ELECTROMYOGRAPHIC STUDIES ON THE HUMAN RESPIRATORY MUSCLES

—STUDIES ON THE ACTIVITY PATTERN OF NEUROMUSCULAR UNITS (8)—

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The muscles participating in the respiratory movement are grouped into inspiratory and expiratory muscles, and each group of them are, further, classified into principal and accessory respiratory muscles, the former acting during quiet breathing, the latter coming into play during forced breathing. As to the human respiratory muscles, the following classification as shown in table 1 is generally accepted. In addition, the latissimus dorsi, serratus dorsalis caudalis and quadratus lumborum muscles are also considered to participate in the

Table 1.

Principal inspiratory muscle	Accessory inspiratory muscle	Principal expiratory muscle	Accessory expiratory muscle
diaphragm m. intercostalis externus intercartilaginous portion of m. intercostalis internus m. transversocostalis longus et brevis	m. sternocleidomastoideus m. levator scapulae mm. scaleni m. trapezius m. rhomboides m. pectoralis major et minor m. serratus dorsalis cranialis m. serratus lateralis m. subclavius extensors of the spinal column	interosseous portion of m. intercostalis internus m. transversus thoracis	m. rectus abdominis m. transversus abdominis m. obliquus abdominis externus et internus m. sacrospinalis

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respiratory movement, but among the investigators there is no agreement on their function.

This classification in table 1, however, was not made on the basis of the direct investigation on the human subject, but was plausibly presumed from the observations on the anesthetized animal such as the dog, cat and rabbit being abnormally fixed in the supine posture. As several workers (5, 37) already pointed out, there is no guarantee that the respiratory muscles of the biped, the man, and those of the quadrupedal animal are exactly the same, and also that each and all respiratory muscles always act in an identical fashion without regard to the animal's posture. Furthermore, we cannot most probably disregard the influence of anesthetics upon their activity (1). In these connections, the present authors tried to examine electromyographically the respiratory muscles of the normal human subject and also to clarify the activity pattern of a single neuromuscular unit with which they are constructed.

METHOD

All attainable muscles of neck, trunk and extremities were examined on five healthy adult males. Possessing various postures such as the standing, sitting, sidelying and supine postures, the subject was asked to perform three different types of the respiratory movements, that is, quiet breathing, forced breathing and forced breathing accompanied by the movement of the shoulders and upper limbs as shown in fig. 1. Action potentials were led off by a coaxial needle electrode and recorded together with the respiratory movement of the thorax by an electromagnetic oscillograph. For recording the respiratory movement an electrical

Fig. 1. Schematic illustration of the forced breathing accompanied by the movement of the shoulders and upper limbs. A: expiration; B: inspiration.

pneumograph of a variable resistance type composed of ZnSO_4 -solution contained in a rubber tube and Zn-electrodes connected with a battery was used.

In order to see the respiratory participation of the so-called antigravity muscles such as the trapezius, supraspinatus, sacrospinalis muscles, etc. (33), the correlation between the temporal variation of the discharge intervals of a single neuromuscular unit and the respiratory movement was examined. In this procedure, if the respiratory variation in the discharge intervals was not so evident as to fail to obtain the distinct correlation between them, then calculating the serial correlation coefficients between successive discharge intervals, the correlogram (30) was drawn, of which was tested whether a period in it coincides with the period of respiration or not.

As to the latissimus dorsi, serratus lateralis, triceps brachii muscles, etc., which do not act even during forced breathing, the nature of the subliminal excitatory state set up by the impulses descending from the respiratory centers to the motoneurons which innervate the respective muscles was examined. For

this procedure the same method as used in the study of the attitudinal reflexes in normal persons (32) was applied. Thus, the muscle in question was kept in the state of weakly sustained voluntary contraction of a constant strength, and the discharges of a single neuromuscular unit were recorded together with the respiratory movement. Then, on its record the correlation between the temporal variation of the discharge intervals and the respiratory movement was examined. For illustrating plainly the temporal relation between the changed manner of the discharge intervals and the respiratory movement, the interval diagram such as fig. 3 and on was drawn, in which abscissa and ordinate represent time and the discharge interval respectively, and the lower curve shows the temporal course of the respiratory movement, downstroke indicating inspiration.

As to the muscles in the deeper layer which failed to be examined on the healthy persons, an examination was performed on patients during surgical operation, and in addition the respiratory muscles of patients with marked muscular atrophy accompanied by severe dyspnea (for example, spinal progressive muscular atrophy) were also examined for comparison.

RESULTS AND DISCUSSION

The results obtained in the standing and sitting postures are summarized in table 2 and are schematically illustrated in fig. 2. In this table, the third column shows the presence (+) or absence (-) of the antigravitic function. The fourth, fifth and sixth columns show the manner of the respiratory participation during three different breathing types respectively, in which I represents the inspiratory participation and E the expiratory participation and respective numbers indicate the degree of their participation, greater numbers showing the stronger participation. The seventh column shows the inspiratory (I) or expiratory (E)

Fig. 2. Schematic illustration of the human respiratory muscles in the standing and sitting postures.

— : principal inspiratory muscle.
 - - - : accessory inspiratory muscle.
 — : principal expiratory muscle.
 - - - : accessory expiratory muscle.

Numbering is the same as in table 2.

Table 2.

	Muscles.		Antigravitic function	Quiet breathing	Forced breathing	Forced breathing with the movement of the shoulders and upper limbs	Respiratory im- pulses from the respiratory centers
1	m. trapezius	pars descendens	+	I	II	III	III
2		pars transversa	+	I	II	III	III
3		pars ascendens	—		I	II	II
4	m. levator scapulae		+	I	II	III	III
5	m. rhomboides		+	I	II	III	III
6	m. sternocleidomastoideus		—		I	I	I
7	mm. scaleni		+	I	II	III	III
8	m. serratus lateralis		—			E	E
9	*m. transversocostalis longus et brevis		+	I	II	II	II
10	m. deltoideus	pars spinata	+	I	II	III	III
11		pars acromialis	—			I	I
12		pars clavicularis	—			E	E
13	m. supraspinam		+	I	II	III	III
14	m. infraspinam		—			I	I
15	m. subclavius		—		I	II	II
16	m. teres major		—			I	I
17	m. teres minor		—			I	I
18	m. pectoralis major		—				I
19	m. pectoralis minor		—				I
20	*m. serratus dorsalis cranialis		+	I	II	II	II
21	*m. serratus dorsalis caudalis		—		E	EE	EE
22	m. latissimus dorsi		—			I	I
23	m. transversus thoracis		—	EE	EEE	EEE	EEE
24	m. triceps brachii		—			I	I
25	m. biceps brachii		—				E

Table 2. (*Continued*)

26	m. extensor carpi radialis et ulnaris	—			I	I
27	m. flexor carpi radialis et ulnaris	—				E
28	m. rectus abdominis	—				E
29	m. transversus abdominis	+	E	EE	EE	EE
30	m. obliquus abdominis externus	+	E	EE	EE	EE
31	m. obliquus abdominis internus	+	E	EE	EE	EE
32	*m. quadratum lumborum	—		E	EE	EE
33	m. semispinalis capitis	+	I	II	III	III
34	*m. semispinalis cervicis et thoracis	+	I	II	III	III
35	m. multifidus	+	I	II	III	III
36	m. longissimus lumborum	+	E	EE	EEE	EEE
37	*m. longissimus thoracis	+	E	EE	EEE	EEE
38	m. iliocostalis lumborum	+	E	EE	EEE	EEE
39	*m. iliocostalis thoracis	+	E	EE	EEE	EEE
40	*m. spinalis	+	I	II	III	II
41	*m. interspinalis	+	I	II	III	III
42	m. intercostalis externus	+	II	III	III	IIIII
43	m. intercostalis internus	intercartilagineous portion (I-IV or V)	+	III	IIII	IIII
44		" (V or VI-)	+	E	EE	EE
45		interosseous portion	+	EE	EEE	EEE
46	diaphragm	—	III	IIII	IIII	IIII

The function of muscles marked with * was estimated without direct investigation.

impulses which spread over the motoneurons of the respective muscles descending from the respiratory centers, and also their intensity by the respective numbers.

Now, comparing table 2 with table 1 we can find several important discrepancies between them. The pars descendens and transversa of the trapezius, levator scapulae, rhomboides, pars spinata of the deltoides and supraspinatus muscles which are generally regarded as an accessory muscle were, proved to participate, even during quiet breathing, actively in the inspiratory movement as well as to support the shoulder girdles antigravitationally (33). Thus, as shown in fig. 3 (A), the shortening of the discharge intervals occurred synchronously with inspiration, indicating the increasing of their muscle tone during the inspiratory movement. These respiratory variations of the discharge intervals which were usually not so evident during quiet breathing, will be more obvi-

Fig. 3 (A). Interval diagram of m. trapezius (pars descendens) during quiet breathing (sitting posture). (B). Correlogram of (A).

ously revealed by drawing the correlogram as shown in fig. 3 (B). As will be discussed later, these respiratory variation seen in the discharge intervals are not a passive phenomenon due to the stretch reflex, but are a sign of the active respiratory participation caused by the impulses descending from the respiratory centers. The semispinalis capitis and multifidus muscles, the extensors of the spinal column, were also proved to show the respiratory participation as well as the antigravitic function. Other extensors of the spinal column, *i.e.* the

Fig. 4 (A). Relation between the respiratory variation of the discharge intervals of a single neuromuscular unit and respiratory movement during forced breathing (sitting posture) in m. trapezius (pars descendens). Downstroke indicates inspiration. Time: 1/50 sec.

Fig. 4 (B). Interval diagram of m. trapezius (pars descendens) during forced breathing (sitting posture).

semispinalis cervicis and thoracis, spinalis, interspinalis muscles, etc., for which no examination was done by the present authors, will be naturally considered to have the similar function as that of two muscles mentioned above.

During forced inspiration, the activity of all those muscles mentioned above remarkably increased (fig. 4 (A), (B)), and their enhancement was accomplished by the marked shortening of the discharge intervals and recruitment of active neuromuscular units during the inspiratory phase. In addition, still other muscles, *i.e.*, the pars ascendens of the trapezius, subclavius and sternocleidomastoideus muscles were called into action. As for the sternocleidomastoideus muscle, however, action potentials were very rarely led off during extreme forced inspiration, but when the trunk muscles (inclusive the intercostal muscles) showing strong atrophy (in the case of spinal progressive muscular atrophy) or when the head being fixed passively, its activity still more increased.

During forced inspiration with the shoulders and upper limbs thrown back (fig. 1 (B)), the pectoralis major and minor, pars acromialis of the deltoideus, infraspinam, teres major and minor, latissimus dorsi muscles and the extensors of the upper limbs (the triceps brachii, extensor carpi radialis muscles, etc.) came, although slightly, into play during the inspiratory phase. Furthermore, in these muscles, when sustained weak voluntary contraction with a constant strength, the marked shortening of the discharge intervals of a single neuromuscular unit occurred synchronously with quiet inspiration. This fact illustrates that the motoneurons which innervate these muscles do always receive the inspiratory impulses from the respiratory centers, although they are too weak to set the motoneurons into firing during quiet breathing. The latissimus dorsi muscle whose respiratory function didn't been still definitely settled (3, 9, 12) was proved by the present experiments to participate in inspiration (fig. 5).

Fig. 5. Interval diagram of m. latissimus dorsi during quiet breathing under weak voluntary contraction (sitting posture).

Probably, the transversocostalis longus and brevis and serratus dorsalis cranialis muscles, for which no examination was done, will exhibit also the inspiratory function as shown in table 2.

Quiet expiration is, although chiefly accomplished by passive processes yet carried out by the active participation of several muscles, that is, the inter-

costal, transversus thoracis, obliquus abdominis externus and internus and transversus abdominis muscles. According to almost all results hitherto reported, the abdominal muscles (inclusive the rectus abdominis muscle) were generally regarded as accessory muscles, but as shown in table 2, all abdominal muscles with antigravitic function, excluding the rectus abdominis muscle, were always acting as expiratory muscles even during quiet breathing (fig. 6 (A), (B)). As

Fig. 6 (A). Relation between the respiratory variation of the discharge intervals and respiratory movement during quiet breathing (sitting posture) in *m. obliquus abdominis externus*.

to the rectus abdominis muscle, however strong the expiratory movement may be, no action potential was led off from it, but its motoneurons were proved to receive the expiratory impulses as other abdominal muscles. Furthermore, the sacrospinalis muscle (the longissimus lumborum and iliocostalis lumborum muscles) was also confirmed to have the expiratory participation as well as antigravitic function. Although there was no chance to examine the longissimus thoracis and iliocostalis thoracis muscles, the same function will be reasonably bestowed to them.

During forced expiration the activity of these muscles was intensified; and during forced expiration of fig. 1 (A), in addition to them the pars clavicularis of the deltoides and serratus lateralis muscles came into play with very slight degree of the expiratory participation.

Fig. 6 (B). Interval diagram of *m. obliquus abdominis externus* during quiet breathing (standing posture).

Fig. 7. Interval diagram of *m. serratus lateralis* during quiet breathing under weak voluntary contraction (sitting posture).

Thus, contrary to the usual concept of its inspiratory function, the serratus lateralis muscle was proved to have the expiratory function as shown in fig. 7.

The function of the serratus dorsalis caudalis and quadratus lumborum are, as mentioned above, not yet settled, and are generally regarded as inspiratory during quiet breathing and as expiratory during forced breathing (3, 9, 11, 12, 25, 37). But some workers (15) have the different opinion about the function of the former, that is, during forced breathing it also act as an inspiratory muscle. As the present authors regret no chance to examine their function, it is left for future study. But analogizing from the function of the sacrospinalis muscle, it may be reasonably considered that they have the similar function as the sacrospinalis muscle, that is, acting as an expiratory muscle during quiet as well as forced breathing.

Although the function of the intercostal muscles has been a subject of debate and yet cannot be regarded as definitely settled (4, 6, 9, 13, 14, 16, 17, 24, 25, 27, 28, 29, 31, 35), they are generally considered to have the following function, namely: the external intercostal and intercartilaginous portions of the internal intercostal muscles are engaged in carrying out the inspiratory enlargement of the thoracic cavity and the interosseous portions of the internal intercostal muscles in its expiratory diminution. The present experiments on the human subject also proved that they act in the similar fashion as in the animal. Thus, the intercartilaginous portions of the internal intercostal muscles in the 1st-IVth or Vth intercostal spaces strongly participated in inspiration, suggestive of their important rôle in the inspiratory movement, while those below the Vth or VIth intercostal space showed the opposite function, that is, the expiratory participation; thus indicating close coincidence with the observations made by Gessel (17) on the dog. As to the external intercostal and interosseous portions of the internal intercostal muscles, as Gessel (17) and Bronk and Ferguson (6) already pointed out from the experiments on the dog and cat, the degree of their participation was weaker and in addition the feature of their participation was highly labile, changing feature with slight changes in the breathing type and also in different parts of the thorax. Nevertheless, the generalization can be made that the external intercostal muscles participate chiefly in inspiration and the interosseous portions of the internal intercostal muscles in expiration (fig. 8 (A), (B), (C)). Moreover, there was some parts where the continus

Fig. 8 (A). Relation between the respiratory variation of the discharge intervals and respiratory movement during quiet breathing (sitting posture) in m. intercostalis externus (the Vth intercostal space).

train of action potentials was recorded without cessation throughout the whole respiratory cycle, showing good correspondence to the observations of Bronk and Ferguson (6), Anderson and Lindsley (2) and Wachholder and McKinley (36) made on the animal. But under this condition as Gessel pointed out, reinforcement of action potentials, that is, the shortening of the discharge intervals and recruitment of active neuromuscular units, was also occurred synchronously either with the inspiratory or expiratory phase, indicative of their active respiratory participation by the augmentation of muscle tone (fig. 9 (A), (B), (C)). Hence, it may be said that some parts of the inter-

Fig. 8 (B). Interval diagram of m. intercostalis externus (the VIth intercostal space) during quiet breathing (sitting posture).

Fig. 8 (C). Interval diagram of the interosseous portion of m. intercostalis internus (the VIth intercostal space) during quiet breathing (sitting posture).

Fig. 9 (A). Relation between the respiratory variation of the discharge intervals and respiratory movement during quiet breathing (sitting posture) in the interosseous portion of m. intercostalis internus (the VIIth intercostal space).

costal muscles do act as respiratory as well as antigravity muscles. In fig. 10 is shown one example in which the different groups of discharges appeared alternately according to each respiratory phase, and it may be thought that they

were derived from the external and internal intercostal muscles respectively due presumably to the position of the tip of electrode just inserted upon the boundary surface of both muscles.

As to the muscles of the hips and legs, no respiratory participation was observed.

Fig. 9(B). *Upper*—Interval diagram of m. intercostalis externus (the VIIth intercostal space) during quiet breathing (standing posture).

Fig. 9(C). *Lower*—Interval diagram of m. intercostalis externus (the VIth intercostal space) during forced and quiet breathing (standing posture).

Fig. 10. Action potentials led off from the intercostal muscle (the VIth intercostal space) in quiet breathing (sitting posture). *Lower curve*: pneumogram; Time: 1/5 sec.

In the sidelying and supine postures the antigravity muscles lost their original function and consequently their inspiratory participation also went off. Under these conditions, therefore, quiet inspiration may be carried out chiefly by the diaphragm, external intercostal and intercartilagenous portions of the internal intercostal muscles (fig. 11), and expiration by the abdominal (fig. 12 (A)), interosseous portions of the internal intercostal (fig. 12 (B)) and transversus thoracis muscles. And if compared with those acting in the standing

and sitting postures, the fewer muscles will act as inspiratory muscles in the sidelying and supine postures, but, on the other hand, weaker power will be demanded to elevate the thoracic cage antigravitationally during inspiration. Accordingly no particular enhancement or weakening of the activity of those muscles will be necessary for carrying out normal inspiration, and in fact, so far as the intercostal muscles were concerned, any marked change was not

Fig. 11. Interval diagram of m. intercostalis externus (the VIth intercostal space) during quiet breathing (supine posture).

Fig. 12 (A). *Upper*—Interval diagram of m. obliquus abdominis externus during quiet breathing (sidelying posture).

Fig. 12 (B). *Lower*—Interval diagram of the interosseous portion of m. intercostalis internus (the VIth intercostal space) during quiet breathing (supine posture).

observed in their activity pattern (fig. 11). On the contrary, during normal expiration in the sidelying and sitting postures, there appeared naturally the stronger activity of the abdominal and intercostal muscles owing to the diminution of the passive sinking of the thoracic cage by its own weight (fig. 12).

All these observations mentioned above led us to suggest strongly that the motoneurons innervating each and all muscles of the neck, trunk and upper limbs are influenced, although different in their intensity, by the respiratory impulses descending from the respiratory centers. And, if the impulses were strong enough to set the motoneurons in firing, the muscles innervated by these motoneurons will actively participate in the respiratory movement not only in the standing and sitting postures but also in the sidelying and supine postures, while if they were so weak to set the motoneurons only in the subliminal excitatory state without firing, the muscles will show no active, respiratory participation. But, if the motoneurons in question were previously excited in certain excitatory state by afferent and/or efferent impulses due to reflex or volition, then the respiratory impulses will at once reveal their effects, bringing the muscles in the respiratory participation. The respiratory function of the antigravity muscles in the standing and sitting postures are nothing else but this case.

Considering thus, it may be said that there is no essential difference between the principal and accessory respiratory muscles, and it is, therefore, impossible to draw a sharp line of distinction between them. If we, nevertheless, venture to classify them, the diaphragm, external intercostal and intercartilagenous portions of the internal intercostal muscles may be classed as the principal respiratory muscles and the interosseous portions of the internal intercostal, transversus thoracis, abdominal muscles as the principal expiratory muscles, and all the other respiratory muscles as the accessory respiratory muscles.

In the antigravity muscles, the extent of the respiratory variation in the discharge intervals of a single neuromuscular unit varies with the magnitude of the average discharge interval and the intensity of the impulses descending from the respiratory centers as well. Thus, when the average interval being some 0.10 msec., its extent was about 0.03 msec. during quiet breathing and about 0.05 msec. during forced breathing (fig. 3 (A), 4 (B), 9 (B)), while when the average interval being as long as 0.15–0.20 msec., its extent became still larger (fig. 6 (B), 9 (C)). In the intercostal muscles from which action potentials were recorded during only one respiratory phase, the average discharge interval was, as shown by Anderson and Lindsley (2) at the shortest about 0.10 msec. during quiet breathing, but further shortened to as short as 0.05 msec. during forced breathing.

During quiet breathing almost all active neuromuscular units of the antigravity muscles, such as the trapezius, sacrospinalis muscles, etc., discharged asynchronously at the same rate with each other (the phenomenon of syntonization) (fig. 6 (A)), while in the intercostal and abdominal muscles this phenomenon often failed to be observed (fig. 8 (B), 12 (A)). During forced breathing, however, the phenomenon of syntonization was also disappeared even in

the antigravity muscles; and this fact will be naturally explained by assuming that the motoneurons of lower excitability were excited into firing at the slower rate through the plenty of impulses descending from the respiratory centers.

The phenomenon of the so-called synchronization was often seen in the paralytic muscles of such patients as suffering from spinal progressive muscular atrophy or anterior poliomyelitis, but never seen in healthy persons. Moreover, in all respiratory muscles, especially marked in the intercostal muscles, the activity of one neuromuscular unit was frequently substituted for the other during quiet breathing (the phenomenon of rotation), but during forced breathing this phenomenon was rarely seen. Thus, these phenomena may indicate that the contractile process of the respiratory muscles is accomplished in an identical fashion with that of other volitional muscles; and in addition the slow rate of firing (about 0.10 msec.) and the phenomenon of rotation may strongly suggest that, when viewed from the standpoint of energy economic, the activity of the respiratory muscles is effected in a very rational feature as to bring about no sign of fatigue. The enhancement of the muscular activity during forced breathing was, as mentioned above, brought about by two ways as in the voluntary contraction, that is, the marked shortening of the discharge intervals (fig. 4, 9 (C)) and recruitment of active neuromuscular units (fig. 6 (A), 12 (A)).

Gessel (18, 19, 20, 21, 22, 23, 26) has concluded from the experiments on the animal that there is a marked difference in the discharge intervals between the inspiratory and expiratory muscles. Owing to his results, while the course of the discharge intervals in the inspiratory muscles shows a slowly augmenting pattern, the course in the expiratory muscles shows a rapidly augmenting pattern or steady state pattern. In the present experiments, no definite pattern of discharges was recorded, however uniformly the respiratory movement may be carried out, varying largely with a slight change of the intensity and manner of the respiratory movement, and furthermore no particular pattern was ascribed either to the inspiratory or expiratory muscles, indicating no essential difference of the discharge pattern between them. These features will be seen in fig. 8 (A), (B), (C), fig. 10 and fig. 12 (A). Nevertheless, the pattern shown schematically in fig. 13 was most frequently recorded during quiet breathing both in the inspiratory and expiratory muscles, so that this pattern may be most reasonably regarded as the basic respiratory pattern common to the inspiratory as well as expiratory muscles and consequently considered to indicate the temporal course of the excitatory state of both inspiratory and expiratory centers.

Fig. 13. Schematic illustration of the activity pattern of a single neuromuscular unit. A_1 , B_1 : the antigravity muscle; A_2 , B_2 : the intercostal muscle.

From the consideration of the interval diagrams shown above, we shall find a phase difference between the peak and valley of both tracings of the course of the interval diagram and respiratory movement (fig. 14); the

Fig. 14. Relation between the course of the interval diagram (*upper line*) and respiratory movement (*lower line*). A: the inspiratory muscle; B: the expiratory muscle.

time when the discharge interval becomes the shortest being a little earlier than the time when the thorax attains the extreme enlargement or diminution. This fact does offer a valuable hint for consideration of the mechanism of the respiratory centers and at the same time strongly support the belief that the respiratory variations of the dis-

charge intervals in the antigravity muscles is not a passive phenomenon due to the stretch reflex but an active process caused by the impulses from the respiratory centers.

CONCLUSION

The results obtained in the above experiments have led the present authors to the following conclusions.

As shown in table 2 each and all muscles of the neck, trunk and upper limbs are influenced by the inspiratory or expiratory impulse of different intensity descending from the respiratory centers, and according to their intensity, some muscles participate in quiet breathing acting as principal respiratory muscles, while others participate in forced breathing acting as accessory respiratory muscles. And the manners of their participation are considerably different from the results hitherto reported.

As regards the activity pattern of a single neuromuscular unit with which each respiratory muscle is constructed, we cannot find such an essential difference between the inspiratory and expiratory muscles as Gessel and his co-workers stated, showing the same pattern of fig. 13 in both muscles, and moreover, between the discharge pattern and respiratory movement, we can find a phasic discrepancy which will offer an influential hint for the study of the mechanism of the respiratory centers.

For the several muscles whose function is not yet definitely settled, the present authors await for a future chance to research.

In addition to the muscles whose action directly enlarges or diminishes the thoracic cavity, there are certain other muscles of the larynx, pharynx, oral cavity and face which may be properly designated as accessory respiratory muscles in a broad sense (8, 10, 13), and the present authors are now planning to study on them still further in detail.

After all, as to the mechanism of respiration, there remains many important problems yet unsettled, but the fact that the respiratory action is endowed with the intermediate character of automaticity of the heart and voluntary character of the skeletal muscle—this fact of the dual activity may give a strong clue to

solve many pending questions in this field.

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