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The Cold Pressor Test and Autonomic Function: A Review and Integration

WILLIAM LOVALLO
University of Oklahoma Health Sciences Center

ABSTRACT

The purpose of the present paper is to review the literature on the cold pressor test and to discuss the ways in which these investigations have pointed toward a model of homeostatic function. The research employing the cold pressor test includes studies of psychosomatic illness, factors influencing autonomic response to stress, the relationship between psychological disorder and autonomic responsivity, as well as studies of cortical influences on autonomic function, and the relationship between stress and task performance. From these studies, several parameters of a potential model of homeostasis are selected and discussed. Particular emphasis is placed on the role of autonomic balance and initial values in influencing autonomic response to stress.

DESCRIPTORS: Cold pressor, Homeostasis, Autonomic balance, Law of Initial Values, Stress.

This paper has two purposes. The first is to present the bulk of physiological and psychological research employing the cold pressor (CP) test and the second is to discuss homeostasis. The second purpose derives from the first since the majority of CP studies reviewed either raise questions best answerable by a theory of homeostasis, or otherwise provide indications of how such a theory might be constructed. The intent of this approach is to provide an adequate account of CP research and a reasonable framework within which to view the experimental results.

Physiological Responses to CP

The CP test was first used as a means of experimentally increasing blood pressures in studies of hypertension (Hines & Brown, 1932). The test consisted of a half-hour baseline period during which several blood pressure (BP) measurements were made, followed by a 1-min immersion of a hand or foot in ice water during which BP was taken twice. The patient's BP was monitored until it returned to baseline after withdrawal (Hines & Brown, 1932). The normal CP effect was a rise in systolic and diastolic BP of about 10 to 20 mm Hg, and it was later discovered that the effect depended upon intact innervation from the immersed extremity. When a CP test using the foot was given to a patient with total anesthesia below the fifth lumbar dermatome no BP change was noted, while immersion of the hand led to a normal rise (Sullivan, 1941; see also Pickering, 1958). This point is of interest since vascular responses to warm immersions are thought to depend on a change in circulating blood temperature at the hypothalamus while response to CP seems to be controlled largely by neural impulses from the periphery (Appenzeller, 1970). While the main source of the rise in BP seems to be peripheral vasoconstriction, the contribution of increased cardiac output is also significant. This arises as a result of hypothalamic discharge along the inferior cardiac nerve (Shapiro, 1961).

A number of studies have examined local vascular responses to CP. During long immersions of the hand, the capillary beds of a given finger tip initially constrict and then periodically dilate for brief periods (Lewis, 1929). The wave-like vascular response, known as the Lewis Wave, indicates a periodic weakening of sympathetic tone (Appenzeller, 1970, p. 49). Another term for the

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Address requests for reprints to: William Lovallo, Department of Psychiatry and Behavioral Sciences, University of Oklahoma Health Sciences Center, P. O. Box 26901, 800 N. E. 13th Street, Oklahoma City, Oklahoma 73190.

phenomenon is cold-induced vasodilation (CIVD). Cier (1938) studied vasomotor activity in dogs following functional removal of the spinal cord. Shortly after immersion of a paw in ice water, the paw was found to regain its normal temperature. Recovery was abolished following sciatic nerve section. The response was thought to be controlled by a paravertebral ganglionic reflex mechanism in which sensory stimulation leads to vasodilation via antidromic stimulation by way of the gray rami (Gellhorn, 1943). Greenfield, Shepherd, and Whelan (1950) have found the CIVD to occur in chronically denervated fingers. The evidence thus suggests that dilation to cold may also occur as a peripheral phenomenon. Engel (1959) examined the effects of three durations of CP immersion: 2, 3, and 4 min. Measurements were taken at rest and during the final 2 min of immersion of the foot. Systolic and diastolic BP, heart rate (HR), and pulse volume were each affected differently at the end of the varying immersion times. Skin conductance level (SCL) increased initially but returned to baseline rather rapidly as did respiration and finger temperature. Thus, when the initial generalized arousal to CP is ignored, the major response to long immersions appears in the cardiovascular system.

The preceding studies indicate that: The initial CP response is cutaneous vasoconstriction, increased HR, and increased arterial pressure. These responses are primarily neurogenic reflexes depending on intact peripheral innervation. It would appear that the cold stimulation excites pain and temperature fibers which enter the spinal cord in the dorsal roots and run rostral via the lateral spinothalamic, anterior spinothalamic, and spinotectal tracts. The first two tracts proceed to the thalamus and thence to the somesthetic cortex. In the medulla, they send collaterals to the reticular formation. Fibers from the spinotectal tract enter the tectum which is, in part, responsible for the elaboration of reflex mechanisms. Thus, CP stimulation affects cortical, subcortical, and probably limbic structures via the reticular formation and tectum. Additionally, peripheral factors intervene to some extent. The sympathetic activation varies with immersion time producing the waxing and waning of the Lewis Wave. Finally, while vasoconstriction is noted in the skin, blood vessels in muscle tissue are known to dilate (Appenzeller, 1970).

Visceral Response Components–Stimulus Specificity and Stereotypy

The study of psychosomatic disease has been based partly on determining the organismic and environmental factors which interact over time to produce somatic illness. In this connection Alexander (1957) spoke of two principles: *Individual-Response Specificity* and *Stimulus-Response Specificity* and speculated on their roles in the etiology of psychosomatic disorders. A number of studies employing the CP have been conducted to examine these concepts. One of the first was by Lacey, Bateman, and Van Lehn (1952) who examined HR, HR variability, and SCL in response to mental arithmetic, word association, hyperventilation, and CP. The results indicated a greater-than-chance occurrence of a maximal score on the same variable for all stressors for a given *S*. This *interstressor response specificity* suggested that for many people, one autonomic response tends to predominate regardless of the stressor at hand. A similar study by Lacey and Lacey (1958) using female *S*s also suggested the occurrence of *interstressor response stereotypy;* the *S*s tended to show idiosyncratic patterns of response across stressors.

Sternbach (1960) compared several physiological responses to startle, epinephrine, norepinephrine, CP, and exercise. The results showed that startle and epinephrine led to qualitatively similar responses. Comparison of published response magnitudes for CP and exercise shows that virtually all physiological systems measured changed in the same direction for both stimuli and differed by less than the means for startle and epinephrine. Thus both CP and exercise appear to produce a nearly identical arousal pattern. Wenger and Cullen (1958) reported a study of physiological responses to 14 stimuli. They found that the pattern of response was nearly the same for mental arithmetic and word fluency tasks, somewhat similar for CP, and different for most of the remaining stimuli. Thus, the difference between stimuli also seems important in determining the response, which suggests some validity for the concept of *stimulus-response specificity.*

Wenger, Clemens, Coleman, Cullen, and Engel (1961) replicated the Lacey et al. (1952) study using the same stressors but measuring a larger number of physiological responses. They found less evidence for *individual-response specificity* than Lacey et al. (1952) and still less of a stereotyped pattern of response across stressors. Again, they found that the characteristics of the stimulus influence the response. Thus, *stimulus specificity* as well as *individual-response specificity* and *response stereotypy* enter into producing the pattern of visceral response.

Lacey and Lacey (1962) extended this analysis by showing that CP responses in several autonomic measures were reproducible over a 4-yr interval. Children were given 2 CPs in one test session in a given year and 2 CPs during the same week 4 yrs later. Results showed a somewhat better than chance occurrence of the same pattern of autonomic responses in both test sessions. The Laceys referred to this effect as *intrastressor response stereotypy,* which appears to apply over long time periods and in spite of intervening maturational effects. Engel (1960) published results which support both Wenger and Cullen (1958) and Lacey et al. (1952). He measured systolic and diastolic BP, respiration rate, SCL, HR, HR variability, and finger temperature in response to an automobile horn sounding, mental arithmetic, decoding scrambled proverbs, exercise, and CP. The data revealed that the patterns of response were different across the various stimuli, supporting the concept of *stimulus-response specificity.* Furthermore, response patterns appeared to be idiosyncratic to the individual *S*s indicating a measure of *individual-response specificity.* These findings are supported by the results of another study using normal females (Engel & Bickford, 1961).

More recently, Wieland and Mefferd (1970) studied long-term variation in physiological activity. Three *S*s were tested daily for 120 days, and a part of the procedure included measurement of activity at rest, during CP, and during recovery. In attempting to evaluate the variables influencing their long-term measures at any one point, they proposed conditioning, environmental influences, activity, alerting, circadian rhythms, and novelty as being important. The most striking finding was that over time, intraindividual variation was as great as interindividual variation in activity both at rest and during stress. At this point, it is difficult to assess the bearing of these results on the status of the concepts of *stimulus* and *response specificity* and the authors do not address this issue. The importance of these studies is their attempt to characterize the pattern of autonomic responses in terms of their various environmental and organismic components.

In the process of analyzing the components of autonomic responses, Lacey, Kagan, Lacey, and Moss (1963) proposed four constructs: *Interstressor Stereotypy,* the tendency to respond maximally with one system regardless of the stressor; *Intrastressor Stereotypy,* which means that for a given *S*, the pattern of response tends to be similar with repeated exposure to a stressor; *Stimulus Stereotypy,* which is that different stimuli tend to elicit different responses; and they proposed *Symptom Stereotypy* by which psychosomatic patients show maximum reaction in the autonomic response consistent with their somatic complaint.

CP Studies of Psychosomatic Disorders

The studies discussed below have attempted to evaluate tendencies toward response stereotypy in psychosomatic patients. This research partly focuses on the Lacey group's fourth construct, *symptom stereotypy.*

Hines and Brown's (1932) study revealed that subjects could be distinguished into three categories (normals, hyperreactors, and hypertensives) on the basis of baseline and CP responses in BP. Normals showed the lowest basal and response BP levels, hypertensives the highest, with hyperreactors in between. These results were confirmed by additional studies (Hines & Brown, 1933, 1936, 1939; and Hines, 1940). A number of other investigations (Briggs & Oerting, 1933; Pickering & Kissen, 1936; Ayman & Goldshine, 1938; Yates & Wood, 1936; Shapiro, 1961) confirmed or found results very similar to those obtained by Hines and Brown. On the basis of CP test results, Dieckmann and Michel (1935) were able to separate pregnant women into normals, hyperreactors, and hypertensives. Randall, Murray, and Mussey (1935) suggested the possibility of using the test to detect cases of hypertensive toxemia. In recording the CP responses of pregnant women, Bak (1937) noted that some hypertensive BP response curves showed an abnormal fluctuation above and below baseline, and a slow return to normal. He also noted that in cases of hypertensive toxemia, the response is often a drop (a paradoxical response) in BP followed by damped fluctuations about the baseline.

Hines (1937) administered CP tests to 400 school children and found that a portion of those showed hyperreactive BP responses. Further investigation revealed that nearly all of the hyperreactive children had a hypertensive in the immediate family. These results are of interest in suggesting the value of long-term studies of psychosomatic disease.

Eyster, Roth, and Kierland (1952) studied peripheral vascular activity in patients with atopic dermatitis and found BP responses to CP which were in the hyperreactive range. No cardiac acceleration was noted. The authors also observed that this and other abnormal cardiovascular responses became more normal on remission of the dermatitis. Wenger, Clemens, and Cullen (1962) tested the hypothesis that patients with different psychosomatic disorders show different patterns of autonomic response to stress. The patients had either gastric ulcers, non-ulcerative gastrointestinal disorders, neurodermatitis, or other dermatological disorders. Rest data showed that all patient groups were higher than normal in sympathetic activity. In response to CP, the neurodermatitis and non-ulcerative patients showed greater HR increases and smaller rises in diastolic BP than normals. In general, the patient groups did not differ from one another, but differed from normals in the ways mentioned. The results of these two experiments are in direct disagreement with respect to HR and BP responses. Wenger et al. (1962) used only male *S*s and suggested that the use of male and female *S*s in the earlier study contributed to the discrepancy.

It appears that experiments in which response to the CP has been used to differentiate between patients with various psychosomatic disorders have met with limited success. This may result from two causes. The number of factors influencing such autonomic responses is large and their interactions are poorly understood. Also, the amount of effort expended in this direction has not been great enough to provide a systematic breakdown of the relevant subject and environmental parameters.

CP Studies on Psychological Disorders

A number of studies have evaluated the proposition that various psychological disorders are accompanied by differential responses to cold immersion. White and Gildea (1973) compared CP responses in controls, hypertensives, and anxiety reactive *S*s. The hypertensives showed the highest BP response of any group, and the slowest return to basal level. The responses of anxiety patients fell between normals and hypertensives on HR and BP measures. Rosen (1951) compared CP response of hysterics to those of several other patient groups. The mean response measures for the non-hysterical patients showed normal BP increases. Observations of changes from basal levels among hysterics showed an average *decrease* of 22.0 mm Hg systolic and an increase of 1.0 Hg diastolic for the first min, and *decreases* of 47.0 mm Hg systolic and 0.7 mm Hg diastolic for the second min. These paradoxical (i.e., response changes opposite to normal) results for hysterics were interpreted by Rosen as due to a denial of expressions of anxiety, accompanied by inhibition of vasomotor responses to stressors or painful stimuli such as the CP. The results of an earlier study by Reider (1938) tend to confirm Rosen's findings. A two-part study published by Igersheimer (1953) also compared CP responses among several patient groups and attempted to determine the CNS level which controls the response to CP stimulation. Normals showed greater BP increases than schizophrenics and manic-depressives, and increases slightly higher than the neurotics. Some schizophrenics showed the paradoxical response. In general, the psychoneurotics showed CP responses intermediate to those of the normals and schizophrenics. His results were discussed in terms of Gellhorn's (1953, pp. 429–432) theory.

Wenger, Clemens, and Cullen (Note 1) reported results of a study comparing normals with schizophrenics and non-psychotic patients in a controlled resting state and in response to CP. During rest, the schizophrenics showed BPs which were not different from those of other psychiatric patients. Their autonomic balance ($\bar{A}$) scores in fact showed a predominance of sympathetic activity as compared to normals. In response to CP, schizophrenics failed to differ from the other patients in the study. In general, these results fail to support Igersheimer's (1953) findings. Changes in drug therapy for schizophrenics, especially the introduction of the use of chlorpromazine in the mid 1950's, may be a significant variable underlying the differences in these results.

Clearly, disorders of a functional psychological nature are accompanied by related changes in physiological function, although various forms of psychological disturbance do not appear to be associated with unique patterns of CP response. An explanation of these results would seem to require some account of altered perception of the stimulus, of altered symbolic meaning of the stimulus, and a shift in the responsivity of the ANS. That these possibilities exist will be discussed in connection with pain.

The Role of Central Processes in Controlling Responses to CP

A number of papers discussed have suggested that cortical processes can modify physiological responses and pain sensations to CP stimulation.

Cortical Studies. Few articles have dealt directly with the involvement of the cortex in CP responses. The earliest paper that has come to the attention of the reviewer is that by Rizzolo (1929). Dogs' forelimbs were placed in ice water for 3 to 10 min, and cortical excitability was measured pre- and post-immersion at points on the motor cortex. The cortical motor point of the right forelimb increased in excitability with immersion times up to 3 min and then decreased. The effect was less pronounced at other motor points. It would be interesting to examine the possibility of parallel courses in the habituation of the cortical excitability effect and the peripheral vasoconstrictive response. Nakao, Ballin, and Gellhorn (1956) showed that decreases in BP led to increased activity in the hypothalamus and on the cortex and that increased BP led to the opposite change in these measures. The central inhibitory role of the aortic and carotid baroceptor afferents will be discussed below, but it is apparent that these influences can directly or indirectly affect cortical activity.

Igersheimer (1953) also investigated the role of the cortex in the CP response mechanism. In order to determine the CNS level mediating the CP response, 15 medical students were given a CP test under deep levels of anesthesia, during which the cortex is depressed and presumably any remaining peripheral response would be subcortically controlled. At such degrees of anesthesia, a response decrement of 26% was observed, indicating a substantial degree of cortical control, assuming no anesthesia effects on brainstem structures. The overall results of the Igersheimer studies were interpreted as indicating that the CP response is controlled largely by subcortical structures, particularly the hypothalamus and medulla, and is based on a neurogenic reflex.

A more recent study by Griffin (1963) suggests that neocortical areas influence the magnitude of the CP response. Comparisons were made between habituation of CP responses in leucotomized schizophrenic patients, normals, and non-leucotomized schizophrenics. Leucotomized patients showed higher basal BP levels and required significantly more immersions before habituating than did the normals or schizophrenics. Other work on CP habituation is reported by Glaser and Whitlow (1957), Glaser, Hall, and Whitlow (1959), and Greenwood and Lewis (1959). Sterman, Clemens, and Wenger (1966) noted that upon CP immersion, EEG alpha rhythm (8–12 Hz) was blocked but that for some *S*s alpha recovered during the immersion period, while for others recovery did not occur until after withdrawal from the water. In the "rapid recovery" group, HR, BP, and log palmar conductance showed more rapid recovery during immersion than for the "slow recovery" *S*s. However, rest levels of these measures were not so simply related to alpha recovery latency or to recovery trends. According to the authors, "it is likely" that some active central process leads to response reversals during immersion. They cite studies indicating that stimuli acting on mesencephalic and hypothalamic structures which produce excitatory responses also activate bulbar structures which tend to counteract such responses. Forebrain efferents to the lower structures mediate cerebral regulation of these areas and also allow for the expression of the effects of prior conditioning (Clemente, Sterman, & Wyrwicka, 1963). Such cortical effects are interesting in light of Rizzolo's (1929) finding of a lowered excitability threshold of the motor point of the immersed limb with long immersion times, and the results of Griffin (1963) emphasizing the role the frontal cortex plays in the establishment of habituation of response to CP. Lovallo, Parsons, and Holloway (1973) found that the peripheral vasomotor response to and recovery from CP is altered in patients who have suffered cortical lesions.

In general, then, effects of CP stimulation can be modified by inhibitory action of the frontal-basal forebrain and bulbar brainstem structures. The cortex may also affect the CP response more indirectly via memory effects related to affective associations to the painful stimulation. These studies are discussed in the next section.

Pain and Pain Modification. A review of studies of cold stress indicates that cold-immersion effects cannot be understood without considering affective states such as pain. Appenzeller (1970) points out that the response to CP is partly due to the pain induced by the ice water. Edes and Dallenbach (1936) took subjective reports by *S*s which indicated that the sensation passed through several stages from a feeling of cold, increased cold, pain, to increased pain, which leveled off, decreased pain, and then cold alone. This evidence indicated that the sensations of cold and pain were mediated by separate classes of fibers since the cold sensation was present throughout while pain had a later onset and earlier disappearance. Wolf and Hardy (1941) reported a pain study which provided reports of the progression of pain states occurring with various water temperatures. It was found that BP increased, leveled off, and decreased in direct proportion of the reported pain, and so the BP response seems to be associated with the pain rather than the cold sensation *per se* (see also Wolf & Hardy, 1942). Importantly, the two sensations (cold and pain) can be perceived and independent and the perception of pain is directly correlated with changes in peripheral response. This view is supported by Hilgard (1969).

Some evidence suggests that the reported sensation of cold-pain may be modified. Barber and Hahn (1962 and 1964) tested the effects of hypnosis on pain reports and on physiological response magnitude. Following pain suggestion, a hypnotized group reported pain to immersion in room temperature water. Their pain-state reports were the same as those of a waking control group given a CP indicating that hypnosis is capable of modifying subjective pain states. The BP measurements were suggestive of a hypnosis-induced BP increase, but were nonconclusive. Hilgard, Cooper, Lenox, Morgan, and Voevodsky (1967) measured pain states using the Wolf and Hardy (1941) rating scale. *S*s in a suggested analgesia group had significantly lower pain states to CP than control *S*s. The HR measurements also indicated that hypnosis was responsible for smaller responses in the analgesia-hypnosis group. The results of both of these studies indicate that the experience of pain and the related autonomic arousal may be subject to hypnotic control. Doupe, Miller, and Keller (1939) studied the hypnosis effect on vasomotor responses to both stimuli. In addition, they showed a lack of affective reaction (squirming, grimacing) to the stress. This partial response decrement led the authors to conclude that suggested analgesia failed to block the physical representation of the stimulus but reduced the affective reaction (pain).

The hypnosis studies indicate that vasomotor responses to stress can be modified. It is reasonable to assume that suggestion is mediated cortically. In this manner, cortical influences may be able to modify the magnitude of the CP response. Considered with the other studies cited, these results suggest that two mechanisms mediate the CP response. The first part of the response is due to the physical cold stimulus *per se* and is most likely controlled subcortically. The second phase of the response is due to the cold pain. The pain state, having arousing and negative affective properties, accounts for a portion of the sympathetic arousal and may act cortically and subcortically. Hypnosis and other verbally mediated stimuli appear able to affect the cortically mediated, pain-related portion of the response. Murphy and Gellhorn (1945) demonstrated widespread interaction between cortex and the hypothalamus. Given such extensive cortical, limbic, and diencephalic interrelationships, cortical effects on the response to noxious stimulation may be significant.

The Law of Initial Values and the Principle of Autonomic Balance in Models of Homeostasis

As a means of conceptualizing the above research, this section will first review multiple stressor studies, then discuss the Law of Initial Values (LIV), and then present research demonstrating a relationship between CP response and task performance under stress. Finally, Teichner's (1968) approach to the problem of initial values will be presented followed by Wenger's (1948) and Gellhorn's (1968a, 1968b, 1969, and 1970) systems of characterizing autonomic balance.

Multiple Stressor Studies

Studies using more than one stressor have produced results of interest in studying the LIV (Wilder, 1957). An understanding of responses to multiple stimuli is essential since environmental stimuli never occur in isolation but usually appear in complex patterns (Goldberg, 1966). Blitz and Dinnerstein (1968) performed experiments which demonstrate that the CP effect (an immersion of one hand) could be blocked by prior, contralateral CP stimulation but the authors did not suggest any explanation for the effect. Blitz and Dinnerstein suggest that subcortical effects may reduce afferent pain stimulation and thus also reduce sympathetic activity during the second immersion. This finding seems interesting and deserves to be replicated.

Teichner (1965) using multiple stressors studied the relationship between CIVD latency and emotional stress. It is known that CIVD latency normally decreases upon each successive immersion. All subjects were given 1 CP test per day for 4 days plus no-shock, weak-shock, or strong-shock on days 2 and 3. The strong-shock group showed an increase in CIVD latency on days 2 and 3 and also on day 4 after being told that no shock would be given. The weak-shock group increased their latency on days 2 and 3, but the latency dropped on day 4. The no-shock groups showed the expected continued decline in CIVD latency. Assuming that anticipatory emotional arousal occurred in the strong-shock group on day 4, it can be concluded that the emotional reaction increased the CIVD latency. This in effect suggests increased SNS activation which is mediated cortically.

Mefferd and Wieland (1965) tested the hypothesis that cognitive activity could modify physiological response. The dependent variable was electrodermal activity, which peaks about 40 sec following CP immersion but which reaches a maximum just after the beginning of cognitive tasks. To overlap the maximum sympathetic response to both stimuli, Mefferd and Wieland began a word association task 30 sec after immersion. The results were that the galvanic skin response (GSR) during immersion dropped immediately upon the start of the word association to levels no greater than word associations alone. These results were confirmed in later experiments using: passive exposure to a passage being read plus CP (Sadler, Wieland, Mefferd, Benton, & McDaniel, 1967) and a reaction time task plus CP (McDaniel, Mefferd, Wieland, Sadler, & Benton, 1968) all with the same paradigm as above. The results of these experiments were attributed to the effect of cognitive activity distracting the subjets' attention from the pain stimulus, since cognitive activity was ongoing when cold-pain reached a maximum at 40 sec.

Sadler, Mefferd, Wieland, Benton, and McDaniel (1969) tested the conclusion that cognitive activity alone could distract subjects from their pain state and reduce sympathetic activation. Subjects began a passive listening task prior to CP thus separating maximal arousal to the two. The ongoing cognitive activity failed to reduce activation to CP. The authors concluded that cognitive activity alone did not reduce activation and suggested that results of past studies were due to subcortical influences. Without underestimating the importance of brainstem mechanisms, an alternative explanation is possible. In the earlier studies, the superimposition of maximal arousal to CP and the onset of a cognitive task should have produced an orienting response to the task onset. This could be expected to produce a narrowed attentional field and thus less attention to other afferent stimuli, and a shift in attention from the cold-pain. Attentional mechanisms may in fact be important here, not because of cognitive activity, but because the subject was required to reorient himself to the beginning of a new task thus bringing attentional mechanisms into play.

In addition, the reading or listening tasks employed did not require active, overt responses of the subject, and also required less information transformation than a word association task does. This would render the Sadler et al. tasks less distracting than an orienting response to the onset of a task. Germana (1968 and 1969) clearly distinguishes between cortical-autonomic effects in cases where the task is passive and where it requires formulation of overt responses. The ongoing cognitive activity 40 sec after the initiation of the reading task could not have had as strong an attentional effect as the orienting response to the onset of a word association task, as used by Mefferd and Wieland (1965).

It should be clear from the above studies that sympathetic arousal is not simply additive, but the arousal due to two or more stimuli interacts cortically and/or subcortically and can modify output to the final common pathway. In any event, the possibility that cortically mediated activity is important in these results cannot be ruled out. A remaining problem is the development of a system of characterizing autonomic response which can encompass results of studies showing decreased response to multiple stressors (e.g., Mefferd & Wieland, 1965) and those showing an increase (e.g., Teichner, 1965).

The LIV

Wilder (1957) discussed what he called the LIV:

> Not only the intensity but also the direction of a response of a body function to any agent depend to a large degree on the initial level of that function at the start of the experiment. The higher this initial level, the smaller is the response to function-raising, the greater is the response to function-depressing agents. At more extreme initial levels, there is a progressive tendency to no response and to paradoxical reactions, i.e., a reversal of the usual direction of the response.

Lacey and Lacey (1962) tested the LIV by measuring response to CP in three ways: absolute change, change expressed as the percentage of the pre-stimulation level, and change measured by the T score. The latter as a measure of response is based on the standard deviation of attained stress level from the expected stress level derived by a regression analysis. They found support for the LIV and stated that of the three response measures, data transformed to T scores were most effective in demonstrating the effect of initial values on response values.

Relationships Between CP Responses and Task Performance. In a second experiment in Teichner's 1965 paper, subjects were classed as fast and slow dilators based on their CIVD latencies. All subjects were then given a choice response task which became increasingly conflict arousing (and, hence, sympathetically activating) over trials. If the slow dilators are considered high in sympathetic tonus, the arousal due to conflict allowed them to improve their performance initially, until overall arousal reached non-optimal levels and their performance declined. If the fast dilators can be considered low in chronic levels of sympathetic tonus, the conflict-induced arousal allowed them to improve their performance continuously within the range of stress provided. The CIVD latencies of each group predicted behavior under stress in a manner something like the inverted U function. Thus, autonomic activity may be related to performance on certain tasks when stress levels are defined. Teichner (1966) tested the hypothesis that CIVD latency could predict behavior on a task which was sensitive to arousal levels and attention. Subjects were separated into short- and long-latency dilators and tested in either a cold room (55°F) or warm room (80°F) on a monitoring task. Fast dilators showed relatively better target detection performance at 55° than at 80°, while slow dilators showed the reverse. Again, these results show that cold immersion response characteristics are related to arousal levels and that when performance is studied in a stressful situation, autonomic arousal interacts with attention and performance. Lovallo et al. (1973) and Lovallo and Zeiner (Note 2) have studied peripheral vasomotor responses to CP. In the former paper, it was noted that some *S*s appeared to show increased finger volume to CP while others showed a decrease. The latter experiments evaluated the possibility that the direction of change in digital volume was related to some measure of peripheral vasomotor activity at rest. It was found that *S*s who showed decreased digital volume to CP had large pulse wave amplitudes at rest while *S*s who showed increased finger volume had small pulse wave amplitudes at rest. It thus appeared that degree of peripheral vasoconstriction at rest was related to direction of change in finger volume to CP. If so, these results demonstrate the effect of initial values on the direction of response.[1] Gellhorn and Louffbourrow (1963) summarize experiments which have shown clearly that the response to stress is a function of the stimulus and, more importantly, ongoing levels of autonomic activity. Teichner and Levine (1968) presented a study in which fast and slow dilators were classically conditioned in rooms at either 50° or 90°F. Conditioning procedures included a light paired with shock. The conditional response was vasomotor activity. It is well known that electric shock is a sympathetically arousing stimulus and as such elicits vasoconstriction in control conditions. However, subjects conditioned under 50° showed vasodilation to the shock and later as a conditional response to the light alone. The 90° group showed the normal constrictive response. The CR was in fact a change in ongoing level of activity, rather than a unidirectional response, the relevant parameter being background arousal level.

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[1] Data from our laboratory (Lovallo & Zeiner, Note 3) have shown that within a given subject, the direction of vasomotor response can be manipulated. Each *S* was given 3 CP tests on 3 separate days with the room temperature at 12°C, 22°C, and 32°C. Under the warm temperature, initial pulse wave amplitude was large and CP response was a drop in blood volume level. When the room temperature was cold the initial pulse wave amplitude was small and in response to the CP, blood volume levels increased or failed to change. When the *S*s were tested at 22°C, intermediate rest levels and responses were observed.

Scherrer (1959 and 1962) demonstrated the effect of basal BP on BP response to hypothalamic stimulation. Low initial BP, followed by hypothalamic stimulation leads to increased BP and increased firing of the splanchnic and renal nerves. High initial BP, followed by hypothalamic stimulation leads to reduction in these measures. Long-duration stimulation may elicit an increased BP followed by a decrease during stimulation. The form of this response is suggestive of the Lewis Wave discussed earlier. He concluded that post excitatory inhibition can follow spontaneous or elicited sympathetic activity and that this inhibition of ongoing activity is central in origin and is inherent in central autonomic function. This research stems from the earlier work of Bronk, Pitts, and Larrabee (1940). A possible neurophysiological description of the effect of initial levels on cardiovascular responses to CP would be as follows. Immersion of an extremity in ice water leads to afferent stimulation of the spinothalamic and spinotectal tracts which ascend via the medulla and send collaterals to the reticular neurons which are in intimate association with cardiovascular regulating areas in the medulla. Their excitation causes increased cardiac output and vasconstriction in the skin and hence increased BP. The baroceptors in turn increase the rate of afferent firing via buffer nerves to the same medullary areas in order to inhibit the ongoing responses. This negative feedback system thus serves to maintain homeostasis. If in a normal organism, levels of BP are high prior to CP stimulation, afferent feedback via baroceptors will serve to provide initially high levels of inhibitory activity. Stimuli which tend to further increase BP will then cause greater inhibitory than excitatory tendencies and the response will show little if any rise in BP or perhaps a sudden drop (reversal). Lacey (1956) in discussing the LIV wrote:

> . . . the more powerful influence of parasympathetic inhibitory mechanisms, and their potentiation by sympathetic excitation, suggest the following interpretation of the dynamics of a cardiovascular response. As the pre-stimulus level of functioning increases, there is a disproportionately greater homeostatic restraint, both in increased magnitude and decreased latency and, as the magnitude of induced activation increases, there is a disproportionately greater increment in counter reaction.

Stress Response, Performance, and the LIV. The idea that ongoing levels of autonomic activity change due to stress, and that the direction of the change is a function of ongoing levels of activity provides the basis for Teichner's (1968) model of stress response. The model also takes account of fluctuations of attention in response to varying rates of information input (seen as stressors) from the environment. The information-load parameters are under control of mechanisms parallel with, and similar to, those regulating physical stressors. The essential feature of this system is the relationship between environmental stimuli (inputs) and states of compensatory reactions — these include stressful inputs and stress responses, respectively. Environmental stimuli (whether physical or symbolic) change over time. Thus, they have a rate-of-change parameter. The rate of change could be conceived of as rates of change of firing in afferent neural inputs. Compensatory responses, or outputs, to stimuli at the CNS or peripheral level have a similar rate of change which can be expressed as the rate of change of efferent neural discharge. The rate of change is viewed here as the critical response parameter. Under normal environmental stimulation and normal organismic states, the rate of change of input in ratio with the rate of change of the output is referred to as the Input rate/Output rate ratio. According to Teichner (1968) this ratio has some normal range of values within which the change in input is compensated for by the change in output. For example, a drop of 3°F in environmental temperature (a change in input rate) would be matched by some output phenomena represented peripherally by mild vasoconstriction, reduced sweating, and perhaps some increase in muscle tension. When the input and output are nearly equal, the ratio has a value somewhere near one. When the rate of change in input changes more rapidly than output phenomena are able to cope with (i.e., match with a similar change), the value of the ratio exceeds some optimal value and a stress reaction occurs.

Since the physiological systems in question are assumed to operate within certain limits of the ratio, the output must maintain a change rate similar to that of the input. To do so under rapid rates of input change, reversal reactions may occur. Thus when a hand is placed in ice water, the change in output is a vasoconstriction and increased BP. At some point, the vasoconstrictive output cannot change its rate (e.g., under maximal vasoconstriction). So during long immersions, the change in output toward vasoconstriction fails to match the rate of input change. At this point, a reversal reaction occurs, accompanied by vasodilation and decreased BP. The rate of change of output can again increase to a level which can match the rate of the input and the value of the ratio decreases to within normal limits. It should be remembered that in this model the rate of change is more important than the direction of change.[2]

Another concept of importance is attentional bandwidth, which refers to the proportion of incoming stimuli (inputs) which are attended to. During information overload (a stressor) the attentional bandwidth narrows to eliminate unnecessary stimuli and decrease rates of input change. Bandwidth changes are said by Teichner (1968) to be directly related to the amount of cortical projection area devoted to processing inputs. Attentional bandwidth could have implications for understanding the effect of attention and pain in influencing CP responses. This concept is also directly applicable to Teichner's (1965 and 1966) results in which physiological response interacted with performance.

Initial level of physiological activity is apparently important in determining magnitude and direction of a given response. This consideration is certainly important for an understanding of responses to multiple stimulation such as that employed by Mefferd and Wieland (1965). The interesting results of the studies by Teichner (1965 and 1966) and Teichner and Levine (1968) suggesting the effects of ongoing level of response on task performance point to the importance of understanding the relationships and mechanisms involved. The fact that many hypertensives have not only high resting BP but also show abnormally large BP increases to CP perhaps indicates some fundamental change in mechanisms controlling the relationship between initial levels and final response. More studies of the LIV are needed to better understand stimulus-response relationships for various physiological systems.

Autonomic Balance

Another determinant of physiological responsivity is autonomic balance. The terms *vagotonia* and *sympathicotonia* (Eppinger & Hess, 1917) were originally used to characterize individuals who were relatively parasympathetic or sympathetic in response to stimulation. Various attempts have been made to systematize such differences in response tendency as a means to better understand normal and abnormal states. Following earlier work with children (c.f., Wenger & Cullen, 1972), Wenger (1948) described a method by which a profile of resting autonomic activity was obtained from a large group of normal male *S*s. A number of autonomic variables were measured and diastolic BP, log change in palmar skin conductance, salivary output, volar forearm skin conductance, palmar skin conductance level, oral temperature, and heart period were found to be most useful in describing a factor of autonomic function. These measures were then employed to develop a score of autonomic balance (an estimate of the autonomic factor) which was derived separately for each *S*. The distribution of these scores was symmetrical about a mean of 70 and had a standard deviation of 8. This system has allowed individuals to be tested at rest and their autonomic balance (or imbalance) determined by comparison with the normative data. In this way, the relative parasympathetic or sympathetic dominance of a given individual can be known. This line of research has provided an important tool for evaluating some changes in autonomic function accompanying psychosomatic disorders and other states. The most thorough review of this extensive line of research is given by Wenger and Cullen (1972).

Gellhorn (e.g., 1970) has attempted to conceptualize autonomic balance in a somewhat different way, but again with the purpose of understanding normal and abnormal states of systemic physiology. According to Gellhorn (1968a, 1968b, 1969, and 1970), a stimulus which excites the sympathetic division of the ANS will have certain peripheral and central effects. Peripheral effects would be increased

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[2] In connection with Teichner's concept on the rate of change of the output matching that of the input, the same concept exists in psychophysics. Consider that the perceived intensity of a stimulus is the output (the percept) and that the input is the afferent neural firing rate from the receptor. When inputs are near normal environmental levels, the output matches the input quite closely. This is expressed another way in that within normal environmental levels of stimulation j.n.d.'s are small. This must be so when the change in input is matched closely by the change in output. At levels of stimulation increasingly distant from normal levels, j.n.d.'s become larger. That is the input change is marked less well by the change in output. When the change in input can no longer be matched by changes in output, stress reactions occur. This psychophysical concept seems closely parallel to Teichner's concept of response to physiological and symbolic stimuli under normal and stressful levels of stimulation.

HR, vasoconstriction, increased BP, pupillary dilation, increased skin conductance and increased somatic activity. Centrally, cortical desynchronization is noted in the EEG. Activation of the parasympathetic system would result in the opposite changes in most of these measures. Activation of the SNS and related somatic structures is referred to as *ergotropic* activity. In the same way, activation of the PNS and its accompanying effects is referred to as *trophotropic* activity. In general, activity of the ergotropic system is associated with responses which are action-oriented. Trophotropic activity is associated with non-action-oriented behaviors.

An important concept in Gellhorn's system is that of *tuning* which refers to the ability of the ergotropic or trophotropic system to respond to a given stimulus. In normals, ergotropic and trophotropic tendencies are balanced so that the appropriate autonomic response occurs to a given stimulus. When the balance of tuning shifts, the reciprocal relationship is less effective and the organism is more likely to respond according to its state of tuning. An ergotropically tuned system is therefore more sympathetically responsive, and less likely to show appropriate parasympathetic rebound. When imbalance is severe, the LIV may fail to hold. For example, in hypothalamic stimulation studies (Gellhorn, 1959), application of a sympathetic stimulus during rebound to a prior sympathetic stimulus led to paradoxical responses characteristic of decreased sympathetic activation, indicating an induced shift in the balance of tuning and consequent failure of the LIV. Most studies of CP effects in hypertension have found high resting BP and abnormally large responses. The LIV would predict that hypertensives, having higher initial values, would show smaller BP increases than normals. The Hines and Brown's studies indicate hypertensives have larger responses. An exception is indicated in the study by Bak (1937) who found paradoxical BP responses to CP in cases of hypertensive toxemia. This serves to indicate the need for additional work on the interaction of autonomic balance and initial values in determining physiological responses. Gellhorn's (1970) system seems valuable as an initial attempt to assess the role of changes in autonomic balance in understanding various states of disorder.

The above discussion is an attempt to integrate the efforts of Wilder (1957) and Teichner (1968) on the LIV and those of Wenger et al. (1962 and Note 1) and Gellhorn (1970) on autonomic balance. To summarize the collective contributions of these workers: three important parameters which determine stress responses are *dynamic range* of the system, its *set point*, and the *initial value* of function when the stress is applied. The dynamic range is simply the range of values over which the autonomic system in question can efficiently operate. Set point is analogous to the setting of a thermostat. When the operating level of the system exceeds the value tolerable by the set point, countervailing tendencies are brought to play. This may lead to a reversal. The work of Gellhorn and Wenger above seems most relevant to this construct. Third, given a dynamic range and set point, the initial level of function from which change occurs is important. When the initial value is near the set point and the function moves toward the limit of the dynamic range, a reversal is more likely than if the function moves toward the set point. The work of Wilder, Lacey, and Teichner seems most relevant to this aspect of autonomic function.

Conclusions

While no unified model or theory yet exists to systematically account for the results discussed here, reasonable progress has been made in outlining the requirements or features that such a theory might contain. A theory of homeostasis would need to account for certain relevant variables. First, the nature of the stressor is critical. That is, the response likely to be elicited by the stimulus should be understood in terms of the number of systems it affects and the degree to which each may be activated. The work of Engel (1960) on stimulus-response specificity and of the Lacey group (Lacey et al., 1963, and Lacey, 1967) as well as Wenger and Cullen (1958) on response patterns provide a basis for further research in this area. A second variable is individual differences in autonomic response tendency which need to be specified to determine the kinds of response pattern differences noted between *S*s. The papers by Lacey and Lacey (1958) on response-stereotypy, and by Engel (1960; Engel & Bickford, 1961) on individual-response specificity as well as those of Wenger et al. (1961, 1962, and Note 1) are forays in this direction. Also relevant to the issue of individual differences is Gellhorn's (1968a, 1968b, and 1970) system and the autonomic balance measurement of Wenger (Wenger & Cullen, 1972).

A third and much-related factor is the meaning the stimulus has for the organism. For example, stimuli, regardless of intensity, which have rapid onset can elicit flight reactions in animals and startle reactions in humans. Cognitive factors, learning, and expectancies are important here. The works discussed above on pain and its modification and the influence of cortically-mediated effects on CP response are relevant to this issue. Fourth, an ultimate model of homeostasis must incorporate the LIV. The importance of the LIV is indicated in Lacey and Lacey (1962) and in Teichner's (1968) system. It is not suggested here that these factors are independent. Instead, they most likely interact in rather complex ways. Neither is it suggested that this list is exhaustive, but it is intended to emphasize some of the major themes represented in research using the CP. These would appear to be some of the pertinent variables participating in and influencing homeostasis at the systemic level.

The foregoing discussion, while far from integrating the results of the clinical observations and experiments employing the CP test, may hopefully provide an understanding of a few of the important themes arising from studies of systemic physiology. The emphasis placed on the LIV and autonomic balance is related to three important issues. The first issue is the nature of the servomechanism underlying homeostasis and its dynamic characteristics. The second is the way in which a supposed servomechanism is set and how it can be reset. Normally, the mechanism is balanced, but studies of disordered states suggest that at times and in given individuals the mechanism becomes differentially sensitive, i.e., the set point is changed. A third question emerging from the first two is, how do the LIV and varying degrees of autonomic imbalance interact? Additional knowledge of the ways in which cortical, limbic, and diencephalic mechanisms interact and act upon mesencephalic mechanisms would assist greatly in answering the above questions.

Summary

Clinical observations and experiments using the CP as a stressor have proven valuable in the advancement of psychophysiology. This is particularly true in evaluation of autonomic activity in normal and abnormal states. The physiological effects of the CP are discussed including early cardiovascular studies of hypertension, studies of mechanisms mediating response to CP, and generalized responses to stressors, including CP studies which attempted to define the parameters of autonomic responses. It has been suggested that both individual differences in response to stress and the characteristics of a given stimulus interact in determining autonomic responses. A discussion of these factors in psychosomatic disease is presented including a study of the etiology of hypertension and an analysis of response stereotypy. Along similar lines, studies of autonomic responsivity in psychiatric disorders are discussed.

The role of the cerebral hemispheres in mediating the response to CP and the effects of CP on these structures is considered. These include studies of cortical excitation, the role of the cortex and forebrain in mediating inhibitory tendencies, and studies of pain and its modification. A number of studies are reviewed in which CP has been administered in conjunction with other stimuli to determine the effect of multiple stimulation. The importance of both cortical and subcortical influences is emphasized in analyzing the effects of multiple stimuli. Three studies are presented in which the CIVD latency during CP is used as an independent variable to predict performance in stressed and unstressed conditions.

As a means of elucidating principles important in understanding homeostasis and its disorders, discussion of the LIV and of autonomic balance are presented. The LIV is viewed as important to evaluation of magnitude and direction of response, to understanding multiple stressor effects, and to interaction of base levels of activity and task performance under stress. The concept of autonomic balance is utilized in characterizing the propensity of a system to respond either in a sympathetic or parasympathetic direction. The interaction of initial values and autonomic balance is emphasized.

In light of the lack of a comprehensive model of homeostasis with which to integrate this literature, an attempt is made to delineate the basic requirements of such a model.

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Announcement

THERMISTORS FOR BIOMEDICAL USE

Reprints of the 13-page paper, "Thermistors for Biomedical Use," by Meyer Sapoff of Thermometrics, Inc., 15 Jean Place, Edison, NJ 08817, given at the Fifth Symposium on Temperature, are now available upon request.

The various types of thermistors which have been found to be most suitable for biomedical use are reviewed. Fabrication techniques employed for each basic thermistor type are described with particular emphasis placed on their resultant advantages and limitations. For each thermistor structure considered, the relationships which exist between the structure, its fabrication methods, and the cost of maintaining close tolerances and interchangeability are also presented. Since a high degree of accuracy and the rapid measurement of very small temperature differences are usually required, the testing and calibration problems peculiar to such biomedical sensors are discussed. A qualitative discussion of the factors which affect the stability of thermistors is then presented along with quantitative data pertaining to the capabilities of each thermistor type. It is shown that specified requirements often exceed the practical capabilities of the devices used. Anticipated future developments of thermistors for biomedical use are also discussed.