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KINESIOLOGY OF THE MANDIBLE
AN EMG STUDY

by

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INTRODUCTION

In an earlier kinesiologic study the movements of the mandible were analyzed partly by electromyography and partly by cinematography (*Ahlgren,* 1966). However, for a complete understanding of the kinesiology of the mandible it is necessary to record muscle activity and movement pattern simultaneously. In this way it would be possible to solve the problem how the various phases in a chewing cycle are related to muscular contractions. A similar approach has been used to analyze the kinesiology of the foot, finger, and leg (*Hardy,* 1959, *Long et al.,* 1963, and *Bierman & Ralston,* 1965).

The purpose of this study was to develop a polygraphic kinesiologic method and to analyze the kinesiology of the mandible in normal human subjects during lowering — elevation of the mandible and during mastication.

METHODS AND MATERIAL

Two methods have been used, namely, (1) simultaneous cinematography and EMG, (2) simultaneous photocellography and EMG.

The cinematographic and EMG methods applied have been used earlier each separately (*Ahlgren,* 1966). Briefly, the motion pictures were taken with a film speed of 25 frames per sec., and the movements of a protracting bar, attached to a lower incisor, were registered in the frontal and sagittal planes. A fixed bar attached to an upper incisor was used as a reference point. The EMG registrations were taken from the temporal and masseter muscles with intercutaneous wire electrodes and recorded both as direct EMG and as integrated EMG on a Mingograph (Elema-Schönander, Stockholm). A paper speed of 30 mm. per sec. generally was used. However, when the details of the EMG pattern were to by analyzed, a paper speed of 100 mm. per sec. was used. For the present study the cinematographic and EMG registrations were synchronized by an indicating signal that simultaneously lighted a bulb (recorded on the film) and wrote traces on the EMG records.

The photocellographic motion registrations were accomplished by a face-bow with a built in photoelectric cell that recorded the variations in the reflected light from the chin as a sine wave parallel to the EMG tracings. The chin was illuminated by a bulb attached to the-bow (Fig. 1). In some of the cases a flat aluminium plate, attached to a bar from a lower incisor, was placed below the chin to eliminate possible interferences from skin movements during the registrations.

Cinematography gave a detailed picture of the masticatory movements, whereas the photoelectrographic method only could demonstrate the change in phasic relationships between opening and closing movements during mastication*). However, the photoelectrographic method for recording motion was direct and simple.

Recordings were made from 10 normal subjects between the ages 8—15 years. The muscles examined were the temporal and masseter muscles. EMG observations were made during "active"**) opening and closing of the jaws and during chewing, totaling 1000 movements. Test materials during chewing were chewing gum, carrots, and peanuts.

*) A chewing cycle consists of three phases; opening phase, closing phase and occlusal phase (tooth contact position).

**) "Active" is indicative of muscular contractions performed solely by the subject.

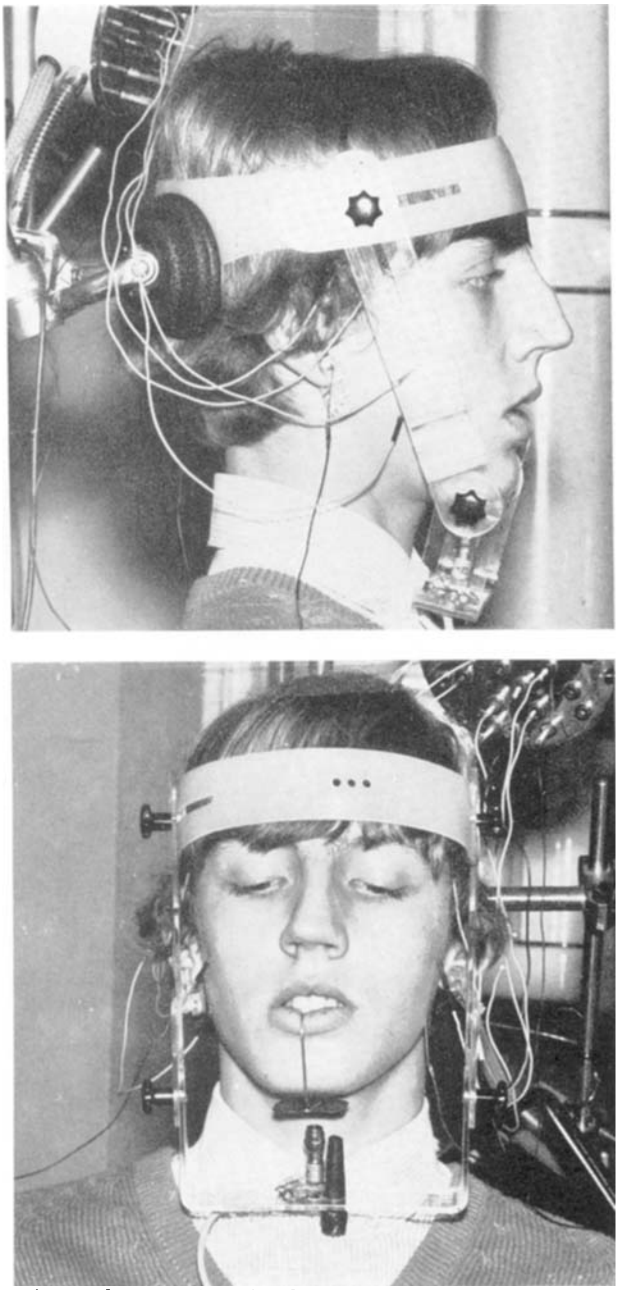

Fig. 1. Experimental setup for simultaneous electromyography and photocellography.

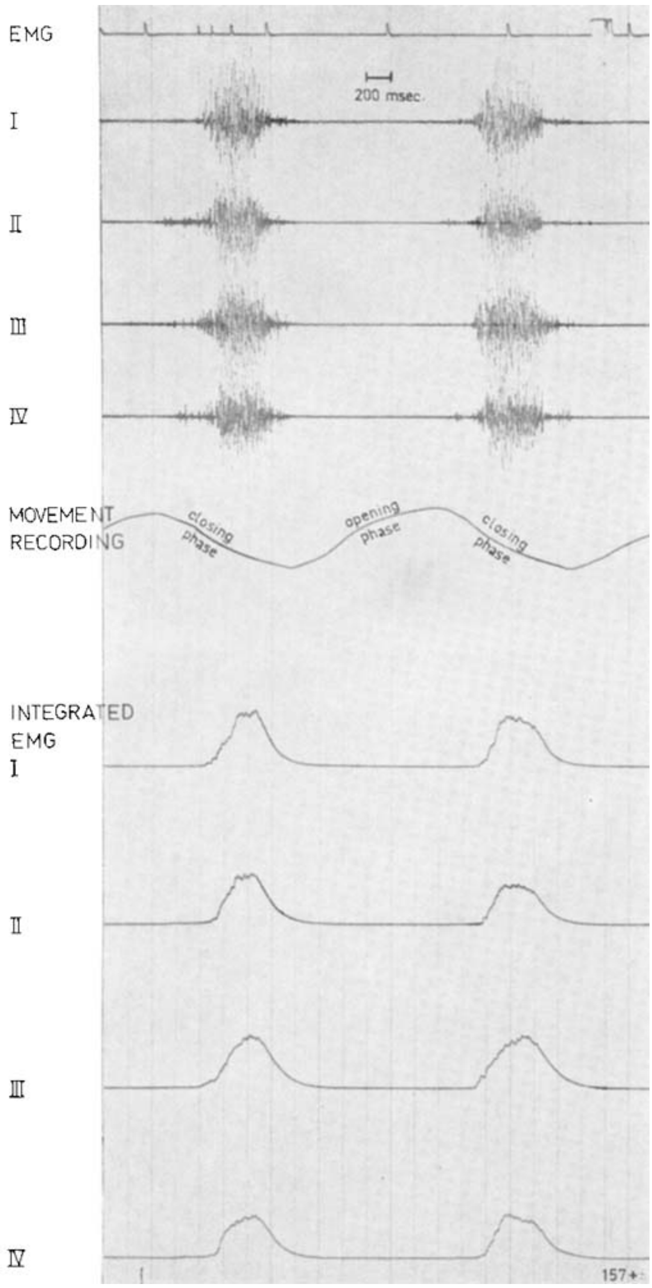

Fig. 2. Electromyographic and photocellographic recording of lowering and elevation of the mandible. I and II left temporal and masseter muscles, III and IV right temporal and masseter muscles. Rate of lowering and elevation of the mandible 54 times per minute.

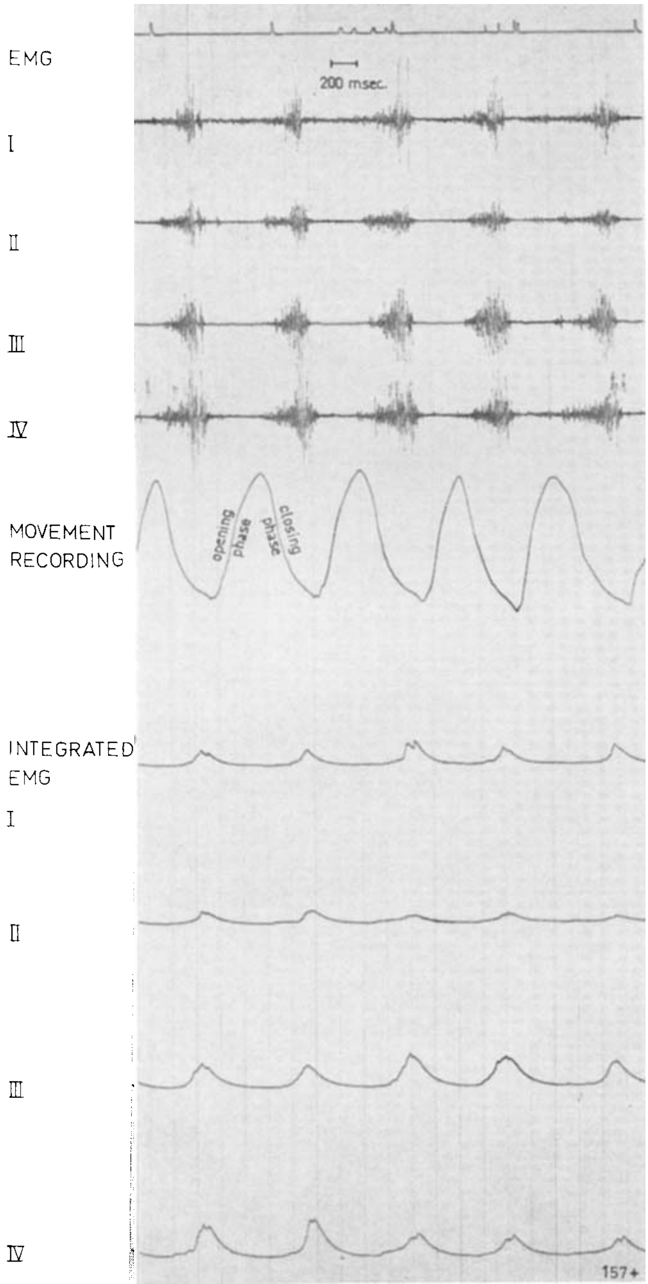

Fig. 3. Electromyographic and photocellographic recording of gum chewing at a rate of 76 times per minute. I and II left temporal and masseter muscles, III and IV right temporal and masseter muscles.

The speed of the movements were controlled by a metronome. The rate of chewing was standardized to 76 strokes per minute during gum chewing and 84 strokes per minute during peanut and carrot chewing. Lowering and elevation of the mandible were performed at a rate of 42, 54, and 72 times per minute. The range of the movements was controlled by the face-bow and the movements never exceeded a limit of 3.0 cm.

RESULTS

A typical EMG response to lowering and elevation of the mandible is shown in Figure 2. During lowering of the mandible no action potentials were recorded from the elevator muscles. Nor did action potentials appear in the beginning of a slow elevation of the mandible. However, if the rate of mandibular lowering and elevation was increased action potentials appeared approximately at the start of the closing phase. The amplitude of the action potentials then gradually increased toward the termination of the motion. Maximal integrated EMG was recorded during the occlusal phase. At the start of the occlusal phase a short "silent" period of approximately 30 msec. appeared in the EMG. During the occlusal phase the amplitude of the action potentials then gradually decreased and finally disappeared at the initation of a new opening phase.

Figure 3 shows the typical EMG response to masticatory movements during gum chewing. No action potentials were usually recorded in the temporal and masseter muscles during the opening phase. With the change in phasic relationships the elevator muscles became agonists and action potentials started to appear approximately 50 msec. after the initiation of the closing phase. Thereafter, the potentials gradually increased in size toward the end of the movement where maximal integrated EMG appeared.

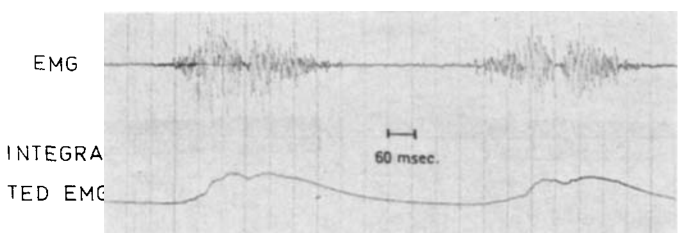

Fig. 4. Electromyogram showing the bimodal EMG pattern of the masticatory stroke.

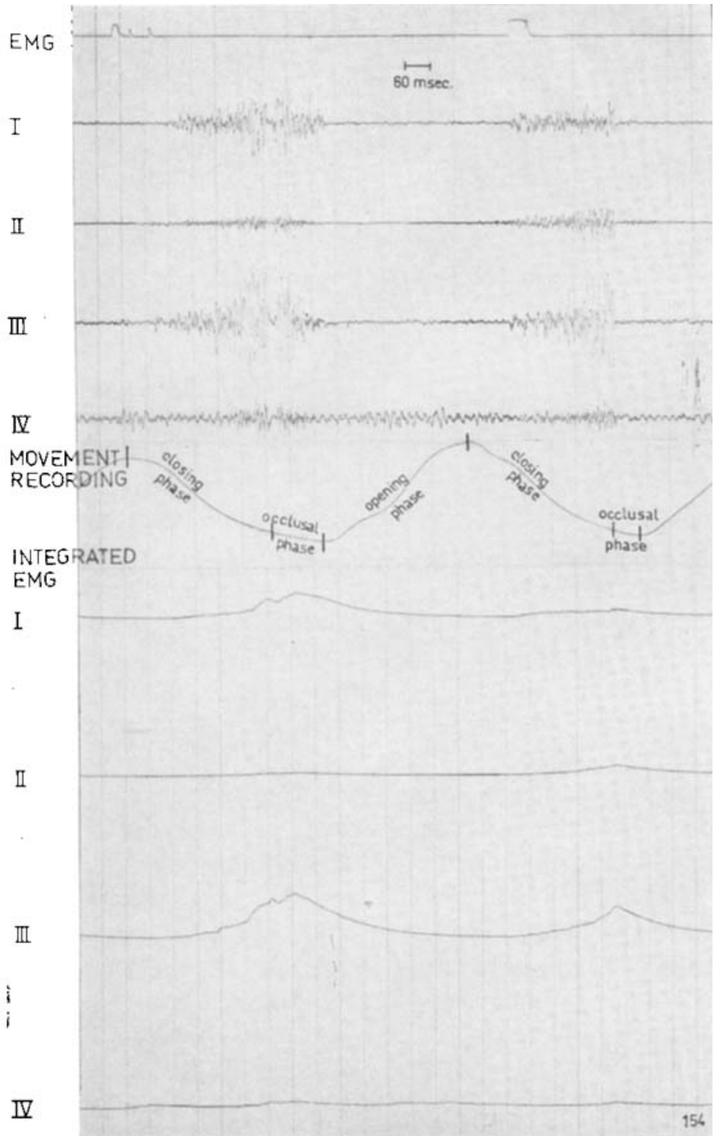

Fig. 5. Electromyographic and photocellographic recording during mastication showing two different EMG patterns, first a two-peaked and then a one-peaked pattern. Chewing rate 76 times per minute.

The peak of the EMG was followed by a short "silent" period of approximately 25 msec., and then the activity gradually disappeared. Thus, the EMG pattern had a bimodal distribution (Fig. 4). The time between the "silent" period and the initiation of the new opening phase — the occlusal phase — had a duration of approximately 80—120 msec. In some masticatory stroke the EMG activity disappeared abruptly after the maximal integrated EMG was recorded (Fig. 5). Similar results were obtained during peanut chewing except an earlier appearance of the EMG activity during the closing phase, approximately at the initation of the motion (Fig. 6).

From the cinematographic-electromyographic records a more detailed analysis of the masticatory cycle was obtained. A typical EMG response to gum chewing is demonstrated in Fig. 7. As was found from the EMG and photocellographic registrations no EMG activity usually was recorded from the temporal and masseter muscles during the opening phase of mastication but approximately at the start the closing phase action potentials appeared in the recorded elevator muscles. Exactly when action potentials appeared during the closing phase was dependent on the speed and the form of the masticatory movement. If the speed of the mandible was high or a large abduction in the chewing stroke was recorded, action potentials appeared immediately at or even before the initation of the closing movement. With a chewing rate of 76 times per minute action potentials appeared approximately 50 msec. after the closing phase was initiated. The action potentials then gradually increased in size toward the end of the closing phase, where maximal EMG activity was recorded. The action potentials then disappeared and a "silent" period for approximately 25 msec. was recorded in the EMG. After the "occusal silent period" action potentials usually continued to occur with decreased amplitudes until the start of a new opening phase. The duration of the occlusal phase was approximately 120 msec. and most of the EMG activity (approximately 75 per cent) was recorded before the occlusal phase. The peak of the integrated EMG appeared approximately 50 msec. before the occlusal phase.

A typical EMG response to carrot chewing is shown in Fig. 8. Action potentials usually appeared in the recorded elevator musc-

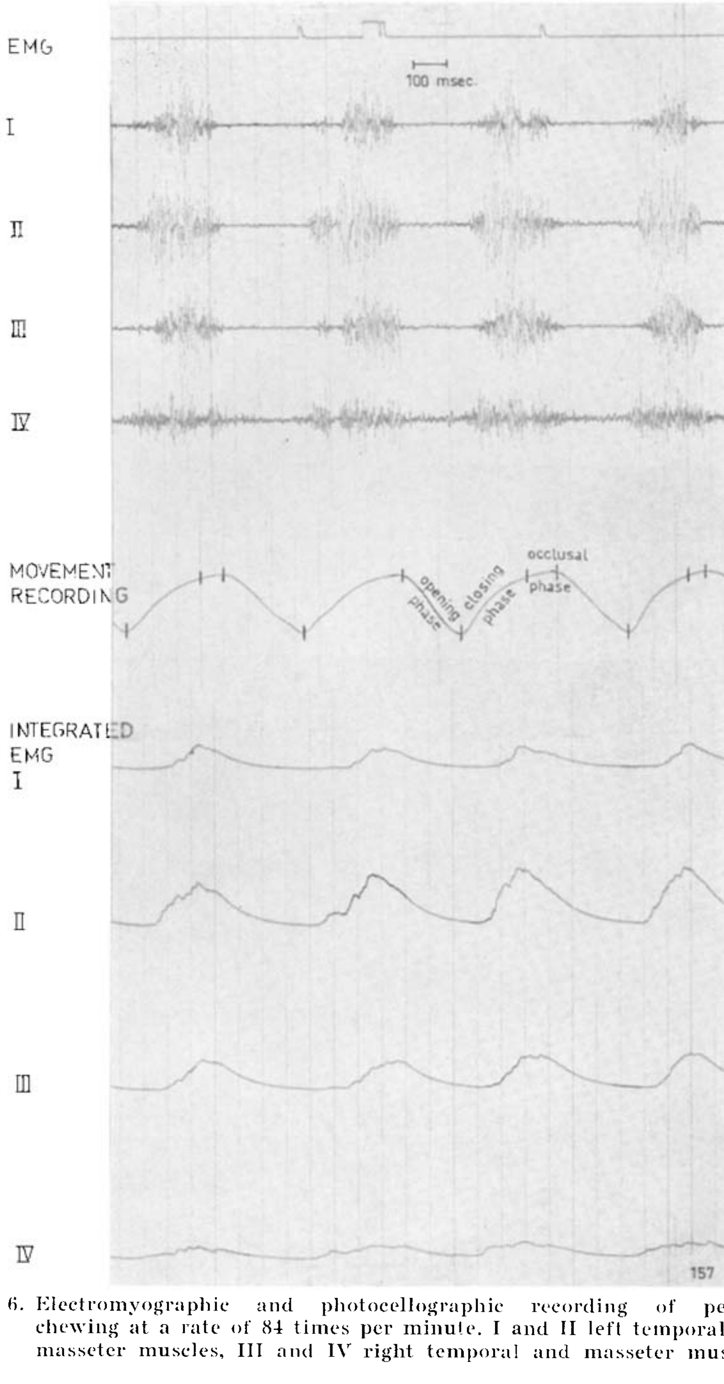

Fig. 6. Electromyographic and photocellographic recording of peanut chewing at a rate of 84 times per minute. I and II left temporal and masseter muscles, III and IV right temporal and masseter muscles.

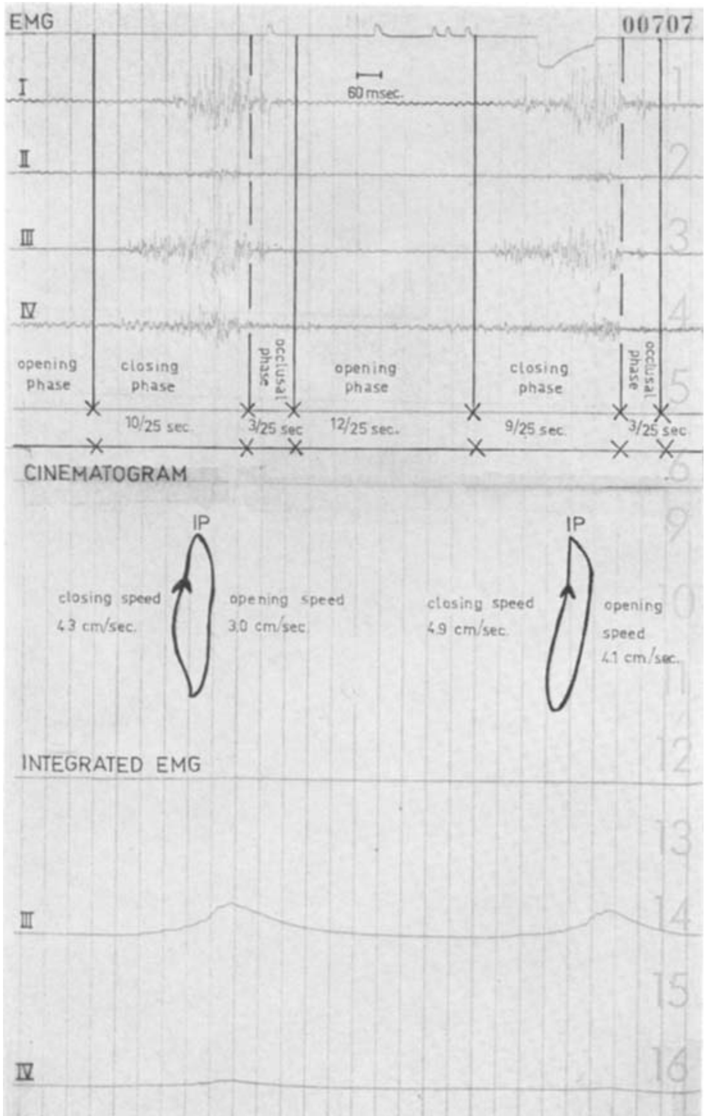

Fig. 7. Electromyographic and cinematographic recording of gum chewing. I and II left temporal and masseter muscles, III and IV right temporal and masseter muscles. IP = intercuspal position.

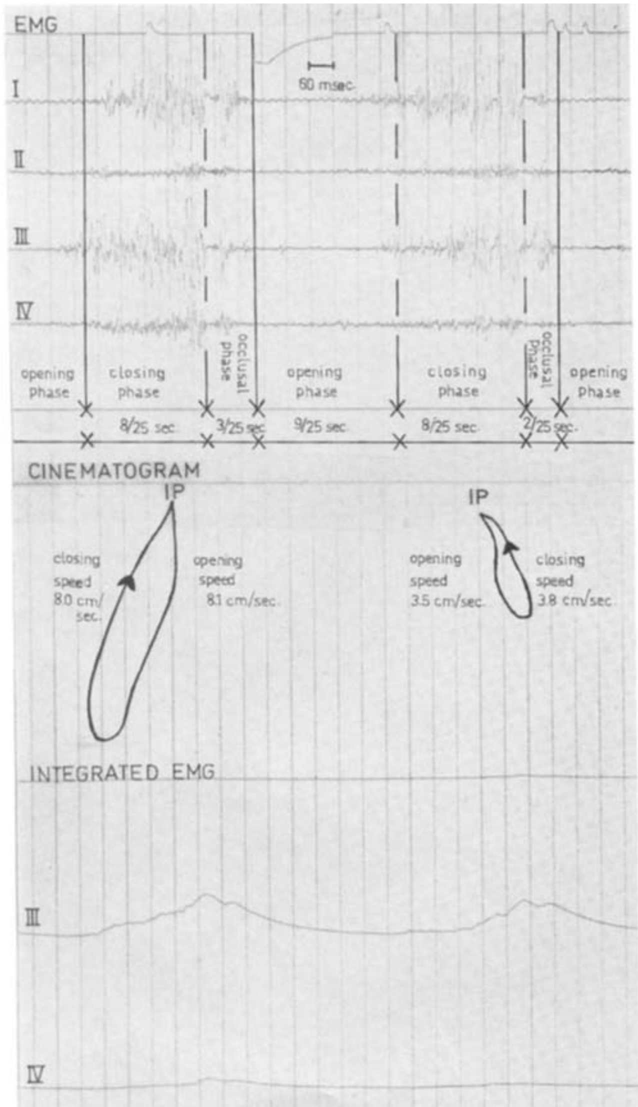

Fig. 8. Electrographic and cinematographic recording of carrot chewing. I and II left temporal and masseter muscles, III and IV right temporal and masseter muscles. IP = intercuspal position.

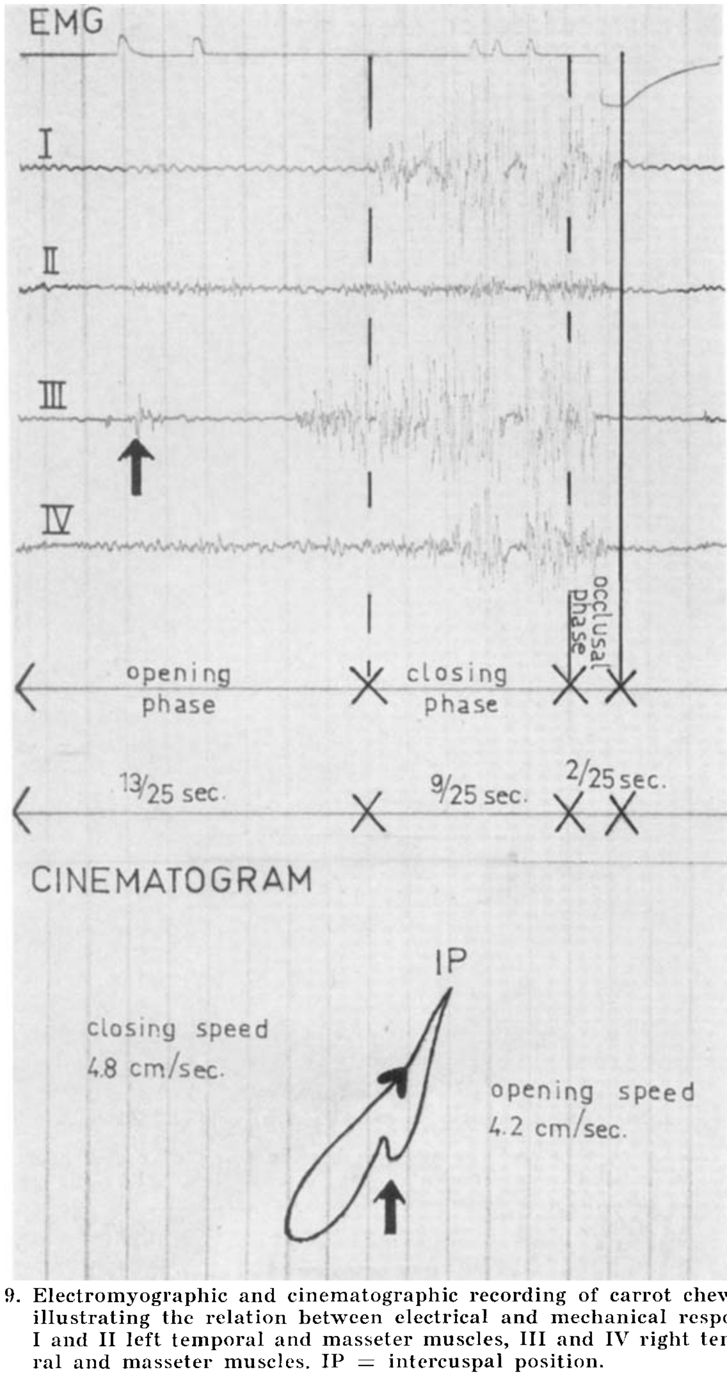

Fig. 9. Electromyographic and cinematographic recording of carrot chewing, illustrating the relation between electrical and mechanical response. I and II left temporal and masseter muscles, III and IV right temporal and masseter muscles. IP = intercuspal position.

les before the termination of the opening phase. They continued to occur and gradually increased in amplitude with the change in phasic relationships. The greatest integrated EMG activity was recorded toward the end of the closing phase, just before the occlusal phase was initiated. When occlusal contact was reached a "silent" period of about 25 msec. appeared. Similar "silent" periods in the EMG pattern were sometimes found also before the occlusal phase was started. The duration of the occlusal phase was between 40—120 msec. The potentials ceased to appear at the start of the opening phase. The duration of the occlusal phase increased toward the end of a chewing sequence. In those chewing strokes (usually at the beginning of the chewing sequence) where intercuspal contact never was reached, maximal EMG activity appeared at the end of the closing phase and then the activity disappeared at the initiation of a new opening phase.

As an illustration of how a small change in the movement pattern of the mandible was accompanied by a specific change in the EMG Fig. 9 is shown. In this record a slight irregularity in the path of motion during the opening phase of a masticatory cycle could be correlated to a specific EMG change.

DISCUSSION

In a previous EMG study it was shown that the inter- and intra-individual variation in the EMG activity of the masticatory stroke was great and in terms of pattern of activity and integrated EMG no clear differences existed in cases with different occlusions of the teeth (*Ahlgren*, 1966). From the results of this study the great variation in muscular behavior during mastication can however be explained by differences in load, speed, and form of the masticatory movements. Earlier conflicting EMG findings regarding mandibular movements also can be explained by the fact that the movements were performed without adequate control (*Graf & Zander,* 1964 and *Schärer & Stallard,* 1965). To allow comparisons of muscular activity the type of movement (active, passive, and resistive), speed, load, and range of the movements must be controlled. This is in agreement with the postulate laid down by *Carlsöö* (1952) and *Ralston* (1961) for EMG studies.

The masticatory cycle can be divided into three phases, the opening phase, the closing phase, and the occlusal phase. During the closing phase the temporal and masseter muscles are contracting isotonically, during the occlusal phase they are contracting isometrically, and during the opening phase they are relaxing. Most of the EMG activity (approximately 75 per cent) of the masticatory cycle usually appeared during the closing phase, the rest of the activity appeared during the occlusal phase. Thus, the EMG pattern recorded during mastication was a response to both isotonic and isometric contractions. It has been shown that a linear relationship exists between integrated EMG and tension during isometric contractions in both leg muscles and jaw muscles (*Inman et al.*, 1952, *Lippold,* 1952, *Close et al.*, 1960, and *Ahlgren,* 1966). A similar relationship also exists during isotonic contractions in the leg muscles, if the conditions of the experiments are highly standardized as far as speed, range, and load of the contractions (*Bigland & Lippold,* 1954, *Close et al.*, 1960, and *Ralston,* 1961). This means that if one wants to study the variations in muscular tension during the masticatory stroke from EMG records the speed, load, and range of mandibular movements have to be standardized. In the experiments conducted in this study these experimental conditions were fulfilled and it can be assumed that integrated EMG is proportional to muscular tension.

It was shown in this study that during mastication maximal integrated EMG preceded the occlusal phase. If the findings of *Inman et al.* (1952), that there is an interval between peak tension and peak EMG of about 80 msec., is valid for the masticatory muscles, it means that maximal tension is developed during the occlusal phase. This hypothesis, however, must be verified by simultaneous registrations of EMG, chewing force, and mandibular movements. Such a study is under way and will be reported within short.

In this study a "silent" period, i. e. inhibition of the elevator muscles, was recorded in the EMG pattern at the initiation of the occlusal phase. There are at least two possible sources for this inhibition. One of these is the jaw opening reflex, elicited by stimulation of the pressure receptors in the periodontal ligament (*Sherrington,* 1917, *Harrison,* 1942, and *Jerge,* 1964). Reciprocal innervation leading to inhibition of the antagonistic elevator muscles is a feature of this flexion reflex. The jaw opening reflex is protective in nature. Thus, the "silent" period in the EMG may be a protective response to the initial tooth contact. On the other hand, the "silent" period also may be looked upon as an inhibition from the Golgi tendon organs of the elevator muscles themselves, so-called autogenic inhibition. It is known that during contraction muscle spindles are unloaded while tendon organs are excited (*Ochs*, 1965); therefore as the tension in the temporal and masseter muscles increases toward the end of the closing phase the tendon organs may be stimulated, causing inhibition of the elevator muscles. However, the close relationship between the "silent" period and the initiation of the occlusal phase indicates that periodontal receptors rather than muscle receptors are operating. Even the condition that peak tension appeared after the "silent" period speaks against autogenic inhibition as a source for this "silent" period. The short duration of the "occlusal silent period" (30 msec.) compared to the prolonged inhibitory states found in autogenic inhibition (50—100 msec.) also speaks for a feedback from the intraoral pressure receptors.

Jerge (1964) has discussed the neurologic mechanism of cyclic jaw movements. He stresses the fundamental importance of the jaw opening reflex and the stretch reflex of the elevators. Due to absence of muscle spindles in the jaw opening muscles he denies the principle of reciprocal innervation for cyclic jaw movements. However, from the results of the present study it appears as the jaw opening reflex is more involved with the control of the closing phase than with the initiation of the opening phase. Thus, a more likely peripheral basis for cycle jaw movements seems to be the inverse myotatic reflex (opening phase) and the myotatic reflex (closing phase) of the elevator muscles. However, under normal conditions it must be considered highly questionable if these reflexes have anything at all to do with rhythmic chewing. Rather, it appears as if mastication like walking is under control of rhythmic activity in supraspinal structures (*Hooker*, 1955 and *Eliason*, 1960).

The relationship between the phases of motion and EMG changes during active flexion — extension of the knee has been studied by *Bierman & Ralston* (1965). They found that EMG activity was recorded from the antagonist muscles toward the end of extension and flexion. It was explained as a decelerating effect for preventing damage to muscle and joint tissue. In this study no antagonistic activity usually was recorded in the elevator muscles during the opening phase, except in very rapid mandibular movements where a decelerating component was found. The difference in antagonistic behavior can be explained by the considerable less momentum developed in the jaw movements than in the leg movements. The observation that during slow motion the elevator muscles did not show activity at the initiation of the closing phase seems to indicate that the passive elastic tension in stretched elevator muscles is a factor in propelling cyclic jaw movements. This is in contrast to *Jerge* (1964) who claimed that stretch reflexes initiated the closing masticatory stroke, but agrees with *Bierman & Ralston* (1965) who did not find the classic stretch reflex in normal human movements.

Another difference between flexion — extension movements in the knee and in the temporomandibular joints was also apparent. In leg movements the agonists showed the greatest amplitude at the initiation of extension or flexion, but in jaw movements the elevator muscles showed the greatest EMG activity toward the termination of the closing phase. This difference in EMG pattern was explained by the ease to move a small mandible and the need to apply force at the end of the chewing stroke.

SUMMARY

A method has been presented for simultaneous recording of mandibular motions and electromyograms. The movements of the mandible were recorded by cinematography or photocellography during mastication and during active lowering and elevation. Simultaneous electromyography (direct and integrated) was performed on the temporal and masseter muscles of 10 normal subjects using intercutaneous electrodes of 0.20 mm. platina wires. The recordings were synchronized and matched. The rate of the mandibular movements were controlled by a metronome.

During active lowering of the mandible no action potentials were recorded from the elevator muscles. During elevation action potentials appeared in the agonists approximately at the initation of the movement. The onset of activity in the temporal and masseter muscles was related to the rate of the movements. The EMG activity then gradually increased toward the termination of the

movement. At the initiation of the occlusal phase a short "silent" period appeared in the EMG. Maximal integrated EMG was recorded *after* this "silent" period.

During the opening phase of chewing no EMG activity was usually recorded from the temporal and masseter muscles, but approximately at the initiation of the closing phase action potentials appeared in the recorded elevator muscles. Exactly when action potentials appeared during the closing phase was dependent on the speed and the form of the masticatory movements. If the speed was high or if a large abduction occured, EMG activity appeared immediately at or even before the initiation of the closing movement. The action potentials then gradually increased in size toward the end of the closing phase. At the initiation of the occlusal phase a sort "silent" period (25 msec.) in the EMG was recorded. Maximal integrated EMG from the elevator muscles was recorded *before* the occlusal phase. After the "silent" period the EMG activity decreased until a new opening phase was initiated. Approximately 75 cent of the EMG activity was recorded during the closing phase, the rest during the occlusal phase. The "silent" period at the initiation of the occlusal phase is interpreted as a protective mechanism for the teeth (jaw opening reflex).

RÉSUMÉ

L'ACTIVITÉ ÉLECTROMYOGRAPHIQUE PENDANT LES MOUVEMENTS DE LA MANDIBULE DANS LES CAS NORMAUX.

On a présenté une méthode pour enregistrement simultané des mouvements mandibulaires et de l'activité électromyographique. Les mouvements de la mandibule ont été enregistrés par cinématographie ou par cellule photo-électrique pendant la mastication et pendant l'abaissement et l'lévation activs de la mandibule. L'électromyographie synchronisée (EMG directe et intégrée) a été faite sur les muscles temporaux et sur les muscles masséters de 10 cas normaux. On s'est servi d'électrodes de fil de platine de 0,20 mm, appliquées sur la peau. La fréquense des movements mandibulaires a été contròlée par un métronome.

ZUSAMMENFASSUNG
ELEKTROMYOGRAPHISCHE AKTIVITÄT BEI BEWEGUNGEN VON DEM UNTERKIEFER IN NORMALFALLEN

Eine Methode für gleichzeittige Registrerung von Unterkieferbewegungen und Elektromyogrammen ist presäntiert geworden. Die Bewegungen des Unterkiefers wurden durch Kinematographie und Photocellographie bei Kauen und bei aktive Unterkieferbeweungen aufwärts und abwärts registriert. Gleichzeitige Elektromyographie (direkte und integrierte) wurde auf die Temporal und Masseter Muskeln in 10 Normalfallen ausgeführt. Hautelektroden von 0.20 mm. Platinumdraht wurden gebraucht. Die Registrierungen wurden synchronisiert. Die Geschwindigkeit der Unterkieferbewegungen wurden mittels eines Metronomes kontrolliert.

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