B1

FIRST MEDITERRANEAN CONFERENCE ON MEDICAL AND BIOLOGICAL ENGINEERING

SORRENTO (Napoli) ITALY — 12 - 17 September 1977

UNDER THE HIGH PATRONAGE OF THE PRESIDENT OF THE REPUBLIC OF ITALY

ORGANIZED BY:
Associazione Italiana di Ingegneria Medica e Biologica (A.I.I.M.B.)

SPONSORED BY:
International Federation for Medical and Biological Engineering (I.F.M.B.E.)

IN COOPERATION WITH:
Israel Society for Medical and Biological Engineering (I.S.M.B.E.)
Société des Electriciens, des Electroniciens et des Radioélectriciens (S.E.E.)
(Section Techniques Biomédicales) France
Yugoslav Society of Medical and Biological Engineering (Y.S.M.B.E.)

DIGEST OF PAPERS

(Vol. II)

1967
A.I.I.M.B.
1977

EDITED BY:
F. DENOTH

STUDY OF ELECTROCUTANEOUS PARAMETERS FOR APPLICATION TO DYNAMIC TACTUAL COMMUNICATION SYSTEMS

by

Kazuo Tanie, Susumu Tachi, Kiyoshi Komoriya and Minoru Abe

Mechanical Engineering Laboratory

Igusa, Suginami-ku, Tokyo, 167, Japan

Introduction

Electrocutaneous communication by means of electric pulse stimuli has been studied. One of the most important problems of their studies is to determine the most relevant parameters of stimuli to transmit the information. These parameters are called informative dimensions of stimuli. In generally, informative dimensions of electrocutaneous stimuli consist of three facters, namely, frequency, space and magnitude. The frequency and space dimension are said to correspond to pulse interval of stimuli and the number of electrodes, respectively. But for the magnitude dimension, though there have been a few attempts to adopt a stimulus current, it has not be completely cleared which parameter is the most relevant.

In the previous paper[1] we studied this problem and found the fact that subjective magnitude of electrocutaneous stimuli relates to the energy per a pulse of stimuli. In order to confirm the fact that the relevant parameter for the magnitude dimension of electrocutaneous stimulation is the energy per a stimulus pulse, this paper describes some problems about the constant energy electrocutaneous stimulation, namely, the design of stimulus energy measurement instrument, the results of measurements of energy threshold and current thresold vs. time chracteristics and comparison between the two, and the estimation of the channel capacities in information transmission via energy modulated stimuli from just noticeable difference.

Constant Energy Electrocutaneous Stimulator

To measure the relation between the electrcutaneous stimulus energy and sensation magnitude, we, as the first step, designed the device which can generate the stimulus pulse with the specified energy. We call the device a constant energy electrocutaneous stimulator(CEES) in the manner of the name of a well-known constant voltage/current stimulator. Fig. 1 shows the block diagram of such a device. It consists of the previously designed general purpose multi-channel simultaneous stimulator(MSS) and energy measurement instrument. The MSS[2] consists of a digital computer(pdp 11/40), a pulse control unit, and output circuit, and is equipped with 256 output channels. Each channel generates an independent pulse signal, parameters

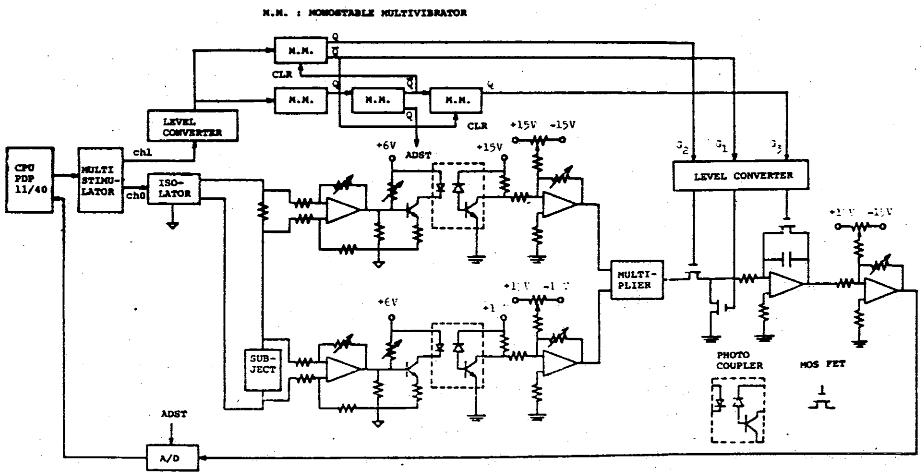
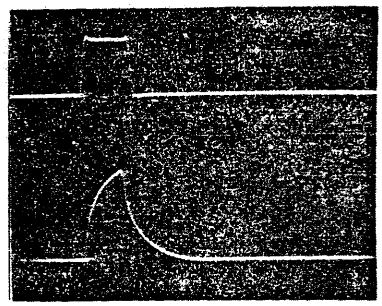


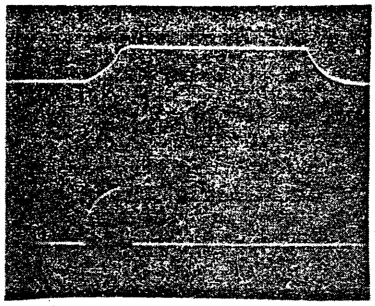
Fig. 1 Constant energy electrocutaneous stimulator.

of which, namely, height, width, frequency, and stimulus duration, can be arbitrarily set by the computer program. The maximum speed for refreshing the parameters is 600[frames/s] when the direct memory access mode is used.

In this CEES, when the output of ch0 in the MSS is presented on to the skin of subjects through the isolator and proper electrodes, the stimulus current is estimated from the voltage between both sides of the resistance which was arranged in series to the skin electrode, and it is multiplied by the voltage between the skin electrodes. This stimulus current and voltage are amplified by differencial amplifiers, and fed to the multiplier through photocouplers, respectively. Therefore, the isolation of the locations of each electrode is assured. The multiplier output is fed to the integrator with set, reset and hold switches so that the output is integrated during a stimulus pulse interval. The set, reset and hold operations of the integrator are controlled by the pulse signal from ch1 in the MSS similar to the pulse waveform from ch0 except the height. The integrator output, namely, energy per a stimulus pulse is returned to the computer through the A/D converter. To practice the constant energy stimulation, the stimulus pulse height or width are regulated so that the error between the measured pulse energy and specified one is minimized. In Fig. 1 the symbol ADST means a A/D converter start pulse terminals. In Fig. 2, the waveforms observed at the main terminals are shown.



(a) Stimulus current.(upper)
(b) Stimulus voltage.(lower)



(c) Integrator output.(upper)
(d) Multiplier output.(lower)

Fig. 2 Waveforms.

The Relation Between Energy Threshold and Pulse Interval, and Its Time Dependece Characteristics

1. Experimental Method

Apparatus: The output of ch0 of the MSS is presented on to the skin of a subject via wet electrodes(Beckman, ϕ8mm) and isolator(San-ei Instrument Co. Type 5361). Three electrodes are located on the skin just above the triceps brachii along the direction of the muscle 20mm apart from each other. The two outer electrodes are connected and used as a common, and the negative pulse is presented to the central electrode. The stimulus pulse is presented as constant current pulse.

Test Procedure: To measure the threshold there are several methods. In this experiment we adopted the method of limits, since it makes possible to measure rapidly. Using the pulse height(current) as a parameter, a ascending series from identifiable level and a descending series from unidentifiable level are presented. The pulse height is changed by the step of $\Delta I = 10\times(1/255)$mA in each series. A plus sign is recorded when the subject reports to feel the stimulus and a minus sign when he reports not to feel the stimulus. Each series is stopped as soon as his report is changed from + to - or from - to +. In these series, the stimulus energy is measured using above-mentioned energy measurement instrument and its value typed out by the computer, as soon as the stimulus with a specified pulse height is presented. An estimate of threshold is made from two series, taking the midpoint between the two kinds of stimulus energy where the change occurred.

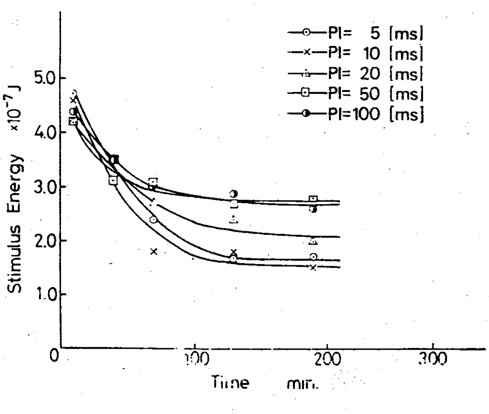


Fig. 3(a) Energy threshold vs. time characteristics. (subject K.T.)

In order to investigate the time dependence characteristics of the relation between energy threshold and pulse interval, they were measured five or six times during about three or six hours. In this experiment two subjects of age 25 and 30 were used.

2. Results

Fig. 3 shows the result for subjects K.T. and K.K., namely, time dependence characteristics of threshold energy. Each mark in the figure indicates the results for the pulse interval of 5, 10, 20, 50 and 100ms, respectively. In this result, it is found that the energy threshold of the subject K.T. decreases rapidly during about 30 minutes after electrodes were located, and the subject K.K. decreases a little. But the energy threshold of both subjects has a tendency to become a constant value as the time proceeds. Fig. 4 shows the result for both subjects, namely, time dependence characteristics of current threshold. It is found that the current threshold has a tendency to increase as the time proceeds for two subjects.

In Fig. 3, it seems that the decrease of threshold during 30 minutes after electrodes were located is due to time dependence characteristics of the impedance of electrodes, and the difference between the results of both subjects is due to the difference of skin impedance of each subjects. As we are measuring the stimulus voltage from the voltage across the electrodes, it isn't avoided that the impedance of parts except recepters under the skin should affects the experimental results. But, notice that the energy threshold keeps a constant value as the time proceeds, though the current threshold increases. This may mean that the impedance of parts except recepters under the skin(for example, impedance of electrodes, etc.) is much smaller than that of recepters as the time proceeds. Because, if not, the energy threshold measured by above-mentioned energy measurement instrument must have a tendency to increase according to the increasing of current threshold. Therefore, the energy threshold may be considered to, approximately equal to the stimulus energy, when that keeps a constant value.

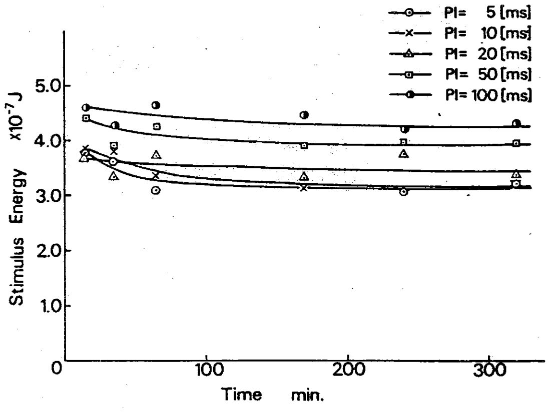


Fig. 3(b) Energy threshold vs. time chracteristics. (subject K.K.)

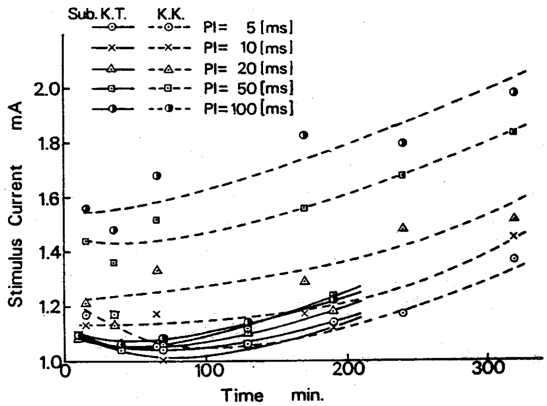


Fig. 4 Current threshold vs. time characteristics.

From the above observation, when we estimate the stimulus energy from the constant part of threshold curve in Fig. 3, it is concluded that the relation between the stimulus energy and subjective magnitude is not affected by external conditions more than stimulus current, since threshold curve is, generaly, one of contours of equal subjective magnitude.

The energy threshold-pulse interval characteristics were replotted from the constant part of the data in Fig. 3. As a result, it was found that threshold curves for electrocutaneous stimulation have a monotonous tendency, comparing with a tone and mechanical vibration. Such characteristics are favorable for information transmission systems.

Just Noticeable Difference and Channel Capacities in Information Transmission via energy modulated stimuli

1. Experimental Method

To measure just noticeable difference(jnd) for the subjective magnitude, two pulse trains which have the same pulse interval, width and stimulus-duration-time but have different energy per a stimulus pulse are presented to a subject, using the above CEES. A subject first feels the two alternatively presented stimuli, which are tentatively named A and B. When he memorizes, he presses the keyboard. Then he is presented either of the stimuli randomly and judges which of the two original stimuli he just felt. He judges 50 times for each pair of stimuli, and answers A or B according to his judgement. If we assume that the stimuli A and B are presented equally and randomly, we can get the information transmission rate by the formula of AB method[3],

$$R=1+1/2\Big[(p_a+q_b)\log_2\frac{1}{p_a+q_b}+(p_b+q_a)\log_2\frac{1}{p_b+q_a}-p_a\log_2\frac{1}{p_a}-q_a\log_2\frac{1}{q_a}-p_b\log_2\frac{1}{p_b}-q_b\log_2\frac{1}{q_b}\Big].$$

where p_a is the probability of receiving an A when A is sent, q_a is the probability of receiving a B when B is sent, and p_b is the probability of receiving a B when Bis sent, and q_b is the probability of receiving an A when a B is sent. When the stimulus with energy E is completely distinguished from the stimuli with energy $E+\Delta\alpha$ and $E-\Delta\beta$, respectively, that is, the discriminability of the both pairs of stimuli is 1bit from above equation, jnd is calculated by $\Delta E=(\Delta\alpha+\Delta\beta)/2$. Channel capacities are estimated from the jnd by the following equation,

$$I_m=\mathrm{Log}_2\{\int_a^b(1/\Delta E)dE\}$$

where a is the threshold and b is the pain threshold.

In this experience, stimulus conditions are similar to those of above section except the number of subjects. Five subjects were used in this experience.

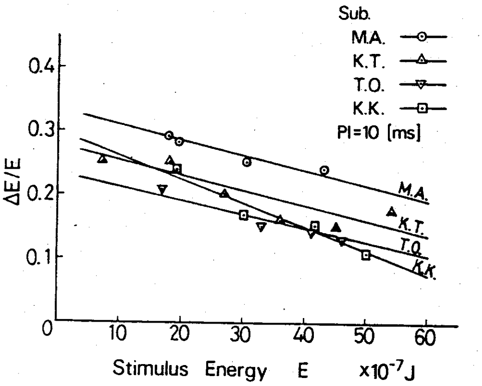


Fig. 5 Just notceable difference to various energy levels.

Table 1 Channel capacities estimated from jnd.(bits)

Sub. \ PI	10 ms	20 ms	50 ms	100 ms
K.T.	3.9	4.1	3.2	3.3
K.K.	3.8	*	*	2.8
M.A.	3.5	2.0	*	*
T.O.	3.9	3.1	*	*
K.N.	*	*	2.9	*

2. Results

Fig. 5 shows a example of the result of jnd. In this fiqure the abscissa represents the stimulus energy levels in which the jnd was measured, and the ordinate represents the normalized jnd. This figure is the result for pulse interval 10ms. It is found that the normalized jnd has a tendency to decrease with the stimulus energy level for each subject. This was the same, also, for PI=20, 50 and 100ms. Table 1 shows the channel capacities in information transmission via energy modulated electrocutaneous stimulation estimated from jnd for five subjects. The channel capacities are found to be 3.0bits to 4.0bits for all subjects while they decrease with the increase of pulse interval. Fig. 5 shows that the subject K.T. has the best discriminability. It may be due to the fact that he is skilled at this experiment very much.

Table 2 Channel chapacities estimated from jnd for vibrotaction. (bits)

Freq.	C.C.
5 Hz	3.9
20 Hz	3.2
70 Hz	2.3

There have been a few attempts to measure the channel capacities for vibrotaction. To compare with the channel capacities for the electrocutaneous stimulation, in table 2 those for vibration parallel to the skin are indicated. It is found that the channel capacities for electrocutaneous stimulation are equal to or more than those for vibration.[4]

References

1. S. Tachi, K. Tanie and M. Abe, "Experiment on the magnitude sensation of lectrocutaneous stimuli," 1977 Symposium on Biomechanics, ASME, June,1977.

2. K. Tanie, S. Tachi, et al., "Development of a multi-channel simultaneous stimulator," Journal of Mechanical Engineering Laboratory, Vol. 31, 1977, pp. 104-116.

3. W.A. Munson and J.E. Karlin, "The measurement of human channel transmission characteristics," Journal of Acoustic Society of America, Vol. 26, 1954, pp.542-553.

4. T. Kajima, et al, "Sensations for vibrations parallel to the skin and just noticeable difference," J.J.M.E.B.E.,Vol 11, 1973,pp. 94-99.