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The relationship between stimulus reactivity and heart rate in two inbred strains of *Mus musculus*

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In previous studies combining multivariate and behavior genetic analyses, we found that locomotor activity can be distinguished experimentally from stimulus reactivity and is under separate genetic control. The present study is the first in a series designed to investigate the physiological correlates of stimulus reactivity (the initial responses of an animal to novel/complex stimuli). Heart rate was monitored for six males and six females each of two strains of inbred mice—DBA/2J and LG/J—during testing of stimulus reactivity. DBAs had low stimulus reactivity scores (long latencies to approaching novel stimuli and low exploration scores), although they maintained fairly high activity scores. Heart rate associated with initial and later approaches to novel stimuli in the DBAs was highly unstable and high in magnitude. LGs, on the other hand, had high stimulus reactivity scores accompanied by low and stable heart rates throughout the testing situation. Physiological strategies suggested by the work of Lacey and of Obrist are discussed.

In their natural environment, the survival of most rodents is likely to be enhanced by an appropriate balance between exploration of novel events and an initial avoidance of them. In the laboratory setting, exploratory behavior is most commonly measured by recording activity in a compartment devoid of novel stimulus objects or, less frequently, by counting approaches to novel stimuli. To test the comparability of these approaches, Simmel (1975) and Simmel and Eleftheriou (1977) employed a genetic analysis, testing recombinant inbred strains of mice in an arena divided into novel and nonnovel sides. A factor analysis of several behavioral measures recorded during a 10-min testing period yielded two separate factors: locomotor activity and initial responses to novel stimuli, or stimulus reactivity. Further analysis demonstrated a strong major gene effect for the measures of stimulus reactivity, showing that these measures are controlled by genes at the H-24^c and H-1^b loci in Linkage Group 1. This degree of genetic specificity was not present for the measures of locomotor activity, further demonstrating the distinction between the factors. These findings were supported in a recent study using different inbred strains of mice (Simmel, Haber, & Harshfield, 1976).

These data suggest a further question: How do the specific genetic components operate to produce stimulus reactivity in the rodent? One answer might be found at the level of the autonomic nervous system and its regulation of the cardiovascular system.

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Recent research on cardiovascular functioning has identified two important determinants of heart rate change other than activity per se. First, the work of Lacey and his associates has shown that the physical parameters and demands of the situation affect heart rate (Lacey & Lacey, 1970, 1974). Situations or stimuli which require environmental intake are accompanied by a phasic heart rate decrease; those which require environmental rejection are accompanied by a phasic heart rate increase.

Obrist and his associates have found that coping strategies are a second determinant of heart rate change (Obrist, 1976; Obrist, Howard, Lawler, Galosy, Meyers, & Gaebelein, 1974). When confronted with a stressful situation, an individual will cope with it either actively or passively. Active coping elicits a tonic heart rate increase associated with preparation for overt activity; passive coping elicits a heart rate decrease associated with preparation for inactivity. The strategy selected will remain constant for an individual across most situations.

The present experiment was designed to examine the relationship between stimulus reactivity and heart rate.

METHOD

The 72 subjects were drawn from two strains of inbred mice, DBA/2J and LG/J. The subjects were reared either two or three per cage from the age of weaning (21 days) until the age of testing (60 days).

This study involved three experiments. Control Condition 1 involved recording only the behavioral responses of stimulus reactivity to confirm the expected genotype differences in stimulus reactivity. Control Condition 2 involved recording the behavioral responses following a sham operation to control for the effects of the operation on stimulus reactivity. The experi-

mental condition involved the simultaneous recording of behavioral responses and heart rate. The 24 animals in each condition were divided equally into cells according to strain and sex.

Control Condition 1

Each subject was tested for 10 min in a black Plexiglas box, 20 cm square with sides 20 cm high, diagonally bisected by a partition, with a 4-cm opening in the center running from the top to the bottom of the partition. One half of the arena (the stimulus side) contained black and white murals on all three walls. The other half of the arena (the plain side) had no stimuli covering the flat black walls. The entire arena was placed on a selective activity meter (Model S, Columbus Instrument Company) calibrated so that identical movements on either side yielded identical activity scores.

Each trial began when the subject was placed in the plain side of the arena. The following behaviors were recorded by two experimenters: (1) the latency of the first crossing from the plain side to the novel side of the arena (LAT), (2) the number of seconds spent on the novel side (NOV), (3) the number of crossings between the two sides (ARX), and (4) gross locomotor activity measured by the activity meter (ACT).

All testing was conducted in an interior room measuring 9.33 m^2. Illumination was provided by three 200-W incandescent light bulbs located 1.63 m above the testing apparatus. Time of testing was between 1030 and 1200 h.

Control Condition 2

Each subject in this condition underwent a sham operation 5 days prior to testing. The animal was placed in an individual cage during the recovery period. On the 6th day after surgery, the animal was tested in an identical manner to Control Condition 1.

Experimental Condition

One week prior to testing, each animal was implanted with a bipolar electrode (Plastic Products Company) to monitor heart rate changes. The animal was then placed in an individual cage and allowed 5 days to recover. On the 6th day after surgery, a lead was connected from the mouse to a Grass dc preamplifier and into a tape deck for data storage. The animal was allowed 5 min to adapt to the lead and then placed into the testing arena. The testing procedure was identical to the other conditions except for the monitoring of heart rate. The data were later played back from the tape deck through a Grass tachograph preamplifier (Model 7 P4 D) to determine instantaneous heart rate. (Specific details concerning the surgery and recording procedures may be obtained from the first author.)

RESULTS AND DISCUSSION

Baseline Data on Stimulus Reactivity

A two-way analysis of variance for genotype and sex was performed on each of the behavioral measures from Control Condition 1 (no surgery). The results confirmed the expected behavioral differences in stimulus reactivity for the two genotypes. The LG/Js (LGs) showed a pattern which is consistent with relatively greater exploration, crossing more quickly ($F = 25.9$, $p < .01$), more often ($F = 28.8$, $p < .01$), and remaining on the novel side for a longer period ($F = 16.5$, $p < .01$) than did the DBA/2Js (D2s). Males also crossed more quickly than females ($F = 4.8$, $p < .05$) and remained on the novel side longer ($F = 7.4$, $p < .05$).

Effects of Surgical Intervention and Physiological Recording Procedures

To determine effects of the operation on stimulus reactivity, a one-way analysis of variance was performed on the pooled scores from Control Condition 1 (no surgery) vs Control Condition 2 (sham operation). No significant differences were found for any of the behavioral measures. The operation did not affect stimulus reactivity.

To determine the effects of the physiological recording procedures on stimulus reactivity, a one-way analysis of variance was performed on the pooled scores from Control Condition 1 (no surgery) vs the experimental condition. There were no differences for the variables LAT, NOV, and ACT. There was a significant difference for ARX. The lead from the electrode to the polygraph sometimes caught on the top of the testing arena, producing fewer arena crossings in the experimental condition.

Heart Rate and Stimulus Reactivity

A two-way analysis of variance on the behavioral measures from the experimental condition produced a clear difference in stimulus reactivity between LGs and D2s.

On all measures of stimulus reactivity, the LGs showed greater exploration than did the D2s. There was no difference in activity (ACT) between the two strains. There were heart rate differences between the strains associated with each of the behavioral measures of stimulus reactivity. D2s showed a large initial heart rate increase and very little heart rate stability along with long latency scores; LGs showed little or no heart rate change and greater heart rate stability along with shorter latencies (see Figure 1). Although there were no differences in heart rate between novel-side time and plain-side time for either genotype, there was an overall magnitude difference in heart rate between the two strains ($F = 4.7$, $p < .05$). LGs had lower overall heart rates and greater NOV scores than did D2s.

There were both heart rate magnitude and stability differences during arena crossings for the two strains (see Figure 2). LG males showed the lowest overall heart rate magnitude as well as a considerable degree

Table 1
Genotype and Sex Means (± SE_m) on Stimulus Reactivity Measures for the Experimental Condition

Strain/Sex	LAT* Mean	± SE	NOV** Mean	± SE	ARX† Mean	± SE
LG/Males	5.8	3.0	424.0	31.9	48.5	5.6
LG/Females	19.5	4.7	392.0	60.0	28.7	6.1
D2/Males	138.0	64.8	153.3	45.2	8.8	1.4
D2/Females	14.7	5.2	178.6	61.8	6.5	1.1

**Strain by sex, $F = 4.40$, $p < .05$* ***Strain, $F = 4.98$, $p < .05$*
†Strain by sex, $F = 4.24$, $p < .05$

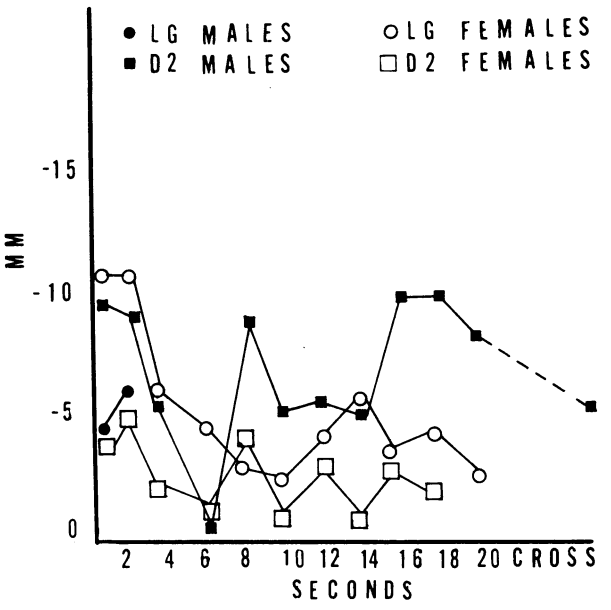

Figure 1. Heart rate during latency period. (Heart rate in millimeter deviations from 800 bpm; 1 mm = 20 bpm.)

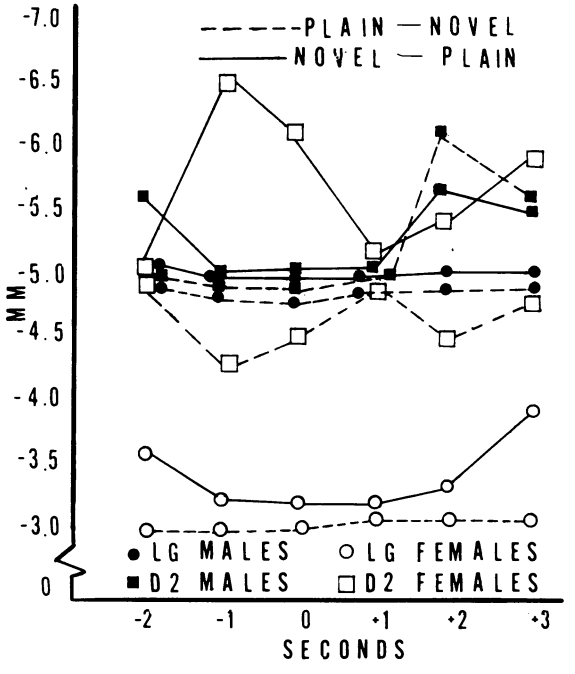

Figure 2. Heart rate during arena crossings. (Heart rate in millimeter deviations from 800 bpm; 1 mm = 20 bpm.)

of heart rate stability during arena crossings, along with the largest number of crossings. LG females showed the largest overall heart rate magnitude and considerable heart rate stability along with an intermediate number of crossings. D2 males and females showed an intermediate overall heart rate magnitude and very little heart rate stability along with the fewest number of arena crossings.

Since there were no differences in activity for the two strains, the heart rate differences associated with the differences in stimulus reactivity can be interpreted either in terms of stimulus setting (Lacey & Lacey, 1974) or coping strategies used to reduce stress (Obrist, 1976). The actual physical parameters of the situation, the stimulus setting, were either not important or not detectable in our experiment. For the stimulus setting to have been important, there should have been a significant heart rate difference between the time the animal was in the plain side vs the novel side. A phasic heart rate decrease should have accompanied exploration in the novel side since this heart rate change is associated with environmental intake (Lacey & Lacey, 1970, 1974). This phasic decrease was either absent or too small to detect in the testing situation used. Any small, phasic changes were probably masked by the changing demands placed on the cardiovascular system by the activity of the animal.

A second possibility in interpreting the heart rate differences could be the result of different coping strategies employed to reduce the stress associated with exploration (Obrist, 1976). The heart rate responses displayed by the D2s confirm that their low exploration scores are due to the stress associated with exploration and their strategy to cope with this stress. The heart rate responses seen during the latency period and during arena crossings are both indicative of the stress produced by the exploration. The direction of the changes, increased heart rate and decreased stability, are indicative of an active coping strategy used by the D2s to deal with the stress. The changes are the result of preparation for overt activity to deal with the source of the stress (Obrist, 1976) and interferes with exploration per se.

The heart rate responses of the LGs indicate that they do not find initial approaches to novel/complex stimuli stressful. Throughout the testing situation, heart rate remains constant and stable and exploration is high.

REFERENCES

LACEY, B. C., & LACEY, J. I. Studies of heart rate and other bodily processes in sensorimotor behavior. In P. A. Obrist, A. H. Black, J. Brener, & L. V. DiCara (Eds.), *Cardiovascular psychophysiology*. Chicago: Aldine, 1974.

LACEY, J. I., & LACEY, B. C. Some autonomic-central nervous system interrelationships. In P. Black (Ed.), *Physiological correlates of emotion*. New York: Academic Press, 1970.

OBRIST, P. A. The cardiovascular-behavioral interaction as it appears today (Presidential address, 1975). *Psychophysiology*, 1976, 13, 95-105.

OBRIST, P. A., HOWARD, J. L., LAWLER, J. E., GALOSY, R. A., MEYERS, K. A., & GAEBELEIN, C. J. The cardiac-somatic interaction. In P. A. Obrist, A. H. Black, J. Brener, & L. V. DiCara (Eds.), *Cardiovascular psychophysiology*. Chicago: Aldine, 1974.

SIMMEL, E. C. Behavior genetic analysis of exploratory behavior and activity through use of recombinant inbred strains of mice: A progress report. *Behavior Genetics*, 1975, **6**. (Abstract).

SIMMEL, E. C., & ELEFTHERIOU, B. E. Multivariate and behavior genetic analysis of neophobia and activity in recombinant inbred strains of mice. *Behavior Genetics*, 1977, **7**, 239-250.

SIMMEL, E. C., HABER, S. B., & HARSHFIELD, G. Age, sex, and genotype effects on stimulus exploration and locomotor activity in young mice. *Experimental Aging Research*, 1976, **2**, 253-259.

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