HEART RATE AND MOTOR BEHAVIOR

IN THE RAT

THE RELATION OF HEART RATE AND SPONTANEOUS MOTOR BEHAVIOR IN THE RAT

By

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SCOPE AND CONTENTS:

The thesis seeks to determine the heart rate of the rat which normally accompanies the performance of spontaneous motor behaviors such as resting, head movement, walking, rearing, scratching, biting, face washing, and licking. The results indicate that different motor patterns are associated with different heart rates. In particular, heart rate increases during behaviors which involve vertical posture and/or phasic movement. Heart rate is also recorded under conditions designed to alter the level of arousal, i.e., food deprivation. Mean heart rate of each of the spontaneous behaviors does not increase as a result of food deprivation. Therefore, heart rate is considered to be primarily an index of motor activity.

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INTRODUCTION

The motivational and emotional aspects of behavior have long been of major concern to psychologists. In 1941, Duffy clarified the study of emotion by distinguishing two relevant variables to be manipulated and measured independently: the direction or goal-orientation of the behavior, and the intensity of the behavioral response. Investigation of the "intensity dimension" involved determing the subject's level of physiological "energy mobilization". Measurement of electroencephalographic changes, muscle potentials, and autonomic responses, such as skin resistance, finger pulse volume, and heart rate led to the development of activation theory (Sternbach, 1966). In broad terms, activation theory predicts a linear relationship between level of motivation and level of physiological and behavioral arousal (Duffy, 1951; Duffy, 1957; Malmo, 1959).

As part of a general approach to the problem of the relation of activation to behavior, several studies have focused on the effects of food and water deprivation upon heart rate. In the majority of cases, heart rate of animals bar-pressing for food or water increased linearly as a function of hours of deprivation (Belanger and Feldman, 1962; Hahn, Stern and McDonald, 1962; Ducharme, 1966). Eisman

(1966) and Doerr and Hokanson (1968) obtained variations of this result. Deprivation may also cause an increase in heart rate when no learning of an instrumental response or associated cues is involved (Moore, 1929; O'Kelly, et.al., 1965; Goldstein, Stern, and Rothenberg, 1966; Sachio, 1968). However, other studies in which learning was not involved showed either no change in heart rate with deprivation (Asdourian and Rimby, 1965; Eisman, 1966; Ducharme, 1966), or a decrease (Simonson, Herschel and Keys, 1948; Ehrlich, 1963; Doerr and Hokanson, 1968). The results of experiments on heart rate and motivation appear conflicting in several respects. This may be due to the fact that other variables, not related to motivation or arousal, also influence heart rate, including age, weight, respiration, fatigue, temperature, hormonal balance, oxygen supply and general nutritional state (Wright, 1965). In particular, heart rate is "...affected to a marked degree by the muscular movements required by the activity in which (the animal) is engaged..." (Duffy, 1962).

One of the classic indices of arousal has been the occurrence of rhythmical slow electrical activity in the hippocampal formation. Such activity can be elicited by sensory stimulation or electrical stimulation of the reticular formation. It is generally associated with behavioral signs of arousal and an activated cortical EEG (Green and Arduini, 1954; Green, 1964). This hippocampal electrical pattern has recently been observed to correlate closely with the performance of certain motor activities (Vanderwolf, 1969). If this central index of arousal bears a relation to motor behavior, heart rate may be postulated to do the same. Specifically, different motor patterns may be associated with different levels of heart rate.

Such an hypothesis, if true, may partially explain discrepancies in the results of studies on motivation and heart rate. Deprivation procedures are known to affect the level of general activity (Siegel and Steinberg, 1949; Finger, 1951; Finger and Reid, 1952; Campbell and Sheffield, 1953; Hall, et. al., 1953; Hall and Hanford, 1954; Sheffield and Campbell, 1954; Hall, 1955; Teghtsoonian and Campbell, 1960; Campbell, 1960; Weasner, Finger and Reid, 1960; Duda and Bolles, 1963), as well as particular motor behaviors (Montgomery, 1952; Thompson, 1953; Fehrer, 1956; Lembert, 1957; Zimbardo and Miller, 1958; Bolles, 1960). However, few investigators have recorded in detail the motor behavior of their subjects. Activity recording devices do not distinguish adequately among different types of behavior, i.e., grooming from walking. Since these behaviors are associated with different patterns of hippocampal activity, they may also differ in heart rate. If so, reported changes in heart rate with motivation may partially reflect alterations in motor activity produced by the experimental procedures.

The motor patterns of the rat have been separated into independent catgories and carefully observed (Bindra and Blond, 1958; Bindra and Spinner, 1958; Bindra and Baran, 1959; Claus and Bindra, 1960; Bindra, 1961; Gray, 1965). As a first step, the heart rate which accompanies these motor patterns under normal environmental and metabolic conditions should be determined. Then, the effects of deprivation and learning procedures may be assessed with greater accuracy.

The first experiment in the present study is designed primarily to determine the heart rate changes which are normally associated with the performance of specific spontaneous behaviors in the rat.

Many experimenters have reported the results of food and water deprivation upon heart rate and the level of general activity in the rat. The second experiment is designed to supplement this knowledge with a description of heart rates of specific motor activities under conditions of food deprivation. The study will also focus on the heart rate of consummatory behavior.

METHOD: EXPERIMENT I

Subjects

The subjects in Part I were 4 male hooded rats weighing between 250 and 300 grams at the time of the operation. The subjects in Part II were 4 male hooded and 1 male albino weighing between 250 and 375 grams at the time of the operation. Food and water were available *ad libitum* in the home cages throughout the experiment.

Surgical Preparation

Operations were performed on animals anesthetized with sodium pentobarbital. Two heart rate electrodes (EEG scalp disc electrodes, E5S, Grass Instrument Company) were inserted under the skin, one just below the diaphragm on one side and one near the shoulder on the other side of the body. Each electrode was connected to a male Winchester connector fixed on the skull by means of jewelers' screws and dental cement. A third male connector fixed to the skull served as a ground for the animal. At least a week was allowed for recovery from the operation.

Apparatus and Procedure

Heart rate recording leads consisted of female Winchester connectors soldered to three-strand shielded phonograph wire leading to the input plugs of a Grass Model IV polygraph. Two channels of the polygraph were used to record heart rate. Animals were allowed freedom of movement in a test box (1 X 1.5 X 1.5 feet) adjacent to the recording machine. The floor of the box was wire mesh covered by paper. A small hole in the ceiling allowed for passage of the recording leads. Three sides of the box were black opaque Lucite. The entire box was shielded by copper wire-mesh connected to ground.

During heart rate recording, the door of the box was partially open and the room lights on. A constant background noise was provided by an electric fan. The experimenter was equipped with an event marker with which to code the movements of the animal on the same record as the heart rate. A hand panel of eight switches operated two channels on the polygraph. Manual depression of each switch resulted in an upward or downward deflection of a specific amplitude on the record. The deflection was maintained as long as the switch was held closed, so that the duration of each movement was recorded. The following activities were recorded:

1. isolated head movements
2. walking (movement of one or more limbs with abdomen raised off floor of the box)
3. rearing
4. face washing
5. licking of fur on the back and abdomen

6. biting of paws and fur on the back and abdomen
7. scratching any part of the body.

In Part I, heart rate samples were taken from each subject in one or more thirty-minute sessions over a two week period. In Part II, each subject was observed for a period of thirty minutes on five consecutive days, except the fourth day on which the test session lasted 10 minutes due to breakage of the recording leads. All recordings were made in the afternoon from 1:00 P.M. to 4:30 P.M. The specific time at which each subject was observed was varied from day to day.

All records were manually counted in full. Heart rate was analyzed in beats per second. The duration of movements was determined to the nearest tenth of a second. Each sample analyzed was a minimum of one second in duration. A baseline resting heart rate was obtained by counting all heart beats not occurring during a recorded movement.

METHOD: EXPERIMENT II

Subjects

Five male hooded rats and one albino male from the previous experiment served as subjects. Subjects weighed between 300 and 375 grams at the start of the experiment. None of the animals had experienced food or water deprivation prior to the experiment.

Surgical Preparation

Operations were performed using Nembutal anesthesia. Heart rate electrodes were inserted under the skin as in the previous experiment. The head piece consisted of Winchester connectors attached to the heart rate electrodes, the ground, and a cortical bipolar electrode. A five-contact plastic male Amphenol plug (Tiny Tim, series 223) encased the Winchester connectors and permitted attachment of the recording leads with a minimum of handling of the animal. At least one week was allowed for recovery from the operation.

Apparatus and Procedure

Recording leads consisted of shielded phonograph wire connected to a female Amphenol receptacle which snapped onto the head piece of the animal. Heart rate recordings were obtained with a Grass Model VII polygraph. Heart rate was transferred through the polygraph driver amplifier to magnetic tape on an Ampex tape recorder. Heart rate was taped in the FM mode at a speed of 1 7/8 inches per second, with adjustment of the baseline, amplitude and frequency filters of the polygraph to maintain the signal within the proper range for recording. Movements of the animal were recorded vocally through a microphone. Each of the behaviors monitored was signified by a distinct vowel sound voiced for the duration of the movement. Activities selected for observation included;

1. walking
2. rearing (standing on hind legs with forelegs raised)
3. face washing
4. licking
5. scratching
6. biting
7. sniffing and digging in sawdust
8. half-rearing (sitting on hindlegs with forelegs raised slightly)
9. waiting at the food platform.

Subjects were allowed freedom of movement in a test box (2 X 1 X 1.5 feet) located in the same room as the recording equipment. The bottom of the box was covered with a thick layer of sawdust. The sides and top were formed of copper wire-mesh pulled taut around wood supports and connected to ground on the polygraph. A sliding panel opened onto a platform at one end of the box where food pellets were placed during the test session. During recording, the room lights were off. A red lamp placed behind the box afforded clear observation of the animal. The room temperature was constant at 75° F. Operating noise from the polygraph, tape recorder, and electric fan provided auditory masking.

The test session lasted for thirty minutes. During the first five minutes, the animal adapted to the test box and controls were adjusted to obtain the best record of the signal. After fifteen minutes of recording heart rate and movements of the animal, a single food pellet was placed in the test box. Approximately ten minutes of recording followed introduction of the food.

Each animal received from five to seven days of exposure to the test situation before being deprived. Deprivation days were spaced from two to five days apart to allow the animal to regain his pre-deprivation weight. Each subject was tested twice at 23 hours and twice at 47 hours of deprivation. The total number of test days per subject ranged from 21 to 26. On some days when subjects were regaining their pre-deprivation weight, heart rate was not recorded. The subject was placed in the test box with all recording equipment turned on in order to simulate a recording session as closely as possible. Such occasions were rare. Generally, heart rate of each subject was recorded every day. Subjects were tested at the same time each day, either in the morning or the evening.

The taped heart rate was analyzed by a Hewlett-Packard electronic counter. The counter was set to count the number of heart beats occurring per second with an interval of .03 to .05 seconds between samples. The experimenter recorded the totals displayed by the counter while listening to the vocal reproduction of the animal's behavior.

RESULTS: EXPERIMENT I

Heart Rate of Spontaneous Activities

Part I. Data from four animals were analyzed. Each of four spontaneous behaviors had a particular heart rate which accompanied its performance. The minimum amount of time on which the heart rate of each behavior was based was 92 seconds. The activities showed a significant ranking in terms of mean heart rate from lowest to highest: resting, 414 beats per minute; walking, 480 beats per minute; face washing, 498 beats per minute; and licking, 510 beats per minute (Friedman Analysis of Variance by Ranks, $p = .000072$).

Part II. The results of Part I were confirmed and extended with data from five additional animals on eight spontaneous behaviors. Table I shows a ranking of activities according to mean heart rate from lowest to highest.

The effect of activity on heart rate was highly significant by an analysis of variance, as shown in Table 2 ($F = 49.0$, $df = 7/28$, $p < .001$). A comparison of pairs of activities by the Tukey _a_ procedure resulted in the following significant differences: resting and each of the other activities, scratching and rearing, scratching and face washing, scratching and licking, head movement and rearing, head movement and face washing, head movement and licking, biting and face washing, biting and licking, walking and face washing, walking and licking, rearing and licking, and face washing and licking.

Figure 1 shows the heart rate of each activity on each test day. Day 4 was omitted because the test session lasted only 10 minutes. It can be seen that the rank order of activities was quite stable from day to day.

Figure 2 shows that the rank order of behaviors was also stable throughout the course of the test session. The heart rate of each activity declined during the test session. Analysis of variance (see Table 3) revealed significant effects of both activity ($F = 32.08$, $df = 5/20$, $p < .001$) and duration of the session ($F = 39.72$, $df = 2/8$, $p < .001$) on heart rate.

Amount of Time Spent in Spontaneous Activities

The mean number of seconds recorded for each activity is presented in Table 4. Resting and face washing are performed the most. Moderately frequent activities include biting, scratching, rearing and walking. Isolated head movements and licking occupy the least amount of time. Thus, there is no relation between the heart rate accompanying an activity and the frequency with which that behavior is performed.

Table 1

Mean Heart Rates (b/sec) of Spontaneous Behaviors

Activity	Subject					Mean
	A	B	C	D	E	
Rest	6.64	5.93	6.36	6.19	6.51	6.29
Scratch	7.08	6.27	6.87	6.59	6.78	6.80
Head Movement	6.90	6.52	6.97	6.46	6.81	6.89
Bite	7.42	6.30	6.82	6.72	6.82	6.92
Walk	7.25	6.65	6.96	6.57	7.17	6.92
Rear	7.45	6.59	7.44	6.77	7.15	7.08
Face Wash	7.94	6.74	7.46	7.13	7.68	7.27
Lick	8.01	7.07	8.22	7.52	7.99	7.83

Table 2

Analysis of Variance:

Effect of Activity on Heart Rate

Source	df	MS	F
Activity (A)	7	.98	49.0*
Subjects (S)	4	.89	
A X S	28	.02	

*p < .001

Table 3

Analysis of Variance:

Effect of Activity and Session Duration on Heart Rate

Source	df	MS	F
Activity (A)	5	2.374	32.08*
Session Interval (B)	2	3.455	39.72*
Subjects (S)	4	1.795	
A X B	10	.103	.068
A X S	20	.074	
B X S	8	.087	
A X B X S	40	1.520	

*$p < .001$

Table 4

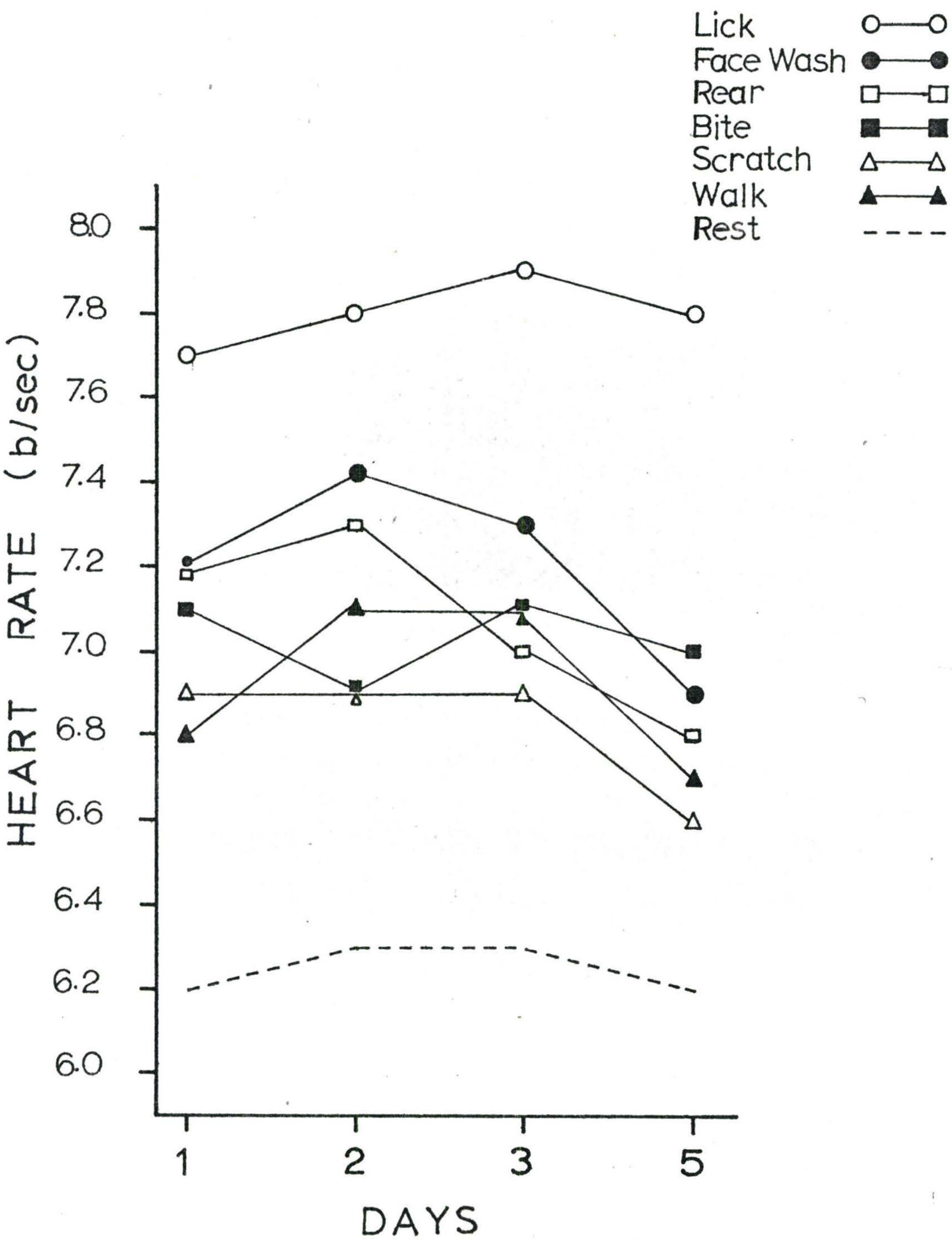
Mean Number of Seconds Spent in Spontaneous Behaviors

Day	Walk	Rear	Face Wash	Lick	Scratch	Bite	Mean
1	132.00	82.08	146.26	51.72	67.58	67.30	91.16
2	86.98	81.24	170.00	62.64	105.72	170.98	112.93
3	77.38	115.36	160.50	75.78	155.26	192.60	129.48
5	52.70	83.06	112.08	43.80	120.86	196.60	101.52
Mean	87.27	90.44	147.21	58.49	112.36	144.31	

Activity columns: Walk, Rear, Face Wash, Lick, Scratch, Bite.

Figure 1

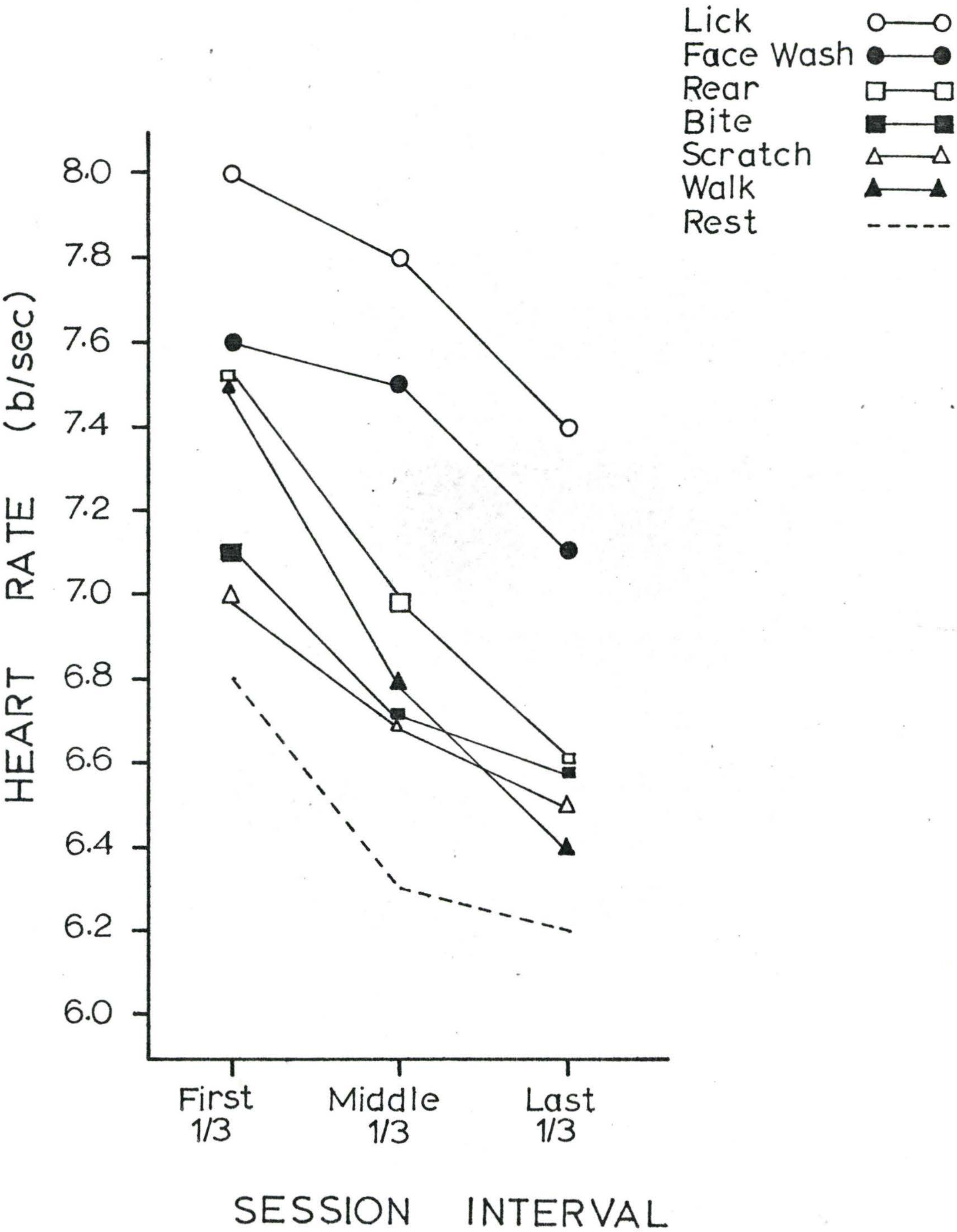
Heart rate of spontaneous behaviors over days



Note. Each point is based on a minimum of 215 seconds of the behavior

Figure 2

Within-session heart rate of spontaneous behaviors



RESULTS: EXPERIMENT II

Heart Rate of Spontaneous Activities

The behaviors selected for observation differed somewhat from those in the first experiment. Two activities related to eating (sniffing and waiting at the food platform) and a variation of rearing (half-rearing) were included. Resting, biting, and licking were omitted due to insufficient sampling.

A ranking of the various activities according to mean heart rate is given in Table 5. The rank order of activities stayed substantially the same from one level of deprivation to another. The non-deprivation data of this experiment and the data from Experiment I showed the same rank order of behaviors. The overall mean heart rate of behaviors common to both sets of data was also the same. An analysis of variance, presented in Table 6, showed activity as the only significant effect ($F = 35.00$, $df = 6/30$, $p < .001$). Food deprivation had no effect on heart rate of the various activities.

Heart Rate of Consummatory Behavior

The analysis of variance shown in Table 7 shows the effect of eating on heart rate. Heart rate during the first quarter of eating behavior is significantly lower than that during the last quarter ($F = 14.00$, $df = 1/5$, $p < .05$). This increase occurred under both deprivation and non-deprivation conditions.

Habituation of overall heart rate occurred during the course of the experiment. A significant decrease in heart rate was evident from the first day of recording to the last (t test for correlated means, $p < .025$).

Amount of Time Spent in Spontaneous Activities

Between 0-hour and 23-hour deprivation levels, there was a significant increase in the amount of time spent in three of the behaviors (t test for correlated samples, $p < .05$). The behaviors were related to eating, food-seeking, or exploring. Sniffing (exploring sawdust) showed a 406.7% increase, waiting at the food platform, 143.8%, and chewing feces, 178.9%.

Table 5

Mean Heart Rates (b/sec) and Ranks of Spontaneous Behaviors

Activity	0-Hour Deprivation		23-Hour Deprivation		47-Hour Deprivation	
	rank	mean	rank	mean	rank	mean
Sniff	1	6.52	1	6.35	2	6.42
Wait at Food Plat-Form	2	6.56	2	6.53	1	6.23
Half-rear	3	6.66	3	6.57	3	6.71
Scratch	4	6.81	6	6.82	6	6.94
Walk	5	6.83	5	6.72	4	6.79
Rear	6	7.07	4	6.69	5	6.90
Face Wash	7	7.37	7	7.21	7	7.26

Table 6

Analysis of Variance: Effect of
Activity and Deprivation on Heart Rate

Source	df	MS	F
Activity (A)	6	1.05	35.00*
Deprivation (B)	1	.27	3.38
Subjects (S)	5	.69	
A X B	6	.03	.50
A X S	5	.03	
B X S	30	.08	
A X B X S	30	.06	

Note. Data from the 23-hour and 47-hour deprivation levels were combined for the analysis.

*$p < .001$

Table 7

Analysis of Variance: Effect of Duration of Eating Behavior on Heart Rate

Source	df	MS	F
Deprivation (A)	1	.35	1.75
Duration of Eating (B)	1	.28	14.00*
Subjects (S)	5	1.09	
A X B	1	.00	
A X S	5	.20	
B X S	5	.02	
A X B X S	5	.02	

$*p < .05$

DISCUSSION

The state of activation or arousal has been associated with activity in the reticular formation of the brain (Lindsley, 1951). Ascending reticular activity gives rise to rhythmical slow activity in the hippocampal formation. Thus, the occurrence of hippocampal synchronous slow activity has been regarded as an index of activation (Green and Arduini, 1954; Green, 1964). Heart rate acceleration, a result of descending reticular activity, has also been used as an important indicator of arousal (Malmo, 1959).

The two measures of arousal do not agree with respect to their relation to behavior. Vanderwolf (1969) has demonstrated a specific relation between hippocampal rhythmical slow activity and motor behavior patterns. In the rat, hippocampal EEG synchronization accompanies the performance of walking, rearing, and postural shifts, but does not accompany face washing, licking, or chewing. A distinct relation also exists between heart rate and motor behavior such that different spontaneous behaviors are associated with different heart rates. However, in the present study, behaviors which show hippocampal EEG synchronization, such as walking and rearing, have intermediate or high heart rates; whereas, activities which do not show EEG synchronization, such as resting, scratching, face washing and licking, have low, intermediate or high heart rates. Thus, no simple relationship exists between heart rate and the central measure of arousal.

However, heart rate is highly correlated with oxygen utilization (Carlsten and Grimby, 1966). The observed relation of heart rate to behavior may be best understood in terms of the metabolic demands of body tissues. Two factors are particularly important: vertical posture and phasic movement. A shift from a horizontal to a vertical posture is accompanied by increased heart rate in man. (Wang, Marshall, and Shepherd, 1960; Chapman, Fisher and Sproule, 1960). Increased sympathetic activity in response to the pooling of blood in the lower extremities presumably contributes to heart rate acceleration. Perhaps rearing, face washing, and licking have higher heart rates than walking and scratching because the former activities are performed in an erect position. Muscular activity during phasic movement also is accompanied by heart rate acceleration (Carlsten and Grimby, 1966). Several factors such as muscle pumping, sensory input from the joints, and metabolic changes contribute to the heart rate increase (Wright, 1965). Thus, in the present study, scratching, walking, and head movements are associated with higher heart rates than standing motionless. The effects of vertical posture and phasic movement appear to summate. Behaviors which involve both factors, such as face washing and licking, were observed to have the highest heart rates. Since heart rate is so closely related to movement, future research should be directed to the simultaneous recording of heart rate and EMG of several muscle groups during spontaneous behaviors.

A number of investigators, employing heart rate as an index of arousal, have reported that the heart rate of lever pressing behavior increases with increases in deprivation level (Belanger and Feldman, 1962; Hahn, Stern, and McDonald, 1962; Ducharme, 1966; Doerr and Hokanson, 1968). These experiments failed to take account of the effects on heart rate of movements other than bar-pressing. Other behaviors may have been responsible for the heart rate acceleration found during a bar-press response. Bolles (1960) has noted that grooming activities occur with a high probability "... after an animal has eaten, drunk, or explored." Grooming behavior is associated with a high heart rate; and, as in other forms of exercise, heart rate does not return to normal immediately after the grooming behavior ceases. In the present study, data from four animals indicated that face washing and licking cause an increase in the heart rate of subsequent resting behavior. Heart rate did not return to the normal resting level for as long as 10 seconds following the grooming. Such a post-grooming increase may have influenced the heart rate of subsequent bar-pressing in experiments where the heart rate was recorded only during bar-pressing. Whether the incidence of grooming following eating or drinking increases with increases in deprivation is a subject for further experimentation.

In any case, food or water deprivation increases the level of general activity (Siegel and Steinberg, 1949; Hall, et. al., 1953; Hall and Hanford, 1954; Hall, 1955; Finger, 1951; Finger and Reid, 1952; Duda and Bolles, 1963). When deprived, an animal becomes sensitized to environmental stimulation, especially to cues related to the state of deprivation (Campbell and Sheffield, 1953; Sheffield and Campbell, 1954; Teghtsoonian and Campbell, 1960; Campbell, 1960). Reaction to environmental stimulation often includes an increase in the exploratory behaviors of walking and rearing (Montgomery, 1952; Thompson, 1953; Fehrer, 1956; Lempert, 1957; Zimbardo and Miller, 1958; Richards and Leslie, 1962). Performance of such behaviors could also have caused heart rate acceleration.

Data from the second experiment of this study show that the heart rates of various spontaneous behaviors do not increase as a result of deprivation in animals which have not learned to lever press for food. Observation of the deprived animals suggested that much of their behavior was oriented toward cues related to obtaining food. Such behavior lacked strenuous muscular effort and consisted mainly of gentle digging and sniffing in the sawdust as well as waiting motionless at the food platform. Untrained animals in their home cages do not exhibit a heart rate increase with deprivation (Ehrlich, 1963; Eisman, 1966; Ducharme, 1966; Doerr and Hokanson, 1968). They, also, are not likely to perform vigorious motor behaviors.

Rather, activities which in this study were found to have characteristically low heart rates (resting and standing still) increase in frequency, while high heart rate grooming activities (face washing and licking) decrease (Bolles, 1963). Thus, it is possible that many of the heart rate changes observed in experiments on food deprivation are secondary to changes in motor activity. Much of the earlier work should be repeated with careful observations made of the details of motor behavior.

SUMMARY

Heart rate and motor behaviors of normal rats were recorded simultaneously. It was found, in two experiments, that different motor behavior patterns are associated with different characteristic levels of heart rate ranging from six to eight beats per second. The rank order of motor behaviors from lowest to highest heart rate is as follows: standing or lying motionless, scratching, head movements, biting, walking, rearing, face washing, and licking the fur. The rank order was found stable across days and during the course of the test session. The heart rate associated with a particular pattern of behavior was not affected by food deprivation of either 23 or 47 hours. The finding of previous studies that heart rate increases with deprivation may be a secondary result of the effect on heart rate of motor behavior. Cardiac acceleration was observed to accompany behaviors which involve either vertical posture or phasic muscular contractions. It was concluded that heart rate functions primarily as an index of muscular activity.

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