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DELAYED COLD-INDUCED VASODILATATION AND BEHAVIOR [1]

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The latency of cold-induced vasodilatation of the hand was found to be sensitive to the threat of shock and related to individual differences in performance on a task involving a conflict between a gain in money and a risk of shock.

When the body is kept warm and the hand is immersed in cold air or water, there is an immediate vasoconstriction in the fingers which may be observed as a rapid drop of surface temperature of the fingers. In 1929, Lewis observed that with continued immersion, a reflexive vasodilatation occurs. That is, after some time, the veins dilate bringing warm blood to the surface. This may be observed as a sudden reversal of the decreasing finger-temperature curve. Over a period of prolonged immersion, there may occur a phasic vasoconstriction-vasodilatation in the finger which is exhibited as a sinusoidal-like finger-temperature curve. This phenomenon, known variously as a *Lewis wave*, as a *reflexive vasodilatation*, as *cold-induced vasodilatation*, or as a *temperature-hunting reaction*, has been of considerable interest to physiologists concerned with cold acclimatization. Under standard testing conditions the parameters of the curve have been found to be fairly consistent from day to day for a given individual. However, between individuals there are large differences. Some people show the classical reflex described; others show a single vasodilatation to some upper limit of warming after which their hand cannot be cooled again; some rewarm after a brief immersion, while others require a relatively prolonged immersion. Finally, some people fail to show the hunting reaction at all and simply cool down to the level of the air or water. These individual differences have not yet been explained.

Meehan (1957) experimenting with daily hand cooling curves, reported an unusual result with one of his *S*s. On the first 2 days of immersion, *S*, a college student, provided identical 20-min. cooling curves. The curves were characterized by the usual negatively accelerated decreasing finger temperature and a sudden, marked vasodilatation at 10 min. of exposure. On the third day the curve was similar except that the amount of rewarming was somewhat less. On the fourth day Meehan reported that *S* arrived, having just completed an important examination. He appeared very tense and was visibly agitated. Nevertheless, Meehan conducted the cooling test as usual. On this day *S* showed no vasodilatation whatsoever. The cooling curve dropped monotonically to an asymptote at the temperature of the water. Furthermore, although the experience is normally reported as painful, *S* experienced so much pain on this day that he refused to return for further tests.

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Edna Dahlquist, Terrence Walsh, and Edward Youngling acted as research assistants.

The cold-pressor test has been available for a considerable time as an index of a hyperreactive vasomotor system and has been studied with ambiguous results in connection with emotional states. Meehan's observation goes considerably beyond the implications of the cold-pressor test, however. If verified, it has implications for the problem of individual differences in cold acclimatization and suggests an emotional basis for these differences. It also has implications for the psychophysiology of arousal. That is, it is conceivable that differences in the parameters of the cooling curve may be characteristic of emotional or arousal states. This study was initiated, therefore, to explore the possibility of relationships between Lewis waves and behavioral measures.

Experiment I

Method

Subjects.—Fifty-four undergraduate college students, male and female in equal number, enrolled in the summer session, were used as *S*s. The *S*s were paid for their participation.

Apparatus.—Since the parameters of the hand-cooling curve depend importantly on the body's thermal balance and since the hunting reaction is elicited most easily when the body is warmer than usual, the experiment was conducted in a temperature-controlled chamber maintained at 90° F., 50% RH. The water bath, controlled at a temperature of 34° F., was stirred slowly and automatically. The *S* sat with his right arm hanging loosely at his side and, during immersion, with his hand through a port into the water up to the wrist. No contact was made with the sides of the water bath by the hand nor of the chair with any part of the arm (so as not to influence circulation). The end of a 24-gauge copper-constantan thermocouple taped to the index finger provided a continuous temperature curve on a Leeds and Northrup "Speedomax." An external switching device permitted measurement of water temperature from a second thermocouple taped to the same finger so as to protrude .5 in. beyond the nail. Electric shock was provided with an inductorium and electrodes placed on the ventral and dorsal sides of the right arm just below the elbow. Shock levels, preselected by *E* as strong and very weak were calibrated by measuring the output of the inductorium at different positions through a 151,000-ohm load. Through this load a strong shock was 1,660 v., peak current of 11 ma.; weak shock was 242 v., peak current of 2 ma. Shock duration, constant at 2.0 sec. was controlled with an electronic interval timer.

Procedures.—To approach face validity in the sense of a genuine stress, *S*s were told that they were participating in the evaluation of a harmless, pain-killing drug. They were provided with a 5-point rating scale with which they were to report intensities of pain when they felt a change in pain status. They were also told that the cold immersion was a standard pain test and that in addition to evaluating the drug in regard to it, it was desired to evaluate the drug's effectiveness in reducing the pain of electric shock.

The experiment was carried out in four successive, daily, test periods. Each *S* was always run at the same time of day. Each test period required *S* to sit quietly for 20 min. prior to immersion in order to raise body warmth level. At a verbal signal he immersed his hand. The *S* was in isolation in the chamber, but could make his verbal reports or ask to be released with an intercom which carried his voice to *E* who watched him through a one-way window.

The *S*s were assigned at random into a strong-shock group, a weak-shock group, and a no-shock group. The two shock groups received shocks on the second and third experimental days 15 min. after immersion of the hand into the water. On the second and third days, and for the no-shock group on all days, the electrodes were not attached. A "drug" consisting of a small measure of colored water was taken orally on the second and third days. The *S*s knew every detail of the experimental procedures except when the shock would be administered during immersion and that they were being given the same substance as drug on the second and third days. They were told that a drug and a placebo were being administered in balanced fashion on those 2 days but not told when each was given.[2]

Results

Of a total of 54 starting *S*s, 13 were not completed. Of these, 7 were lost

[2] After completion of the experiment, *S*s were informed of the actual nature of the experiment.

before any immersion and 6 quit during or after the first immersion. These last 6 *S*s will be described briefly below.

Since it was desired to classify *S*s according to the nature of their cooling curves, but independent of the experimental treatments, an examination was made of the distributions of the parameters of the curve obtained on the first day. Among the parameters examined were the latency of vasodilatation, the rate of cooling to vasodilatation, the minimum finger temperature, maximum rewarming, rate of rewarming, and length of cycle. A vasodilatation was defined as a sudden warming of the finger of at least 3° F. A number of correlations were suggested, but the measures which served to discriminate among *S*s most clearly were the latency of vasodilatation and the cooling rate to vasodilatation. This is in agreement with a similar analysis performed by Yoshimura and Iida (1950). Since latency can be obtained from the temperature records by inspection, it was used for classification.

Using latency to vasodilatation during the first exposure, the 41 completed *S*s were classified into three groups: (*a*) those with a latency of <270 sec., (*b*) those with a latency of 270–400 sec. inclusive, and (*c*) those with a latency of > 400 sec. The resultant distribution of *S*s in the experimental design is shown in Table 1.

Using latency of vasodilatation as

TABLE 1

Number of *S*s in Exp. I

	< 270	270–400	> 400	*N*
No shock	4	8	6	18
Weak shock	2	6	5	13
Strong shock	4	5	1	10
N	10	19	12	41

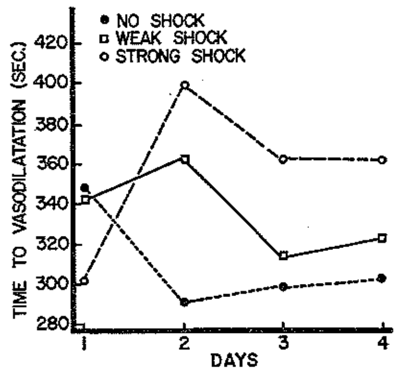

Fig. 1. Latency of vasodilatation of the 270–400 sec. group.

the dependent measure presented a logical problem. If the effect of the treatments were to reduce the latency, then the < 270-sec. group was restricted by already having a very short latency. Conversely, the > 400-sec. group contained *S*s who never showed a Lewis wave and if the effect of the treatments were to be an increase in latency, then this group could show no change. Thus, the clearest effect of the treatments was most likely to be seen in comparisons within the 270–400 sec. group. These data, therefore, are those to be presented.

Figure 1 presents the mean time to vasodilatation of the three treatment groups on each day. The figure shows that the duration of vasoconstriction was reduced in the control group after the first experience. In the weak-shock group it was increased on Day 2, but reduced thereafter although it never reached the latency of the no-shock group. The high-shock group started with a slightly shorter latency on Day 1 than the other two groups, but exhibited a marked prolongation of vasoconstriction on Day 2, an increase of about 100 sec. between days. The latency on the remaining 2 days was shorter than that of Day 2, but still represented a great increase over Day 1 and over the other two groups.

Figure 2 presents the same results using rate of cooling to vasodilatation as the dependent variable. Since this measure takes account of both latency and temperature, it must be interpreted differently than either alone. That is, here a decreased rate represents an increased or prolonged vasoconstriction; a decreased or shortened vasoconstrictive effect is shown by an increased rate. As may be seen, using this measure which smoothed the data considerably, allows generalization of the latency results to cooling rate.

The pain reports elicited from *S*s were highly variable and difficult to interpret after the first day possibly because of the administration of shock after that day. The mean pain ratings obtained on the first 15 min. of the first day are shown in Fig. 3 and here it may be seen that reported pain decreased with continued immersion for all groups. The > 400-sec. group consistently reported greater pain than the other two groups. The other two groups experienced essentially the same amount of pain.

Earlier we noted the loss of six *S*s who quit during or after the first day's test. Thus, none of these *S*s experienced the electric shock. All of them

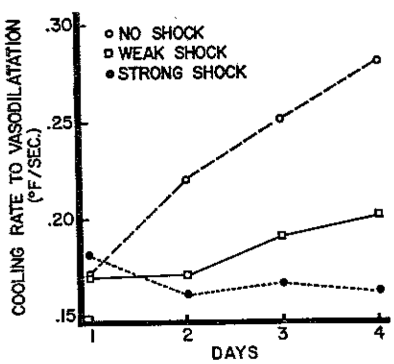

FIG. 2. Cooling rate to vasodilatation of the 270–400 sec. group.

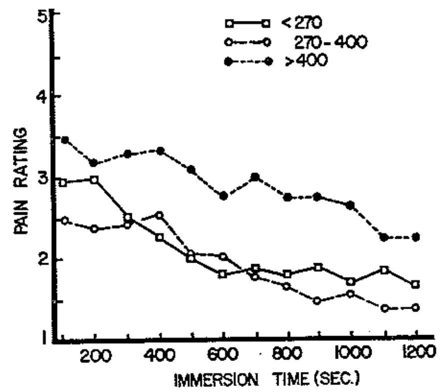

FIG. 3. Mean pain ratings of the three Lewis wave groups as a function of immersion time.

were immersed for at least 400 sec. Every one was found to be characterized by three things: (*a*) a complete absence of vasodilatation during the first day's immersion, (*b*) a self-initiated withdrawal from the experiment, and (*c*) a current or recently experienced intense, real life, emotional experience.

Experiment II

The purpose of this experiment was to extend the previous one by examining the relationships between individuals classified by first exposure latency to vasodilatation and performance in an independent situation in which performance might be thought of as sensitive to arousal.

Method

A *conflict-uncertainty* task was developed using preliminary experimentation to select its procedural and apparatus characteristics. The apparatus was a small panel containing six doorbell buttons arranged in a circle. A seventh button in the center of the circle turned on a pilot light at the top of the panel. The *S* was instructed to turn on the light with the center button and to turn it off with one of the peripheral buttons. He was told that on the first trial all of the six buttons would turn the light off; on the second trial all but one would work; on the third trial all but two, etc., until only one button worked. He was also told that the arrangement of wrong buttons would not be consistent from trial to trial. Actually, all buttons always turned off the light.

Just before the first trial S was given a strong, 2-sec. shock defined as in Exp. I, through electrodes attached to the wrist of the working hand. He was informed previously that this was a sample of the shock he would receive each time he pressed a wrong button. He was informed that he would accumulate a sum of money throughout the test regardless of errors, starting with 5 cents on the first trial, which it will be recalled had no risk, and cumulating to $1.00 if he completed all trials. He was told that he could quit at any time and keep his accumulated earnings. Since, although unknown to S, all buttons were correct on all trials, no S ever received more than the sample shock. The first trial began 60 sec. after the shock. In addition to the procedures described, continuous recordings were made of the index-finger temperature of the nonworking hand.

The hand-cooling procedures were carried out as before with a 20-min. equilibration to 90° F., 50% RH, followed by a 20-min. water immersion at 34° F. No shock or electrodes were involved.

Subjects.—Thirty-three male, undergraduate students were used as paid Ss. None of these had had any prior experience with any of the procedures used.

Results

Nine Ss vasodilated between 270 to 400 sec.; 24 vasodilated at $>$ 400 sec.; none vasodilated at $<$ 270 sec. Although most of the 33 Ss required only a few minutes to complete the task, one S of the $>$ 400-sec. group, required over an hour. This S's data will be presented separately. The remaining Ss are shown in Fig. 4 in terms of mean time to select among the six buttons and mean finger temperature of the nonworking hand. The finger temperatures shown are for 30 sec. before the sample shock, 30 sec. after it, and at the time of each decision.

The results shown in the upper part of Fig. 4 indicate that the $>$ 400-sec.

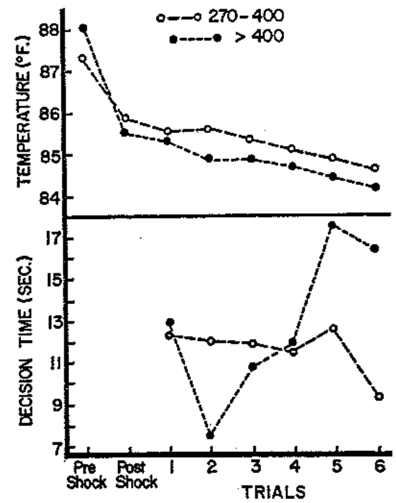

FIG. 4. Finger temperature (top) and decision time (bottom) of the two Lewis wave groups during the conflict-uncertainty task.

group started with a higher finger temperature. With shock the $>$ 400-sec. group dropped to and remained at a lower finger temperature than the other group which indicates a greater rate and amount of vasoconstriction. Both groups showed a progressively increasing vasoconstriction as the task progressed.

Inspection of the decision times in the lower half of the figure shows that the $>$ 400-sec. group started with a slightly longer decision time than did the other group, but with the first involvement of risk (Trial 2), this group showed a marked decrease in decision time. After the second trial, the curve rises steeply so that at first it still represents a faster decision time than for the 270–400 sec. group, but later it crosses the curve of this group and as the risk increases further, it rises to a maximum of over 17 sec. and then drops slightly. The decision times of the 270–400 sec. group, on the other hand, showed a more-or-less continuous decrease with increasing risk, and on the last trial, not unlike

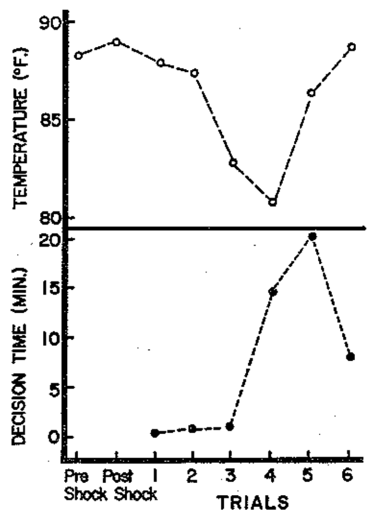

FIG. 5. Finger temperature and decision time of one extreme *S* during the conflict-uncertainty task.

the > 400-sec. group, they showed an end effect.

One *S* in the last experiment, not included in the above results, required over an hour to complete the task. His data are shown in Fig. 5. These data are very interesting although not completely consistent with the previous ones.

Note that the ordinate of Fig. 5 is in minutes rather than seconds. The *S* started with a slow decision time. His decision times then increased linearly until the third trial. This represents a large increase relative to the previous figure. On the fourth trial it took him over 14 min. to make a decision, on the fifth trial over 20 min. Looking at the finger temperature of this *S*, there is some suggestion of a mirror-image relationship although with a time lag. In any case, it is clear that as finger temperature reversed, decision time showed a decrease, although with a lag. This *S* started with a finger temperature of 88.2° F. as compared to 88.0° F. for the mean of the > 400-sec. group in the last figure. However, the minimum temperature reached for that group was 84.4° F. whereas the minimum of this *S* was 80.6° F.

Discussion

The results of Exp. I appear very clear in supporting Meehan's (1957) observation that cold-induced vasodilatation may be influenced by emotional stress. That experiment also suggests that the latency of vasodilatation can be increased by the threat of shock and that the degree to which the latency is affected depends on the intensity of the threat. The continuation of effect to the fourth day by both shock groups, even though they were assured that they would not be shocked on that day, suggests a conditioning phenomenon, and, to the extent that this can be verified, suggests the possibility of a more or less lasting alteration of the cooling curve. On the other hand, the results suggest that in the absence of additional stress, *Ss* habituate to the cold water experience.

When the results of the treatment effects of Exp. I are considered along with the characteristics of the dropout *Ss* of that experiment and along with related observations (Meehan, 1957; Teichner, 1963), the hypothesis is suggested that ability to adapt (latency) to cold stress under conditions which permit a reflex vasodilatation is related to a relatively high chronic arousal characterized by a tendency to vasoconstrict under emotion-producing stresses. A direct source of support for this hypothesis comes from results showing a delayed indirect vasodilatation in schizophrenics as compared to normals (Henschel, Brozek, & Keys, 1951) and vasomotor habituation of the orienting response (Sokolov, 1960; Unger, 1964). Related support may also be found in other studies which have reported inadequate peripheral vascularization in schizophrenics (e.g., Abramson, Schloven, & Katzenstein, 1941; Shattock, 1950) and experiments finding vasoconstriction following induced emotional states (Hovland & Riesen, 1940;

Mittleman & Wolff, 1943; Newton, Paul, & Bovard, 1957).

Experiment II provided a more direct test of the hypothesis that individuals who tend to delay or to not show a temperature-hunting reaction tend to represent highly or overly aroused *S*s in other characteristics. These results suggested that such *S*s vasoconstrict more rapidly and to a greater amount following shock and while enduring the risk of shock. Of considerable interest was that during the conflict-uncertainty test, these *S*s showed first a decreased and then an increased decision time as the risk increased. Such a result would be expected on the basis of an inverted-U shaped curve as an arousal model (Hebb, 1955; Malmo, 1958). Further support lies in the finding that the 270–400 sec. *S*s showed only a decreased decision time with increased risk.

The results as a whole appear to indicate the importance of further study of the relationship between arousal measured behaviorally and peripheral vascularization and suggest that the latency of cold induced vasodilatation may provide a measure of individual differences in vasomotor reactions and in the relationships between vasomotor reactivity and behavioral measures.

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