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# SPATIAL SUMMATION OF PAIN FOR LARGE BODY AREAS*

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## ABSTRACT

Spatial summation of pain was investigated using high intensity infra-red radiation. Cutaneous pain thresholds were determined for a total of eight subjects using apertures ranging from 1 $cm^2$ to 200 $cm^2$ on the face area, and 10 $cm^2$ to 1500 $cm^2$ for large body areas. Two methods of determining threshold - reaction time and method of constant stimuli - were utilized. Skin temperature at threshold was determined by a radiometric measuring device especially designed for use during skin heating with infrared quartz lamps. Values so determined were checked by a computer solution of skin temperature rise using the best available data on the optical and thermal properties of the skin and found to be in close agreement. Results indicate that final skin temperature at threshold varied from 39.3°C to 46.7°C depending on subject, size of aperture, and area of body irradiated. A significant lowering of final skin temperature at threshold for the larger area occurred for all subjects when comparing apertures 1 $cm^2$ and 3 $cm^2$ on forehead and face areas, and apertures 10 $cm^2$ and 40 $cm^2$ on chest and back. A slight decrease in final skin temperature at threshold was generally noted for aperture sizes 5 $cm^2$ and 200 $cm^2$ on face areas but was not consistent for all subjects. When 40 $cm^2$ apertures were compared with full back and chest exposures, a higher threshold for the very large areas was obtained for three of the four subjects used.

In interpreting these results as to spatial summation, more information is needed regarding heat flow patterns for areas in the 1 - 3 $cm^2$ range to assess the extent of spatial summation present. For larger areas, this has been shown not to be a factor. For these areas, spatial summation is indicated but limited in degree. No large and consistent degree of spatial summation has been demonstrated for pain as it has for heat, warmth and cold.

The following investigation has dealt with the relationship between cutaneous pain threshold and size of area stimulated in order to ascertain whether there is a significant amount of spatial summation for cutaneous pain. The term "spatial summation" has been used to describe certain neurophysiological phenomena, such as the summation occurring at the ganglionic synapses, but its meaning for this study is that put forth by Hardy, Wolff & Goodell (10) in their original inquiry into this phenomenon, i.e., as the area exposed to stimulation is increased, (a) intensity of sensation increases and (b) the intensity of the stimulus necessary to evoke threshold sensation decreases.

During the past quarter of a century a number of investigations have been conducted on this topic in the hope of elucidating the nature of the nervous system underlying the sensation of pain. Evidence in favor of spatial summation would indicate that pain might be represented by the same system as other cutaneous sensory modalities. Evidence against spatial summation would provide considerable support for the view that pain is subserved by special neural equipment. Various stimuli have been used to produce the sensation of pain and the investigations have included all three qualities of pain sensation - pricking, burning and aching. However, the results obtained have proved conflicting in regard to whether the phenomenon actually exists for pain. In some cases criticism has been leveled at the methods used. When only positive evidence for spatial summation is considered, it becomes apparent that spatial summation exists to a rather limited degree compared with the summative properties of warmth and cold.

For our purposes the investigations can be divided into those which have used the thermal radiation method for inducing pain and those which have used all other

methods. The investigations prior to 1958 have been summarized by Greene & Hardy (7). Briefly, the latter group include an investigation by von Frey in 1897 using intense pressure, a study by Woolard in 1940 using electric shock, Wolff & Hardy's study in which they immersed the finger and whole hand in cold water, Bishop who used pressure in 1949, and Breig with needle scratch at constant pressure, speed, and angle in 1953.

Greene himself used both cold immersion and needle scratch in 1958, and Hall (8) and Benjamin (3) reported the use of contact heat. Of this group, Woolard, Breig, Hall and Benjamin interpreted their findings as indicating summation. For Woolard, when a distance of less than 1 cm existed between the sites of two shock stimuli of equal intensity, the pain seemed to emanate from a single point but was of greater intensity than that produced by a single stimulus. For Breig, the distance the needle travelled over the skin was almost constant from area to area indicating that the impulses from individual terminal endings of nerve fibers stimulated by the passage of the needle are superimposed on one another in a summative fashion. Using contact heat Benjamin found significant decreases in final skin temperature at threshold for larger areas, as did Hall.

Investigations making use of the thermal radiation technique have been primarily those of Hardy and his colleagues. Although these investigators explored the summative properties of stimuli induced by other methods, they felt that such tests stimulated touch and pressure receptors along with pain receptors; also such results were not and could not be sufficiently quantitative. In 1940, using the thermal radiation method they had developed to circumvent these objections, Hardy et al (10) found areas from 0.07 $cm^2$ to 0.95 $cm^2$ in size needed progressively less

energy to reach threshold, indicating a slight amount of spatial summation. Their findings were not significant for areas ranging from 0.95 $cm^2$ to the largest area studied of 28.30 $cm^2$. They concluded that the slight summation might be due to greater lateral heat flow from the smaller areas and the influence of the increasingly strong sensation of heat preceding the pain threshold for larger areas upon the subjects' judgments of threshold. Another explanation offered by Weddell (16) was the influence a "hot spot" might have on the threshold sensation if the same "spot" were included in both larger and smaller areas. This could occur if there were a fall-off in the intensity of radiation from center to periphery which he demonstrated was the case with a dolorimeter constructed in a manner similar to that of Hardy et al.

Although the closer correlation between pain threshold and the skin temperature reached at the end of stimulation rather than the total amount of energy delivered to the skin was known at this time, the technical means for measuring skin temperature during irradiation were not yet available. Therefore, Greene & Hardy (7) in 1958 re-investigated the problem of spatial summation for forehead areas in approximately the same size range as Hardy et al's (10) 1940 study. At this time a technique for directly measuring skin temperature during irradiation by means of a Golay infra-red detector was developed. The study also ruled out lateral heat flow as a factor in decreasing threshold by comparing a single 16 $cm^2$ area with two 8 $cm^2$ areas. Their results indicated a drop of 1°C in final skin temperature at threshold between areas of 2.47 $cm^2$ and 7.8 $cm^2$. Hardy found no such drop in his 1940 study between areas in this general range - 0.95 $cm^2$, 3.46 $cm^2$, and 7.10 $cm^2$. Measurements, in this older study were in terms of energy in gm cal/sec/$cm^2$ required to bring the skin temperature up to threshold from an assumed base of 34°C. As with the 1940

study, the 1958 investigation did not indicate summation for areas larger than 7.8 $cm^2$. Since the largest area irradiated was 28.3 $cm^2$, the possibility still existed that areas larger than 28.3 $cm^2$ might show the phenomenon of spatial summation, particularly if very large skin areas could be uniformly irradiated. For this reason, the current study was undertaken.

## Methods

### Apparatus

The heat source consisted of a lampbank radiator composed of an array of eight quartz infra-red lamps in cylindrical reflectors of stainless steel. These lamp-reflector units were mounted horizontally in a vertical frame of structural aluminum sections rigidly attached to a platform-chassis. Figure 1 illustrates the electrical

Figure 1

circuitry for this lampbank. From this diagram it can be seen that the maximum capacity of the lamps was 420 volts. Variations in house current were reduced to a minimum by an adjustable feedback voltage regulator.

This radiator was designed to produce uniform irradiation intensities up to 0.16 cal/cm$^2$/sec on local or whole-body skin areas of human subjects (erect or in a sitting posture) at a distance of 27 inches. Figure 2 illustrates the arrangement of this apparatus. For irradiation of large body areas, the subject stood on the platform as shown in Figure 2, directly in front of the heat source. Superimposed

Figure 2

between subject and source was a large fast-action automatic focal-plan shutter. Figure 3 illustrates the electrical circuitry for this shutter. Placed in the "operate"

Figure 3

position with the interval timer set for the desired exposure, closing switch S-1 released the spring-driven shutter one-half its distance sothat an aperture in the center of the shutter exposed the subject to the lampbank. At the end of the pre-set interval, the shutter was released completely, ending the exposure. Calibration of exposure time was made by means of a photo-electric cell mounted so as to be activated during the "open" period of the shutter. In order to limit and

vary body area exposed a diaphragm hung from an overhead trolley was placed between subject and shutter and fitted with removable shields positioned for various body areas.

For measurement of face areas, the subject was seated on the platform-chassis. Superimposed between the source and the subject was a large diaphragm with a single opening in the center. The subject's head was placed at this circular opening. Again this arrangement placed the subject's face 27" from the lampbank where irradiation was most uniform. A sliding panel was connected by a pulley arrangement so an operator could expose the subject's face to the lamps by pulling the lever. Size of area was controlled by a series of removable panels. Exposure time was determined by a photo-electric cell exposed for the period of irradiation.

Intensity of radiation was measured with a surface wide-angle thermopile which had been calibrated with a U. S. Bureau of Standards radiation standard having a spectral energy distribution similar to that of the source. The color temperature of both source and standard was 2630°K.

However, uniformity of field was found to be only approximate. Determination by a point by point survey showed a ± 15% variation of irradiance within the effective area. This variation in field intensity is shown in Figure 4 and in the

Figure 4

least desirable situation, i.e. at the edges, could result in a difference in heating of about ± 1.5°C from the mean value. However, as the major areas were within either the 80% or 90% contour, this lack of uniformity was considered acceptable.

Skin temperature was measured prior to radiation by a Stoll-Hardy radiometer. This radiometer was calibrated by means of a Leslie cube. Precision was $\pm$ 0.2°C. Skin temperature at the end of the exposure was determined by both theoretical equation and direct measurement during irradiation. The equation used for calculating the temperature increment during irradiation was the simplified form of the differential equation for one-dimensional heat flow assuming that 76% of the incident radiation is absorbed near or at the surface. Figure 5 shows this equation

Figure 5

which utilizes the known values of the thermal constants of the skin - the reflectivity and the thermal inertia of the skin - plus the energy values as measured by the wide-angle thermopile and the exposure time.

A problem of major importance in the use of this equation was the skin reflectance. Figure 6 shows the spectral reflectance of white skin and the spectral irradiance of the quartz lamp source and calibrations standard. The similarity of

Figure 6

these latter two ensures accurate measurement of source irradiance by our radiometer. It also illustrates the per cent reflectance of white skin for the spectral energy distribution used in this study and utilized for our calculations of skin temperature rise.

In order to confirm the final skin temperatures obtained by means of the above heat flow equation, several different methods of measuring skin temperature directly during irradiation were explored. These attempts resulted in the design and construction of a special radiometer for use with this type of energy source. This radiometer and its calibration have been completely described in the first section of this report. The radiometer, mounted between the quartz lamps so as to view the

skin from normal incidence, had a 96% response time and a precision of $\pm$ 0.1°C. Figure 7 compares those values determined by radiometer with those obtained by

Figure 7

equation for the approximate time range dealt with. The discrepancy between the two is due to the fact the reflectance from white skin for the far infrared spectral region was found to have a different function with this energy source than that provided by the equation. The final skin temperatures reported in this paper were obtained by adding the skin temperature rise determined by this radiometer and illustrated in Figure 7 to the pre-radiation skin temperature, unless otherwise indicated.

Subjects

Four subjects were used for the measurement of the face areas; two men and two women, all laboratory personnel. Two of these subjects had had previous experience with threshold determinations.

For measurement of anterior and posterior body surfaces three paid subjects were used, two men and one woman, in addition to three of the subjects who had participated in the face area determinations. It was not possible to retain all subjects for all determinations. Subjects used for each determination will be specified under results.

There was some temerity on the part of subjects to participate in experiments involving "radiation" and "pain" even after complete explanation of the limits and safeguards in the experimental plan. Apprehensive subjects were not used.

Procedure

Thresholds were determined by two methods: a) reaction time and b) method of constant stimuli. For reaction time, the subject was irradiated until he signalled "pain". For method of constant stimuli, the subject was irradiated with a pulse of pre-determined length and reported "yes" or "no" at the end of the exposure as to whether he had experienced pain. These exposure times had been selected to cover the range of skin temperature around threshold in one-second intervals and each subject was systematically exposed to this entire time series. Subjects were told we were interested in pain threshold not pain tolerance. They were instructed to report the first trace of pain. They were asked to pay careful attention to the distinction between the intense heat which preceded pain and the very first race of pain itself which was a pricking sensation.

The following routine was used for the termination of pain thresholds. For face areas, the irradiance was set at 108 mc/sec/cm$^2$ and allowed to equilibrate; the subject's initial skin temperature as the site to be exposed was read and recorded; the subject was positioned so that this site would be exposed to the radiation. For reaction times, the shutter was raised and site irradiated until the subject signaled "pain"; the operator noted the time while closing the shutter; time was recorded. For pulsatile stimuli, the operator irradiated the subject for a pre-determined period of time by opening the shutter for this interval; at the end of the exposure the subject gave a report of "yes" or "no"; this report was recorded. In all cases 60 seconds or more as necessary were allowed to elapse between trials so subject's skin temperature could return to pre-exposure levels.

For whole body areas, the irradiance was set at 113 mc/sec/cm$^2$ and 1-2 minutes

allowed to equilibrate all the lamps; the subject's initial skin temperature was surveyed over the area to be exposed; the subject was positioned so that the entire site would be exposed to the irradiation uniformly at the diaphragm. For reaction time, the interval timer was pre-set for a period longer than threshold, the shutter was released and the site irradiated until the subject signalled "pain" and moved away from the area; the operator noted time from the time clock activated by the photo cell; the shutter closed automatically; operator recorded time. For pulsatile stimuli, the shutter time was pre-set for the desired exposure time; the site was irradiated until the shutter closed automatically; subject gave a report of "yes" or "no". An appropriate period of time was allowed to elapse before the next trial.

Exposures were made on the face with areas of 1, 3, 5, 10, 40 and 200 $cm^2$. Body exposures ranged from 10 and 40 $cm^2$ to 900 and 1500 $cm^2$. The procedure was laborious requiring several thousand individual exposures. Adequate time had to elapse after one exposure before that particular skin area could be irradiated again; and the total daily irradiation to which a subject was exposed had to be limited in order to avoid lasting sensory effects.

Final skin temperature at the end of each exposure was the value used to determine threshold. For extended areas, a survey of skin temperature was systematically made over the entire area according to a pre-arranged body diagram. Both mean skin temperature and maximum skin temperature recorded during the area survey have been used in determining threshold for large skin areas.

For pulsatile stimuli, the %-yes reports in 0.5°C intervals for each subject were

plotted in the form of probability curves using final skin temperature as the independent variable. Figure 8 shows the results for one subject obtained with

Figure 8

different face areas. The probability of a report of pain is plotted on the ordinate in per cent and the skin temperature reached at the end of the exposure is shown on the abscissa. The final skin temperature at the 50% - yes response point obtained in this manner was considered threshold. For the reaction time series, the mean final skin temperature was considered threshold.

## Results

### Experiment I

Thresholds for face areas 1 $cm^2$ and 3 $cm^2$ were determined for three subjects using pulsatile stimuli. In this case only, the apparatus used was the Stoll-Hardy dolorimeter (9). Irradiance was set at 200 $mc/sec/cm^2$. Final skin temperatures were determined by adding skin temperature rise (illustrated in Figure 7) as measured by the specially designed radiometer to the pre-exposure skin temperature. The size of the areas and arrangement of the apparatus precluded direct measurement of skin temperature during irradiation. Table 1 indicates the values obtained.

Table 1

These values cannot be compared with those obtained with the lampbank radiator because the spectral distributions for the two sources differ making necessary corrections for both reflection and penetration into white skin in the case of the dolorimeter. Both of these factors serve to increase reported values by a still - to-be-determined amount. Hence these final skin temperatures are not to be regarded as absolute values but are presented for comparison purposes only.

The significance of the difference between the probability distributions for the areas concerned was determined by means of chi-square for each subject separately. This procedure has been followed in each case where threshold values were ascertained by the %- "yes" responses. Summed chi-square values test the significance of the results over all subjects where no reversals in direction of difference occur. All tests of significance have been made at the .05 level of confidence.

The values in Table 1 indicate a consistent drop in skin temperature for all subjects

at threshold for the 3 $cm^2$ area as compared with the 1 $cm^2$ area. Similar results for very small, although not identical, areas have been found by other investigators, such as Hardy et al (10) and Greene and Hardy (7) using radiant heat, Hall (8) using contact heat, and Woolard (18) with electric shock. For such small areas Bishop (4) and later Greene (6) suggested an explanation in terms of the spatial summation of peripheral nerve fibers subserving one parent axon. Although Hardy, Wolff & Goodell (9) indicate that lateral heat flow is a problem only with areas under 1 $cm^2$, reports from the subjects and examination of the area of erythemia following irradiation brought out the possibility that a certain amount of lateral heat flow from the 1 $cm^2$ area into the surrounding tissues was required before threshold was reached making the size of the effective area somewhat larger than the exposed area.

Further information on patterns of heat flow with this type of source is needed before a definitive answer as to amount of spatial summation can be given.

Experiment II

Thresholds for face areas 5 $cm^2$, 10 $cm^2$, 40 $cm^2$, and 200 $cm^2$ were determined for four subjects using pulsatile stimuli. Table 2 indicates the values so obtained.

Table 2

Thresholds for face areas 5 $cm^2$, 10 $cm^2$, 40 $cm^2$ and 200 $cm^2$ were determined for the same four subjects using reaction time. Table 3 indicates mean reaction times so obtained.

Table 3

Analysis of variance using a 4 x 3 table (12) with all subjects for areas of 5 $cm^2$, 10 $cm^2$, and 200 $cm^2$ gave an $F$ of 8.27 for the differences between the areas. With 2, $\infty$ df, this $F$ is significant at $p < .05$. The critical difference was determined for $p < .05$, and revealed only the difference between the 5 $cm^2$ and 200 $cm^2$ areas as significant.

Analysis of variance using a 3 x 4 table with three subjects - JDH, KS & DM - for all areas gave an $F$ of 12.89 for the differences between the areas. With 3, $\infty$ df, this $F$ is also significant at $p < .05$. The critical difference was determined for $p < .05$ and revealed the differences between the 5 $cm^2$ area and the 200 $cm^2$ area as well as between the 10 $cm^2$ area and the 200 $cm^2$ area as significant.

Both Tables 2 and 3 indicate that an individual subject may show a decided and consistent decrease in threshold with larger areas but this may not be true for all subjects. The total picture is one of a slight decrease in final skin temperature as area size increases so that the difference becomes significant when the smallest area is compared with the largest area.

Such data roughly corroborate the previous findings of Hardy (10) and Greene & Hardy (7) and extend these findings for face areas as large as 200 $cm^2$.

The influence of method on pain threshold can be seen from Table 4. Here are recorded the differences between threshold values obtained using pulsatile stimuli and reaction time.

Table 4

In all cases the threshold values are higher for reaction time than those obtained by the method of constant stimuli, as might be expected. This difference remains fairly constant from one aperture to the next in this size range and body area but differs from subject to subject. This difference depends on the subject's physiological reaction time, the subject's attitude in regard to the certainty needed before making a response, and the operator's error in estimation when reading the time clock. Such results point out that studies using reaction time may over-estimate threshold determined by other methods to some unspecified degree, and should be taken into account when comparing values in the literature.

Experiment III

Thresholds for total back and chest areas (ranging in size from 900 $cm^2$ to 1500 $cm^2$ depending on the size of the subject) along with the 40 $cm^2$ area for various regions of the back and chest were determined using pulsatile stimuli for five subjects. Two subjects had participated in Experiment II. The remaining three were naive and had no previous experience with threshold determinations. Table 5 illustrates the values thus obtained.

Table 5

The threshold is higher for the larger areas, a reversal of what might be expected from spatial summation effects. For this reason an analysis of the responses as they were gathered over time was instituted for the three subjects on which this was feasible and thresholds calculated. Table 6 shows the results of these determinations.

Table 6

There is a dramatic increase in threshold for the total body areas when the responses of the first five days are compared with those obtained later. Reports from the subjects revealed that they were apprehensive in the beginning when suddenly exposed to a surge of intense heat. Thus their original reports were made on the basis of a "tingling" sensation which they later found preceded the pricking pain sensation itself. These results clearly indicate the influence of previous experience on the part of the subject in determining threshold values. For the 40 $cm^2$ area the same kind of increase in threshold is seen. Here threshold decreases in the last five days which is not true of the total body areas. Interpretation is difficult due to the inadequate size of the sample for the last five days for the large areas. Even so, the total picture is not one of spatial summation.

In order to further evaluate these findings, thresholds for the 40 $cm^2$ area were determined area by area for each portion of the back and chest. Certain sections of the back and chest were found to be more sensitive than others. The highest threshold obtained (least sensitive area) was compared with the threshold for the total area involved. Table 7 illustrates this information.

Table 7

Experiment IV

Thresholds for two small areas - 10 $cm^2$ and 40 $cm^2$ in size - were determined on

the backs of three subjects by means of reaction time. All three were well experienced subjects by this time. Table 8 summarizes this data.

Table 8

Analysis of variance gave an $F$ of 22.72 for the differences between the areas. With 1, 114 df, this $F$ is significant at $p < .05$.

The data in this table indicate a significant threshold lowering with increased area size for all three subjects, a fact apparently not consistent with previous data. One subject, DM, has participated in both the above experiment and the experiment summarized in Table 3 for reaction time threshold for these same areas on the face. In the former, no spatial summation is indicated. For the back areas, there is a clear difference between the two areas. There is also a clear difference between areas of 1 $cm^2$ and 3 $cm^2$ for the face with this subject.

Discussion

When reported in terms of final skin temperature, i.e. the temperature to which the skin must be raised regardless of the initial skin temperature in order to produce pain, few studies note thresholds below 40°C or above 50°C. The thresholds reported here lie within this range. Within this range, thresholds vary from subject to subject and for any particular subject from one area of the body to another. Such differences appear to be routinely encountered in studies on pain sensation.

In our case the face area of all subjects was less sensitive than the back or chest. In some instances the difference was slight while in others it was considerable. Data gathered in the course of this investigation but not cited also showed different thresholds for various sub-portions of the chest, back and face. The more sensitive areas for some subjects were not always the same for other subjects. Variations in skin texture, thickness, pigmentation, pattern of peripheral innervation and condition of the peripheral vascular system have all been cited as influencing threshold variation from subject to subject as well as from area to area for the same subject. It would be interesting to learn how much exposure of the face to temperature extremes not experienced by the clothed body contributed to this higher threshold. Scholander et al (13) noted that the unclothed Australian aborigine apparently continued to sleep with skin temperatures frequently reaching levels above pain thresholds for European whites. In addition to the above factors, method of measurement and experience on the part of the subject were also found to influence threshold values. Again these findings have been well-documented and discussed (2).

Turning to the problem investigated by this study, the conflict encountered in the literature over the question of spatial summation for pain is reflected in our data. Change in threshold value with area size varies both in amount and sometimes in direction from subject to subject and is not consistent from one portion of the body to another. For example, Table 2 shows a decrease of 2.0°C for the first subject when area size is increased from 5 to 10 $cm^2$. The same subject shows no decrease when area size is again increased to 40 $cm^2$ or fourfold, but again shows a decrease between 40 and 200 $cm^2$. The end result is a drop of almost 3°C in threshold value or a significant amount of spatial summation. No other subject follows this pattern of decrease or shows as large a drop in threshold. There is in general a slight lowering of values for all subjects and no reversals when a comparison of 5 and 200 $cm^2$ areas is made. Table 3 which uses a different method of measuring threshold confirms this picture.

The lower limit of the range reflects the influence of area size in some cases where threshold itself remains relatively constant. Again there are exceptions. When the extremes are compared, the 5 $cm^2$ area with the 200 $cm^2$ area, all subjects show a considerable decrease in the lower limit.

For those areas ranging from 5 to 200 $cm^2$ in size there appears to be only one pattern which is consistent for all subjects. This is the lower threshold for a 40 $cm^2$ area when compared with a 10 $cm^2$ area on the back and chest. These values are illustrated in Table 8. Both decrease in threshold and range are consistent and clear-cut for all subjects for the larger area. Results for similar size areas using the face can be compared by means of Table 3 where reaction time was also used to obtain threshold values. This comparison illustrates that not only is

threshold sensitivity influenced by body location but also the degree and consistency of spatial summation. Weddell's observations (15) that patterns of cutaneous innervation differ from body area to body area and differ for the same body area with different subjects may well be pertinent in this case. Imperfect localization for pain in the cortex should also be considered. Interesting to note is that spatial summation for pain is actually greater and threshold values lower in those body areas where two-point discrimination for touch has been found least sensitive (17).

Such results as those indicated in Tables 2, 3, 8 lead to the conclusion that spatial summation exists to a limited degree for pain but that there is no clear-cut step-by-step lowering of threshold as area size increases until an upper limit is reached such as has been shown to be the case with heat (11). Figure 9 illustrates the wide differences found in the summative properties of heat and pain.

Figure 9

The comparison of the threshold values for the 40 $cm^2$ area with the full back and chest exposures in Table 6 shows for three of four subjects a reversal of what might be expected for spatial summation. This reversal continues to be true even when threshold changes over time are compared. Care was taken to assure uniform irradiation over these areas. Instructions to subjects included using the same end-point for all reports. Differences in the pattern of heat flow from small versus very large areas might play a role. Other factor to be considered are inhibition, intersensory effects, and cortical information processing.

Inhibition for pain and other senses as well as intersensory inhibitory effects have been well explored. Inhibition's role in limiting spatial summation has been

suggested by Brindley (5) in the case of vision as operating through a feedback mechanism to produce an upper limit of area beyond which summation ceases. However, Treisman (14), by assuming a positive correlation between sources of neural noise, develops a model primarily for vision which avoids the necessity of postulating such inhibition to account for cessation of summation with areas above a certain size. Beecher (1) finds evidence for the fact that central control of peripheral reception may extend at least as low as the first synapse encountered in the cord by the "noxious impulse". Well-known are the effects of hypnosis on pain perception, of suggestion as in the "placebo effect", etc.

Such phenomena were shown to be pertinent during the present investigation in the following way:-

Two areas of the back found to be equally sensitive were simultaneously irradiated. One area was twice as large as the other. During about 75% of the trials for all subjects, the sensation was reported as rapidly increasing warmth sensation developing into pain. Pain was perceived from the larger area even after both areas had reached identical final skin temperatures above subject's pain threshold. Since a more intense pain has been shown to mask a lesser stimulation this is evidence for spatial summation. When irradiation to the larger area was reduced in intensity approximately 15% below that of the smaller area, the sensation was one of rapidly increasing warmth for the larger area but with pain suddenly perceived initially in the smaller area without the preceding sensation of increasing heat. "Sensation" appeared to switch from one area to the other at pain threshold. Pain in the smaller, more intensely irradiated area continued to mask pain from the larger area after this area had reached a final skin temperature above the usual threshold. Although these data could not be quantified they clearly indicated by their differential masking effects that the summative properties of warmth and pain are dissimilar.

The influence of cortical processes on pain perception can be facilitory as well as inhibitory. Beecher (1) stresses the importance of the past experience and attitude of the individual on the pain experience. In our case, a distinction should be made between perception and the subject's report of pain. Nevertheless, it is felt if pain summation existed to a considerable degree the values reported for full back and chest areas would be well over the pain tolerance level and this was clearly not the case. Subjects affirmed that they were reporting threshold pain.

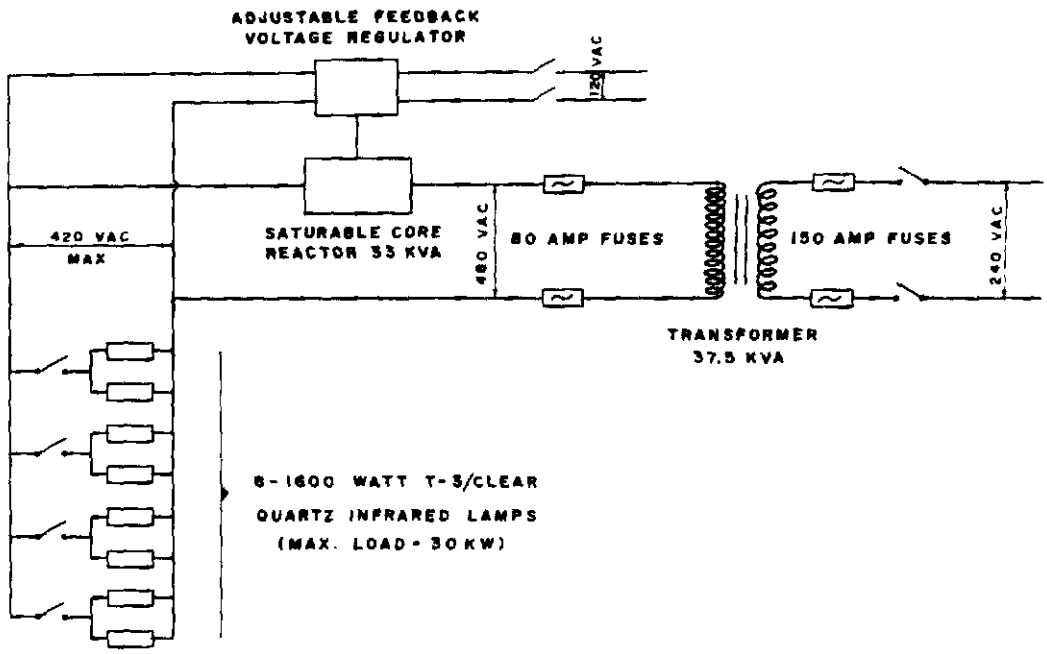
To consider also is the influence that knowledge of area size had on pain perception. With the smallest areas subjects did not know and could not always distinguish differences in size. Knowledge of exposure to large scale areas was impossible to avoid and in addition, the feeling of widespread heat was another unavoidable clue although subjects were carefully instructed to attempt to disregard these clues. Such influence cannot be ruled out.

Subjects were also asked if the intensity of pain at threshold was greater for the larger areas, since skin temperature at threshold may not vary but the presence of summation might increase the intensity of the sensation as found by Woolard(18). No subject seemed to feel this was so. Although the pain was spread over a larger area and in this sense more uncomfortable, it was not more intense.

It is concluded that the large degree of spatial summation seen in the case of heat, warmth and cold is not a property of the pain system. Rather it appears to function in such a way as to limit the amount of pain which reached consciousness from the periphery. Indeed both the limited amount of summation reported and to some extent the

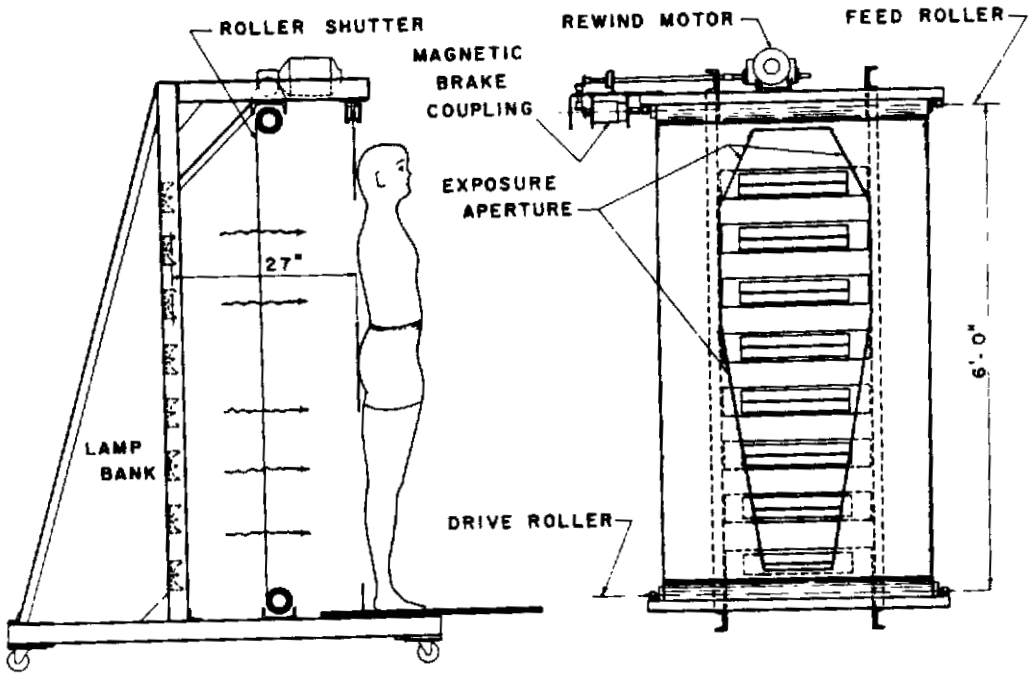
reversal in threshold values with very large areas may be due to the imperfect operation of this factor. It operates less well in those areas least sensitive to touch. The value of this property of pain for the human has been pointed out by Hardy, Wolff and Goodell (10) in their original investigation of pain summation.

Figure 1



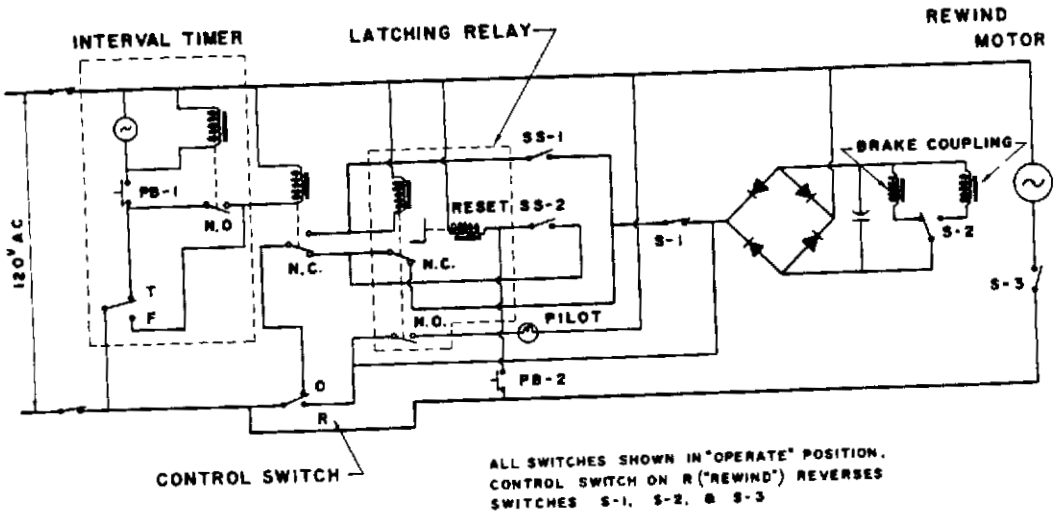

Electrical circuitry for quartz lamp radiator

Figure 2




Diagramatic representation of subject being irradiated by quartz lamp radiator.

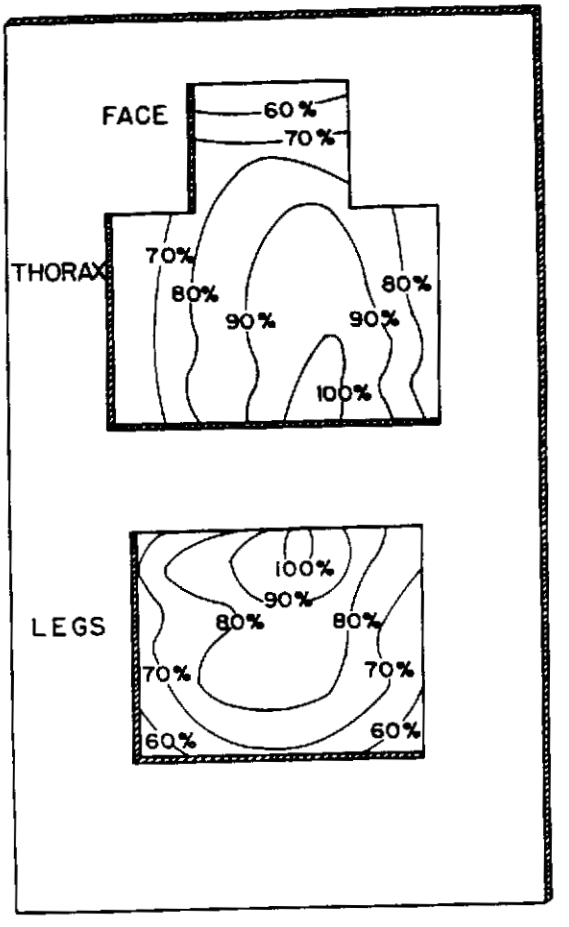
Figure 3




Electrical Circuitry for spring-driven shutter.

Figure 4






RADIATION DISTRIBUTION
IN EXPOSURE AREAS

Survey of irradiance for experimental area -
113 gm cal/sec/cm$^2$ = 100%

Figure 5

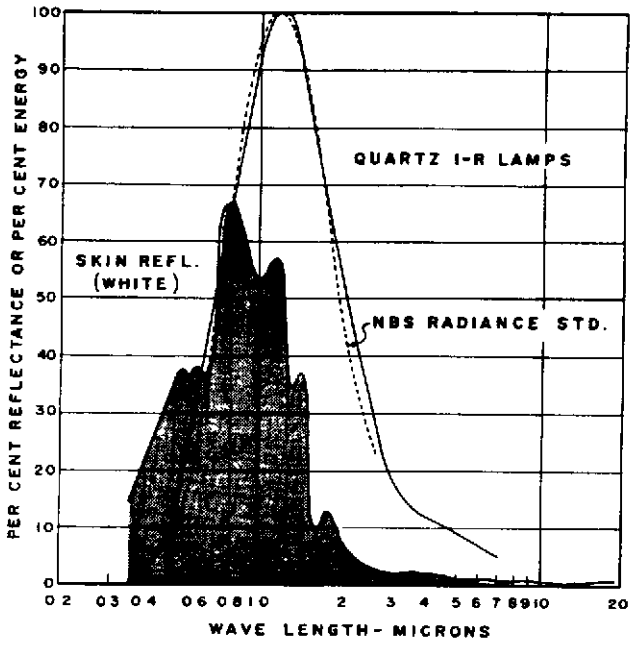
1. $$T_s = T_o + \frac{2Qr\sqrt{t}}{\sqrt{\pi k \rho c}}$$

2. $$T_s = T_o + \alpha\sqrt{t}$$

3. $$\alpha = \frac{T_s - T_o}{\sqrt{t}} = \frac{2Qr}{\sqrt{\pi k \rho c}}$$

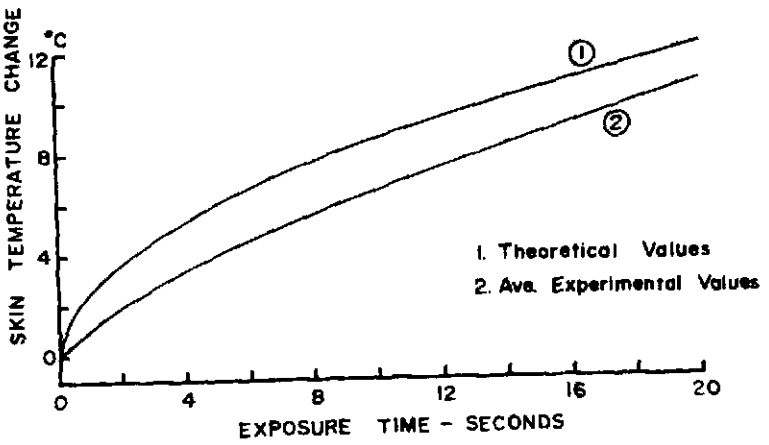
Equation for skin temperature rise.

Figure 6



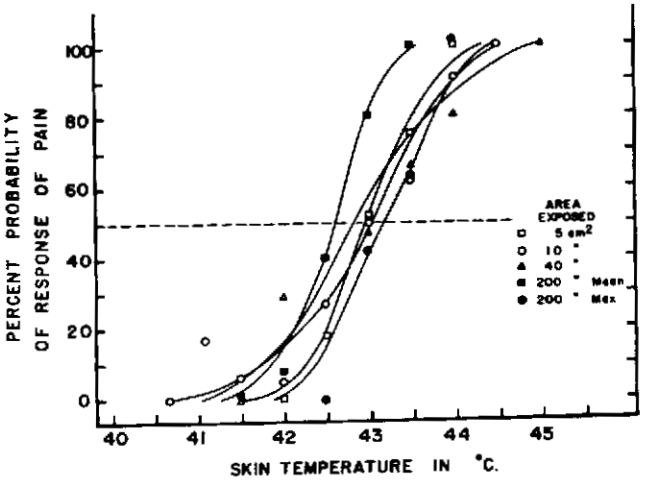

Spectral distribution of source calibration standard, and reflectance of white skin.

*Figure 7*



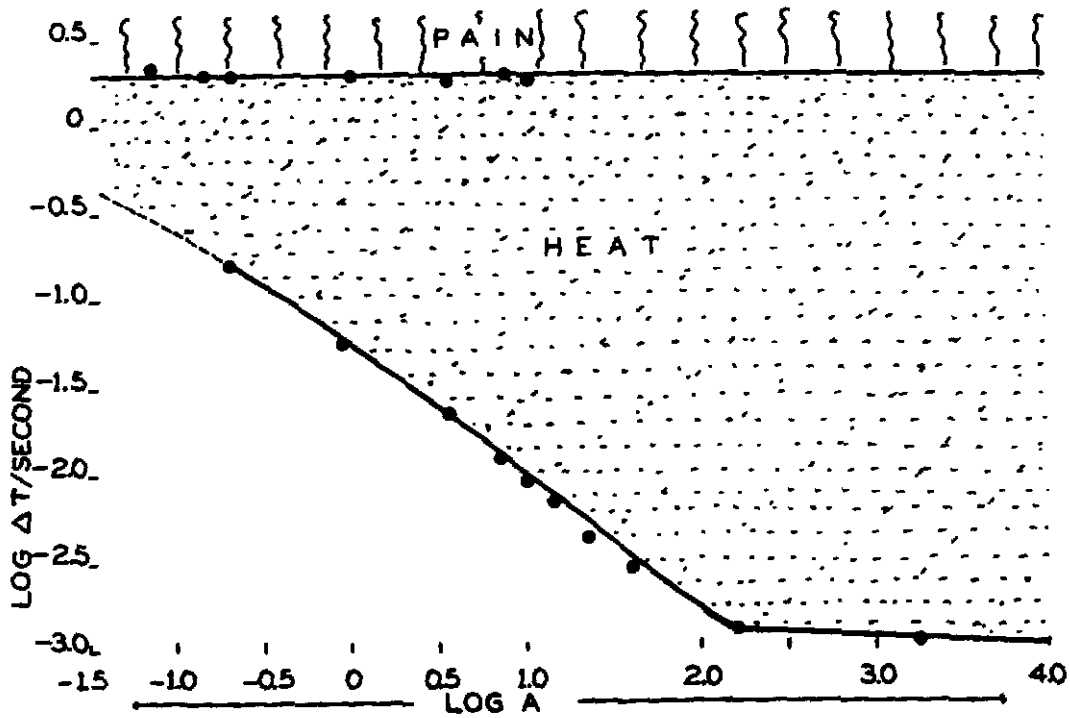

Comparison of theoretical and experimental values for skin temperature rise during irradiation.

Figure 8




Probability of report of pain for one subject as a function of skin temperature.

Figure 9




Comparison of the spatial summation of heat and pain sensations.

TABLE 1

FINAL SKIN TEMPERATURE AT PAIN THRESHOLD

IN °C FOR FOREHEAD AREAS 1 $cm^2$ AND 3 $cm^2$

USING PULSATILE STIMULI

| SUBJECT | AREA SIZE | | | | CHI SQUARE | df |
|---|---|---|---|---|---|---|
| | 1 $cm^2$ | | 3 $cm^2$ | | | |
| | Threshold | Range | Threshold | Range | | |
| KS | 49.0 | 45.5-50.7 | 48.3 | 44.5-50.1 | 10.24 | 10 |
| DM | 49.0 | 46.5-51.5 | 48.0 | 44.5-50.1 | 50.22* | 12 |
| JDH | 48.3 | 44.5-50.7 | 47.3 | 44.5-49.5 | 15.92 | 10 |
| | | | | $\Sigma\chi^2$ | 76.38 | 32 |

*Significant at $p < .05$

TABLE 2

FINAL SKIN TEMPERATURE AT PAIN THRESHOLD IN °C FOR FACE AREAS OF VARYING SIZES USING PULSATILE STIMULI

| Subject | 5 $cm^2$ Threshold | Range | 10 $cm^2$ Threshold | Range | 40 $cm^2$ Threshold | Range | 200 $cm^2$ Threshold | Range | 200 $cm^2$ Threshold* | Chi Sq. | df |
|---|---|---|---|---|---|---|---|---|---|---|---|
| JDH | 44.4 | 41.7-46.7 | 42.4 | 39.4-45.4 | 42.7 | 41.4-43.9 | 41.6 | 40.8-42.3 | 42.0 | 75.23** | 12 |
| LD | 46.5 | 45.1-47.6 | 46.3 | 44.2-47.7 | --- | --- | 46.5 | 42.6-47.1 | 46.9 | 9.549 | 12 |
| KS | 42.3 | 40.8-43.8 | 42.8 | 40.3-44.3 | 41.9 | 39.3-43.3 | 42.1 | 39.8-42.8 | 42.7 | 37.93** | 12 |
| DM | 42.9 | 41.3-43.8 | 43.0 | 41.3-44.3 | 43.0 | 40.9-44.4 | 42.5 | 40.8-43.3 | 43.0 | 18.91 | 12 |

*Using maximum final skin temperature

** Significant at $p < .05$

TABLE 3

FINAL SKIN TEMPERATURE AT PAIN THRESHOLD IN °C FOR FACE AREAS OF VARYING SIZES USING REACTION TIME

| Subject | Area Size 5 $cm^2$ Threshold | 5 $cm^2$ Range | 10 $cm^2$ Threshold | 10 $cm^2$ Range | 40 $cm^2$ Threshold | 40 $cm^2$ Range | 200 $cm^2$ Threshold | 200 $cm^2$ Range | 200 $cm^2$ Threshold* |
|---|---|---|---|---|---|---|---|---|---|
| JDH | 45.0 | 43.4-46.5 | 42.9 | 41.2-43.9 | 43.0 | 42.6-43.4 | 42.0 | 41.6-42.4 | 42.4 |
| LD | 46.7 | 45.8-48.3 | 46.7 | 45.5-48.0 | --- | --- | 46.6 | 43.3-47.6 | 47.2 |
| KS | 44.1 | 42.7-45.8 | 44.6 | 44.0-44.9 | 43.4 | 42.1-44.5 | 43.6 | 42.0-44.5 | 44.4 |
| DM | 44.6 | 43.6-45.1 | 44.7 | 43.8-45.6 | 44.7 | 43.2-46.5 | 44.6 | 43.6-45.4 | 45.0 |

*Using maximum final skin temperature

TABLE 4

TEMPERATURE DIFFERENCES BETWEEN REACTION TIME AND PULSATILE STIMULI THRESHOLDS IN °C

| Subject | 5 $cm^2$ | 10 $cm^2$ | 40 $cm^2$ | 200 $cm^2$ |
|---|---|---|---|---|
| JDH | 0.6 | 0.5 | 0.3 | 0.4 |
| LD | 0.2 | 0.4 | --- | 0.1 |
| KS | 1.8 | 1.8 | 1.3 | 1.5 |
| DM | 1.5 | 1.7 | 1.6 | 2.1 |

TABLE 5

COMPARISON OF THRESHOLDS IN °C FOR 40 $cm^2$ AREA WITH TOTAL EXPOSURES OF BACK AND CHEST USING PULSATILE STIMULI

| Subject | Chest | | | | | Back | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 40 $cm^2$ Threshold | Total Chest Threshold | Chi Square | df | $p < .05$ | 40 $cm^2$ Threshold | Total back Threshold | Chi Square | df |
| JDH | 40.2 | 40.5 | 21.98 | 14 | NS | 39.3 | 39.6 | 16.32 | 14 |
| WH | 42.4 | 43.7 | 28.88 | 20 | S | 43.8 | 44.5 | 29.16* | 14 |
| MS | 42.0 | 43.7 | 55.56 | 18 | S | 42.7 | 44.4 | 55.68* | 18 |
| CW | -- | -- | | | | 41.5 | 41.0 | 47.84* | 16 |
| LD | -- | 42.0 | | | | | 42.5 | | |
| DM | -- | -- | | | | | 41.1 | | |

*significant at $p < .05$

TABLE 6

COMPARISON OF THRESHOLDS IN °C FOR DIFFERENT TIME PERIODS FOR SMALL AND TOTAL BODY AREAS USING PULSATILE STIMULI

| Subject | Total Chest | | | Total Back | | |
|---|---|---|---|---|---|---|
| | 1st 5 days | Middle days | Last 5 days | 1st 5 days | Middle days | Last 5 days |
| CW | -- | -- | -- | 39.3 | 41.3 | 42.2 |
| MS | 41.5 | 43.9 | 45.1 | 43.2 | 44.4 | 45.0 |
| WH | 41.3 | 43.9 | 45.1 | 41.6 | 44.6 | 45.1 |
| | | 40 $cm^2$ Chest | | | 40 $cm^2$ Back | |
| | 1st 5 days | Middle days | Last 5 days | 1st 5 days | Middle days | Last 5 days |
| CW | -- | -- | -- | 42.0* | 41.4 | 41.8 |
| MS | 40.8 | 42.9 | 42.9 | 41.4 | 43.6 | 43.3 |
| WH | 41.2 | 43.3 | 43.0 | 42.6 | 44.3 | 43.4 |

*Reaction time

TABLE 7

COMPARISON OF THRESHOLD IN °C FOR LEAST SENSITIVE 40 $cm^2$ AREA WITH TOTAL BODY AREA THRESHOLDS USING PULSATILE STIMULI

| Subject | Chest | | Back | |
|---|---|---|---|---|
| | 40 $cm^2$ | Full | 40 $cm^2$ | Full |
| JDH | 40.7 | 40.5 | 41.3 | 39.6 |
| WH | 43.9 | 43.7 | 44.9 | 44.5 |
| MS | 43.6 | 43.7 | 43.4 | 44.4 |
| CW | - | - | 42.2 | 41.0 |

TABLE 8

REACTION TIME THRESHOLDS FOR SMALL BACK AREAS

| Subject | 10 $cm^2$ | | 40 $cm^2$ | |
|---|---|---|---|---|
| | Mean | Range | Mean | Range |
| DM | 42.0 | 40.9-42.9 | 41.2 | 39.9-42.7 |
| CW | 42.4 | 41.0-44.1 | 41.8 | 40.1-42.6 |
| MS | 44.3 | 42.7-46.5 | 43.3 | 42.1-45.0 |

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In interpreting these results as to spatial summation, more information is needed regarding heat flow patterns for areas in the 1-3 $cm^2$ range to assess the extent of spatial summation present. For larger areas, this has been shown not t be a factor. For these areas, spatial summation is indicated but limited in degr

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It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (*TS*), (*S*), (*C*), or (*U*).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Idenfiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

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