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9. Portions of these data were the basis for experiment 3 of a doctoral dissertation [University of North Carolina (1970)]. This part of the research was supported by research grant MH 14121 from the National Institute of Mental Health to V. M. LoLordo and by a National Science Foundation traineeship held by M.B.C. The research was completed under a postdoctoral fellowship at the Institute of Neurological Sciences, University of Pennsylvania. I thank V. M. LoLordo and C. R. Gallistel for their criticism of an earlier version of the manuscript.

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Social Setting: Influence on the Physiological Response to Electric Shock in the Rat

Abstract. *A significant fall in tail blood pressure occurs in paired rats after shock-induced aggression. Pressure returns to baseline levels within 4 hours after fighting. Conversely, single rats subjected to jump threshold measurements or to shocks identical to those used in the aggression paradigm show significant elevations in tail blood pressure. The size of the pressure increase in rats shocked alone appears dependent on the intensity of the shocks, while the pressure fall in rats shocked in pairs occurs over a broad range of shock intensities.*

Shock-induced aggression is a social phenomenon. It will occur if two animals are placed together in an area that does not permit escape and an electric shock is applied to their feet. The animals will attack each other with species-specific aggressive and submissive motor patterns. Many aspects of this behavior have been defined, particularly in the laboratory rat (*1*), and the paradigm of shock-induced aggression has been used to study brain lesions and drug effects (*2*, *3*). If one of the rats is removed, the remaining animal's attack response is replaced by persistent escape attempts. It occurred to us that there might be different physiological correlates of these two different behavioral responses: attack and attempted escape. An analogous situation can be drawn from the human psycho-physiological experiments where anger and attention directed outward have been correlated with a norepinephrine-like physiological pattern, while anger and attention directed inward, anxiety, and fear have been associated with an epinephrine-like physiological pattern (*4*, *5*).

In experiment 1, 16 experimentally naive 90-day-old, male NIH Osborne-Mendel rats were randomly separated into eight fighting pairs, which were maintained for the duration of the study. The animals were housed separately and fed freely on rat chow. Shock-induced fighting rates and jump thresholds were determined as described (*2*). Briefly, shock-induced fighting involved the presentation of 50 footshocks of 2-ma intensity to paired rats. The shocks lasted 0.4 second and were presented every 7.5 seconds. An attack percentage for each rat pair was obtained by counting the number of shocks which initiated an attack response. Jump thresholds were determined by delivering a series of graded shocks to each rat alone. The intensity of the shocks ranged from 0.07 to 0.5 ma. A jump threshold for each rat was obtained, being that current intensity at which the rat jumped 50 percent of the time. Tail blood pressure (*6*, *7*) was measured by placing the rat in a warmed restrainer (*8*). Blood flow to the tail was then occluded by inflating a tail cuff to 200 mm-Hg. The cuff pressure was gradually released and the first pulsations were detected by impedance plethysmography (*9*). The impedance pulse was superimposed on the pressure tracing and recorded (*10*). By proper calibration, the pressure at which the first pulsations appeared distal to the cuff could be reproducibly determined and was interpreted as the tail blood pressure. Pulse rate was also determined from the plethysmographic tracing.

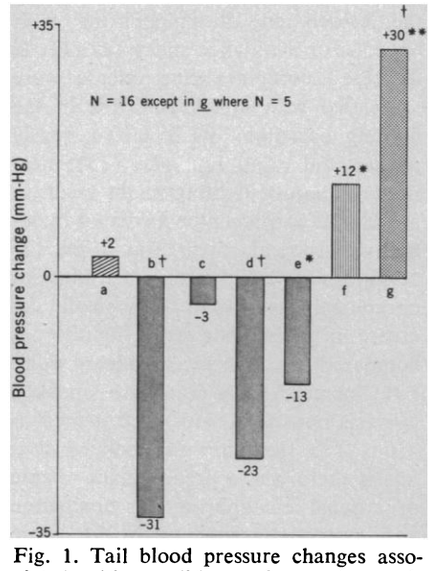

Fig. 1. Tail blood pressure changes associated with conditions of experiment 1 (a) Control, rats placed in cage between blood pressure measurements; (b to e) fighting paradigm on four consecutive days, rats paired; (f) jump threshold, rats alone; (g) fighting paradigm, rats alone; $*P < .05$ by paired t-test, two-tailed; † $P < .01$ by paired t-test, two-tailed.

Tail blood pressure and pulse were measured under the following conditions: (i) before and 3 to 5 minutes after shock-induced fighting on four successive days; (ii) 4 hours after shock-induced fighting on one of the aforementioned days; (iii) before and 3 to 5 minutes after jump threshold determination on one day; (iv) before and 3 to 5 minutes after a subsample of five rats received the fighting protocol of 50 2-ma shocks while alone in the box; and (v) before and after a control period in which the rat pairs were simply kept in cages together for 45 minutes.

Mature Osborne-Mendel rats are relatively aggressive, attacking after approximately 67 percent of their shocks. Their mean jump threshold for this experiment was 0.26 ma, identical to Sprague-Dawley males tested under similar conditions. The effects of the experimental conditions of experiment 1 on tail blood pressure are illustrated in Fig. 1. Shock-induced fighting was followed by a consistent fall in mean tail blood pressure. This fall reached statistically significant levels on 3 of the 4 days measured, with a mean drop over the 4 days of 17.5 mm-Hg. The failure to reach significance of day 2 remains unexplained. There was no change in pulse rate. The tail blood pressure had returned to baseline levels 4 hours after fighting. Conversely, when shock was delivered to single rats with either the parameters of intensity and timing identical to those of the fighting paradigm or the variable intensities of the jump threshold determination, there was a consistent rise both in tail blood pressure and in pulse rate.

Experiment 2 evaluated the role of differing shock intensities in relation to

tail blood pressure changes. A second group of experimentally naive 90-day-old Osborne-Mendel rats were randomly separated into two groups (A and B) of eight rats, each of which was further subdivided into four pairs which were maintained throughout the study. On four successive days of week 1, group A rats received footshocks in the fighting paradigm while paired, and group B rats received footshocks of identical parameters while isolated. During week 2, group A rats were shocked singly, and group B rats were shocked while paired. Four different shock intensities were used—2 ma, 1 ma, 0.5 ma, and 0.25 ma—in such a fashion that each pair of rats was the first to receive one of the four shock intensities in either the fighting or isolate paradigm and then went on in a balanced rotational order to receive the other three shock intensities in both paradigms. Tail blood pressure and pulse rate were measured as in experiment 1.

The physiological effects of the experimental conditions of experiment 2 are illustrated in Fig. 2. In the isolated situation there is a tail blood pressure increase that declines as the shock intensity declines. In contrast, for all shock intensities in the fighting paradigm there is a tail blood pressure decrease that bears no clear relation to intensity of shock. At each shock intensity the tail blood pressure response is significantly different ($P < .05$ by paired t-test, one-tailed) for the two paradigms in replication of experiment 1. The behavior of the rats in the isolated condition varies from vigorous escape attempts at the 2-ma intensity of shock to only a minor startle response at the 0.25-ma intensity. The attack percentage in the fighting paradigm falls from 58 percent at the 2-ma intensity to 10 percent at the 0.25-ma intensity. At the 0.25-ma intensity the rats huddle quietly together most of the time.

The social setting in which an aversive stimulus is delivered seems to determine not just the magnitude but also the direction of tail blood pressure response to that stimulus. The persistence of the tail blood pressure decrease in the fighting paradigm, despite a marked drop in attack percentage at lower shock intensities, suggests that differing attack levels are not directly responsible for the decrease in pressure. We conclude, therefore, that it is the presence of another rat in the fighting paradigm which results in the differing pressure

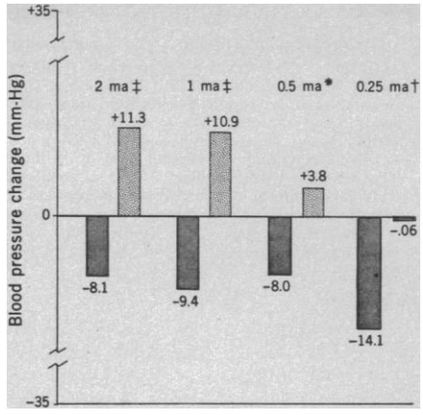

Fig. 2. Tail blood pressure changes associated with conditions of experiment 2 (groups A and B combined); solid bars, fighting paradigm, rats paired; hatched bars, isolate paradigm, rats alone; * $P <$ .05 by paired t-test, one-tailed; † $P <$ .005 by paired t-test, one-tailed; ‡ $P <$ .0005 by paired t-test, one-tailed.

response as compared to the isolated situation. The observation that depletion of tritiated brainstem norepinephrine occurs when rats are shocked alone but not when they are shocked together (*11*) provides an additional example of differing physiological response to social setting.

One explanation for the above results is that there is a difference in catecholamine secretion between aggressive and avoidance (or escape) situations. Particularly in primates and man, norepinephrine has been linked to aggressive, outgoing behavior in contrast to the association of epinephrine with anger-in or avoidance states (*4*, *12*). If increased norepinephrine release were associated with attack behavior in the fighting paradigm, its localized neural release and rapid reuptake (*13*) after the cessation of fighting might result in an arterial baroreceptor-mediated hypotensive rebound, as is found on the cessation of intravenous infusions of norepinephrine (*14*). The small decrease in pulse rate after fighting as compared to the large, significant pulse rate increase after rats are shocked alone is consistent with such a mechanism. If in the jump and isolated situations there was a predominant release of adrenal epinephrine, its dissipation and systemic effects might be more prolonged, again fitting the observations of this study.

Alternatively, the drop in tail blood pressure may be a reflection of increased vasoconstrictor tone which has been reported to result in an apparent lowering of systolic blood pressure as measured in the rat's tail in comparison with simultaneous aortic pressure determinations (*7*). Such increased peripheral vasoconstrictor tone might develop in circumstances that recognizably threaten the animal with injury, serving a possible function of lessening hemorrhage in superficially wounded animals. However, the persistent tail blood pressure decrease at 0.25 ma in experiment 2, despite the relative absence of attack behavior, suggests that even the opportunity or preparation for attack may be sufficient to induce the observed hypotensive response. Consequently, further study is necessary to define the precise etiology of the differential effects on tail blood pressure exerted by shock in social and isolate situations.

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