tensity of the light. The rate was specified in terms of the duration between two consecutive pecks (the "interresponse time"). At each intensity, a range of interresponse times were reinforced. Going from dimmest to brightest light, these ranges were, in seconds, 195 to 214; 51.9 to 57.1; 10.9 to 12.0; 2.79 to 3.07; and 1.35 to 1.48. The time range between the minimum and maximum reinforced interresponse time, at each intensity, was one-tenth of the minimum reinforced interresponse time.

Figure 1 shows the function (training curve) relating the reinforced rate of responding to the intensity of the light on log-log coordinates. The training curve has been plotted twice in order to facilitate inspection of each pigeon's performance. The training function has a slope of approximately 1.0 for the dimmer intensities and a lower slope for the brighter.

The five intensities may be designated the training stimuli because reinforcement was correlated with them. In addition to the training stimuli, there were four test stimuli. The intensity of the test stimuli bisected logarithmically the interval between successive pairs of training stimuli. Thus, the test and training stimuli constituted a series of nine stimuli in 3 db steps. When a test stimulus was present, no response was ever reinforced. Pigeons ordinarily cease responding to nonreinforced stimuli. The behavior was maintained in the present experiment presumably because the pigeons could not discriminate between training and test stimuli when there were nine stimuli that differed along only a single dimension. The pigeons were given several months of daily experimental sessions.

Figure 1 shows the rate of responding as a function of the intensity of the light. Medians of seven sessions are plotted. The session-to-session variability was sizable, but medians for seven-session periods did not change significantly over several months. Rates obtained with the test stimuli appear as points enclosed in squares. If a point falls on the straight line between the training stimuli, then the pigeon's rate for the test stimulus is the geometric mean of its rates for the adjacent training stimuli. To a fair approximation, the rates obtained with the test stimuli fall at the geometric means. This is what would be predicted if, as Stevens (*3*) has found with human observers, the subjective brightness were a power function of luminance. (The basic form of this relation is $R = kS^n$, in which R is the response, S is the stimulus, and k and n are empirical constants.) Fechner's logarithmic law of subjective magnitude would predict rates at the arithmetic means, and this prediction is not as well supported by the present data. Admittedly, no clear choice between the two hypotheses can be made on the basis of these data, partly because the interval between training stimuli was only 6 db. With a greater range for bisection, it would probably be possible to increase the certainty of a choice between arithmetic and geometric means.

It is primarily the arbitrary training curve, and not the sensory system of the pigeon, that determines the overall slopes of the curves in Fig. 1. We cannot, therefore, state the exponent of the power function controlling apparent brightness for pigeons. We can say only that the interpolations made to the test stimuli are compatible with power functions. Since these interpolations may have been influenced by the particular training curve we used, other training curves would have to be tried before our findings could be taken as general.

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References and Notes

1. D. S. Blough, *J. Exptl. Anal. Behav.* **1**, 31 (1958).
2. This research was supported by grants Nos. G-6435 and G-14341 from the National Science Foundation.
3. S. S. Stevens, *Psychol. Rev.* **64**, 153 (1957).

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Temperature Change: The Basic Variable in the Early Handling Phenomenon?

Abstract. Rats which had been handled or which had been subjected to lowered temperature without handling during the first week of life showed significant reduction of adrenal ascorbic acid when stressed, while appropriate controls did not. Exposure to lower temperature, and consequent lowering of skin or body temperature, may be the crucial factor in handling.

Laboratory rats which are handled during infancy are less emotional and more resistant to stress than nonhandled rats (*1*, *2*). Attempts to explain this relationship have implied that gentling (*3*), trauma (*4*), or stress (*2*) is the essential factor contributed by handling. Levine and Lewis (*5*) tried to specify what physical dimensions of the handling procedure are responsible for the effects obtained. To evaluate the effectiveness of various early treatments, they employed depletion of adrenal ascorbic acid due to stress as a convenient measure of physiological changes attributed to handling (*6*). They found that merely relocating the nest cage for 2 minutes daily was as effective as handling in producing animals which showed significant adrenal ascorbic acid depletion to cold stress at 14 days of age, while nonhandled control animals showed no significant depletion. Consequently, Levine and Lewis concluded that contact with the experimenter was not important and that the effects of handling are due to "any of several modes of extra-stimulation" (*5*, p. 369).

Handling is maximally effective during a critical period in the first week of life (*7*). Therefore vision and hearing, nonfunctional at this age, are obviated as modes of extra-stimulation in early handling. Since nonhandled pups receive frequent, and apparently intense, cutaneous stimulation from the mother, neither handling nor moving the nest cage seems adequate to provide significant added cutaneous (or proprioceptive) stimulation. In addition, it does not seem possible to augment olfactory or chemical stimulation by moving the nest cage. Temperature, the remaining sensory modality, demands further consideration.

Before moving the nest cage, Levine and Lewis removed the mother. In our laboratory this procedure scatters the nursing litter, exposing the pups to cooler air outside the nest. The poorly developed temperature-regulating mechanism, combined with a high surface-area-to-body-volume ratio in the hairless young rat, may result in lower skin or body temperature when a pup is out of the nest. Handling, as well as removing the mother (and dispersing the litter), exposes the pup to cooler air outside the nest. In addition to providing extra-stimulation via temperature receptors in the skin, this exposure might lower the body temperature of the pup enough to alter on-going enzymatic reactions involved in developmental processes, possibly producing permanent changes in physiological mechanisms underlying emotional- and stress-reactivity.

Direct measurements of skin or body temperature, and of neurologic,

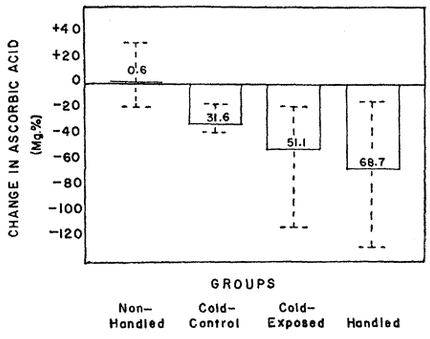

Fig. 1. Comparison of adrenal ascorbic acid depletion in the early treatment groups. Bars represent mean depletion, dashed lines indicate range among litters within each group, and mean values are on the bars. Mg %, milligrams per 100 grams.

metabolic, or physiological changes concomitant with handling, would be needed to verify these speculations. Because of the technical difficulties of obtaining such measurements, the following experiment was designed as an initial test of the hypothesis that the effects of handling are due to lowered skin or body temperature.

Thirteen Holtzman Sprague-Dawley litters, totaling 118 pups, were assigned by litter to one of four treatment groups. Animals in group H (N=30) were handled daily for 2 minutes. Animals in group NH (N=31) were not handled. Animals in group CE (N=31) were exposed daily to low temperature. Animals in group CC (N=26) were treated exactly like those in group CE, but were not exposed to cold. Pups in group CE were exposed to cold by placing the nest cage, containing mother and litter, in a refrigerator at 7° to 10°C. Cages housing pups in group CC were placed in a nonfunctioning refrigerator maintained at room temperature (23°C). Groups CE and CC remained in their refrigerators for 12 minutes, the approximate time that group H litters were out of their cages during the handling procedure. Cages were transported gently to minimize disturbance. All treatments began on the day following birth and continued for 6 days, thus encompassing the first week, the critical period for handling.

Depletion of adrenal ascorbic acid in response to cold stress was selected to evaluate the effectiveness of treatments because it yields clear-cut differences between handled and nonhandled animals at an early age, and because it permitted us to replicate some of Levine's excellent work (*2*). At 12 days, the earliest age for significant depletion by cold stress (*8*), half the pups in each litter were killed by cervical-spinal separation. Adrenals were removed, weighed, and analyzed for ascorbic acid content. The remaining pups were placed in small, metal containers inside a refrigerator for a 90-minute cold stress at 5°C preceding removal of adrenals and assay for ascorbic acid. The assay method and data treatment have been described elsewhere (*6, 8*).

The results are graphed in Fig. 1. Mean depletions of ascorbic acid, expressed in milligrams per hundred grams, were determined by subtracting the mean value for the stressed animals from that of the nonstressed animals within each treatment group. A Mann-Whitney U test (*9*) of the differences between stressed and nonstressed animals in each group demonstrated significant reductions in adrenal ascorbic acid at the .01 and .05 levels for the stressed animals in groups H and CE, respectively. There were no significant differences in ascorbic acid levels between stressed and nonstressed animals in the NH or the CC groups.

These results indicate that the essential aspect of the handling procedure is a drop in environmental temperature accompanying removal from the nest. Subjecting the pups to low temperature on days 2 through 7, although they were somewhat insulated in the nest by the mother, produced the same effect as handling (which exposed pups to room temperature for the same amount of time). The small, nonsignificant depletion in adrenal ascorbic acid in group CC we attribute to the mother's leaving the nest briefly when the cage was moved. When the mother leaves, the pups are dispersed and exposed to room temperature until they are returned to the nest by the mother. It seems likely that significant depletion at 14 days for Levine's cage-moved group resulted not from moving the cage, but from exposing the pups for 2 minutes during the mother's absence. Perhaps this exposure, longer than in our CC group, produced the significant change. On the other hand, Levine's animals were assayed at 14 days and are not entirely comparable with our CC animals, assayed at 12 days.

We have demonstrated that exposing the young pup to cold, mitigated somewhat by the nest and the mother, produced essentially the same effect as handling. Kalberer (*10*) has subsequently reported that cold treatment in early infancy produced a significant weight gain similar to that found in rats that have been handled in infancy. It remains to be demonstrated that handling does, in fact, affect skin or body temperature in infant rats, and that such a change has the same effects on later behavior as handling. Neurologic, physiological, and biochemical mechanisms for such temperature-produced effects also await further investigation (*11*).

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References and Notes

1. E. W. Bovard, *Psychol. Rev.* **65**, 257 (1958).
2. S. Levine, *Sci. American* **202**, 80 (May 1960).
3. O. Weininger, *J. Comp. and Physiol. Psychol.* **49**, 1 (1956).
4. S. Levine, J. A. Chevalier, S. J. Korchin, *J. Personality* **24**, 475 (1956).
5. S. Levine and G. W. Lewis, *J. Comp. and Physiol. Psychol.* **52**, 368 (1959).
6. S. Levine, M. Alpert, G. W. Lewis, *Science* **126**, 1347 (1957).
7. T. Schaefer, dissertation, Univ. of Chicago (1957); G. G. Karas, thesis, Purdue University (1958); S. Levine and G. W. Lewis, *Science* **129**, 42 (1959).
8. S. Levine, M. Alpert, G. W. Lewis, *J. Comp. and Physiol. Psychol.* **51**, 774 (1958).
9. S. Siegel, *Nonparametric Statistics* (McGraw-Hill, New York, 1956), p. 116.
10. W. D. Kalberer, paper presented at Midwest Psychol. Assoc. Ann. Meeting, Chicago, Ill., 6 May 1961.
11. This work was supported by grant No. MY3651 from the National Institute of Mental Health. One of us (F.S.W.) held an NIMH predoctoral fellowship in 1960–61. We thank John Cowan for aid in implementing the assay procedures.

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Magnitude Estimation of the Brightness of Brief Foveal Stimuli

Abstract. Eighteen observers judged the apparent brightness of light flashes that varied in both duration and luminance. The median numerical estimations (made relative to a standard flash) confirmed three principles: the reciprocity between luminance and duration (Bloch's law), the enhancement of brightness at about 50 milliseconds (Broca-Sulzer effect), and the power-law relation between brightness and energy (Stevens's law).

Detection of a brief flash of light is a function of its energy. Threshold studies of Bloch's law have shown that luminous power is integrated over time up to around 100 msec (*1*). Summation