Shock-Elicited Pain and Its Reduction by Concurrent Tactile Stimulation

Abstract. *Human affective reactions to nociceptive electrical stimulation were attenuated by application of a tactile stimulus to the shocked site. No alteration was perceived when the same tactile stimulus was applied to a similar contralateral site. These results and a lack of alteration at sensation threshold demonstrate the effect to be more than simple masking and support the Melzack-Wall theory.*

Recently, Melzack and Wall (*1*) have proposed a spinal gating mechanism which appears to have important implications for the control of pain in man. Although the anatomical foundations for this theory are based upon a substantial amount of animal research, evidence supporting its applicability to human pain phenomena has relied chiefly on observations related to pathological states. This report supplements such clinical evidence by presenting relevant findings obtained from normal subjects in an experiment involving shock-elicited pain.

The Melzack-Wall theory takes note of the fact that the myelinated fibers of larger diameter carrying precise tactile information into the dorsal columns also send collaterals to impinge upon the first cells of central spinothalamic transmission (T-cells). The small unmyelinated fibers which are thought to subserve the perception of pain, temperature, and crude touch are, however, the main form of input to these T-cells. While the direct synaptic influence of both forms of T-cell input is excitatory, Wall's experiments (*2–5*) have shown that sustained activity in these afferents quickly gives rise to opposing feedback effects. These effects are thought to be mediated by certain small "gating" cells of the substantia gelatinosa which exert presynaptic inhibition on both the large and small fiber endings. It is hypothesized that activity in the small fibers serves to inhibit the gating cells, thus allowing effective synaptic transmission to occur. Conversely, activity in the large fibers is assumed to excite the gating cells, which in turn inhibits effective peripheral transmission to the T-cells. Finally, it is these first cells of central spinothalamic transmission which are presumed to signal the presence of a nociceptive stimulus via the sensation of pain.

The immediate utility of the theory is that it suggests alternative (nonsurgical) methods for limiting spinothalamic discharge in cases of intractable pain of peripheral origin. Indeed, it has already been reported (*6*) that in several such cases relief was supplied by stimulating the appropriate cutaneous nerve so as to excite only the critical (gate closing) fibers of large diameter arising from the area of the painful focus. While suggestive, these results must be tempered by the lack of any experimental rigor in the manner in which "relief" was measured, as well as an inability to control for any placebo effects the elaborate procedure itself might have had on the patients.

In the present investigation we sought to overcome these and other deficiencies inherent in the use of clinical populations by constructing a well-controlled laboratory experiment in which normal subjects (12 healthy male volunteers between the ages of 21 and 30) were used. Nociceptive stimulation was supplied by means of a 60-hz constant current shock delivered to the subject's left forearm through a concentric electrode (*7, 8*). This system is capable of delivering an intensity series ranging from below threshold to above tolerance without producing any harmful effects. A subjective rating scheme was employed to gauge the subjects' *affective* response to the shocks; this method contrasts with traditional psychophysical procedures [that is, magnitude estimation (*9*)] which tend to ignore the emotional overtones of the stimulus in order to obtain the purely sensory component—"stimulus intensity." The experimental procedure is simple and begins by presenting subthreshold stimuli which steadily increase in intensity step by step. The subject is asked to make four judgments: (i) when he first detects that the stimulus was presented ("threshold"), (ii) when it first becomes annoying or "uncomfortable," (iii) when it has reached a level that may actually be called "painful," and, finally, (iv) when he feels that he cannot accept the next higher shock in the series ("tolerance").

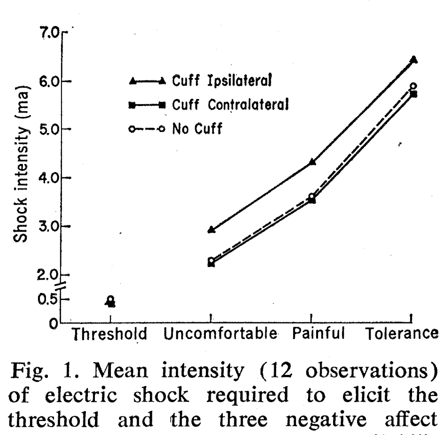

Fig. 1. Mean intensity (12 observations) of electric shock required to elicit the threshold and the three negative affect judgments as a function of the availability and location of the tactile stimulus.

Discharge of large fibers in the area of the painful focus was produced by the use of a carefully selected tactile stimulus. Although direct nerve stimulation may be a more potent elicitor of large fiber activity, there is no guarantee that the resulting discharge pattern resembles that produced by natural stimuli, and, presumably, the phylogenetic development of the hypothetical gating mechanism presupposes some selective advantage for the organism in dealing only with natural stimulation. (Anecdotal evidence for this contention is also somewhat suggestive in that self-administered tactile stimulation—that is, rubbing the affected area—is a common, if not universal, response to many types of pain.) Our selection of an appropriate tactile stimulus was guided by Wall's observation (*10*) that the largest diameter afferents to the T-cells are maximally responsive to light touch, but that they adapt very quickly if the stimulus is maintained (*11*). The actual stimulus employed was a sawtooth-like pressure gradient applied through a standard blood pressure cuff positioned on the subject's left forearm, just distal to the shock electrode. Every 8 seconds the cuff underwent a 3-second inflation, reaching a peak pressure of 110 mm-Hg before a solenoid valve was opened to rapidly deflate the cuff. The shock was presented 0.75 second into the inflation and remained on for 1 second (cuff pressure increased from 30 to 70 mm-Hg during this shock interval).

The sensation produced by this tactile stimulus was considered to be comparable to light touch of a dynamic variety and, therefore, would seem to be an adequate stimulus for eliciting repetitive large fiber discharge (*10*). Since the cuff encompassed a large area of skin immediately adjacent to the nociceptive focus, this procedure should have been optimum for generating the spinal gating effect (R. Melzack, personal communication). The comparison, or control, condition was an identical series of concurrent tactile-nociceptive presentations, except that the cuff was applied to the contralateral (unshocked) forearm. Thus both conditions employed the same dual stimulation and phasing parameters to control for any general distraction, or other attention-related effects, but only the ipsilateral condition presented maximum opportunity for direct spinal inhibition. A third shock series without any concurrent tactile stimulation was also given to estimate the magnitude, if any, of such a general distraction effect.

All 12 subjects were given preexperimental shock experience to familiarize them with the range of sensation produced by electric shock. They were then given detailed instructions in the nature of the subjective judgments that they were required to make for the remaining three shock series (cuff ipsitateral, cuff contralateral, and no cuff). It is important to stress that at no time were the subjects given any suggestion that the location of the cuff might alter the sensation produced by the shocks; rather, the presence and changes in location of the cuff were explained as being necessary in order to *measure* "local and nonlocal vascular changes" as produced by electric shock. The order of presentation for the three cuff conditions was completely counterbalanced over the 12 subjects, with each of the six possible orders occurring twice. The shock series proceeded in identical fashion for all three conditions, employing steps of 0.1 ma until threshold was reached, and then continuing on to the tolerance level in 0.4-ma steps.

The results of the experiment are presented in Fig. 1. Neither the presence nor the lateral location of the cuff had any effect on the subjects' ability to perceive threshold stimulation. By way of contrast, the amount of current required to elicit each of the three "negative affect" judgments was significantly higher in the experimental (ipsilateral) versus the control (contralateral) condition. The ratings observed under the contralateral condition were, however, nearly identical to those observed under the shock-alone condition. One-tailed t-tests (*12*) showed the critical ipsilateral-contralateral differences to be reliable for all three negative affect judgments ($P < .01$ for "uncomfortable," $P < .025$ for "painful," and $P < .05$ for "tolerance").

The results of this experiment indicate that a mild tactile stimulus was able to reduce the nociceptive quality of electric shock only when it also had the opportunity to produce the spinal gating effect. It seems highly unlikely that the present results can be explained as being due to simple masking or distraction, since such effects typically reflect the relative intensities and temporal phasing of the stimuli. In the present experiment these stimulation parameters were not themselves important factors. The effect of the cuff was instead totally dependent on its location since its application to the contralateral arm resulted in essentially no alteration of the judgments as compared to those obtained when only shock was presented. Much more important, however, was the specificity observed within the ipsilateral condition. That is, the effectiveness of the ipsilateral cuff was itself limited to only the more intense shocks associated with verbal reports of negative affect (threshold shocks, in contrast, are usually perceived as a mild, and often pleasant, tingling). The failure of the ipsilateral cuff to produce even a slight elevation in threshold argues very strongly against the possibility that its effectiveness at higher intensities was due to distraction or masking.

Although this specificity of the inhibitory effect to nociceptive intensities is difficult to explain in terms of other readily available hypotheses (that is, lateral inhibition, indirect vascular effects of the cuff, and others), it is entirely consistent with the mechanism of spinal gating as outlined by Melzack and Wall. That is, threshold stimulation would serve to excite only the relatively large diameter afferent fibers since electric current, even when applied cutaneously, apparently acts directly on the nerve rather than through receptors (*13*). In the present experiment, therefore, only when the current was increased to levels sufficient to trigger the smaller fibers would the Melzack-Wall theory then predict T-cell discharge to increase, and only at these nociceptive levels would the intended "gate closing" effect of the cuff exert a significant effect on this central discharge.

In conclusion, the present results are consistent with the postulated existence of a spinal gating mechanism capable of selectively reducing the affective reaction to a compound tactile-nociceptive stimulus. Although pain may have an adaptive energizing role in certain emergency situations, perhaps the behavioral significance of such a mechanism lies in the fact that pain, in excessive amounts, can also be considered to be biological noise when adaptive responding depends on the accurate reception of precise tactile information. Although the size of the present effects were small in the clinical sense, their clear existence nonetheless suggests that further research in this area may prove to be of clinical value.

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References and Notes

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11. Although a vibrotactile stimulus has been shown to overcome this tendency toward adaptation in cats (*14*), an attempt to use vibration to reduce the noxiousness of electric shock in man has produced mixed results, serving to reduce the effect at low shock intensities but to enhance the negative properties of the shock at higher intensities (*15*). Since the first effect of an incoming large fiber volley is to produce a transient *increase* in T-cell discharge (prior to the inhibitory effect), it would seem reasonable to avoid vibration as a method for inducing large fiber discharge since it could result in a serendipitous summation of the a-c shock and vibratory volleys. Ideally, the most effective method would be to employ a tactile stimulus whose dynamic properties were selected to ensure a more sustained large fiber discharge so that the secondary inhibitory effect would be fully developed by the time the nociceptive stimulus was applied.
12. Although not reported here, the critical current levels were also a function of ordinal position, being somewhat higher as the subject progressed from the first to the third series. However, the counterbalancing procedure enabled this source of variation to be algebraically eliminated from the data prior to the assessment of the cuff effects.
13. A direct mode of action is supported by the observation that the superficial application of ethyl chloride, sufficient to abolish normal cutaneous sensation, does not alter the threshold for cutaneous electrical stimulation (*16*) and, further, that the sensations produced by cutaneous electrical stimulation are the same as those obtained when direct stimulation of the underlying nerves is employed (*17*).
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