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THE ROLE OF SKIN SENSATION IN THE PERCEPTION OF STRENGTH OF GRASP

(Skin Sensation and Grasp Strength)

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One of the most vexing problems in the field of upper extremity prosthetics is the inability to substitute for the patient's loss of sensation. This problem has become more severe with the introduction of externally powered prosthetic systems. Previously the patient could obtain some impression of his grasping force and of the character of the object being grasped through tension in the conventional cable and the resultant forces on his stump. Now only the sound of the electric motors or the hiss of the pneumatic actuators and valves are available.

Attempts have been made to substitute for the loss of sensation by the use of vibrators (Alles 1968, Mann 1969, Sueda et al. 1969) or cutaneous electric pulses (Beeker et al. 1967) which change their amplitude or frequency in response to changes in the position or activating force of the prosthesis. Small loudspeakers have been used in the same way to provide auditory as well as vibratory signals (Nojima 1970). Slip detecting devices have been used to increase automatically the gripping force when a grasped object has begun to slip from the hand (Salisbury et al. 1967). These attempts to replace or substitute for sensation have been only partially successful, and none are widely used at the present time.

We believe that the absence of sensation may be the major reason for the high rate of rejection of externally powered prostheses. Consequently, we have begun studies on the development of methods and

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devices which may be used with powered prosthetic systems to replace the sense of strength of grasp (Klasson 1970).

This study was initiated to determine the importance of the sensory elements of the skin of the hand with regard to the ability of a person to sense the strength of his grip.

METHODS

Thirteen adult normal volunteers, five males and eight females, with no history or physical findings of sensory or motor abnormalities in the upper extremities were studied. The dominant hand was used in all experiments.

A strain gauge instrumented force transducer diagrammed in Figure 1 was developed to measure the grasping force developed between the thumb and index finger in pinch grasp. Amplified signals from the device were displayed on a dual beam oscilloscope and recorded on an ultraviolet recording galvanometer. With this system we could continuously observe and record the gripping force. The alternate channel of the oscilloscope was used to display a signal equivalent to one kilogram-force.

The subject was instructed in the purpose of the experiment and the methods to be employed. He was seated comfortably with the dominant forearm resting on the arm of his chair. The force transducer was positioned such that it fell between the subject's thumb and index finger. He was allowed to grip the device several times to obtain familiarity with the testing system.

The force transducer was calibrated with a one kilogram laboratory weight and the second channel of the oscilloscope adjusted to display a horizontal line equivalent to one kilogram. The subject was then asked to grip the device on verbal command while watching the screen. He was asked to increase his gripping force until the point of light indicating his gripping force was superimposed on the displayed one kilogram signal. When it was certain that the subject understood the testing procedure, recordings were made. Figure 2 demonstrates a typical oscillographic tracing as seen by the subject. This test was repeated six times. The screen was then turned from the subject's view, and he was asked to repeat the test series, gripping each time with a force of one kilogram. This entire sequence was repeated three times, making a total of eighteen trials with visual feedback and the same number without visual help.

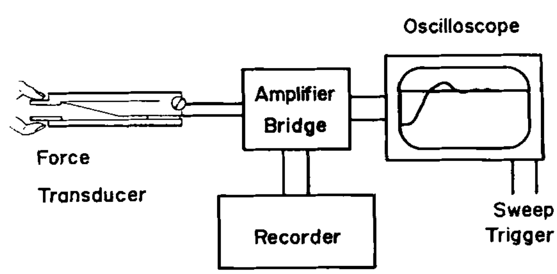

Figure 1. Diagram of the experimental apparatus.

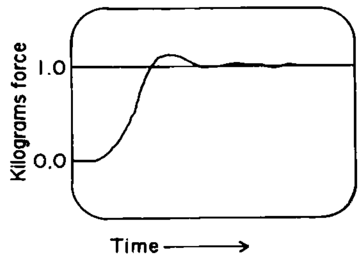

Figure 2. A typical oscilloscopic tracing as seen by the subject during visual tests.

Digital nerve blocks using Citanest 2 per cent* were then used to anesthetize the skin of the thumb and index finger. The digits were checked for pinprick sensitivity and the ability to perceive gross pressure. No test was done unless the subject could not feel a sharp needle or direct pressure on the skin of the digits in any area which touched the force transducer. When anesthesia was complete a test sequence exactly as before was carried out. The test situations outlined above were classified as normal visual, normal nonvisual, anesthetic visual and anesthetic nonvisual.

RESULTS

Figure 3 demonstrates the average recorded gripping force and the range of force values recorded in the eighteen trials by each subject in each test situation. In addition, Figure 3 shows the average force for the entire group and the average standard deviation for the group in each test situation.

Using visual feedback and all other normally available physiologic mechanisms, the subjects were able to provide a grasping force of one kilogram with a high degree of accuracy and repeatability. When the subjects could not see the oscilloscope there was a great increase in the variability of the response, as indicated by the larger individual ranges and the increased group standard deviations. This increase in average standard deviation from 0.021 Kgf to 0.164 Kgf was subjected to a t-test ($t = 7.88$, n–24, $P < 0.001$), which indicated a significant increase in variability when visual feedback was eliminated. The same increase in variability of recorded force is noted when the anesthetic visual group is compared to the anesthetic nonvisual group.

To ascertain the effect of skin anesthesia, the anesthetic visual and anesthetic nonvisual results were compared to their normal visual and normal nonvisual results. No significant differences could be found in either the absolute values for gripping force or in the variabil-

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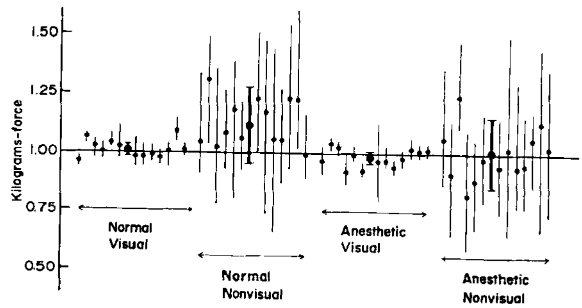

Figure 3. The average force in kilogram and the range of values obtained for each of the 13 volunteers in each test situation. The group average force in kilograms ± 1 standard deviation is presented in the center of each group.

ity of the results. Figure 3 demonstrates the similarity of the results in the normal and anesthetic situations. Digital anesthesia did not decrease the ability of the subjects to sense the strength of grip.

There was a significant increase in the absolute gripping force from 1.0 Kgf to 1.12 Kgf ($t = 3.63$, $N = 24$, $P < 0.005$) when visual feedback was removed in the normal test groups.

DISCUSSION

Sensory testing is usually classified on a physiologic basis involving pain, pressure, light touch, and heat sensitivity (Moberg 1958). This type of classification, while useful in determining the character and extent of neural pathology, is not appropriate for studying the sensory functions missing after an amputation. In this situation it seems more reasonable to classifiy sensation on a more gross and functional basis, such as the sense of strength of grasp, the perception of slippage, and the ability to feel the shape and texture of objects. Moberg (1964) repeatedly comments on the necessity for a more functional evaluation of hand sensibility.

We have concentrated our study on the perception of strength of grasp because it seemed more amenable to prosthetic substitution than some of the other possibilities.

Our results suggest that visual feedback is of very great importance in reproducing a predetermined prehension force in an experimental situation, yet we all know that the blind may achieve great manual skill and that mechanics frequently work by touch alone.

Since total anesthesia of the skin of the thumb and index finger did not alter the perception of strength of grasp, we believe that there must be other redundant physiologic mechanisms which can allow individuals to perceive and appropriately change the gripping force. These may include sensory elements in the joints, tendons, tendon sheaths, or at the muscle-tendon junction. Prehension force may be adjusted according to other types of sensory information, possibly including the perception of the characteristics of the grasped object, motion of the object in the grip, or change in joint position with changes in load or grasping force. A further study of these other natural mechanisms may provide more rational approaches in substitution for the absence of sensation in the prosthetic hand and thus lead to improvement in the control of the hand.

SUMMARY

To develop more rationally methods of substitution for lost sensation in the hand in upper extremity amputees, we have studied the roles of vision and skin sensation in the perception of strength of pinch grasp. Our studies indicate that visual feedback in our experimental situation is very important for accurate reproduction of a specified grasping force. Skin anesthesia did not affect the perception of strength of grasp. We conclude that there are probably multiple redundant mechanisms used by the normal person to perceive and adjust the strength of grip. A study of these may provide a more physiologic approach to a partial substitution for the sensation missing in the prosthetic hand.

REFERENCES

Alles, D. S. (1968) Kinesthetic feedback system for amputees via the tactile sense. Thesis. Massachusetts Institute of Technology.

Beeker, T. W., During, J. & den Hertog, A. (1967) Artificial touch in a hand prosthesis. *Med. biol. Engng.* **5**, 47–49.

Klasson, B. (1970) Developments of components for the control of pneumatic prostheses—background current status, and future plans. *Prosthetics Int.* **3**, 29–47.

Mann, R. W. (1969) Efferent and afferent control of an electromyographic, proportional-rate, force sensing artificial elbow with cutaneous display of joint angle. *Basic problems of prehension, movement and control of artificial limbs,* pp. 86–92. The Institution of Mechanical Engineers, London.

Moberg, E. (1958) Objective methods for determining the functional value of sensibility in the hand. *J. Bone Jt Surg.* **40**-B, 454–476.

Moberg, E. (1964) Aspects of sensation in reconstructive surgery of the upper extremity. *J. Bone Jt Surg.* **46**-A, 817–825.

Najima, M. (1970) Personal communications.

Salisbury, L. L., Colman, A. B. & Marcus, L. F. (1967) An electromechanical hand with automatic proportional control of prehension. *Digest of the 7th International Conference on Medical and Biological Engineering,* ed. B. Jacobsen, p. 456. The Organizing Committee for the 7th International Conference on Medical and Biological Engineering, Stockholm.

Sueda, O. & Tamura, H. (1969 Sensory device for the artificial arm. *Proceeding of the 8th International Conference on Medical and Biological Engineering and the 22nd Annual Conference on Engineering in Medicine and Biology, Session 5–9.* The Conference Committee for the 8th ICMBE and 22nd ACEMB, Chicago.

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