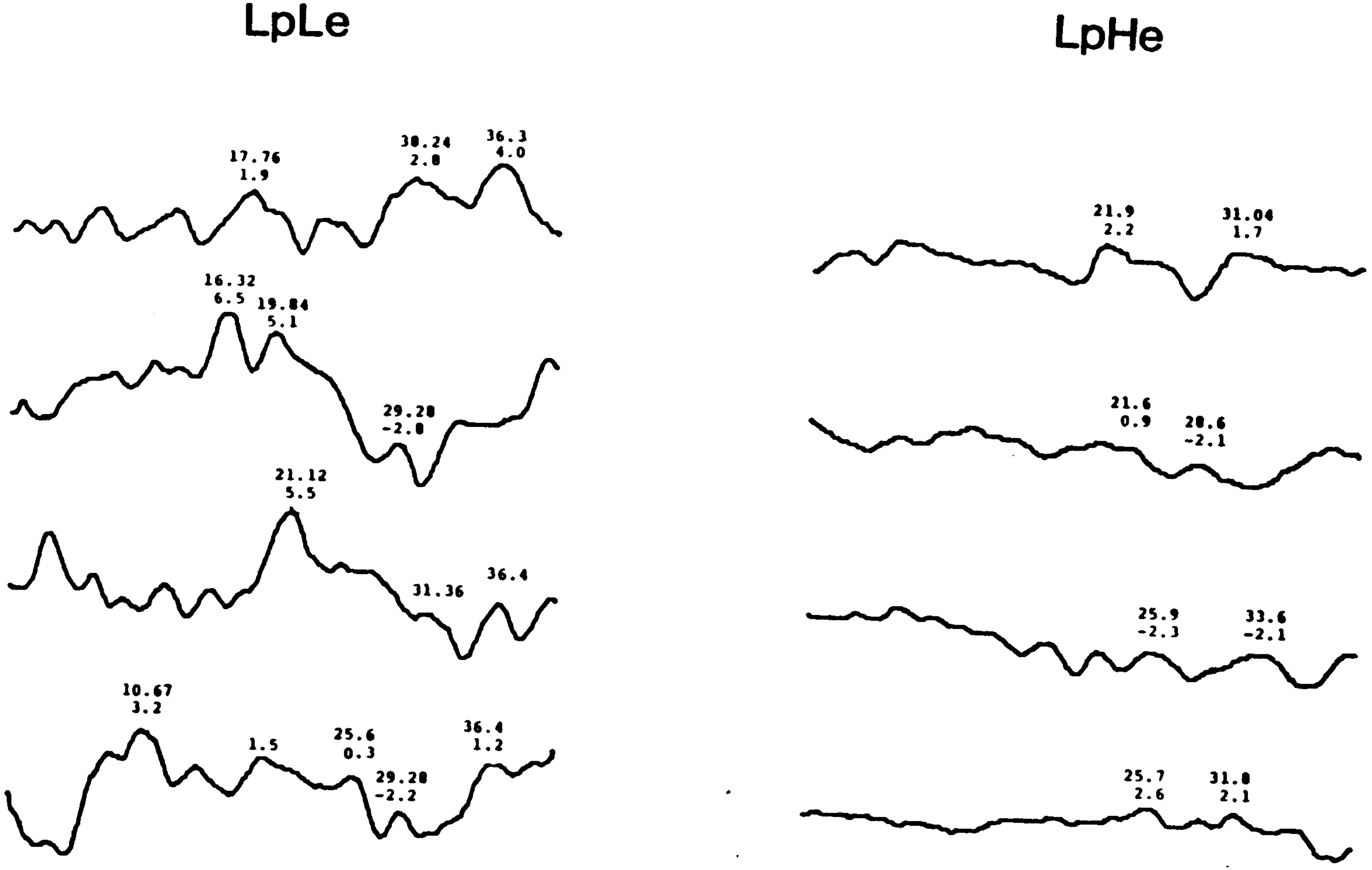
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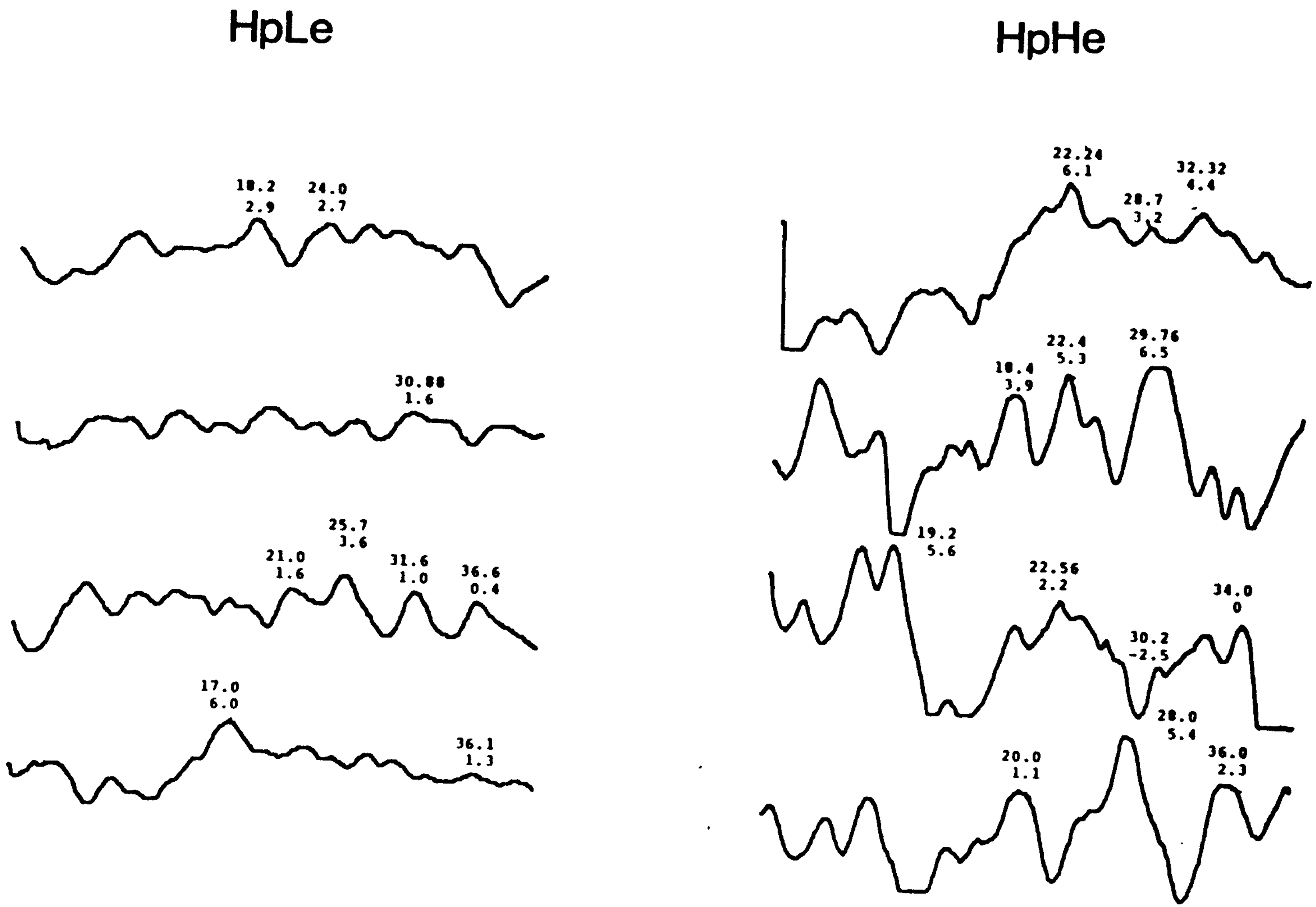
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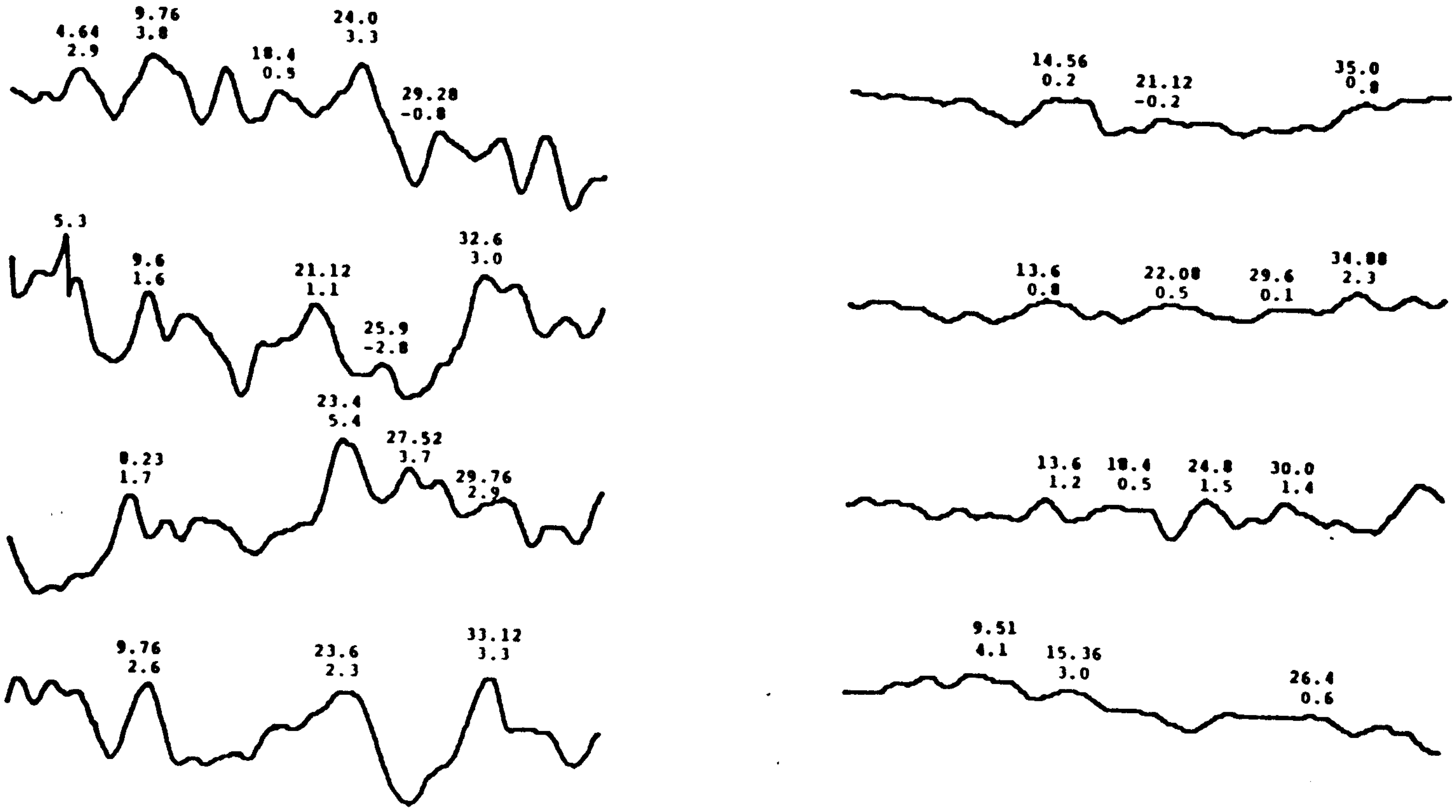
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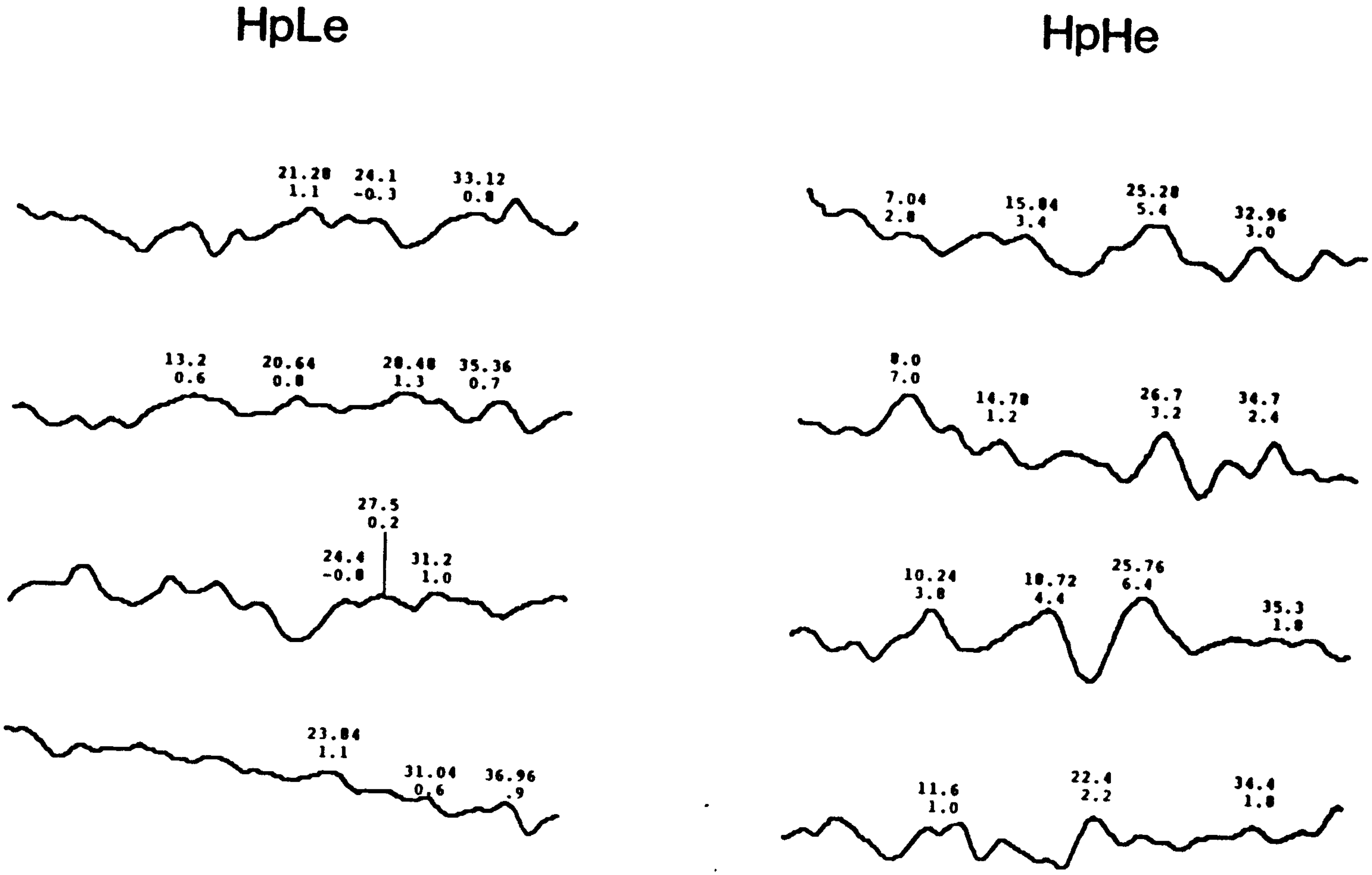
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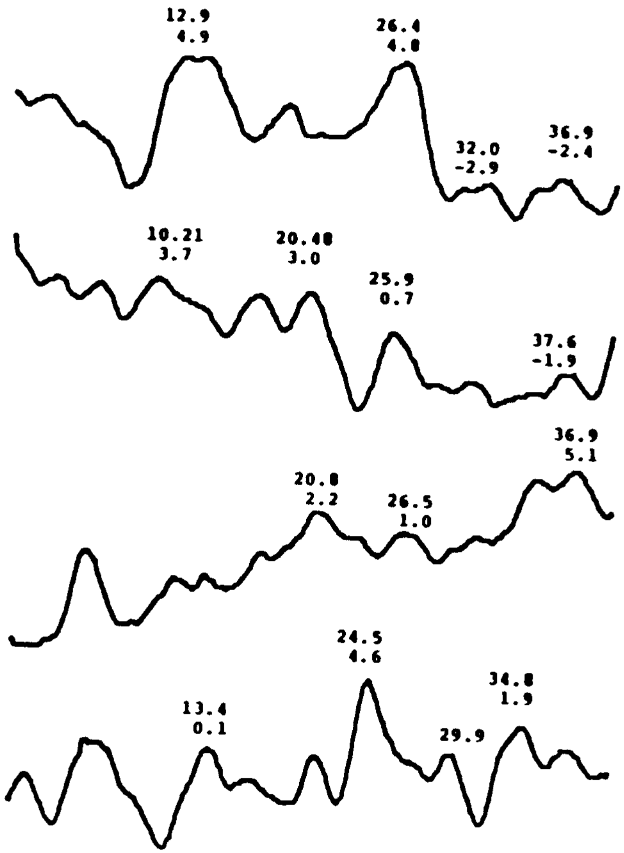

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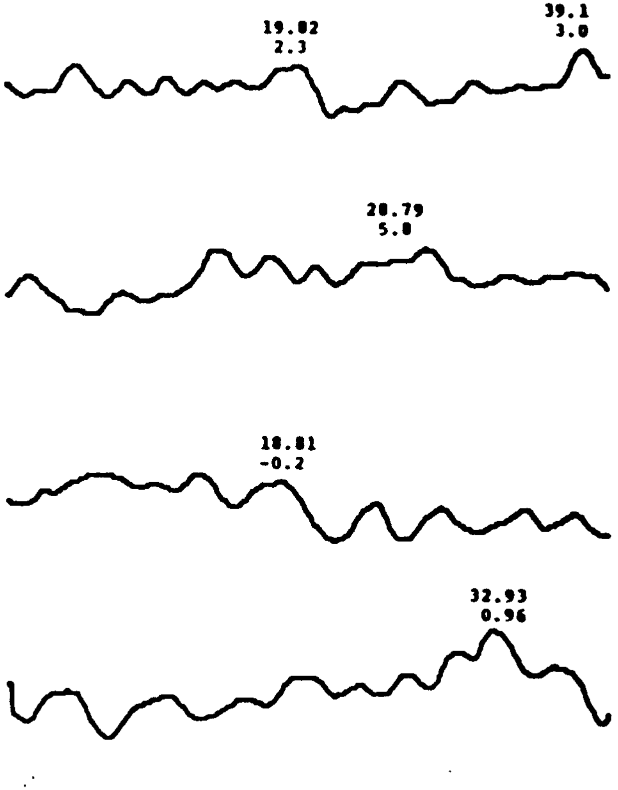

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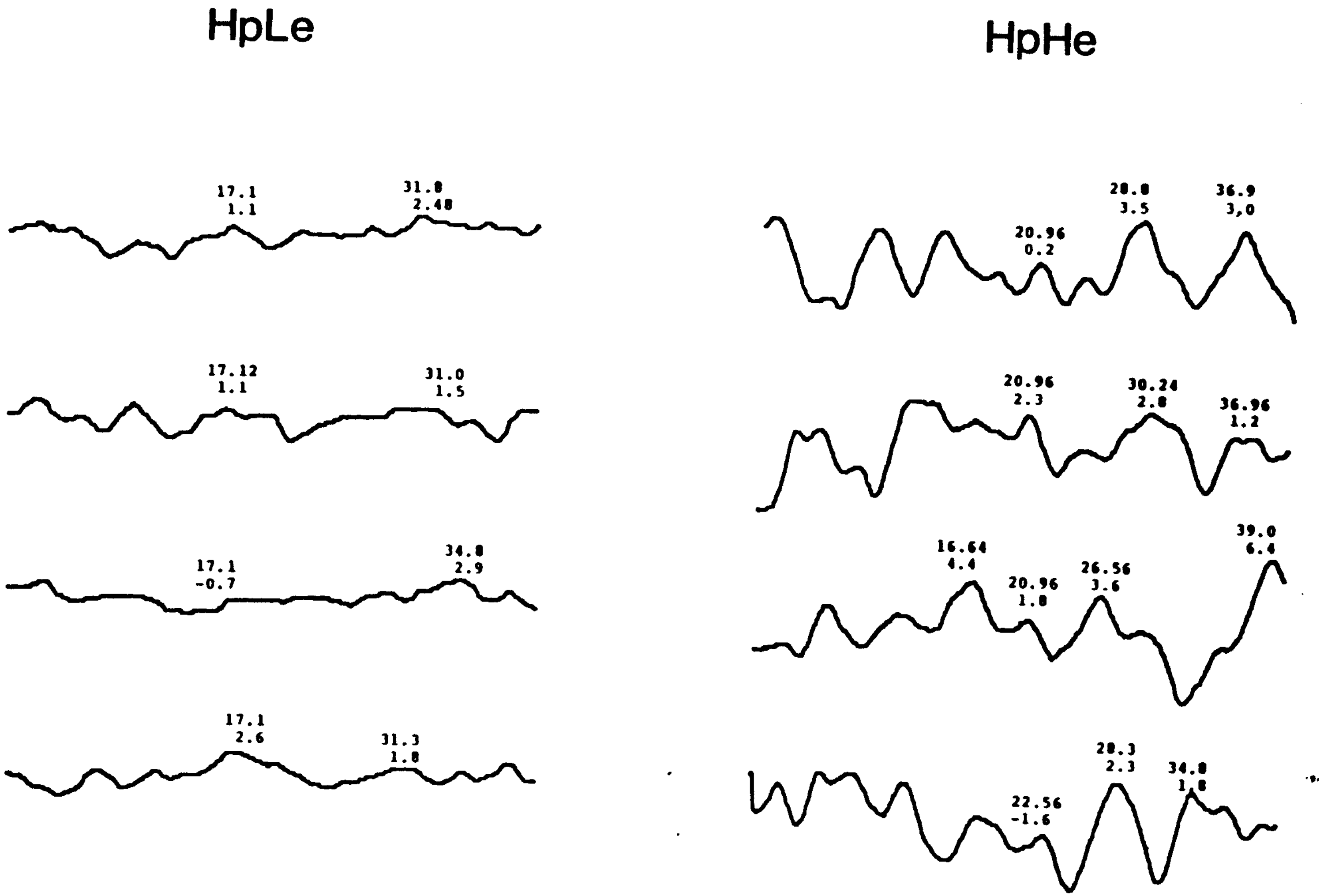
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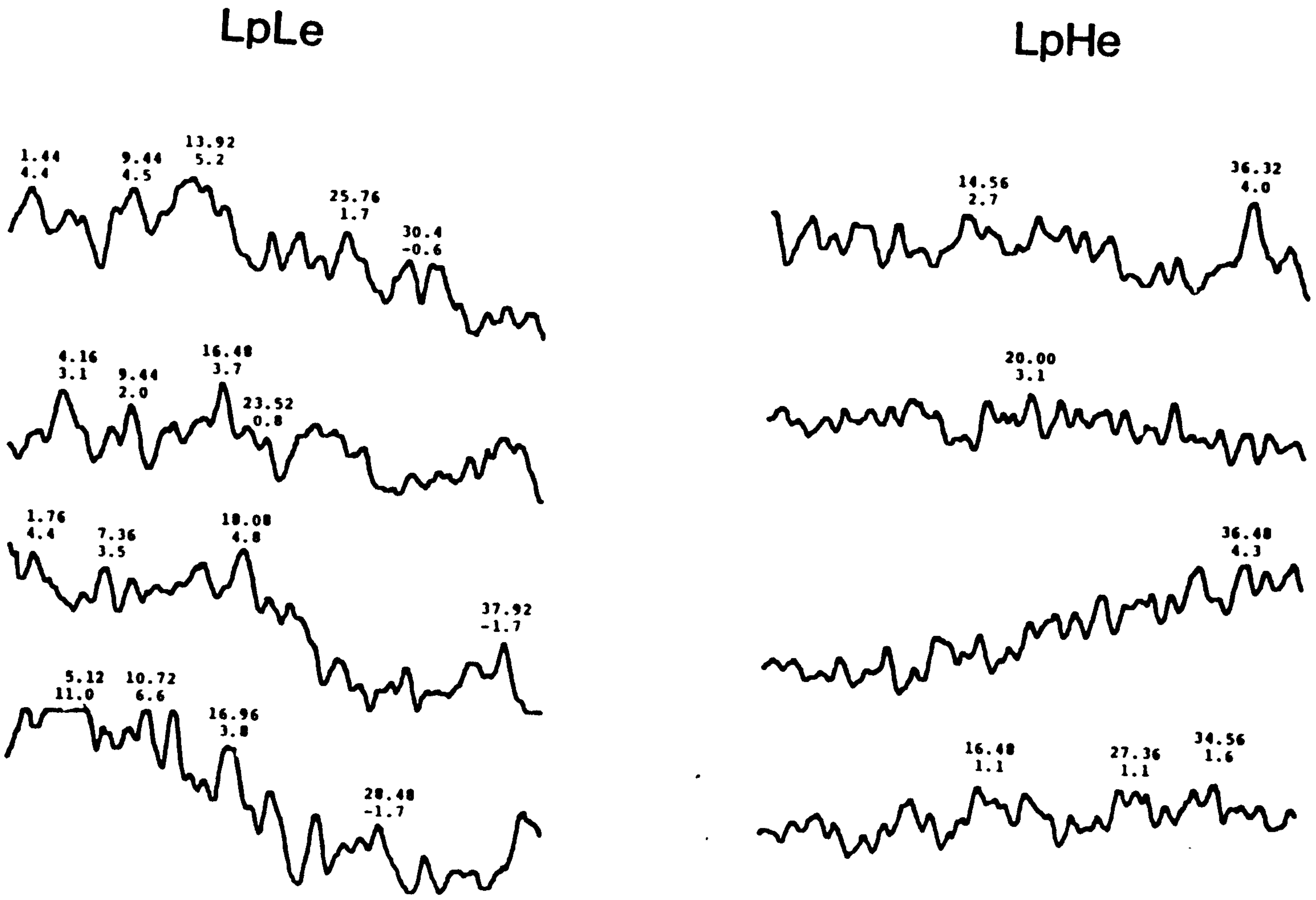
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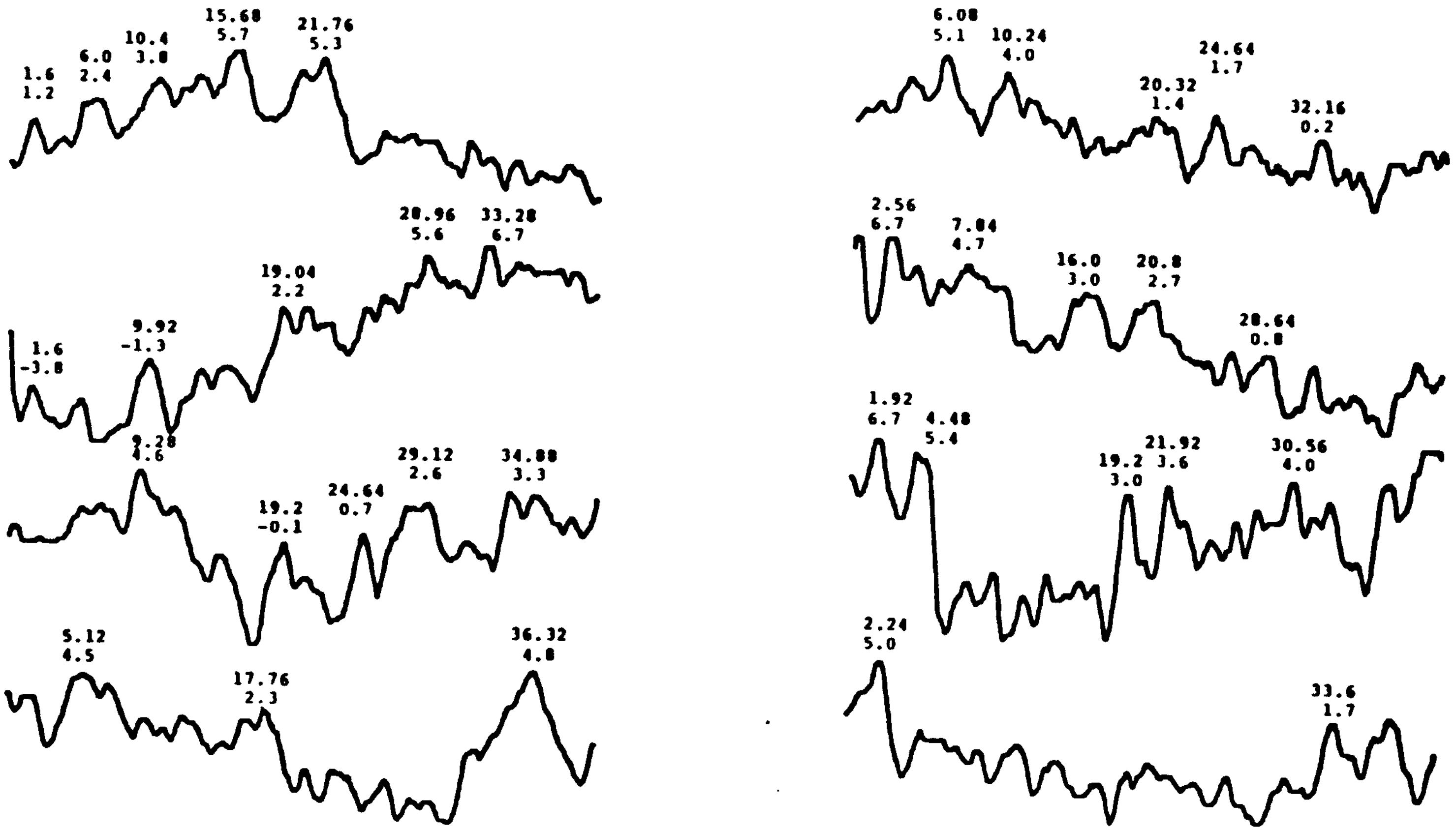

HpLe

HpHe

APPENDIX TWO

PHOTOGRAPHS OF MUSCLES BEING INVESTIGATED

TAKEN FROM
SLIDES OF THE HEAD AND NECK ANATOMY CLASS

Page 196 indicates the depressor muscles

Page 197 indicates the elevator muscles

DEPRESSOR MUSCLES

ELEVATOR MUSCLES

APPENDIX THREE

FREQUENCY TABLE USED IN DETERMINING PITCH STIMULI FOR DIGITAL TAPE

C-16.3515977625Hz
C#-17.3239154815673 8Hz
D-18.3540477752685 5Hz
D#-19.445436477661 13Hz
E-20.601722717285 16Hz
F-21.826765060424 8Hz
F#-23.124650955200 2Hz
G-24.499713897705 08Hz
G#-25.95654296875Hz
A-27.5Hz
A#-29.135236740112 31Hz
B-30.867706298828 13Hz
C-32.703195525Hz
C#-34.647830963134 76Hz
D-36.708095550537 1Hz
D#-38.890872955322 26Hz
E-41.203445434570 32Hz
F-43.653530120849 6Hz
F#-46.249301910400 4Hz
G-48.999427795410 16Hz
G#-51.9130859375Hz
A-55Hz
A#-58.270473480224 62Hz
B-61.735412597656 26Hz
C-65.40639105Hz
C#-69.295661926269 52Hz
D-73.416191101074 2Hz
D#-77.781745910644 52Hz
E-82.406890869140 64Hz
F-87.307060241699 2Hz
F#-92.498603820800 8Hz
G-97.998855590820 32Hz
G#-103.826171875Hz
A-110Hz
A#-116.540946960449 2Hz
B-123.470825195312 5Hz
C-130.8127821Hz
C#-138.591323852539Hz
D-146.832382202148 4Hz
D#-155.563491821289Hz
E-164.813781738281 3Hz
F-174.614120483398 4Hz
F#-184.997207641601 6Hz
G-195.997711181640 6Hz
G#-207.65234375Hz
A-220Hz
A#-233.081893920898 5Hz
B-246.941650390625Hz
C-261.6255642Hz

C-261.6255642Hz
C#-277.182647705078 1Hz
D-293.664764404296 8Hz
D#-311.126983642578 1Hz
E-329.627563476562 6Hz
F-349.228240966796 8Hz
F#-369.994415283203 2Hz
G-391.995422363281 3Hz
G#-415.3046875Hz
A-440Hz
A#-466.16378784179 7Hz
B-493.883300781250 1Hz
C-523.2511284Hz
C#-554.365295410156 2Hz
D-587.329528808593 6Hz
D#-622.253967285156 2Hz
E-659.255126953125 1Hz
F-698.456481933593 6Hz
F#-739.988830566406 4Hz
G-783.990844726562 6Hz
G#-830.609375Hz
A-880Hz
A#-932.327575683593 9Hz
B-987.766601562500 2Hz
C-1046.5022568Hz
C#-1108.730590820312Hz
D-1174.659057617187Hz
D#-1244.507934570312Hz
E-1318.51025390625Hz
F-1396.912963867187Hz
F#-1479.977661132813Hz
G-1567.981689453125Hz
G#-1661.21875Hz
A-1760Hz
A#-1864.655151367188Hz
B-1975.53320312 5Hz
C-2093.0045136Hz

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