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ELECTROMYOGRAPHY OF MIDDLE EAR MUSCLES IN MAN DURING MOTOR ACTIVITIES

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The middle ear muscles contract in response to sounds and modify sound transmission between the ear drum and the cochlea *Wiggers* (1937). These muscles have therefore been traditionally considered to serve acoustic functions *Lüscher* (1930), *Hallpike* (1935), *Metz* (1946), *Jepsen* (1955), *Kirikae* (1960), *Perlman* (1960). However, recent animal experiments reveal the middle ear muscles to contract during generalized motor activities *Carmel & Starr* (1963). These findings suggest that the middle ear muscles may also have important non-acoustic functions. The present studies were undertaken to determine whether the middle ear muscles in man may similarly contract during motor activities. Our findings correspond closely to the recent animal experiments and define a number of motor patterns that may be accompanied by activation of the middle ear muscles.

MATERIALS AND METHODS

Middle ear muscle activity was studied by means of electromyography in two patients.[3] The first patient (RJ), aged 42, had longstanding tinnitus and vertigo, secondary to traumatic inner ear damage. Threshold average air conduction (TAA) was 60 db in the affected ear. Acoustic and caloric functions were normal in the other ear. One week prior to a therapeutic labyrinthectomy, two stainless steel wire electrodes (each 125 μ in diameter) were implanted about 2 mm apart into the tensor tympani in the affected ear. The second patient (WO), aged 45, had a chronic, dry perforation of the tympanic membrane. TAA was 40 db. On the day of tympanoplasty, a single stainless steel electrode was placed into the tendon of the stapedius muscle. Middle ear muscle activity was recorded by an electromyograph, DISA

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[3] One of the authors (GS) gained experience with the experimental techniques as a result of work on cats carried out in the Institute for Experimental Research in Surgery. Director *H. H. Wandall,* M.D., D.M. Sc.

(Herlev, Copenhagen). Tensor activity was recorded bipolarly. Stapedius activity was recorded monopolarly, the indifferent electrode being a silver disk placed on the surface of the ipsilateral ear lobe. In patient WO movements of the stapedius tendon were visualized through an operating microscope.

The patients were supine throughout these studies. They were asked to perform a series of movements using muscles of the face, neck, larynx-pharynx, or of the extremities. Electromyograms of muscles involved in each of the movements were recorded from appropriately located surface electrodes and correlated with middle ear muscle responses. Sound stimuli were generated by an audiooscillator and delivered to the patient via a calibrated speaker or calibrated earphones. A microphone placed next to the patient's face recorded experimental sound stimuli, the patient's own vocalizations, and the sound of an air jet from a Politzer balloon directed towards the cornea. This air jet vas employed to elicit reflex closure of the eyes. Patient RJ was studied daily for one week. Patient WO was studied only on a single day.

RESULTS

The results have been analyzed primarily with regard to the particular motor patterns which are accompanied by activation of the middle ear muscles. Generalizations relating to variability, latency, or duration of middle ear muscle activity must be limited since only two patients were examined in these studies.

Observations on Tensor Tympani Muscle (Tensor).

The tensor showed no spontaneous activity with the patient lying quietly at rest. The appearance of tensor activity could always be correlated with some change in the patient's motor behavior.

1. *Tensor activity associated with facial movements.*

Tensor activity could be regularly elicited by asking the patient to close her eyes. The tensor muscle always became active coincident with or up to 15 msec before the initial periorbital muscle response, and remained active for the duration of eye closure (fig. 1). Increasing the force of eye closure elicited an increase in amplitude and frequency of tensor muscle potentials. No tensor activity could be recorded when the patient's eyes were closed in a relaxed manner. Tensor activity was not as regularly elicited during reflex eye closure as during voluntary eye closure. Reflex eye closure was obtained by directing an air jet against the eye. This procedure elicited tensor responses between 50 and 120 msec after the application of the stimulus (fig. 1). These tensor responses always appeared between 20–60 msec *after* the initial periorbital muscle activity. Tensor responses habituated rapidly with repetition of the stimulus. Activity was no longer evident by the third trial when the air stimulus was repeated regularly every three seconds. Tensor re-

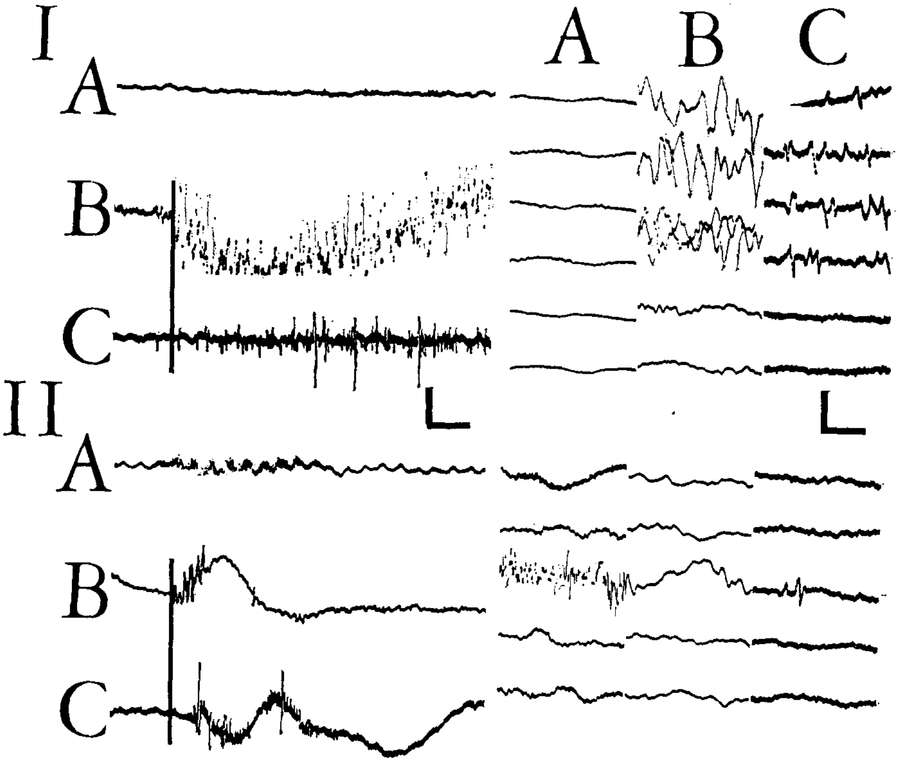

Fig. 1.

Tensor tympani activity associated with eye closure. In the top half of the figure, indicated by I, the patient voluntarily closed the eyes. In the bottom half of the figure, indicated by II, the patient's eyes close reflexively in response to an orbital air jet. A is the output of Microphone located next to the patient's face. B is periorbital muscle activity, and C is tensor tympani activity. The onset of periorbital muscle activity is marked by a vertical black line in the continuous recordings on the left side of the figure. Note that during voluntary eye closure (I) tensor activity precedes periorbital muscle responses, while during reflex eye closure (II) the tensor becomes active only after periorbital muscle responses. Time scale for continuous recordings is 50 msec. Interrupted recordings at a much faster time base are shown on the right side of the figure; time scale is 10 msec. Amplitude calibrations for both continuous and interrupted recordings are 30 μV for tensor tympani and 200 μV for periorbital muscle responses.

sponses reappeared if the stimulus was increased in intensity or if several minutes intervened before testing the patient again. In contrast, periorbital muscle responses to the same air jet were still evident at a time when the tensor response had been habituated. Thus, tensor activity is not invariably associated with periorbital muscle contractions but depends on whether eye closure is elicited voluntarily or reflexively. Tensor activity also appeared in association with other facial movements such as grimacing or smiling. In contrast, movements of the extraoccular muscles or of the jaw muscles were not associated with tensor responses. All these results suggest that tensor activity may accompany voluntary contractions of muscles innervated by the VII cranial nerve.

2. *Tensor activity associated with movements of the pharynx-larynx.*

Tensor activity could always be elicited by asking the patient to talk or hum. This activity increased directly with the intensity of the vocalization. This type of tensor activity represents a non-acoustic function since tensor responses *always preceded or came at the same time as the onset of sound* (fig. 2). The interval separating the onset of tensor activity and the onset of sound was usually about 40 msec but could be as long as 300 msec. Furthermore tensor activity persisted for up to 300 msec after the sounds of vocalization ceased. The time relations of tensor activity to vocalization correspond to results obtained by *Faaborg-Andersen* (1957) in the intrinsic laryngeal muscles in man. The laryngeal muscles become active up to 500 msec before the onset of sound and remain active for a short time after the sound ceases. In the present investigation other movement patterns which involve the muscles of pharynx and larynx such as yawning, laughing, swallowing, and coughing, were also associated with tensor activity.

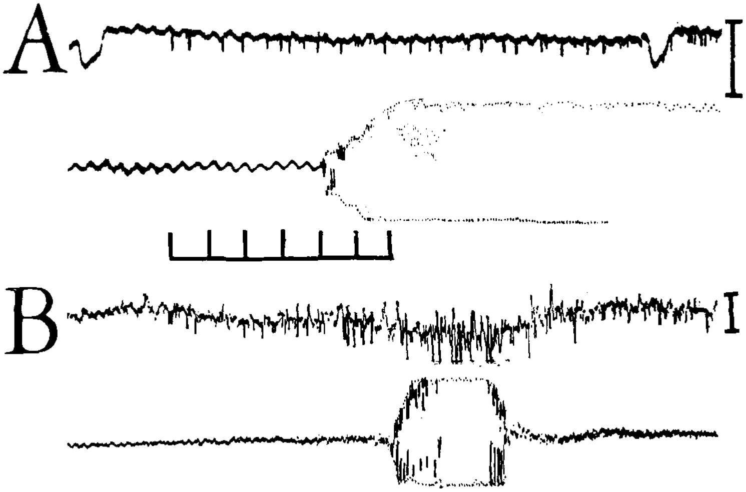

Fig. 2.

Tensor tympani (A) and Stapedius (B) activity during vocalization. The records are from different patients. Corresponding sounds of vocalization, recorded via a microphone in front of the mouth, appear in the traces immediately underneath each EMG record. Note that middle ear muscle activity is initiated prior to the registration of the sounds of vocalization. Each interval on time scale represents 50 msec. Amplitude calibration 30 μV.

3. *Tensor activity associated with bodily movements and with cutaneous stimulation.*

Tensor activity could be elicited by having the patient lift her head from a supine position. The tensor remained active for the duration of this maintained flexed head posture. In contrast active movements of other parts of the body such as clenching the fists or lifting the legs or arms were not associated with tensor activity. Cutaneous stimulation of the contralateral ear with a piece of cotton was associated with tensor responses. These responses were of large amplitude at the initiation of cutaneous stimulation but diminished with continued application of the cotton. Light cutaneous stimuli applied to the legs, arms, or trunk were without effect on tensor activity.

4. *Tensor activity associated with sounds.*

Loud sounds (pure tones or repetitive clicks, 110 db re. 0.0002 dynes/cm^2) only occasionally elicited tensor activity. This activity was initiated between 90 and 300 msec after the sound's onset (fig. 3). We interpret these tensor responses to be one of the motor components of a generalized startle reaction rather than an acoustic reflex *per se*.

First, sounds presented without warning were more likely to elicit tensor activity, than were sounds presented after the patient was forewarned. Second, the latency of tensor responses corresponds to the lantency of skeletal muscle activity during a startle reaction to loud sounds *Davis* (1948). Finally, the latency of acoustic reflex responses in stapedius muscle in man and in both tensor and stapedius muscles in

Fig. 3.

Tensor tympani activity in response to sounds. Top trace is output of audiooscillator during pure tone stimulus, 3000 cps and 110 db re. 0.0002 dynes/cm^2. Sound delivered to patient via earphones. Bottom trace is tensor tympani activity. Vertical black line refers to onset of sound. Time scale is 200 msec. Note initial tensor activity appears about 200 msec after the onset of tone. Amplitude calibration is 30 μV.

animals is only about 10 msec *Perlman* (1939) *Eliasson & Gisselsson* (*1955*); almost one tenth the latency recorded in tensor in the present investigations.

Observations on Stapedius Muscle.

The patient experienced a low, rumbling sound sensation when the electrode was placed in the stapedius tendon. This sensation persisted as long as the electrode remained in place. Electromyographic recordings made during this time revealed the muscle to be spontaneously active. This activity could be modified by the following procedures:

1. *Movements of the muscles of the larynx and pharynx* as in vocalization or in coughing were always associated with an increase in stapedius activity. This increase of activity, a) preceded the onset of sound by up to 100 msec, b) persisted for the duration of sound, and c) returned to pre-vocalization levels only after the sound was completed. (Fig. 2).
2. *Bodily movements* such as lifting or turning the head, or raising the legs were also associated with an increase of stapedius activity.
3. *In contrast, movements of the facial muscles* such as tight voluntary eye closure or eye closure elicited by a jet of air were not associated with a change of stapedius activity. Visual inspection of the middle ear through an operating microscope revealed the tendon of the stapedius muscle to move during vocalization, humming, and coughing, but not to move during eye closure.

DISCUSSION

The present investigations reveal the middle ear muscles to be active during general motor events such as vocalization, yawning, swallowing, laughing, coughing, and both face and head movements. These results correspond closely to the findings in cats that middle ear muscles contract during bodily movements *Carmel & Starr* (1963). Such movement-associated middle ear muscle activity is *non-acoustic* in nature, since it persists in experimentally deafened animals in whom all *acoustic* middle ear muscle responses have been lost. Even vocalization may be considered non-acoustic in its effect on middle ear muscle activity since these muscles respond prior to the appearance of the sounds of speech. In support of this interpretation is the fact that middle ear muscle contractions still occur during vocalizations in experimentally deafened animals.

Most studies of middle ear muscle functions have emphasized their responses to acoustic stimuli. The results from both the present investigations in man and from the recent animal studies reveal that common movement patterns may also be regularly associated with middle ear muscle activity. These findings suggest that middle ear muscle activities may be modified not only by acoustic mechanisms but also by central processes regulating motor behavior. Both types of middle ear muscle activity effect an attenuation of sound transmission through the middle ear. In cats, middle ear muscle contractions my induce up to a 20 db attenuation of cochlear microphonic responses *Galambos & Rupert* (1959), *Simmons* (1959). These middle ear muscle induced changes in sound input should be perceptually apparent. In man, acoustic activation of the middle ear muscles elevates sound thresholds by 5–15 db *Shapley* (1954), *Fletcher & Loeb* (1962). A corresponding threshold shift also results from non-acoustic middle ear muscle activities *Salomon* (1963). The modification of sound input due to non-acoustic middle ear muscle contractions could interfere with our ability to perceive faint sounds. However, the tendency to remain completely motionless while listening for faint auritory cues may serve to minimize such non-acoustic middle ear muscle activities. It may be that central motor processes regulating middle ear muscle activity may themselves be integrated into sensory mechanisms.

The middle ear muscles may be active throughout the day since motor events such as head and facial movements, and vocalization are a part of our daily behavior. These frequent non-acoustic contractions of the middle ear muscles may account for the relatively normal appearance of these muscles in patients with severe impairment of hearing *Eggston & Wolff* (1947) *Klockhoff* (1961), or in animals with hereditary absence of the organ of corti, in whom all sound induced contractions can no longer occur *Thomsen & Salomon* (1963).

The interpretation of middle ear muscle activity as merely serving acoustic functions is too limiting. The fact that contractions occur in association with a wide variety of motor patterns suggests that middle ear muscle activity is intimately correlated with other motor-control systems. An understanding of the integration of middle ear muscle contractions with these general motor events, may provide new insights into the functions of these muscles.

SUMMARY

Electromyographic studies in man reveal the middle ear muscles to be active in association with general motor events such as eye closure, face and head movements, vocalization, yawning, swallowing, coughing, and laughing. These findings suggest that central mechanisms controlling a variety of motor events simultaneously govern middle ear

muscle contractions. A full understanding of middle ear muscle function must take into account these prominent non-acoustic activities.

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