Appendix: Two Papers on Muscle Sound by Hermann von Helmholtz

Experiments on Muscle Noise (1864)

1. One very clearly hears the well-known and often questioned muscle noise in certain circumstances in which the rubbing of the ear or the stethoscope on the skin covering the muscle are completely excluded, when you are in a quiet place, preferably at night, ears tightly plugged with sealing wax or wet paper, and then bring the muscles of the head (e.g. the masseters) into vigorous contraction. As long as the muscles remain in constant tension, one hears a muffled, roaring noise whose fundamental tone [*Grundton*] is not significantly altered by increased tension, while the intermixed roaring noise becomes louder and higher.

Not only the tension of the powerful masticators, the masseters, pterygoidei, and temporals, but also that of much weaker facial muscles, the orbiculares oris and palpebrarum, of the platysma myoides, the levator labii superioris alaeque nasi, of the tongue, etc, make audible noises, all of which are essentially of the same character, only louder, clearer, and purer, like the well-known noises one hears when one puts the stethoscope on the contracted muscles of the arm.

The pitch of the fundamental tone of the musical part of this noise is very difficult to determine because it lies below [925] the lower limit of perceptible pitches.[1] Mr. S. Haughton[2] recently had it determined by several people, for whom it sometimes corresponded to the C of 32 vibrations [per second], sometimes the D of 36; 35 to 36 was also the largest number that Wollaston found for it. I find the same for my masticators, though the pitch for the weaker facial muscles is a little bit lower.

2. I repeated these observations so that I would not produce the contraction of the muscles by my will but rather using an induction apparatus with a vibrating spring that, at the appropriate setting, could give up to 130 vibrations of the spring [per second] and the same number of opening beats [*Oeffnungsschläge*].[3] The induction apparatus stood in another room separated by two closed doors so nothing of its tone could be heard directly. As soon as I put the electrodes on my masseter and brought it into strong contraction, I

heard the tone [*Ton*] of the spring of the induction apparatus.[4] When I changed the adjustment of its [the spring's] screw, then I heard the change [in the muscle].

That the tone belongs to the contracted muscle and not to the direct effect of the electrical currents on the ear follows especially from the fact that the tone only became audible when the current strength was increased sufficiently to give a contraction of the muscle.

3. Likewise, the tone was also heard, though less strongly, through a stethoscope on a young man's arm muscles, which were brought into contraction by induction currents flowing through them. In this case, the ear and auditory nerve of the observer were not affected by electrical currents. Yet one should bear in mind the electric current directly sets the contracted muscle to vibrating like a tensed wire. In order to exclude this possibility, I finally let the current flow through the median nerve of the upper arm [926] and weakened its strength enough that, when applied directly to the muscle, it did not bring it to contraction. As soon as the current affected the nerves strongly enough that strong contractions of the forearm muscles occurred, I heard clearly the tone of the current-interrupting spring. On the contrary, if I moved the electrodes on the upper arm a little to the side so that the effect on the forearm muscles ceased, the tone also disappeared.

It follows that the periodic movement the wire delivered to the nerve in the form of electrical shocks was led from the living nerve to the muscle with unchanged period and finally set it into mechanical vibration, into sound vibrations. The number of vibrations was about 130 per second.

First of all, these attempts seem to me to eliminate any doubt about the existence of a specific contraction-dependent muscle noise and to set aside any explanation of it in terms of friction of the muscle on the surrounding parts.

That an apparently evenly contracted muscle is in fact to be understood as rapidly changing contrary molecular arrangements was inferred by Mr. E. du Bois-Reymond from the appearance of the so-called secondary tetanus.[5] The speed of this change is one of the most important reasons that one must attribute electrical muscle effects to the existence of very small electromotive molecules. But the evidence of such a change mostly rested only on the fact that the muscle current of a tetanized muscle, passed through another nerve, would likewise tetanize that muscle also. About ten changes per second would be sufficient. If it now seems extremely likely that the number of internal changes of a muscle tetanized by induction pulsations from a series of induction loops may be about equal to the number of electric shocks, therefore I believe that direct proof for it [i.e., du Bois-Reymond's theory about the change], as is supplied by the tone of the muscle, is of importance in these circumstances. [927]

I note that also in my investigations of the sensations of tone [*Tonempfindungen*] it was also necessary for the auditory nerves to receive about 130 distinct excitations per second.

At the time, I had no equipment to produce more than 130 opening beats reliably with regular periodicity, but I do not doubt that much higher tones are produced in the muscles. When I let a tuning fork of 120 vibrations [per second] interrupt the current, I hear in the muscle relatively strongly the tone of 240 vibrations, the higher octave of the pitch of the fork, which seemed to have been evoked through the 120 opening beats and the somewhat weaker 120 closing beats. The difference between the strengths of both types of beats was less in this case because the mercury flow was interrupted.

On the other hand, I used a tuning fork to induce tetanus in frog legs. The tuning fork was set between the poles of an electromagnet and, through the arc produced by its motion [the fork's oscillations], created an electric current in the form of steady sine waves in the coils of the electromagnet. I discovered that even 600 oscillations per second induced tetanus. However, I was unable to ascertain sound oscillations in the frog muscles.

On Muscle Tone (1866)

The author earlier discussed this subject and showed that when muscles of humans or rabbits have been set into tetanus by means of the currents of an induction apparatus whose spring carries out regular vibrations, instead of the normal muscle tone one hears a tone at the pitch of the vibrating spring of the induction apparatus. The usual devices of this type only give 40 to 60 vibrations per second; in the exposed sciatic nerve of a rabbit I had earlier induced tetanus through an induction apparatus in which a tuning fork of 120 vibrations interrupted the current and heard the corresponding tone of 120 vibrations from the animal as well as (though not quite so clearly) the first overtone of 240 vibrations. It is difficult to make the rapidly interrupted induction currents strong enough to affect human nerves through the skin because the mercury one must use at the interruption point quickly burns and turns to dust. Through careful adjustment of the appropriately attached secondary closures (partly metallic for the electromagnets, partly water decomposition [929] cells for the spark gap), using a tuning fork of 240 vibrations I managed to apply sufficiently strong impulses to attain tetanus in the median nerve of human forearm muscles, in which the tone of 240 vibrations was clearly audible, which indicated an extraordinarily high degree of mobility in the molecular apparatus of the muscle.

Since the muscle tone observed in this way is a phenomenon of low intensity, demanding quite remarkable attention from the observer, I have often tried to build resonance apparatuses to make it more clearly audible, especially because it was important to me to hear more clearly natural muscle tone that is at the limit of the deepest audible tones and thereby determine its nature. This was only very imperfectly possible acoustically, so that I thought it was possible rather to make vibrations of the muscles, especially in their deeper tones, visible to the eye.

To that end, I use steel springs (clock springs) long enough that their vibration period becomes equal to that of the sound to be perceived. These are inserted between four wire pins clamped at the ends of elastic boards partially separated by full-length cuts. If one places the board on the muscles so that one of its springy sections receives the muscular contractions, they are transferred to the clock spring, which comes into strong, easily visible resonant vibration. Using an apparatus giving 19.5 interruptions per second, human muscles came into strong resonant vibration when the spring was set at 19.5 vibrations [per second], weaker at 39 or 58.5, very weak at 78.

If one seeks the length of the spring that is best set into vibration through the natural contraction of the muscles, one finds it at 18 to 20 vibrations per second. The vibrations [930] in that range are not so regular, and therefore not as strong as they are with artificial tetanus. Because a steel spring resonates too long and therefore does not receive the transmitted mode of vibration fast enough, I found that a similar apparatus with tapered paper strips able to vibrate was better for observing natural muscle vibrations. Their oscillation period is best determined if one holds them against the vibrating spring of a suitably matched induction apparatus, and determines to which period of vibration they resonate most strongly.

These experiments thus show that the number of natural vibrations of human muscle is not 36 to 40, as Wollaston and Haughton believed they had observed, but only 18 to 20. What one hears as a muscle tone is therefore only the first overtone of the true muscle vibration, whose fundamental tone does not lie in the range of audible tones. Moreover, this natural muscle vibration is indeed approximately periodic, but not as exactly periodic as the movements of the vibrating tuning forks and steel springs.

In the hope of making the experiments significantly easier when experimenting with frogs, I have also experimented with their muscles. I succeeded in hearing traces of the tone of 120 vibrations when I hung a weight-bearing frog muscle to a [small] rod inserted into [my] auditory canal. On the other hand, one can very well observe the vibrations of the spring from 16 to 20 vibrations if one hangs the muscle on the above-described board holding the spring and, with an electrical tetanus of a corresponding number of beats, has it lift two ounces.

Spring vibrations of frequency 120 entirely failed to evoke isochroous electrical impulses from the nerve. In contrast, if I set the induction apparatus to 120 vibrations and the resonating spring to 16 vibrations, I saw weak vibrations of the spring that seemed to correspond to the natural vibration period of the frog spinal cord. [931] Moreover, it should be remarked that, as E. du Bois-Reymond first noticed and I myself confirmed, tetanus in the rabbit spinal cord caused by quickly vibrating currents also gave rise not to the sound of the current vibrations but to the natural muscle tone.

Currents of frequency 18 acting on the frog spinal cord, on the other hand, also induced strong isochronous vibrations in the spring. This frequency seems so close to the natural frequency of frog spinal cords that they will fully adapt themselves to currents at this frequency.

Sounding Bodies

Music and the Making of Biomedical Science

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