LEVEL II

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FEASIBILITY OF USING A MEASURE OF HEART RATE CHANGE IN HUMAN ADULTS TO SIGNAL OCCURRENCE OF TONE

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FEASIBILITY OF USING A MEASURE OF HEART RATE CHANGE IN HUMAN ADULTS TO SIGNAL OCCURRENCE OF TONE

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INTRODUCTION

An organism's overt response to a stimulus is the most evident, but not the sole, response elicited by that stimulus. A covert response could be a more reliable and more sensitive response to the stimulus than the traditionally monitored overt response.

Using group statistics, a change in heart rate (HR) of human subjects exposed to auditory signals has been reported. (Davis, Buchwald, and Frankmann, 1955; Zeaman, Deane and Wegner, 1954; Dawson and Davis, 1957; Lang and Hnatiow, 1962; Roessler, Collins, and Burch, 1969; Smith and Strawbridge, 1969; Keefe, 1970).

With the exception of Schachter, Williams, Khachaturian, Tobin, Kruger and Kerr (1971), and Schulman (1973), who examined the HR change of neonates to auditory signals, no investigators have examined the HR changes on a trial-by-trial basis. If HR change is a reliable response, as previous research would suggest, then it may be possible to use its occurrence to signal the presentation of a tone.

A reliable HR response (HR-R) would be extremely valuable in auditory signal detection situations, where operators often become drowsy and fail to respond overtly to auditory signals. The object of this study was to determine the feasibility of employing a measure of HR change in human adult subjects to signal the occurrence of a tone.

The findings of previous reseachers showed the HR change to be diphasic (Lang and Hnatiow, 1962). The diphasic nature of the HR change can create difficulties when one attempts to make statements concerning the parameters affecting HR-R to tone.

Earlier investigators defined HR-R in quite different terms. When their results conflict, it is difficult to determine whether different stimulus parameters or different measurements of the HR are responsible for the discrepancy.

The reported effects of stimulus repetition upon HR vary among investigators. Habituation of this response to repeated stimulus presentations having a fixed interstimulus interval (ISI) was reported by Davis et al. (1954) using a measurement of the deceleration of HR, following tone onset and by Lang and Hnatiow (1962) who defined their measure of HR-R as the difference between acceleration and deceleration. No habituation of the components of the HR curve across trials was found by Keefe (1970) and Roessler et al. (1969) when a variable ISI was used. Roessler measured the amount of HR acceleration to tones of different intensities and a variable ISI. Due to differences in these studies between stimulus variables, and response measurements, effects of stimulus repetition upon HR are unclear.

The role of stimulus intensity upon HR is clear, regardless of the measuring technique; as the stimulus intensity increases, so does the measure of HR-R. Zeaman and Wegner (1956) employed a measure of HR-R which reflected the total fluctuation of HR, and this measure increased as the stimulus intensity increased.

The measure used by Roessler et al. (1969), which was dependent upon HR acceleration, increased to the greater stimulus intensities. A measure dependent upon HR decrease (Davis et al. 1955) also became greater with higher stimulus intensities.

The effect of a motor response or a verbalization requirement to the presentation of a tone on HR was examined by Roessler et al. (1969) and Dawson and Davis (1957). Roessler noted that in an earlier study requiring a motor response to tone (1963) that the magnitude of the HR-R was greater than in a later study (1969) requiring no overt response.

Dawson and Davis examined the response requirement effect upon their HR-R measure which reflected the amount of deceleration. The subjects in the experimental group depressed a button on the cessation of a tone, and those in the control group merely listened for the tone.

The magnitude of the HR-R measures did not differ significantly for the two groups. Therefore it has yet to be shown that a motor response requirement increases the magnitude of an HR-R to tone.

In all of the studies reviewed, the tone was presented binaurally to the subjects via either a loudspeaker or headphones. In a pilot effort, this investigator monaurally presented a series of tones ranging in intensity from 6db to 85db re. 0.0002 dynes/cm^2 to several subjects.

Analysis of the moment-to-moment HR on a trial x trial basis revealed no reliable HR-R. Therefore, the role of the method of stimulus presentation, as well as the existence of HR-R to a single tone presentation, was ambiguous.

To date, no investigation has been made of the HR change on a trial-by-trial basis using human adults as subjects. However, Kaplan (1971) recorded an apparent change of HR in a sleeping subject, when loud tones were presented.

The findings of Schachter et al. (1971) and Schulman (1973) question the existence of a reliable HR-R to a single presentation of an auditory stimulus. Schachter et al. (1971) exposed neonates to binaurally presented loud clicks. Two measures of HR-R were used; one which reflected deceleration from baseline, while the second measure reflected the subsequent acceleration.

Comparing subjects' responses to live and control trials, an HR-R was significant on 67% of the live trials. Schulman (1973) exposed neonates to loud tones and examined the increase of HR from baseline on an individual subject trial block basis. She found a significant HR-R in less than 30% of the trial blocks.

The purpose of the present study was to determine if HR-R to tone on a trial-x-trial basis could be used as a reliable indicator of the occurrence of a tone and to determine the effects of stimulus presentation (monaural, binaural), stimulus intensity (15,85db), response requirement (free, motor) and trial type (live, control) upon HR-R as measured by several methods.

METHOD

SUBJECTS

Ten male Army personnel, 18-33 years old, participated in the experiment. Subjects were randomly assigned either to the monaural or binaural stimulus presentation group. For this study, subjects were tested individually during the two daily sessions for two consecutive days.

APPARATUS

ECG Recording. The subject's heart rate was monitored by use of Beckman surface electrodes in conjunction with a Beckman A-C coupler, Type 9806A. The electrode configuration used had one of the two active electrodes on the left side of the subject's chest at the intersection of the fifth intercostal space and the midclavicular line.

The other active electrode was placed similarly on the right side while the indifferent electrode was placed on the clavicle. A Beckman Type S-11 Dynograph recorder was used to record the ECG tracing which had a very pronounced R-wave component. The ECG signal was also recorded by a Honeywell magnetic tape recorder, Type 5600C.

ECG Measurement. The recorded ECG from the magnetic tape recorder was fed into the EKG R-wave detector (Lee Bio-electronics, Inc.). With the detection of an R-wave, a pulse was triggered.

An interbeat timer (Biotechnology, Inc. 1301R) measured the interval between pulses to the nearest millisecond, and a digital recorder (Hewlett-Packard 5055A) printed the time on a strip chart. An event marker on the digital recorder noted presentation of a tone.

The 10 beats prior to the tone, those beats completely within duration of the tone, and the first 10 beats post tone offset were measured. All R-R intervals were converted to beats per minute (bpm).

Tone Source. The tones were generated by a pair of Hewlett-Packard audio oscillators, Model 200 ABR. Intensity of the tones was regulated by a pair of Hewlett-Packard 350-D attenuators. Subjects received the tones from TDH Type 49 earphones with MX-41/AR ear cushions.

Tone Switching. Tones were switched on and off by Potter and Brumfield KRP11D relays with General Electric IN599 diodes across the coils. Oscilloscopic tracings revealed a clean presentation and cessation of tones. This investigator saw no evidence of a click on the scope nor heard any click when the tones were presented via earphones.

Tone Presentations and Programming. Sequence and duration of tones and other stimuli were controlled by programming logic, utilizing BRS-Foringer Digibits.

Intensity Control and Measurement. Output of a TDH Type 49 earphone was carefully calibrated for a range of inputs from the oscillator with which it was to be used. To obtain such a calibration, the following procedure was followed.

Within the booth, an artificial ear, Bruel and Kjaer Type 4151, equipped with a condenser microphone, B&K Type 4132, was suspended from the subject's console by elastic bands and a wire to eliminate low frequency building vibration.

The earphone to be calibrated with that oscillator, was placed upon the artificial ear. Atop the earphone, to insure a tight fit, was placed a standard 500 gram weight. A B&K cathode follower, Type 2613, was connected to the condenser microphone.

The cathode follower was the input source for a B&K Type 2112 sound analyzer outside the booth. The 2112 provided the frequency filtered input to a B&K Type 2305 level recorder. From the level recorder, the sound pressure level of the stimulus from the earphone was obtained.

Outside of the booth, a Hewlett-Packard 400H audio frequency voltmeter was connected across the oscillator output. An attenuator box was connected between the output of the oscillator and the matching transformer to the earphone.

The oscillator was set for the specific frequency. The gain control of the oscillator was then adjusted so that the voltmeter registered a given voltage which was the unattenuated signal. The SPL on the level recorder was again noted, and so on.

The range of intensities measured was typically from 85 down to 12 db. Since the response curves for the two earphones differed, this procedure was then repeated for the other oscillator-earphone network to insure equal stimulus intensities from each earphone.

Ambient Noise. The ambient noise within the artificial ear inside the booth was analyzed and spot recordings were taken for several minutes each hour during the working day. The ambient noise levels were lower than the standard specified by the American Standard S3.1-1960 for acceptable levels of noise within audiometric testing chambers.

The standard requires that the ambient noise within a 1/3 octave band centered about the following tested frequencies--500, 1000, 2000, 3000, 4000, 6000 and 8000 cycles per second (Hz) respectively, not exceed 34, 35, 42, 47, 52, 57 and 62 db. The obtained SPLs within the 1/3 octave bands for these tested frequencies were respectively--9, 7, 6, 7, 7, 7 and 8 db.

Subject Test Chamber. Throughout testing, subjects were seated in a comfortable wooden armchair, within a double-walled, double-doored, sound-attenuated booth, manufactured by Industrial Acoustics Company. The booth contained a small console with a counter on which the subject could rest his arms.

On the counter to the subject's right was a button mounted on a slightly inclined surface. A red cuing light was located on the console, directly in front of the subject. Beneath the cuing light was the receptacle for the headphones. The booth was dimly illuminated by a high intensity reading light, fastened to the console.

Within the booth the subject could be seen and heard by the experimenter. The subject could speak into a console-mounted microphone and be heard over a speaker in the control room. The booth was equipped with a video monitor.

Booth temperature varied between 74° and 76° F.

PROCEDURE

Prior to the first session of testing, each subject was told that electrodes would be attached to his chest to monitor ongoing electrophysiological activity. The subject was also given specific instructions for that session.

Each session was approximately one hour long. Subjects were allowed five minutes to habituate to the booth before the trials began. Each session consisted of 40 trials, with inter-stimulus intervals ranging from 40 to 120 seconds and having a mean of 80 seconds.

On half the trials a tone of 1000 Hz, 2-second duration, and either 15 or 85 db (re. 0.0002 dyne/cm^2) depending on the session was presented to the subject via earphone(s). These were termed live trials.

The other trials were called control trials. In this case, however, the subject received no tone. The order of trials was randomized.

For the first two sessions the subjects were instructed to relax, keep all movement to a minimum, and listen for tones. During session one, 15 db tones were presented, while 85 db tones were administered in session two. These were the "free response" sessions, no overt response was required of the subject.

Sessions three and four were "motor response" sessions. At the offset of the tone, the subject was to depress a button, mounted on an inclined platform in front of him, with the first finger of his right hand. The subject was to keep the button depressed until a small red cuing light, also mounted in front of him, turned off.

This light was activated by the subject initially depressing the button and remained on for two seconds. Tones of 85 db were presented in session three while 15 db tones were presented in session four.

The fixed order of experimental sessions confounded the effects of the intensity and response requirement variables.

RESULTS

The HR data were examined in two ways: on a grouped data basis, to determine if the results of previous studies were replicated; and on a trial by trial, subject by subject basis in order to determine the feasibility of using a measure of HR change to signal the occurrence of a tone. Additionally, since the order of the experimental sessions was fixed, which confounded the effects of intensity and response requirement, the grouped data measures were examined for any systematic change over time.

GROUPED DATA

Two dependent measures of the HR data were examined on a grouped data basis. The fluctuation score employed is similar to the HR-R measure used by Zeaman and Wegner (1956). The fluctuation score reflects the moment-to-moment HR changes occasioned by a tone.

It is the mean of the absolute deviations of each of the first five complete post-tone onset beats from the pre-tone baseline HR which is the mean of the last 10 complete beats pre-tone.

The second measure investigated is the acceleration score which is the mean of the fastest two beats of the first five beats post-tone onset; Roessler et al. (1969) determined a measure similar to this to be the most sensitive measure of HR change.

A trial type (2) x intensity (2) x presentation (2) x response requirement (2) x trials (15) analysis of variance (Dayton, 1970) using the fluctuation score of HR as the dependent variable was performed. Method of presentation is a between subjects variable while the remaining factors are within subject variables.

Due to experimental equipment failure, only 15 trials of each trial type are examined. Results of this analysis are presented in Table 1. The only significant main effect ($\underline{F}$=3.21, $\underline{df}$=14/112, $\underline{p} \leq .05$) is the trials factor (C). Graphing the fluctuation score across trials (see Figure 1) reveals a gradual increase during the session.

Subsequent testing, using Fisher's least significant difference test (LSD) shows the later trials 15, 14, and 10 to be significantly greater than the initial trials 2 and 3. The results of Fisher's LSD test between trials are presented in Table 2.

The intensity x response requirement interaction (BxR) is significant ($\underline{F}$=9.62, $\underline{df}$=1/8, $\underline{p} \leq .05$). Figure 2 shows the motor response requirement increases the fluctuation score to the lower intensity tone, while it decreases the HR-R to the higher intensity tone.

However, testing (LSD) this interaction indicates significance is confined to the 85 db free response being greater than the 85 db motor response. The results of this LSD test are presented in Table 3.

The trials x intensity x presentation interaction (CxBxA) is significant ($\underline{F}$=2.17 $\underline{df}$=14/112, $\underline{p} \leq .05$). The graph of this interaction (Figure 3) again reflects a gradual increase of HR-R as the session progresses. The great variability of this measure is also apparent.

Examination of the data using Fisher's LSD test reveals no significant differences of the corresponding CB points between presentation groups. For all subsequent tests between groups on corresponding cell means, a pooled error term is used.

Since this pooling often involves heterogeneous sources of variance, a reduced number of degrees of freedom is computed to compensate for any bias (Winer, 1971). Within the presentation groups, the greater response on the later trials as compared to the initial trials contributes to the significance of this interaction.

Additionally, within the monaural presentation, the HR-R to trial 9 at 15 db is significantly greater than the HR-R at trial 9 in the 85 db session. However, at trial 14, the situation is reversed; the HR-R is significantly greater to the 85 db tone.

In the binaural group on trial 13, the HR-R to 85 db is significantly greater than the HR-R to the 15 db tone. There are no other significant differences between any of the four possible HR-Rs on a given trial. The results of this LSD testing are shown in Table 4 for the monaural group and Table 5 for the binaural group.

Grouped data were then analyzed using the acceleration score as the criterion measure and the mean of the last two beats prior to the tone as the covariate. A trial type (2) x intensity (2) x trials (15) x presentation (2) x response requirement (2) analysis of covariance with the method of presentation as the between subjects variable was performed.

This analysis (Table 6) shows a significant intensity x response requirement (BxR) interaction ($F=8.56$, $df=1/7$, $p \leq .05$). The motor response requirement is associated with an increase in HR-R with the lower intensity tone and a decrease in response in conjunction with the higher intensity tone.

The form of this interaction (see Figure 4) is very similar to the BxR interaction using the fluctuation score. The significance of the acceleration interaction, shown in Table 7, is due to the 15 dB free response being significantly less than both the 15 db motor response, and the 85 db free response.

The trial type x intensity x presentation x response requirement interaction (TxBxAxR) is also significant ($F=8.83$, $df=7$, $p \leq .05$). This interaction reflects the influence of the trial type and presentation factors which are nested in the significant BxR interaction.

The graph of this interaction (Figure 5) reveals the monaural presentation cell means lie above the binaural presentation cell means. However, Fisher's LSD test indicates the between-group differences are limited to the 85 dB free monaural control trial mean being significantly greater than the corresponding binaural control trial mean ($85.93 > 79.74$, $p \leq .05$).

The results of the LSD testing within each presentation group are presented in Table 8 for the monaural group and in Table 9 for the binaural group.

The significance of the TxBxAxR interaction is to a great extent confined to several situations. In the live 15 db binaural condition, the acceleration score increases from the free response to the motor response condition.

The opposite is true in the control 15 db binaural condition. Moreover, the control 15 db binaural free response cell mean is significantly greater than the live 15 db binaural free response cell mean.

In the monaural group, the interaction effect is noted in the divergent plots of the live 85 db cell means and the control 85 db cell means.

There is no difference between the trial types in the free response situation while the live trial cell mean is significantly greater than the control trial cell mean when a motor response is required.

TRIAL BY TRIAL

The data were then examined on a trial-by-trial, subject-by-subject basis. This was to determine if there were measures of HR-R reliably sensitive to the occurrence of a single tone.

The HR of specific ordinal post-tone beats was compared to the baseline HR which was the mean of the last three complete beats prior to tone onset. Sign tests (Siegel, 1956) reveal no consistent HR-R change across subjects.

The significant ($p \leq .05$) results of the individual subject comparisons are presented in Table 10. Within the table, the numbers (1-11) refer to the subject and the sign refers to the direction of change from the baseline, i.e., (+) indicates a significant increase ($p \leq .05$) in HR from the baseline while (-) indicates a significant decrease ($p \leq .05$).

The tests reveal great individual subject differences within specific comparisons. Subjects in the same stimulus situation respond differently. This is seen most clearly with the binaural subjects in the 85 dB free response live trials situation on post-tone offset beat 1.

Here, the significant response ($p \leq .05$) for three subjects is an increase of HR, while a fourth subject shows a significant ($p \leq .05$) decrease in HR and the fifth subject shows no change.

It is also interesting to note the HR-R in the motor sessions. Subjects who show a significant change ($p \leq .05$) in one intensity condition, do not necessarily show a change in the other intensity condition, although the motor response is present in both situations.

This is clearly seen when comparing the sign test results of post-tone offset beat 1 in the binaural 15 db motor response live trial situation to the analagous 85 db motor response condition.

Only subject 5 shows a significant response to the low intensity tone while three subjects (S4, S6, S10) show a significant response to the higher intensity. This indicates that significant effects are not solely dependent upon the required motor response.

Another series of tests were performed to test for increased variability of HR induced by a tone. A Zeaman-like measure was computed which compared the variance of 10 beats pre-tone and 10 beats post-tone. Again, sign tests were conducted.

As shown in Table 11, the only experimental condition which elicits any number of significant results is the binaural 85 db free live trials condition. Here, three of five subjects show greater variability of HR after the occurrence of the tone.

A final series of tests upon individual trials in free response live trial situations only, were performed. In this case, the direction of the most deviate beat from baseline was listed for each of two post-tone off-set periods: ordinal beats 1-3, and 4-10.

These periods in the current study correspond to the areas where acceleration and late deceleration respectively have been reported to be found (Lang and Hnaitow, 1962). Sign tests reveal no consistent direction of change from baseline in either period for any subject.

In addition, on any single subject basis, there is no correspondence between the direction of change in the early period and the subsequent direction of change in the later period.

SYSTEMATIC CHANGE

The grouped data of the current study were tested for habituation and sensitization of HR-R. The significant trials effect and the significant trials x intensity x presentation interaction of the fluctuation analysis indicates sensitization of this response measure during the course of the experimental session. The acceleration analysis does not reflect this trend.

The grouped data measures for each experimental situation were examined on a trial-x-trial, subject-x-subject basis for any indication of a progressive response change. A plot of a subject's fluctuation and acceleration score was made for each trial within a session.

In all of the sampled cases, the line best fitting the 15 data points was essentially linear rather than quadradic or cubic. A product moment correlation between HR-R and trial number was performed.

Under these circumstances, the meaning of any significant correlation is limited to the relationship of the HR-R of a specific subject at a specific point in time; no attempt should be made to predict what that subject or other subjects would do under similar experimental conditions at a later date.

In only one plot of the 16 examined is there a significant ($p \leq .05$) relationship between trial order and response magnitude. Overall, then, a trial-by-trial, subject x subject examination of the grouped data measures reveals no indication of habituation or sensitization of either measure of HR-R within a session in the confounded experimental conditions of this experiment.

DISCUSSION

The experimental sessions were ordered so that HR-R in the free response sessions would not be contaminated by prior association of tone and motor response. Due to the fixed order of presentation, one cannot separate effects due to response requirement and intensity from possible effects due to sensitization or habituation.

However, no reports are in the literature of sensitization or habituation (Groves and Thompson, 1970) of HR-R when a variable ISI is used. Roessler et al. (1969) employed a variable ISI and found no difference in response magnitude between sessions, although the same stimulus array was present in each session.

The pattern of HR-R in the present study between sessions discounts possibility of consistent change of response between sessions due solely to a sensitization or habituation process. However, there did appear within sessions to be a sensitisation effect across trials when the fluctuation measure was examined. The sigmoidal shape of the curve joining the mean response for each session suggests that obtained results are not due to a simple process of response habituation or sensitization.

Results of group data analyses show neither trial type nor mode of stimulus presentation to be a significant main effect. Failure to find a significant difference between control and live trials across all conditions makes the interpretation of obtained results most difficult.

However, within the trial type x intensity x presentation x response requirement interaction of the acceleration measure, the 85 db live trial cell mean is significantly greater than its control trial counterpart in all but one of the four presentation x response requirement conditions.

Neither HR-R measure is sensitive to trial type with the low intensity tone. This lack of a significant trial type factor is not unique. Schulman (1973) employed a control trial condition when monitoring the HR change of neonates to 80 db tones and found no difference between the effects of control trials and live trials upon HR.

Schulman did find the subject factor to be significant. She concluded that individual differences in responsiveness obscured differential effect of trial type upon HR.

Results of group data analyses are similar to findings of Roessler et al. (1969) and Zeaman and Wegner (1956) within constraints of their experiments. These experimenters did not include control trials in their experimental designs. In a free response situation, the louder tone elicits a greater response.

This study also supports Roessler's finding of no HR-R habituation when employing a variable ISI. This study does not confirm Roessler's contention that a motor response requirement will increase magnitude of the HR-R.

It is apparent from intensity x response requirement interaction in both the fluctuation analysis and acceleration analysis that the motor requirement increases magnitude of an HR-R to a low intensity tone while the requirement decreases the HR-R to a loud intensity tone.

Results of the trial-by-trial examination of the data indicates a failure to demonstrate a reliable measure of HR-R to pure tones of supra motor response threshold intensity.

These results, using adult male subjects are similar to the trial-by-trial findings of Schachter et al. (1971) who exposed neonates to clicks, and Schulman (1973) who presented neonates with loud tones. Schachter reported a lack of response in 33% of the live trials while Schulman noted a lack of response to 80 db tones in 70% of the trial blocks.

In the current study, no single test proved significant for all subjects exposed to a common stimulus condition. However, these tests suggest a degree of individual subject response consistency. This is most evident in the binaural 85 db free live situation comparison of post-tone offset beat one to baseline.

Here four of the five subjects show a significant change in HR. The change is an increase in HR for three subjects while the HR of the fourth subject decreases. This 85 db binaural tone situation is the most promising for a reliable HR-R.

However, the great response variability on a trial x trial, subject x subject basis would suggest the infeasibility of using a measure of HR change to signal occurrence of tones of supra motor response threshold intensity.

SUMMARY

Unusual human perceptual capacities have been reported in U.S. and foreign literature. Considering their potential military applications, as well as scientific interest, there is need for evaluating reliability of the phenomena and/or determining procedures for detecting, reproducing and utilizing them. Possible applications of these electro-psychological outputs could include such biofeedback uses as: prediction of overt performance from properties of the internal body electrical responses, and utilization as indicators of stress and fatigue to forestall performance disruption and decay. The purpose of the present study is to determine the feasibility of using a measure of heart rate change in Army personnel to signal the occurrence of a tone.

Should a consistent heart rate response be associated with each presentation of tone, then the absence of a required motor response would indicate either a lack of awareness or fatigue in monitoring personnel. Conversely, a diminution of heart rate response may precede a degradation in overt performance. In either case, the possible use of such a covert response system would provide a means for assessing the alertness of military operators involved in monotonous monitoring positions.

The beat-by-beat heart rate was recorded from each of 10 male Army personnel exposed to tones under different experimental conditions. Two intensities of tone (15 and 85db) are presented either monaurally or binaurally. Subjects are either to listen merely for tones or to make a motor response at the cessation of the tone. All tones are presented via earphones to the subject who is seated in a sound-attenuated booth. All subjects are tested individually.

Trial X trial results indicate great individual variability and the improbability of using a change in heart rate to signal tone detection. Grouped data analyses indicate measures of heart rate change increased with increased tonal intensity, while response requirement and means of tone presentation are not critical in this study.

The inconsistency of a measure of heart response to signal the occurrence of a tone precludes its utilization as a covert response which could predict impending overt response/performance decrement.

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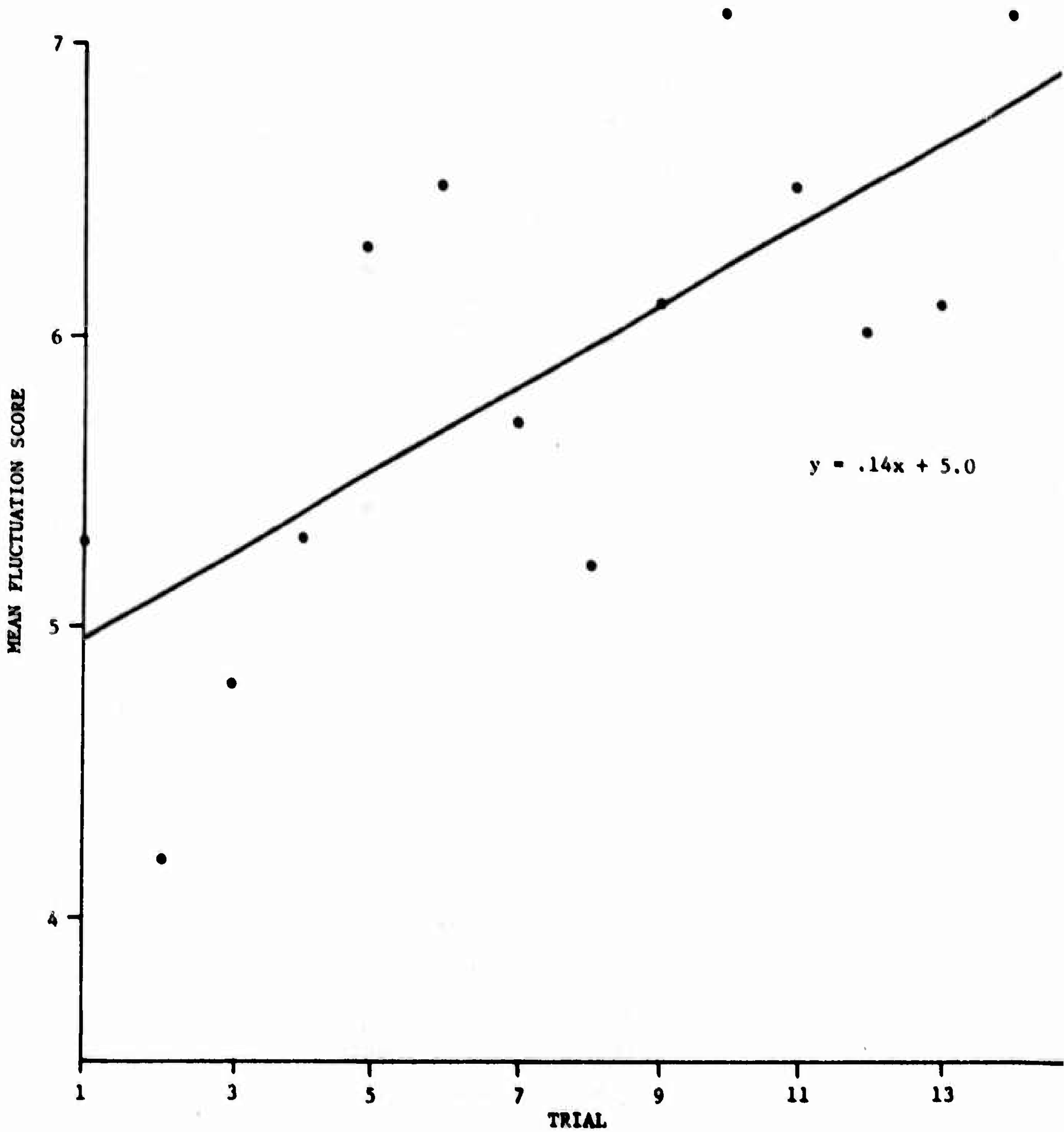

Figure 1. Mean Fluctuation Score as a Function of Trials

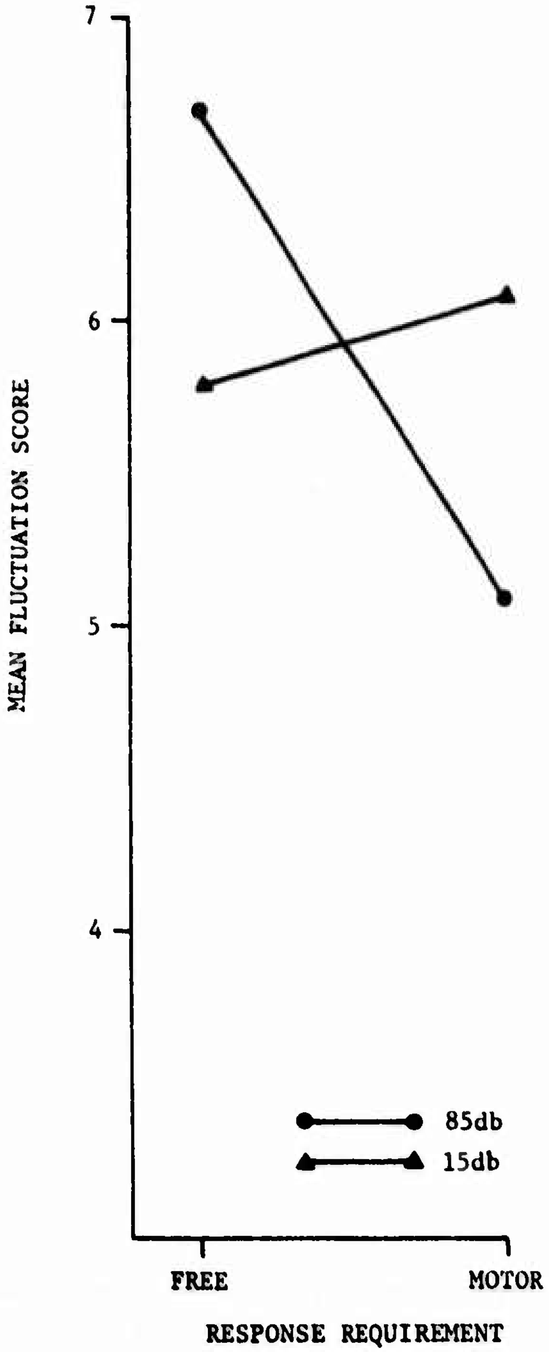

Figure 2. Intensity x Response Requirement Interaction of Fluctuation Score Analysis

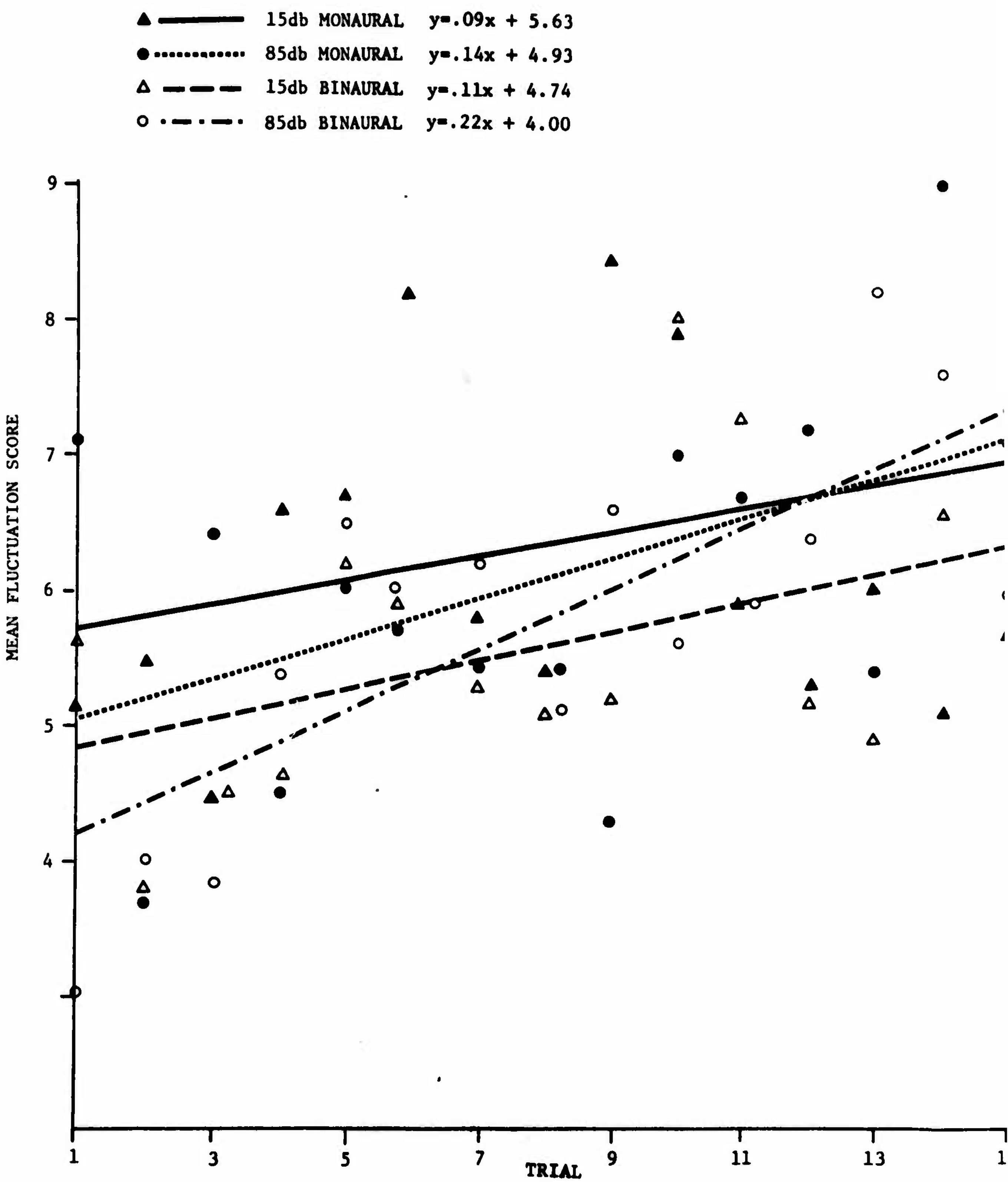

Figure 3. Trials x Intensity x Presentation Interaction of Fluctuation Score Analysis

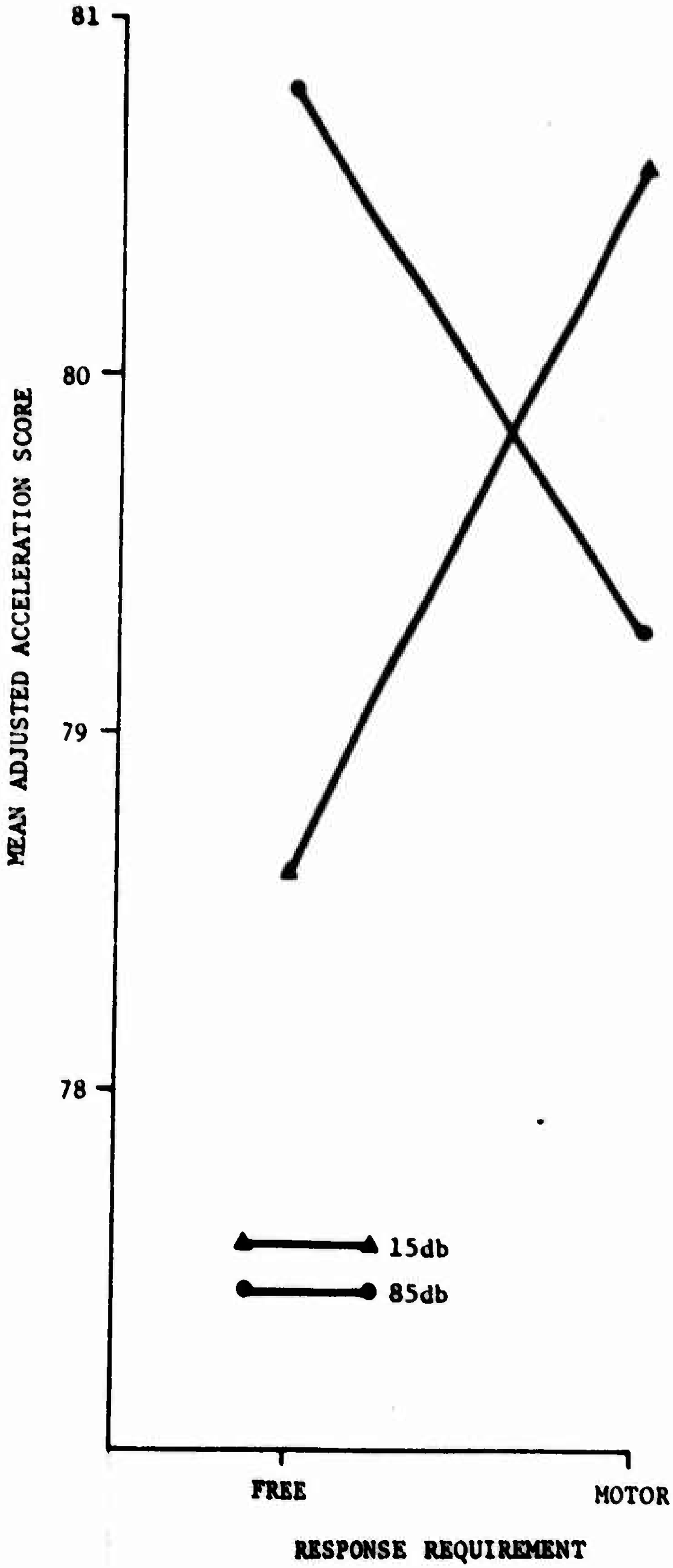

Figure 4. Intensity x Response Requirement Interaction of Acceleration Score Analysis

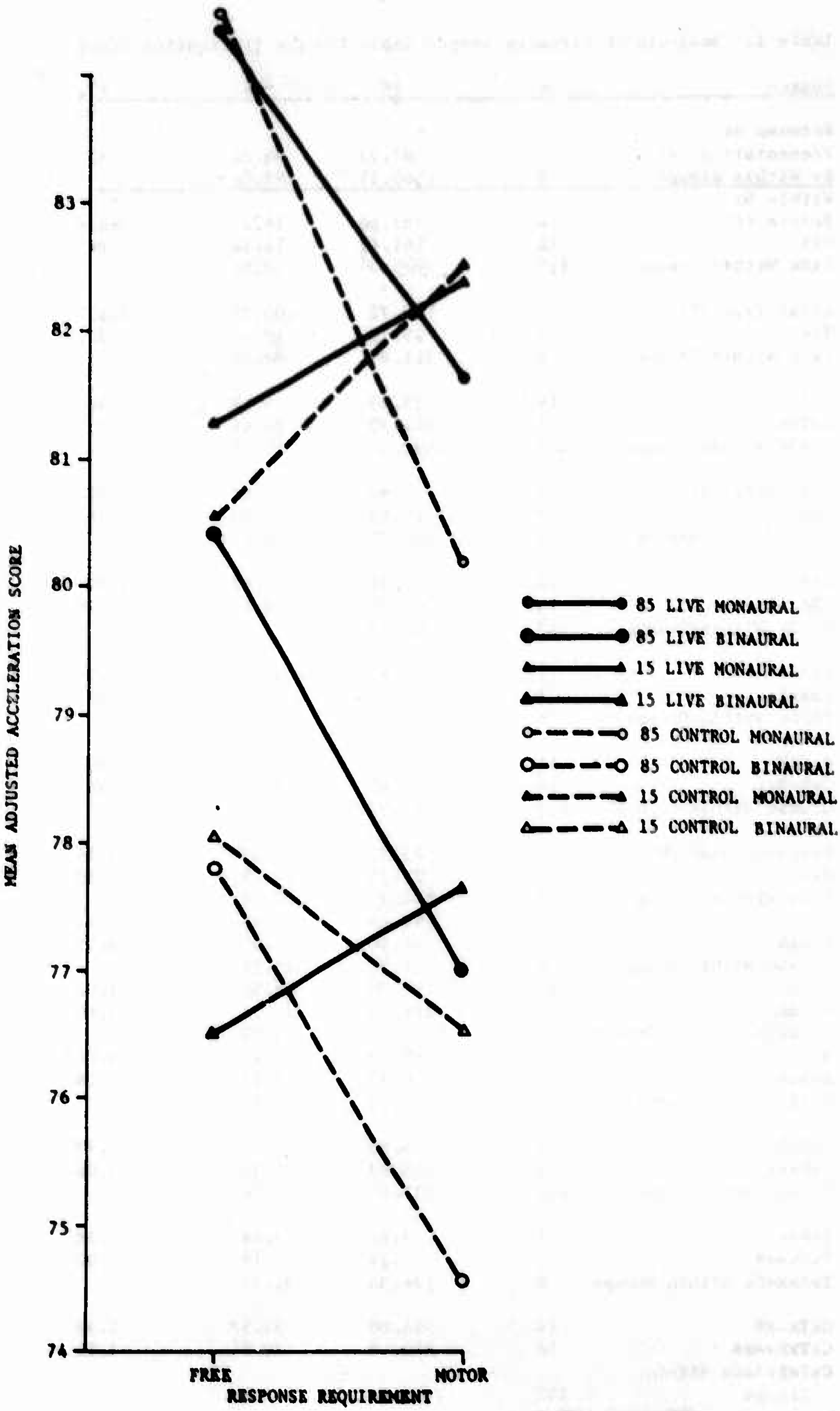

Figure 5. Trial Type x Intensity x Presentation x Response Requirement Interaction of Acceleration Score Analysis

Table 1. Analysis of Variance Source Table for the Fluctuation Score

Source	df	SS	MS	F
Between Ss				
Presentation (A)	1	83.22	83.22	.43
Ss Within Groups	8	1560.29	195.04	
Within Ss				
Trials (C)	14	787.60	56.27	3.21*
CxA	14	161.61	11.54	.66
CxSs Within Groups	112	1965.06	17.55	
Trial Type (T)	1	109.72	109.72	2.81
TxA	1	20.15	20.15	.52
TxSs Within Groups	8	311.87	38.98	
CxT	14	139.69	9.98	.66
CxTxA	14	341.70	24.41	1.61
CTxSs Within Groups	112	1693.39	15.12	
Intensity (B)	1	.48	.48	.02
BxA	1	16.63	16.63	.74
BxSs Within Groups	8	180.93	22.62	
CxB	14	373.38	26.67	1.50
CBA	14	540.82	38.63	2.17*
CBxSs Within Groups	112	1992.11	17.79	
TxB	1	3.85	3.85	.23
TxBxA	1	3.71	3.71	.22
TBxSs Within Groups	8	133.01	16.63	
CxTxB	14	268.22	19.16	1.08
CxTxBxA	14	121.65	8.69	.49
CTBxSs Within Groups	112	1994.99	17.81	
Response Rqmt (R)	1	123.33	123.33	4.55
AxR	1	21.75	21.75	.80
RxSs Within Groups	8	216.73	27.09	
TxR	1	44.69	44.69	2.94
TxAxR	1	44.90	44.90	2.95
TxRxSs Within Groups	8	121.74	15.22	
CxTxR	14	195.33	13.95	1.00
CxTxAxR	14	311.30	22.24	1.60
CxTxRxSs Within Groups	112	1557.03	13.90	
BxR	1	299.29	299.29	9.62*
BxAxR	1	9.13	9.13	.29
BRxSs Within Groups	8	248.77	31.10	
CxBxR	14	224.95	16.07	.93
CxBxAxR	14	256.43	18.32	1.06
CBRxSs Within Groups	112	1933.49	17.26	
TxBxR	1	3.88	3.88	.18
TxBxAxR	1	.14	.14	.00
TxBxRxSs Within Groups	8	174.33	21.79	
CxTxBxR	14	344.00	24.57	1.34
CxTxBxAxR	14	283.38	20.24	1.11
CxTxBxAxSs Within Groups	112	2046.40	18.27	
Total	1199	24111.26		

* $p > .05$

Table 2. Results of LSD Testing within Trials Effect of Fluctuation Analysis

Trial \ Trial	2	3	8	1	4	7	12	9	13	5	6	11	15	14	10
$\bar{M}$	4.24	4.80	5.24	5.34	5.35	5.66	6.02	6.11	6.12	6.34	6.46	6.48	6.90	7.06	7.12
2						*	*	*	*	*	*	*	*	*	*
3								*	*	*	*	*	*	*	*
8													*	*	*
1													*	*	*
4													*	*	*
7														*	*
12															
9															
13															
5															
6															
11															
15															
14															
10															

Note. * indicates $p \leq .05$

Table 3. Results of LDS Testing within Intensity x Response Requirement Interaction (BxR) of Fluctuation Analysis

BxR[a]		22	11	12	21
BxR	$\bar{M}$	5.11	5.79	6.15	6.75
22					*
11					
12					
21					

Note. * indicates $p \leq .05$

[a]First digit indicates intensity: 1 = 15 db, 2 = 85 db.

Second digit indicates response requirement: 1 = free response, 2 = motor response.

Table 4. Results of LSD Testing Within Monaural Presentation Group in Trials x Intensity x Presentation Interaction (CxBxA) of Fluctuation Analysis

C x B \ CxB[a]	022	092	031	042	011	141	121	081	132	082	072	021	062	071	111	131	052	032	051	112	041	102	152	012	122	101	061	091	151	142
M	3.72	4.28	4.49	4.54	5.06	5.07	5.27	5.36	5.41	5.44	5.44	5.49	5.73	5.77	5.95	6.02	6.02	6.44	6.68	6.72	6.83	6.99	7.07	7.15	7.20	7.88	8.15	8.36	8.86	8.94
022																		*	*	*	*	*	*	*	*	*	*	*	*	*
092																						*	*	*	*	*	*	*	*	*
031																								*	*	*	*	*	*	*
042																									*	*	*	*	*	*
011																										*	*	*	*	*
141																										*	*	*	*	*
121																											*	*	*	*
081																											*	*	*	*
132																											*	*	*	*
082																											*	*	*	*
072																											*	*	*	*
021																												*	*	*
062																											*	*	*	*
071																													*	*
111																													*	*
131																													*	*
052																													*	*
032																													*	*
051																														
112																														
041																														
102																														
152																														
012																														
122																														
101																														
061																														
091																														
151																														
142																														

Note. * indicates $p \leq .05$

[a]Coding system: first 2 digits indicate trial number;
third digit indicates intensity: 1 = 15db. 2 = 85 db

Table 5. Results of LSD Testing Within Binaural Presentation Group in Trials x Intensity x Presentation Interaction (CxBxA) of Fluctuation Analysis

CxB \ CxBa	012	021	032	022	031	041	131	081	082	121	091	071	042	011	102	151	112	061	152	062	072	051	122	052	092	141	111	142	101	132
M	3.54	3.76	3.77	4.00	4.48	4.58	4.88	5.06	5.08	5.18	5.23	5.27	5.43	5.61	5.62	5.72	5.92	5.94	5.95	6.02	6.17	6.17	6.43	6.47	6.55	6.59	7.34	7.61	8.01	8.19
012																							*	*	*	*	*	*	*	*
021																							*	*	*	*	*	*	*	*
032																							*	*	*	*	*	*	*	*
022																											*	*	*	*
031																											*	*	*	*
041																											*	*	*	*
131																												*	*	*
081																													*	*
082																													*	*
121																													*	*
091																													*	*
071																													*	*
042																														*
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092																														
141																														
111																														
142																														
101																														
132																														

Note. * indicates $p \leq .05$

[a] Coding system: first 2 digits indicate trial number; third digit indicates intensity: 1 = 15db, 2 = 85 db

Table 6. Analysis of Covariance Source Table for the Acceleration Score.

Source	df	SS	MS	F
Between Ss				
Presentation (A)	1	95.32	95.32	.17
Ss Within Groups	7	3910.09	558.59	
Within SS				
Trials (C)	14	307.38	21.96	.52
CxA	14	653.16	46.65	1.09
CxSs Within Groups	111	4732.00	42.63	
Trial Type (T)	1	333.58	333.58	2.79
TxA	1	19.75	19.75	.17
TxSs Within Groups	7	836.83	119.55	
CxT	14	595.83	42.56	1.13
CxTxA	14	372.24	26.59	.70
CTxSs Within Groups	111	4194.35	37.79	
Intensity (B)	1	44.84	44.84	.63
BxA	1	1.34	1.34	.02
BxSs Within Groups	7	494.97	70.71	
CxB	14	756.70	54.05	1.18
CBA	14	375.44	26.82	.58
CBxSs Within Groups	111	5099.24	45.94	
TxB	1	152.54	152.54	2.97
TxBxA	1	71.18	71.18	1.38
TBxSs Within Groups	7	359.99	51.43	
CxTxB	14	889.49	63.54	1.65
CxTxBxA	14	758.85	54.20	1.41
CTBxSs Within Groups	111	4280.65	38.56	
Response Rqmt (R)	1	234.15	234.15	2.39
AxR	1	47.02	47.02	.48
RxSs Within Groups	7	686.63	98.09	
CxR	14	460.25	32.87	.73
CxAxR	14	222.23	15.87	.35
CxRxSs Within Groups	111	5031.09	45.33	
TxR	1	41.98	41.98	.66
TxAxR	1	2.94	2.94	.05
TxRxSs Within Groups	7	455.34	65.05	
CxTxR	14	698.90	49.92	1.18
CxTxAxR	14	535.64	38.26	.91
CxTxRxSs Within Groups	111	4682.20	42.19	
BxR	1	900.80	900.80	8.56*
BxAxR	1	1.62	1.62	.02
BRxSs Within Groups	7	736.64	105.23	
CxBxR	14	349.60	24.97	.63
CxBxAxR	14	304.05	21.72	.55
CBRxSs Within Groups	111	4366.99	39.34	
TxBxR	1	1.10	1.10	.09
TxBxAxR	1	104.05	104.05	8.83*
TxBxRxSs Within Groups	7	82.46	11.78	
CxTxBxR	14	482.78	34.48	.80
CxTxBxAxR	14	461.84	32.99	.76
CxTxBxRxSs Within Groups	111	4797.61	42.22	
Total	1183	67681.37		

* $p \leq .05$

Table 7. Results of LSD Testing within Intensity x Response Requirement Interaction (BxR) of Acceleration Analysis.

BxR \ BxR[a] / Mean	11	22	12	21
Mean	78.60	79.29	80.61	80.79
11				
22				
12				
21				

Note. * indicates $p \leq .05$

[a] First digit indicates intensity: 1 = 15 db; 2 = 85 db,

Second digit indicates response requirement: 1 = free response, 2 = motor response.

Table 8. Results of LSD Testing within Monaural Presentation Group in Trial Type x Intensity x Presentation x Response Requirement Interaction of Acceleration Analysis (TxBxAxR)

TxBxR[a] / TxBxR	222	211	111	122	112	212	121	221
$\bar{M}$	80.23	80.57	81.33	81.66	82.39	82.48	84.93	85.05
222				*	*	*	*	*
211					*	*	*	*
111							*	*
122							*	*
112							*	*
212							*	*
121								
221								

Note. * indicates $p \leq .05$

[a] Coding system: first digit indicates trial type: 1 = live trial, 2 = control trial; second digit indicates intensity: 1 = 15 db; 2 = 85 db, third digit indicates response requirement: 1 = free response, 2 = motor response.

Table 9. **Results of LSD Testing within Binaural Presentation Group in Trial Type x Intensity x Presentation x Response Requirement Interaction (TxBxAxR) of Acceleration Analysis**

	TxBxR[a]	222	212	111	122	112	221	211	121
TxBxR	M	74.63	76.50	76.60	76.97	77.65	77.74	78.01	80.39
222			*	*	*	*	*	*	*
212								*	*
111								*	*
122									*
112									*
221									*
211									*
121									

Note. * indicates $p \leq .05$

[a]Coding system: first digit indicates trial type: 1 = live trial, 2 = control trial; second digit indicates intensity: 1 = 15 db; 2 = 85 db, third digit indicates response requirement: 1 = free response, 2 = motor response.

Table 10. Sign Test Results of the Individual Comparisons of Specific Ordinal Post-tone Beats to Baseline HR for each Experimental Condition Ordinal Post-tone Beats

EXPERIMENTAL CONDITION	POST ONSET 1	POST OFFSET 1	2	3	4	5	6	7	8	9	10
MONAURAL											
15 Free Live	♦	11-				♦					
15 Free Control	♦	♦				♦					
85 Free Live	9-	♦	9+		♦						
85 Free Control	♦	♦									
15 Motor Live	7-	7-11-								9+11+	
15 Motor Control	7+	♦								♦	
85 Motor Live	7-	7-								11+2+9+11	
85 Motor Control	♦	♦								♦	
BINAURAL											
15 Free Live	4-	8-									
15 Free Control	♦	♦									
85 Free Live	♦	4+5+10+8-			♦						
85 Free Control	♦	♦									
15 Motor Live	♦	5+								5+8+	
15 Motor Control	♦	♦								8-	
85 Motor Live	4+10+	4+6+10								4-10-	
85 Motor Control	♦	♦								5+	

Note. Baseline HR is the mean rate of the last three complete beats pre-tone.

Within the table the numbers 1-11 refer to the subjects and the sign refers to a significant ($p < .05$) direction of change from the baseline; (+) indicates an increase while (-) indicates a decrease.

Table 11. Results of Sign Test Comparisons* of the Variability of the Ten Beats Pre-tone and the Ten Beats Post-tone for Individual Subjects for each Experiment Condition

EXPERIMENT CONDITION	
MONAURAL	
15 Free Live	ϕ
15 Free Control	ϕ
85 Free Live	ϕ
85 Free Control	7-
15 Motor Live	11+
15 Motor Control	ϕ
85 Motor Live	1+ 11+
85 Motor Control	ϕ
BINAURAL	
15 Free Live	ϕ
15 Free Control	ϕ
85 Free Live	5+ 8+ 10+
85 Free Control	10-
15 Motor Live	5+
15 Motor Control	ϕ
85 Motor Live	ϕ
85 Motor Control	ϕ

Note. * Within the table, the numbers 1-11 refer to the subject and the sign refers to either the increased (+) or decreased (-) variability ($\underline{p} \leq .05$).