Enhancement of Tactile Perception in Palpation

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SUMMARY We studied tactile perception in palpation of the precordium to determine the frequency response of the hand and to improve, if possible, the sensitivity of the hand as a transducer for precordial movement. The threshold of tactile sensation was determined for 10 subjects by manipulating the amplitude of movement of an impulse generator at each of a series of frequency settings in the subaudible range (1-40 Hz.) Relatively gross movements were necessary to achieve threshold in the lowest frequencies. A more than fourfold increase in sensitivity was obtained by restraining the fingers with the application of a light but unyielding disc to their dorsal surface. Clinical application of this device permitted the easy perception of a systolic thrust as well as a rapid filling wave in normal adult subjects over the right ventricle at the left sternal edge, an area generally considered to be motionless by conventional palpation.

PALPATION of the precordial movement has been a part of the physical examination of the heart for over 130 years. The information derived from this procedure includes an estimate of heart size, rhythm, evidence of left or right hypertrophy and detection of thrills. For more than a century, graphic records have been widely used to depict the events involved in precordial movement, although the exact relationship between a graphic tracing and one's subjective sense of movement remains controversial. Tactile perception in the art of palpation, however, has not been extensively studied in terms of the frequency response of the hand or with respect to how the sensitivity of the hand might be improved.

Physiologists have shown that the human hand is endowed with certain neurons that are primarily sensitive to positional change and other neurons sensitive to the time rate of positional change or velocity. Therefore, the sensation appreciated by the palpating hand could be derived from a combination of both positional and velocity factors.

To clarify the physical features that may be important in palpation of precordial movement, we undertook an in vitro study in which the amplitude and frequency of a sinusoidal wave form were independently varied to determine the threshold of tactile perception.

Method

To provide a moving stimulus to the palpating fingers, a device capable of delivering a sinusoidal impulse was constructed by mounting a plexiglass disc on the plunger arm of an electromechanical transducer (fig. 1). The disc was 38 mm in diameter and suitable for the light application of the subject's fingers. The forearm was supported in a comfortable position to reduce muscle fatigue during the experiment.

The transducer was driven by a sinusoidal voltage
FIGURE 1. Palpation stimulator - an electromechanical transducer to which a plexiglass disc 38 mm in diameter has been attached.

Figure 2. An example of the voltage signal supplied to the electromechanical transducer. This represents the motion of the palpation disc with time. The units of voltage and time are intentionally omitted.

signal originating from the wave form generator. A single cycle of this wave form was applied to the transducer once every 1.16 seconds (52 beats/min). Figure 2 shows the general type of movement of the palpation disc with time. With one hand lightly resting on the palpation disc, the subject was asked to use his other hand to increase gradually the amplitude setting of the signal until the threshold of sensation was obtained. The subject was not able to look at the disc and therefore was not biased by visual clues. To avoid fatigue, the subject rested between each determination. During these rest periods, the palpating hand was lowered to a comfortable position. This procedure was repeated for each of the frequencies used in the experiment.† It can be shown mathematically that for sinusoidal wave-forms, the ratio of maximum velocity to amplitude is proportional to frequency and that the ratio of maximum acceleration to amplitude is proportional to the square of the frequency. Therefore, by adjusting the frequency setting we could alter the relative contributions of the amplitude, velocity and acceleration. The maximum upward velocity is achieved at the peak slope of the upstroke of the wave form, followed by a downward velocity of equal magnitude at the peak slope of the downstroke of the wave form. The maximum upward acceleration is achieved at the initiation and termination of the wave form, while the maximum downward acceleration is achieved at the peak of the positional wave form. The palpating fingers must presumably distort the wave form somewhat to sense the motion. It is not possible to determine exactly when during the course of this motion the sensation threshold is achieved. The frequencies covered the subaudible range, with settings of 1, 2.5, 5, 10, 15, 20, 30 and 40 Hz. To assure that the result was not dependent on the sequence with which the frequencies were applied to the hand, several subjects made the determination in the reverse order.

The movement of the palpation disc was measured by a strain gauge attached to the underside of the disc. The signal obtained from this gauge was recorded on strip-chart paper. Because we were primarily interested in the relative amplitudes, no absolute measurement of the motion was made (i.e., the gauge was not calibrated). The range of amplitudes was from several hundredths of a millimeter to approximately 1 mm.

After the experiment was performed using the conventional palpation technique, in which the fingers were allowed to ride freely with the palpation surface, another experiment was done in which finger movement was restrained. This was accomplished by bringing a restraining disc into light but secure contact with the dorsal aspect of the palpating fingers (fig. 3). In several subjects the restrained experiment was done

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*The mathematical expression of the wave form was: \( X = A/2 (1-\cos(2\pi f t)) \) for \( 0 \leq t \leq 1/f \), when \( A = \) amplitude and \( f = \) frequency (Hz).

†The frequency represents the number of cycles of the wave form that would be completed per second if the generator were allowed to run continuously. Here we allowed the generator to produce only one cycle and to repeat this cycle once every 1.16 seconds. The frequency related to the quickness with which the wave form was produced, not how rapidly it was repeated.
first to determine whether the results could be shown to be independent of the order in which the two experiments were performed. In this manner, the threshold amplitudes were obtained in both modes for all frequencies used.

Results

The results of this experiment represent an analysis of the frequency response of the human hand in the detection of a particular sinusoidal wave form. Because of the nature of the data, it was convenient to display the results in logarithmic form, with the logarithm of the threshold amplitude plotted on the ordinate and the logarithm of the frequency on the abscissa. Figure 4 is an example of the resulting graph for one of the 10 subjects.

In the free hand mode, the threshold amplitude is highly frequency-dependent above a frequency of 5 Hz, showing that the sensitivity of the fingers is markedly enhanced as the frequency increases. The flatter response curve obtained in the restrained hand mode indicates lesser dependence of sensitivity on frequency. In addition, to elicit the threshold of sensation in the lower frequency range, the free hand must receive a stimulus with an amplitude 4.7 times as large as that of the restrained hand. (log[\(A_{\text{free}}\)] - log[\(A_{\text{restrained}}\)] = log[\(A_{\text{free}}/A_{\text{restrained}}\)] = 0.67 \(\rightarrow\) \(A_{\text{free}}/A_{\text{restrained}} = 10^{0.67} = 4.7\).) These relationships were consistent for all 10 subjects; the average amplitude of the stimulus required to achieve threshold sensation was fourfold greater for the free hand than for the restrained hand (fig. 5). The average difference of the logarithms of the amplitudes for the free hand was approximately 0.6 for the range of frequencies below 5 Hz. This represents a fourfold enhancement of sensitivity. The difference of the logarithms shrinks to approximately zero at 40 Hz, indicating that the sensitivity of the hand to this frequency is the same in both modes (10° = 1).

Discussion

Our experiments reveal an apparent inefficiency of the free hand compared with the restrained hand in detecting the sinusoidal impulse. For the fingers to detect the motion of the disc, the skin must be slightly indented or deformed so as to activate the sensory neurons. In the free hand, the fingers are allowed to move with the wave form. Any overall motion of the fingers represents motion that could have resulted in indentation of the skin but has been wasted. In the restrained mode, however, the fingers are not allowed to ride with the impulse. The result is that all of the motion of the palpation disc results in indentation of the skin on the fingers. This indentation is primarily on the volar surface of the fingers, but owing to the method of restraint (fig. 3), there is an additional stimulation of the dorsal aspect of the finger that increases the total neuronal response to the wave form. Owing to inertia, the free fingers are unable to follow the motion of the palpation disc as the frequency of the impulse increases. Therefore, the effect of the wave-riding phenomenon is progressively reduced. At

![Figure 4](image1.png)

**Figure 4.** Results of experiment for one of the 10 subjects. The graph shows the logarithm of the threshold amplitude vs the logarithm of the frequency of the stimulation for both the free and restrained modes. The frequencies studied are 1, 2.5, 5, 10, 15, 20, 30 and 40 Hz (cps), respectively, from left to right. The units of amplitude \(A\) are arbitrary. The reduction in the log of the threshold amplitude above 5 Hz indicates an enhanced sensitivity to the higher frequencies.

![Figure 5](image2.png)

**Figure 5.** Summary of results for all 10 subjects. The log of the threshold amplitudes for the restrained hand \(A_R\) was subtracted from the log of the threshold amplitude for the free hand \(A_F\) and the mean and standard deviation for this difference were obtained for each frequency setting. The best fitting curve for these results is shown throughout the frequency range of 1-40 Hz (cps). The mean difference is approximately zero at 40 Hz.
a frequency of 40 Hz, the motion is so fast that the fingers are not able to ride with the impulse and the sensitivity of the free hand becomes essentially as good as that of the restrained hand.

The sensitivity of the restrained hand is also enhanced as the frequency increases, probably due to the presence of velocity-sensitive neurons. Extensive studies have been made of the mechanoreceptors of mammalian skin. An excellent review of this work was presented by Burgess and Perl. The results show that certain mechanoreceptors in mammalian skin are primarily sensitive to velocity, while others are sensitive to positional change. The mechanoreceptors can also show a sensitivity to rapid transients of motion that correspond to high-frequency stimulation. This suggests that acceleration and even higher time derivatives of motion such as "jerk" might be contributing factors to the total neuronal response of the tactile sense. An atraumatic percutaneous method for recording nerve impulses in man developed by Valbo and Hagarth allowed for an in-depth study of the individual mechanoreceptors of the human hand, and a later paper from the same laboratory described the types of mechanoreceptors in the human hand. There are three types of intracutaneous mechanoreceptors, one that adapts rapidly to stimulus and two that adapt slowly. Additional rapidly adapting neurons are located in the subcutaneous tissues, probably in Pacinian corpuscles. Despite their deeper location, these also respond to skin deformation. The main distinction in the nerve types is their rate of adaptation to a mechanical stimulus. A rapidly adapting neuron is sensitive to the velocity of the stimulus; the slowly adapting neurons are considered to be primarily sensitive to positional change. Although there are relatively more positional sensors than velocity sensors in the human hand, there is a sound physiologic basis to the concept of velocity dependence in palpation.

It can be shown mathematically that for a sinusoidal wave form, the ratio of maximum velocity to maximum positional change is proportional to the frequency of the wave form. Therefore, the maximum velocity of the impulse should become relatively more important as the frequency increases, and at some point the velocity-sensitive neurons of the fingers should become important in producing the threshold sensation. This would be manifest in enhanced sensitivity to the higher frequencies. Therefore, the physiologic investigations described above support the concept of frequency dependence in the palpation response.

In summary, it is probable that both the free and the restrained hands show preferential sensitivity to higher frequencies as a result of the presence of velocity-sensitive neurons. In addition, the free hand shows additional preference to the higher frequencies because of the wave-riding phenomenon.

The movement of the disc was oriented such that the initial velocity was oriented toward the fingers followed by a velocity away from the fingers with equal magnitude. We have performed several experiments using an inverted form of this impulse, i.e., an impulse that initially moves away from the fingers. The response of the fingers to this wave form was essentially identical to the original results in both the free and restrained modes. In both versions of the impulse there were velocities toward and away from the fingers. The inverted impulse simply reversed the order in which the velocities were applied. Therefore, it is not possible, using this wave form, to distinguish between the response of the fingers to inward vs outward velocities.

A limited number of inferences about the palpation phenomenon can be derived from this study. The varying relationships between peak velocities (both inward and outward) and positional change are not satisfactorily modeled by the simple wave form used in this experimental model. Nevertheless, it is reasonable to infer that the frequency response of the fingers to precordial movement is similar to that of the response to the in vitro wave form.

Therefore, just as the frequency response of the ear must be recognized in evaluating which portion of the cardiac vibration is audible in auscultation, the frequency response of the hand must be recognized in evaluating which portion of the precordial motion is felt in palpation. There are two generally accepted techniques by which a graphic analog of the precordial motion can be obtained: the apexcardiogram and the kinetocardiogram. The apexcardiogram measures the relative motion of the intercostal tissue with respect to the ribs, whereas the kinetocardiogram measures absolute motion of the chest wall. The diagnostic value of both methods has been shown by many clinical studies. The absolute precordial motion appears to relate more directly to the impulse perceived by the palpating fingers. Therefore, the kinetocardiogram seems more relevant to this discussion of palpation. The frequency range for the kinetocardiogram at the point of maximal impulse is known to be from the fundamental frequency of the heart beat up to about 30 Hz. The response of the free hand as indicated by the in vitro model would predict a significant distortion in the perception of this motion. This conclusion is supported by the observation that, of the entire range of movements of the precordium, the portion felt during palpation in normal subjects is the high-frequency activity associated with the onset of systole. The remainder of the precordial movement, especially the diastolic portion, is subpalpable in frequency unless grossly exaggerated by disease, just as a portion of the cardiac vibration is subaudible to the human ear. The enhanced sensitivity of the hand to high-frequency events and the resulting distortion of the perception of the precordial movement has long been recognized. In 1908 Mackenzie wrote, "I am of the opinion that a good deal of confusion in regard to the correct interpretation of the heart movements has arisen from associating the shock conveyed to the chest wall, when the ventricle passes into systole, with the apex beat. The apex beat and this impulse have become so connected that it is assumed that they are one and the same thing. The apex beat due to the left ventricle is a
movement which lasts during the whole of ventricular systole; the shock caused by the ventricular contraction endures for a short space of time, and occurs while the ventricular muscle suddenly hardens and corresponds with the upstroke only of the apex beat."

The results of our in vitro model indicate that the restrained hand is much more uniform in its response to this range of frequencies and should convey to the physician a more realistic impression of the precordial motion. We have therefore modified the restraining apparatus for clinical use (fig. 6). The restraining device must be quite rigid, yet lightly applied to the dorsal aspect of the fingers. No comparable improvement can be obtained by attempting to restrain one hand with the other, or even with the application of heavy weights. Any such attempt inevitably results in compression of the tactile sensory surface of the fingers, with resulting immediate sensory fatigue and a loss of perception of the movement. The patient lies on a conventional examining bed or stretcher. A steel plate approximately 10 cm wide by 60 cm long and about 3 mm thick is placed under the patient so that the region of interest is above the plate. This plate can be lightly padded to reduce patient discomfort. A semicircular lucite support is then positioned over the heart. The support is held securely to the steel plate by the attractive force of two powerful channel magnets (about 25 lb. pull each), which are mounted to the lucite. With this arrangement, the support arm can be conveniently attached and repositioned with a minimum of disturbance during the examination. To this lucite arm is attached a rod-and-pinion adapter capable of positioning the restraining disc on the dorsal aspect of the palpatting fingers. This attachment should be moveable along the support arm to provide the complete range of adjustment required. It is convenient to place the diaphragm of the stethoscope at the point of interest and position the palpating fingers between the stethoscope and the restraining disc. This arrangement allows for the maximum distortion of the skin of the fingers while allowing for auscultation. In a variation of this configuration, the thumb and first finger can be used to hold the rims of the stethoscope and disc simultaneously so that the fleshy volar portion of the fingers is slightly compressed between the two. This procedure seems to provide optimal tactile sensitivity and minimizes sensory fatigue. This technique also allows the physician, with practice, to use the restraining disc while the patient is breathing. We have noted that, after approximately 30 seconds of palpation, sensory fatigue begins to become a factor. Therefore, brief rest periods are desirable.

As soon as contact between the restraining disc and the fingers is established, palpable sensations are magnified and details of precordial motion become more obvious. In normal adults it has been possible to perceive not only a systolic impulse, but also a rapid filling wave at the left sternal edge, an area generally thought to be inert by palpation. One can perceive, as expected, that this rapid filling wave becomes accentuated with the Müller maneuver and diminished with the Valsalva maneuver. Variation with respiration is also detected, with the rapid filling wave becoming more prominent with inspiration. Identification of palpable phenomena is facilitated by combining this technique with auscultation. Because many pathologic states result in abnormal movement that is of low frequency and low amplitude — for example, the "bulges" that may occur in connection with angina pectoris and myocardial infarction — it is possible that significant clinical information might be obtained by enhanced tactile sensation.

In conclusion, our studies indicate that the frequency response of the hand in the conventional palpation technique allows the physician to detect only a small portion of the full range of precordial movement. The restraint technique, though more cumbersome, eliminates the wave-riding effect and therefore flattens (improves) the frequency-response curve for the hand. This gives the physician a more complete impression of precordial movement that may be clinically important in bedside diagnosis.

References

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