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Heart Rate Response to Sound and Light

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ABSTRACT

The heart rate (HR) response to five intensities of sound was examined in 18 subjects and to five intensities of light in 12 subjects. Each subject was tested on four occasions at monthly intervals. After covariance adjustment, significant acceleration to sound was found within the first 5 beats after stimulus onset but no significant deceleration occurred. There were no differences between testings. Individuals' HR acceleration was reliable over testings and differing experimental contexts. No habituation occurred and no consistent relationship between HR response and ego strength was found. There was no significant HR response to light stimulation. The results were discussed in relation to Graham and Clifton's (1966) hypotheses concerning the relationship of the HR response to the orienting reflex (OR).

DESCRIPTORS: Heart rate, Sound stimulation, Light stimulation, OR, Personality, Habituation. (R. Roessler)

Heart Rate Responses to Sound and Light

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A number of recent studies have focused upon the direction of heart rate (HR) response to various types of stimulation. Much of this research appears to have been stimulated by the provocative hypothesis of the Laceys (Lacey, Kagan, Lacey & Moss, 1963) that stimuli which evoke attention to the environment induce cardiac deceleration while those evoking "rejection of the environment" induce acceleration. Obrist (1963) has confirmed the Laceys' findings.

Considerable controversy has arisen regarding the nature of the HR response, however, and apparently contradictory results have been obtained in various experiments. Campos and Johnson, for example, have challenged the Laceys' hypothesis and results in two recent studies (1966, 1967). They concluded that instructions to verbalize produce acceleration in response to a variety of stimuli, while the absence of such a requirement with the same stimuli resulted in HR deceleration. Weiner (1962) had previously emphasized the acceleration effects of the verbalization requirement.

In an earlier experiment (Roessler, Alexander and Greenfield, 1963), the degree of HR response to sound was related to the ego strength personality dimension, although not significantly so. In that experiment verbalization was required. The HR data from the present experiment, in which verbalization was not required, were also examined for a possible relationship to ego strength.

Graham and Clifton (1966) have reviewed the studies through 1965 which are relevant to the HR increase-decrease controversy. They refer to additional problems which have complicated the interpretation of such experiments. One is the use of complex stimulus situations, the many parameters of which make it difficult to ascribe differences to the effect of any one of these parameters. In this experiment only simple quantified stimuli were employed.

Another problem which makes comparison among experiments difficult is the scoring of the HR response. Campos and Johnson used averages of HR scored every 15 seconds for one minute pre-and post-stimulus; Lang and Hnatiow (1962) used the difference between the fastest rate in the first five beats after stimulus onset and the slowest in the next fifteen beats; Johnson and Lubin (1966) used a similar but modified score;

Dykman's group (Galbrecht & Dykman, 1965) used the fastest rate in the five seconds preceding stimulus onset subtracted from the fastest rate during a five second stimulus; other investigators have used a wide variety of scores. Obviously, there might be considerable divergence in results depending upon what score was used. In this experiment, therefore, there was a further examination of the beat-by-beat HR response to stimulation and a comparison of four scores derived from this examination.

It is of particular interest, in view of the acceleration-deceleration controversy, that some of the investigators employing beat-by-beat analyses have found both accelerative and decelerative phases in HR responses to the same stimulus (Uno and Grings, 1965; Lang and Hnatiow, 1962; Geer, 1964; Myers and Gullickson, 1967). Discussing such experiments, Graham and Clifton suggest that the decelerative component of the HR response to simple, non-signal, stimuli is the orienting component (OR) and that the accelerative component is the defense response. They therefore hypothesized that: 1) The deceleration component will habituate over trials; 2) higher intensities of stimulation will evoke acceleration (a defense response) but little, if any, deceleration, and 3) the accelerative component will increase over trials. In a subsequent experiment (Chase and Graham, 1967), only deceleration occurred to both onset and offset of 18 second tones and this response did indeed habituate rapidly. Higher intensities of stimulation did not evoke acceleration but the highest intensity was only 87 decibels (db) presented over a 71 db background of white noise. A wider range of stimulus intensities was employed in this study.

Many of the studies showing accelerative HR responses have employed auditory stimuli. It is possible, as Graham and Clifton point out, that this type of response is modality specific. They noted that the only two studies they found in which other sensory modalities were stimulated failed to show significant acceleratory effects. For this reason, HR responses to light stimulation were also studied in this experiment.

We have been unable to find any study in the literature in which the questions already noted have been examined over time and repeated testings under different conditions. It seems plausible that some of the results obtained are attributable to novelty and unfamiliarity effects or to unquantified variables in the total life situation. In addition, the question of within subject reliability is of interest.

The foregoing issues were examined in the data from the experiment reported here, in which the subjects (Ss) were stimulated with five intensities of sound and five intensities of light on four occasions. There was no task requirement except to pay close attention.

METHOD

A detailed description of the method employed in this experiment is contained in Roessler, Burch and Childers (1966). Only a summary will be provided here.

Ss were 32 male medical and dental student paid volunteers between the ages of 21 and 34. From among the 32 Ss, 18 Ss were selected for analysis of their HR responses to sound stimulation and 12 Ss were selected for analysis of HR responses to light stimulation. Restrictions on the selection of Ss for analysis of the HR data within stimulus modalities were (1) each S had to have HR data on each of four testings (runs), and (2) within modalities, Ss were divided into equal numbers of high and low ego strength Ss, based upon their ego strength (Es) scores from the MMPI (Dahlstrom and Welsh, 1960) and (3) Es groups contained equal numbers of alert and drowsy Ss within runs. These selective criteria substantially reduced the number of subjects available for comparison, especially in the analysis of HR responses to light stimulation, when many Ss became drowsy.

Ss were tested on four occasions at monthly intervals, January through April. The January testing was a condition of unfamiliarity, the February testing a basal one, the March testing a condition of real life stress (all Ss were tested within 10 days of their comprehensive examinations), and the April testing was another basal one. Ss were told prior to the first testing that we were interested in their physiological responses to various intensities of sound and light, that no pain would be involved, and that each subsequent testing would be identical to the first. They were instructed to keep their eyes closed throughout the experiment and to pay close attention to the lights and sounds because they would be asked questions concerning them after leaving the laboratory.

After five minutes of resting data was recorded, Ss were presented with five different intensities of 1,000 cps sound (40, 94, 100, 106 and 120 db) and, separately, five intensities of white light (24.7, 58, 61.7, 65.5 and 74 db). Each stimulus was of 2 secs. duration. Presentation of all stimuli was programmed to coincide with the onset of 10-second epochs and order of presentation of stimulus modalities was balanced within and across testings. Each of the five stimulus intensities was presented 5 times. Within each modality, stimulus intensity was balanced so that each stimulus was presented once in each of five blocks of five trials, and so that each of five inter-stimulus intervals was associated with each intensity only once in the total 25 stimulus presentations. Throughout the experiments, the S lay quietly on a bed with head positioned so that the light was reflected directly on his eyes. Auditory stimulation was delivered through earphones.

The electrocardiogram (EKG) was recorded from the standard EKG lead II position, using 2.0 cm^2 silver-silver electrodes) and commercial Redux paste. Recording was at a paper speed of 30 mm. per sec. on one channel of an 8-channel Grass polygraph, Model 3D. The R-R periods were hand-scored to the nearest 0.5 mm. for two pre-stimulus beats and all of the beats in the 10 secs. following onset of all stimuli. All periods were then converted to beats/minute (bpm).

Following the first run all Ss were interviewed to elicit data on degree of fatigue, intercurrent life stress, drug ingestion and subjective reaction to the experiment. They were also asked questions concerning the stimuli such as "How many intensities of sound were presented?" In later runs this data was obtained by questionaire.

RESULTS

Figure 1 shows the across Ss mean beat-by-beat HR response for each stimulus intensity in each stimulus modality during the February testing. Mean values for beats after 10 have been omitted because such means reflect only the values of those Ss with faster initial HR. These curves are typical of all four testings and also typical of the single responses of individual Ss, although the latter are more variable. The diphasic nature of the HR response to sound stimulation is apparent, with maximal acceleration occurring prior to beat 5 and maximal deceleration prior to beat 10. Generally, the degree of acceleration and deceleration to sound was also directly related to intensity. Although there was a tendency toward acceleration of HR to light, it was less than half that to sound, was of longer latency and was not related to intensity. The decrease in HR to light did not fall below prestimulus levels nor was it related to intensity. Interpretation of this apparent lack of response to light is not clear, however. As previously noted, Graham and Clifton suggested that the decelerative phase may habituate rapidly; this may also be true of the accelerative phase. It is possible therefore, since Fig. 1 shows mean values across all trials, early and late, that early trials show significant responses and later trials do not because of habituation.

These possibilities, and the additional questions posed in the introduction, were therefore approached in the following manner. Five HR means were computed for each epoch of stimulation for both stimulus modalities: 1) mean of the two beats prior to stimulation, 2) mean of the two fastest beats of the first five post-stimulus beats, 3) mean of the two slowest of beats 6, 7, 8 and 9, 4) mean of the two fastest of all beats in the 10 sec. post-stimulus epoch, and 5) the difference between the values of means 2 and 3 above. Mean 4 was computed because it was the score used in a very similar earlier experiment requiring verbalization, (Roessler, Alexander and Greenfield, 1963). Mean 5 was computed because Geer (1964) suggested that it is the "most sensitive measure of cardiac response" and because it is similar to the Lang and Hnatiow (1962) score.

Type VI three way (Es groups, intensity and subsequence) analyses of variance for repeated measures (Lindquist, 1953) on means 2, 3, 4 and 5 above were computed within testings (runs) for both sound and light.[1] Parallel analyses of co-variance for repeated measures were also computed, using mean 1 as the covariant, thereby freeing post-stimulus rates of any pre-stimulus effects. Among the analyses of variance of the HR to light, only two of the subsequence (habituation) terms (runs 1 and 4) for mean 2 were significant and these were not significant after covariance adjustment. There were no significant intensity effects. The only other significant term in the statistical analysis of the HR response to light was the subsequence x intensity interaction on the covariance analysis of run 4. A plot of this significant term showed no systematic differential habituation effects, the significance of the interaction being due to a great deal of cross-over among intensities.

We conclude that, not only is the accelerative response to light absent, as Graham and Clifton suggested it might be, but so too is any consistent deceleration. Moreover, the absence of these responses is not due to rapid habituation. Nor does it appear likely that the relative unresponsiveness of HR to light stimulation is related to lower intensities of stimulation compared to sound. The lowest intensities of sound induced greater HR response than the highest light intensities. We conclude that this is an instance of stimulus specificity. Light is not an effective stimulus to HR, at least in this experimental design. There will be no further presentation of the results of the analysis of HR responses to light, therefore.

The analysis of the HR response to sound within runs revealed that mean 3 (the decceleratory mean) showed no significant intensity effects and only one significant term, the subsequence x intensity covariance interaction ($p < .05$) on run 2. Table 1 shows the adjusted mean values for this interaction on all runs. The absence of any consistent trend toward differential habituation among intensities of stimulation is clear. A four-way (Es groups, intensity, subsequence and runs) analysis of variance showed a significant difference in deceleration between runs ($p < .05$). However, this difference disappeared with covariance adjustment for differences in initial levels. In the data of these experiments, then, there was no significant deceleration despite the apparent deceleration evident in Figure 1. Nor is there any trend toward greater habituation of deceleration to stimuli of higher intensity, as Graham and Clifton hypothesized there would be if deceleration is an OR that is replaced by acceleration (a defense response).

The analysis of variance and covariance of means 2, 4 and 5 revealed 4 and 5 to be almost entirely redundant of mean 2. Mean 2 showed the greatest consistency in significant terms within and across runs. The procedure for selection of the values in mean 4 in most instances selected the same values as those in mean 2. Mean 5 in the absence of a significant deceleration, assumed a value dependent almost entirely on the acceleratory component best represented by mean 2. In this experiment, therefore, the difference between acceleration and deceleration was not "the most sensitive measure of cardiac response" as Geer (1964) reported. For these reasons only the analysis of mean 2 will be presented in discussing the HR acceleratory response to sound.

In every run, both the analyses of variance and covariance intensity terms were highly significant ($p < .001$), for mean 2. The reason is evident from Figure 2, where covariance adjusted values for intensity effects are presented for both sound and light. The generally monotonic acceleratory response to sound in relation to intensity is evident in every run and confirms the results of Roessler, Alexander and Greenfield (1963). The four-way analysis of variance across runs revealed a significant runs difference ($p < .05$). This was entirely attributable to differences in pre-stimulus values; the runs term was not significant in the analysis of covariance across runs and none of the runs interaction terms was significant. There was therefore no significant difference in HR responsivity attributable to differences in experimental context, although the somewhat higher levels on runs 1 and 3 are suggestive of higher levels under conditions of unfamiliarity and real life stress.

None of the subsequence (habituation) terms were significant. However, the covariance intensity x subsequence interaction terms were significant in every run ($p < .05$ - $.001$). The adjusted values are shown in Table 2. The accelerative component did not habituate, a result in agreement with that of Geer (1964) and also with Graham and Clifton's interpretation that phasic acceleration is a component of the "defense reflex", rather than a part of the orienting response. However, the significance of this interaction of intensity with subsequence was not attributable to lesser habituation of higher intensities or an increase in acceleration in later subsequences.

There was only one significant accelerative term involving Es, the analysis of covariance Es groups x subsequence interaction on run 4 ($p < .05$). A plot of this interaction showed greater acceleration in the high Es group but no consistent difference between groups in habituation. Plots of this interaction for the first three runs showed no consistent differences between Es groups. Possible reasons for this absence of consistent differences in relation to Es will be discussed below.

Finally, the question of reliability over testings is of interest. How consistent is the HR accelerative response to sound of individual Ss over runs? This question was answered by calculating Kendall's coefficient of concordance (Siegel, 1956). W was .778 ($p < .001$); individuals are highly consistent over time and life contexts.

DISCUSSION

A number of methodological issues are of importance in interpreting the foregoing results. The first of these is the effect of verbalization. In this experiment, in which no immediate verbalization was required, the range of HR acceleration in relation to the intensity of sound stimulation was from one-half to two thirds (2-4 bpm) of that in the earlier similar experiment of Roessler et al, in which immediate verbalization was required. The requirement to verbalize does increase the amount of acceleration, therefore. However, a significant degree of acceleration remains and there is no significant deceleration in the absence of the verbalization instruction, as Campos and Johnson reported.

The Campos and Johnson score, as previously noted, was based on means of 5 beats every fifteen seconds during and following stimulation. Obviously, such a score is not comparable to any of the scores used in this experiment, in which the epoch of change was only 10 seconds. Since the scores are not directly comparable no conclusive comparison can be made. By the same token, however, Campos and Johnson cannot conclude that their results refute the Laceys' hypothesis because the latter investigators also focused upon the changes occurring in briefer epochs.

Our failure to confirm the interesting hypotheses of Graham and Clifton concerning the nature of the OR and defense response of HR may also be related to method. In retrospect, it seems to us that the conditions of this experiment were such as to optimize defense responses (acceleration) and minimize the OR component (deceleration). Interview and questionaire data revealed that many Ss found the higher intensities of stimulation to be distressing, particularly in the early runs. Since the order of stimulus intensities and the intervals between stimuli were probably difficult or impossible to anticipate accurately, the total psychophysiological "stance" of the Ss was probably defensive and their HR response was therefore one of acceleration to all stimuli. On the other hand, one might argue that the constantly changing intensity of stimulation should evoke the OR response. All of these possibilities are conjectural, of course. A more definitive test of Graham and Clifton's hypotheses would be a design in which one intensity of stimulation was continued until habituation, followed successively by a wide range of stimulus intensities, each habituated separately. Meyers and Gullickson (1967) did obtain results more congruent with the Graham and Clifton hypotheses when they employed a design somewhat like the procedure suggested. The results of this experiment, then, while not supporting the Graham and Clifton hypotheses, dc not convincingly refute them.

Other methodological problems relate to the possible effects of initial values, level of consciusness, respiration and rise time of stimuli. It is clear from our parallel analyses of variance and covariance that initial value effects do occur and should be taken into account if erroneous conclusions are to be avoided. Benjamin (1967) has provided an excellent discussion of the applications and interpretive implications of covariance analysis in psychophysiology. Surprisingly, many of the experiments in which HR deceleration - acceleration was studied did not employ covariance adjustment. A related problem is one recently defined by Schachter and his group (Williams, Schachter and Tobin, 1967), the slope of the pre-stimulus HR, - i. e., whether rate is decreasing or increasing at stimulus onset. No data on the possible effects of this variable is available in this experiment but, in view of the numerous stimulus presentations, it seems unlikely to have affected our results.

McDonald, Johnson and Hord (1964) reported that response levels of HR of drowsy Ss were greater than alert Ss and that drowsy Ss increased their HR over trials. Since we balanced our Ss for alert-drowsy classification within runs, it is unlikely that this variable affected our results within runs. However, since there were more drowsy Ss in later runs, it could have affected between runs comparisons. We think this unlikely because the covariance adjusted scores in later runs were actually lower (Cf. Figure 2).

Respiration data was recorded and analyzed in this experiment and the results will be presented elsewhere. There was no relationship to the results reported here for HR.

A very short rise time following stimulus onset could evoke a HR startle response of an acceleratory type. In this experiment the rise time of the auditory stimuli was less than 1 millisecond; that of the visual stimuli was less than 5 ms. Rise time might therefore be related to the difference between the degree of HR acceleration to light and sound. This seems unlikely because 5 ms. is still a very brief rise time. These brief rise times might be related to the dominance of acceleration and the absence of significant deceleration in both modalities, however.

The absence of any consistent relationship between HR and Es is concordant with the results of Hodges and Spielberger (1966), who found no relationship between manifest anxiety and HR response to threat of shock. Anxiety is usually inversely correlated with Es, and directly, but not always, related to physiological responsivity (Phaehler and Roessler, 1965; Roessler, Burch and Mefferd, 1967). However, Hein, Cohen and Shmavonian (1966) found differences between field-dependent and field-independent Ss. This personality variable is theoretically related to ego strength. The possibility remains that stimuli which evoke a greater range of HR response than the range obtained in this experiment would show differences related to Es.

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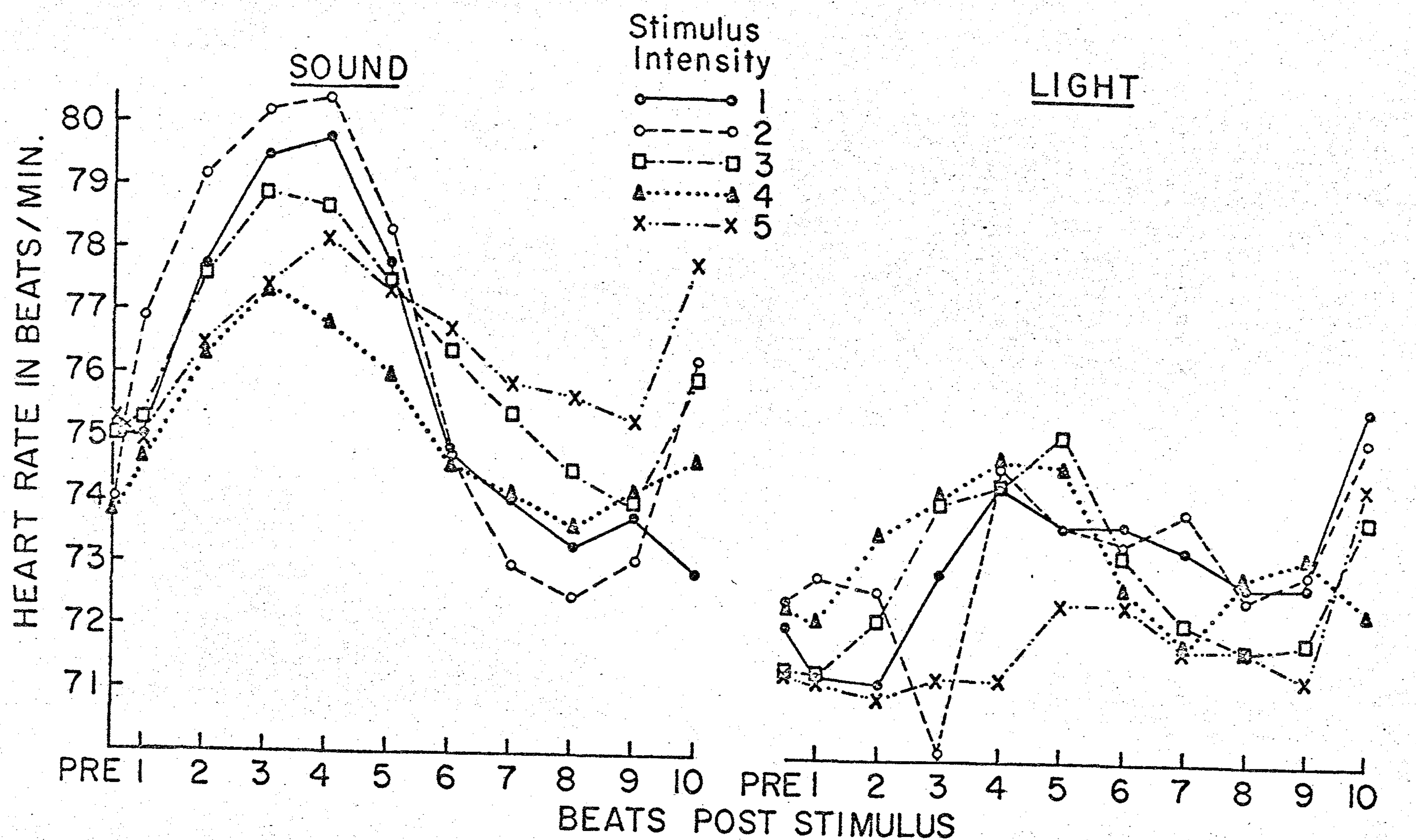
FOOTNOTES

1. Copies of the summary tables of the analyses of variance and covariance are available from the first author on request.

LEGENDS FOR FIGURES

Figure 1. Beat-by-beat pattern of the heart rate response to 5 intensities of sound and light. Each data point is the mean for all subjects. Note the definite acceleration to sound occurring in the first 5 beats, ~~the deceleration occurring in the first 5 beats,~~ the deceleration occuring between beats 5-10 and the lack of consistent pattern of response to light. Rates are unadjusted. (See text for explanation and for intensities in db.)

Figure 2. Heart rate acceleration to 5 intensities of sound and light on four occasions. Note the generally monotonic relationship between sound stimulus intensity and heart rate and the lack of relationship to intensity for light. Note also the decreasing level of heart rate over repeated testings.


SOUND
LIGHT
Stimulus Intensity
1
2
3
4
5
HEART RATE IN BEATS/MIN.
80
79
78
77
76
75
74
73
72
71
PRE 1 2 3 4 5 6 7 8 9 10
BEATS POST STIMULUS

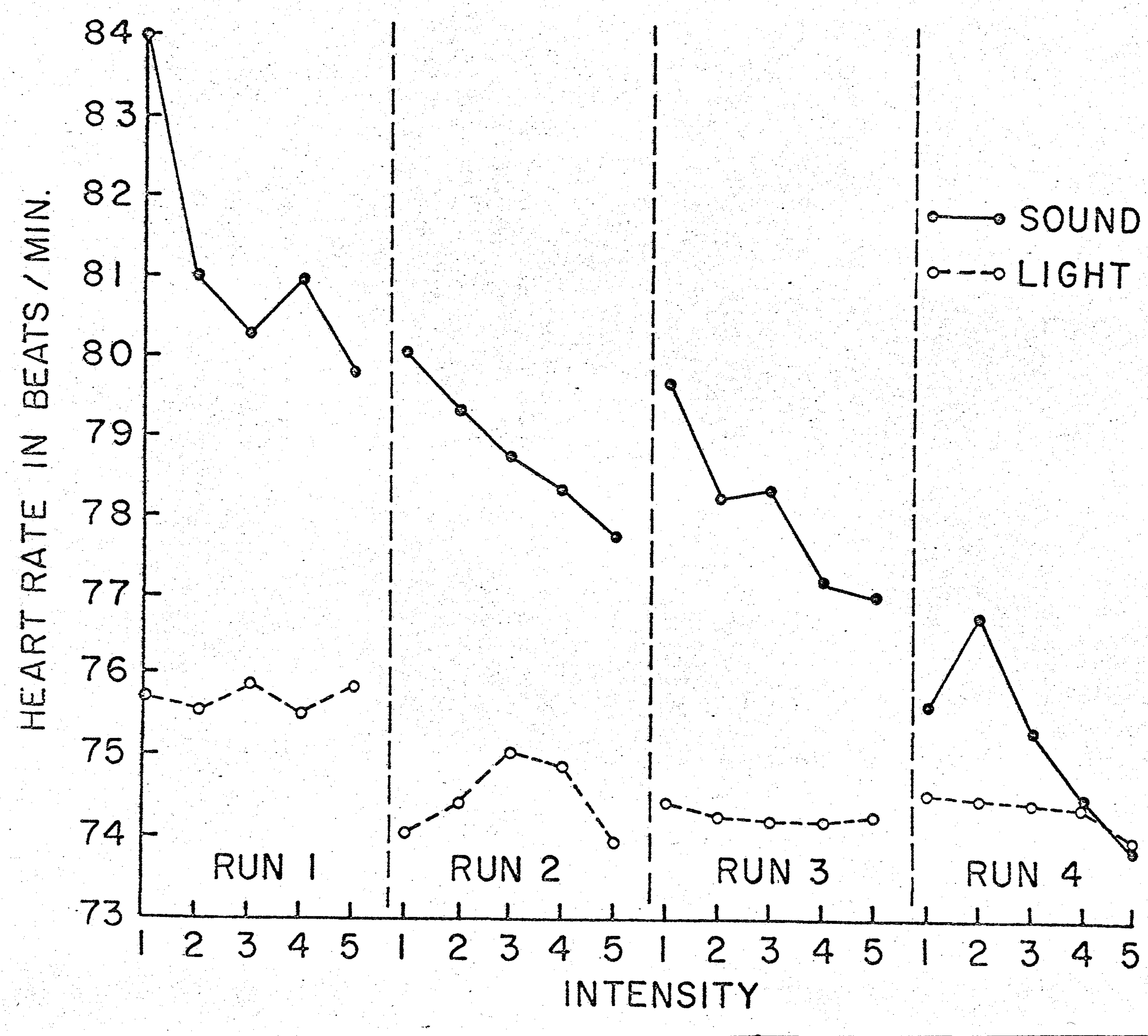

HEART RATE IN BEATS / MIN.
84
83
82
81
80
79
78
77
76
75
74
73
RUN 1
RUN 2
RUN 3
RUN 4
SOUND
LIGHT
1 2 3 4 5 1 2 3 4 5 1 2 3 4 5 1 2 3 4 5
INTENSITY

Table 1

Heart Rate Deceleration to Five Intensities of Sound

Over Five Subsequences

		Run 1					Run 2					Run 3					Run 4				
Subsequence		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Intensity	1	77.5	76.0	75.0	75.9	78.6	75.2	75.6	73.0	74.4	71.1	71.9	72.7	71.4	71.0	71.9	68.8	66.9	68.3	69.2	69.5
	2	75.3	76.5	76.2	75.9	76.7	74.8	76.3	73.9	72.0	74.7	72.3	72.3	72.1	71.4	72.8	69.9	68.5	69.0	68.0	70.0
	3	75.0	76.8	77.4	76.7	77.8	74.9	75.1	73.1	74.8	76.1	70.9	72.2	72.7	71.5	69.8	68.9	69.7	69.0	68.7	69.6
	4	75.0	76.8	76.6	77.0	77.4	75.6	73.9	74.1	74.2	74.3	72.2	73.6	73.0	71.2	71.4	71.9	67.5	67.8	68.2	69.7
	5	74.2	76.4	76.6	75.6	75.9	75.1	73.7	73.9	75.2	74.0	71.1	73.2	69.9	72.4	73.3	69.3	68.1	68.9	69.7	70.2

Table 2

Heart Rate Acceleration to Five Intensities of Sound

Over Five Subsequences

		Run 1					Run 2					Run 3					Run 4				
Subsequence		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Intensity	1	84.8	85.1	83.2	82.0	84.1	83.6	81.0	78.7	79.3	79.5	80.8	80.3	79.3	79.3	80.0	78.1	77.2	76.2	77.4	77.7
	2	82.1	80.9	81.6	81.2	81.4	81.1	79.1	79.4	78.9	78.2	79.4	77.4	77.5	78.7	78.3	76.9	75.8	75.5	76.8	75.3
	3	81.2	82.0	81.1	80.4	80.6	79.3	78.8	78.6	77.9	79.6	78.8	79.5	76.8	77.8	77.3	74.5	75.7	74.6	75.4	75.5
	4	79.9	80.3	80.0	82.0	80.8	78.6	78.2	78.5	77.5	78.6	76.8	78.5	76.9	77.5	77.7	74.8	74.2	74.2	76.1	73.9
	5	77.8	79.2	79.2	79.4	79.6	77.4	77.6	77.2	79.8	77.3	76.1	76.3	75.7	76.1	76.2	72.9	72.7	74.0	73.6	73.5