PATTERNS OF PHYSIOLOGICAL ACTIVITY ACCOMPANYING PERFORMANCE ON A PERCEPTUAL-MOTOR TASK

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I. Introduction.

Air traffic controllers are required to spend considerable periods of time observing radar displays. Such demanding tasks require continuous visual attention. Yet, there is little information regarding physiological measures which might reflect changes in attention to complex visual tasks.

Recently, a number of studies have appeared which suggest that the attentional process in *simple* visual or auditory stimulus situations is accompanied by characteristic physiological changes. One of the most frequently reported patterns of change is heart rate deceleration with skin conductance increase.[1,5,7,10] In addition, Obrist[10] has also reported decreased heart rate variability and respiration amplitude, and Kagan and Rosman[4] report increased respiration rate along with reduced respiration rate variability.

One of the few studies which suggests that a similar pattern of physiological changes may also accompany attention to *complex* visual-motor tasks was conducted by Obrist, Hallman, and Wood.[11] These investigators found that, relative to the initial rest period, heart rate, heart rate variability, and skin resistance were lower during performance, although the decrease was significant only for heart rate variability and skin resistance. However, since they contrasted only the initial rest levels with mean levels obtained over the entire learning session, their data provide no information on possible changes in the trial-intertrial patterns of physiological activity as learning progressed. To the extent that the demands on attention are reduced as proficiency increases, changes in the physiological patterns might be expected.

As one phase of a study concerned with certain effects of stress on performance, all subjects (*S*s) were initially given a series of trials on a perceptual-motor task. Alternate training and rest periods were administered and continuous recordings of a number of physiological variables obtained. Since the tracking task used was a demanding visual task, analyses were made of the patterns of physiological activity obtained in order to provide further information on the attentional process accompanying complex perceptual-motor performance. It was felt that such analyses might also reflect changes in attention as proficiency on the task increased, as well as provide information as to which of the variables recorded best differentiated between the trial and intertrial periods. The data reported are based on control *Ss* employed and are not relevant to the primary purposes and findings of the broader study which will be reported elsewhere.

II. Method.

Subjects. Fifteen male college students between the ages of 18 to 25 were employed. All were right-handed with no prior experience on tracking tasks.

Apparatus. The basic task apparatus consisted of a console containing an oscilloscope which constituted the display for a two-dimensional compensatory pursuit tracking task. The spot on the oscilloscope was driven in a random manner by means of a cam function generator which varied the voltages to the horizontal and vertical deflection plates of the oscilloscope. The *S*'s task was to attempt to keep the spot continuously at the center of the oscilloscope by means of a small control stick located at his right hand. Minimal muscular effort was required to move the stick and an excursion of approximately one inch in any direction from center was sufficient to move the spot to the edge of the scope. Voltages defining the position of

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the target on the oscilloscope (i.e., the algebraic sum of the function generator and control stick voltages) were fed to a PACE TR–20 analog computer and the output voltage (absolute error) led to Beckman Type 9873B resetting integrator couplers.

In addition to the tracking task, reaction time measures were obtained to auditory stimuli presented through headphones. Fifteen 1,000 Hz, 75 db tones of 1.5 seconds duration were presented to each *S* during the training phase. Although the position of the tone stimuli within the trials was randomly determined, each *S* received the tones in the same temporal sequence. The reaction time data are relevant only to a subsequent phase of the larger study and will not be reported here.

A Beckman Type R Dynograph was used to record the physiological variables as well as tracking error. Beckman biopotential electrodes were attached to the lateral walls of the *S*'s chest with the leads connected to a Beckman Type 9857 cardiotachometer coupler. Skin resistance was obtained from two Fels zinc-zinc sulphate electrodes leading to a Fels Model 22A Dermohmmeter. One electrode was attached to the palmar surface of the left hand and the other to the ventral surface of the left wrist. The output of the Dermohmmeter led to another channel of the recorder. Beckman miniature biopotential electrodes were attached immediately above and below the right eye and DC coupled to the recorder. This yielded a gross indication of eye closure as well as blinks. Respiration was measured by means of a thin mercury-in-vinyl tube (Parks Electronics Laboratory), the ends of which were attached to Velcro bands and positioned on the *S* at the base of the rib cage. The mercury belt formed one of the arms of a bridge circuit.

All physiological recording equipment, as well as the task programing apparatus, were located in an adjoining room.

Procedure. The *S* was informed that the training phase consisted of a series of 2-minute trials with a 35-second rest period between each. He was told to try to keep the spot at the center of the scope at all times during the tracking periods. He was further told that while tracking he would occasionally hear a tone through his headphones, and that he should respond to each tone presented by pressing the button located on top of the control stick. It was repeatedly emphasized that he should try to keep absolutely motionless, except for the control stick movements, during both the rest and task periods and not to close his eyes during the rest periods. The *S* was informed that a red warning light would come on 5 seconds prior to the beginning of each trial. Fifteen trials were then administered.

Scoring and analysis of the physiological data. The periods chosen for analysis were the last 30 seconds of a trial, the first 30 seconds of the 35-second rest period following the trial, and the first 30 seconds of the subsequent trial. Four such scoring blocks were selected: (a) Trial 1, intertrial rest period, trial 2; (b) trial 5, intertrial rest period, trial 6; (c) trial 9, intertrial rest period, trial 10; and (d) trial 13, intertrial rest period, trial 14. The trial blocks chosen contained no tone stimuli within the scoring periods. In addition to the above, the 30-second period immediately prior to the warning light signalling the beginning of trial 1 was also analyzed.

The 30-second period prior to trial 1 and each of the 30-second trial and intertrial periods were then divided into 5-second intervals. For each *S* the maximum and minimum heart rates in each interval were scored and means obtained. The difference between the mean maximum and mean minimum heart rate in each period was determined and served as a measure of heart rate variability. Skin resistance was measured at the beginning and end of the scoring period for each trial and intertrial, converted to conductance values, and means computed. The number of eyeblinks occurring in each period was obtained and then converted to a rate-per-minute value. Respiration rate was obtained by counting the number of inspirations in the 30-second periods and converting to rate-per-minute. Rate variability was determined by measuring the difference between the longest and shortest respiratory period (as measured from peak-to-peak inspiration) in each scoring period and expressing the resulting value in terms of seconds. Respiration amplitude was measured from the onset to the peak of each inspiration. The difference between the largest and smallest inspiration in each period served as a measure of amplitude variability. The amplitudes of all inspirations were also summed in each period. This measure was obtained to evaluate possible changes in tidal

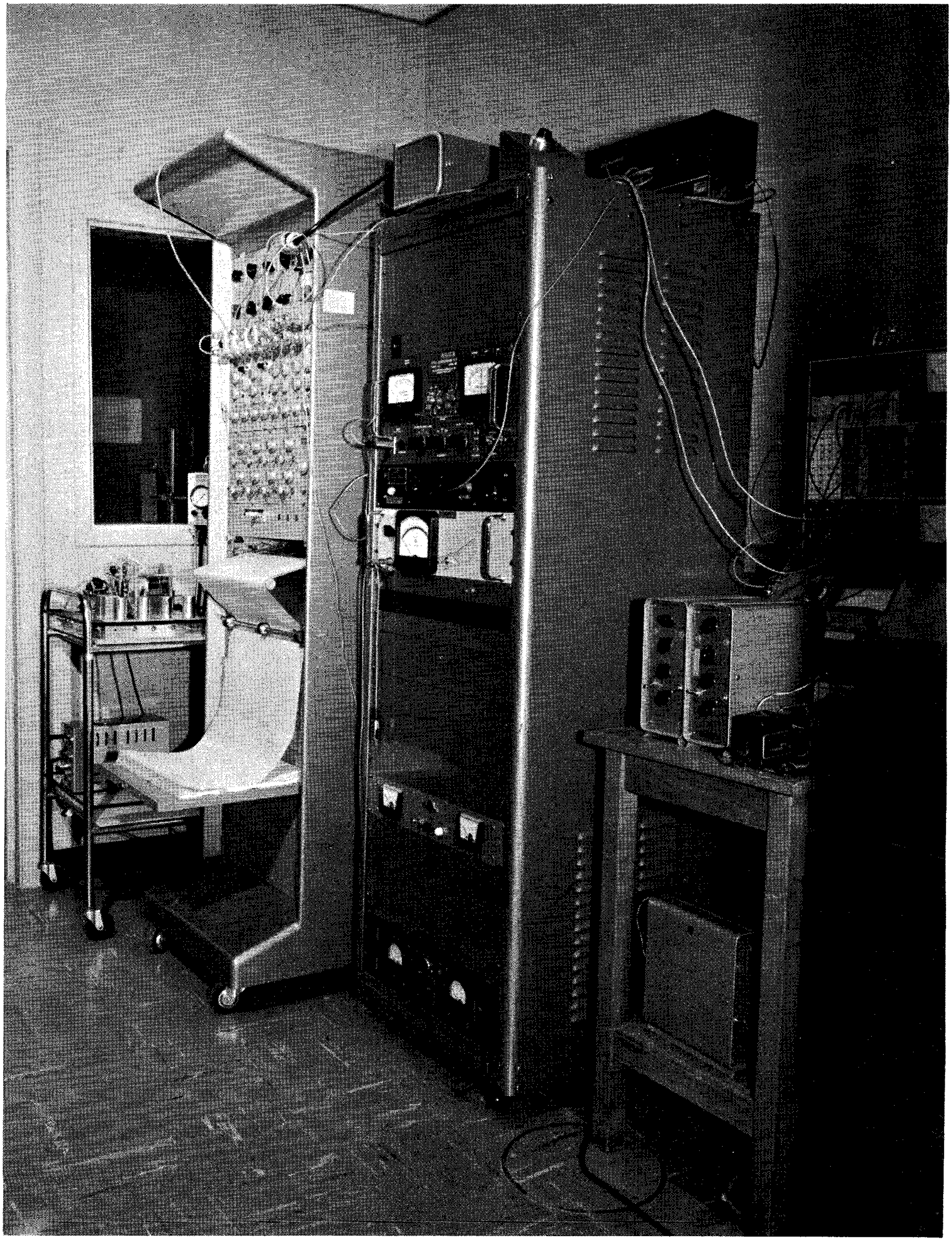

FIGURE 1. Physiological recording and task programming equipment.

FIGURE 2. Subject instrumented for physiological recording and performing task. The displays to the right on the console were not used in this experiment.

volume, although it is realized that measures of chest girth probably only approximate changes in tidal volume, and inferences to volume changes must be made with extreme caution.[14] Since both amplitude measures are relative, the values for each *S* for all trial and intertrial periods were expressed as ratios of the values obtained during the rest period prior to trial 1.

III. Results.

Figure 3 displays tracking errors over the 15 trials. The scores plotted are mean number of integrator resets obtained during the first 30 seconds of each trial. The curve appears fairly typical for a task of this type, with asymptotic level approached by trial 7. There is an increase in variability between trials beginning with trial 11 and an apparent rise in error at trial 15. The increased variability suggests that attention to the task may have been fluctuating, due to possible cumulative effects of fatigue, boredom, or feelings of discomfort competing with task stimuli. Unfortunately, termination of the training session with trial 15 made it impossible to determine whether the increase in errors during the last trial was the beginning of a progressive decline in performance, or whether it was simply an extension of the previous between-trial variability.

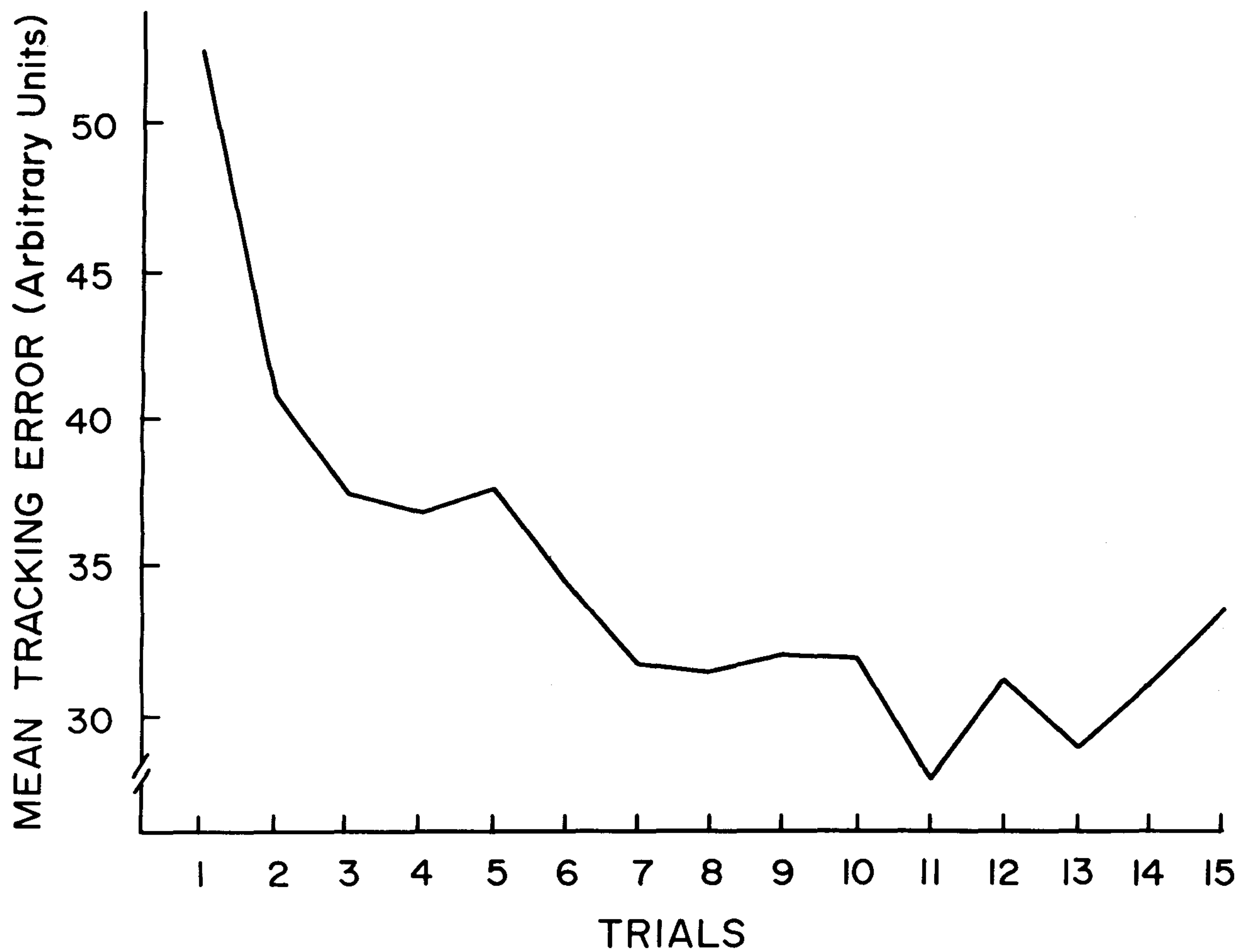

FIGURE 3. Mean tracking error across trials.

Figure 4 displays the mean values obtained for the trial and intertrial periods for maximum heart rate, minimum heart rate, and heart rate variability. Also shown are the values obtained for each of these measures during the rest period (R_I) prior to trial 1. For the sake of brevity, in this figure and in the subsequent ones, each of the separate trial-intertrial periods will be referred to as blocks. Thus, block 1 will refer to trial 1, intertrial, trial 2. Likewise, block 2 will refer to trial 5, intertrial, trial 6; block 3 to trial 9, intertrial, trial 10; and block 4 to trial 13, intertrial, trial 14.

In considering maximum heart rate, there is a general trend in all of the blocks, with the exception of the first one, for heart rate to be noticeably depressed during each of the trial periods relative to its intertrial. Analyses of variance conducted on the three periods within each block, however, yielded significant F ratios for blocks 2 and 3 only. The p-values for the within-block comparisons are shown on this

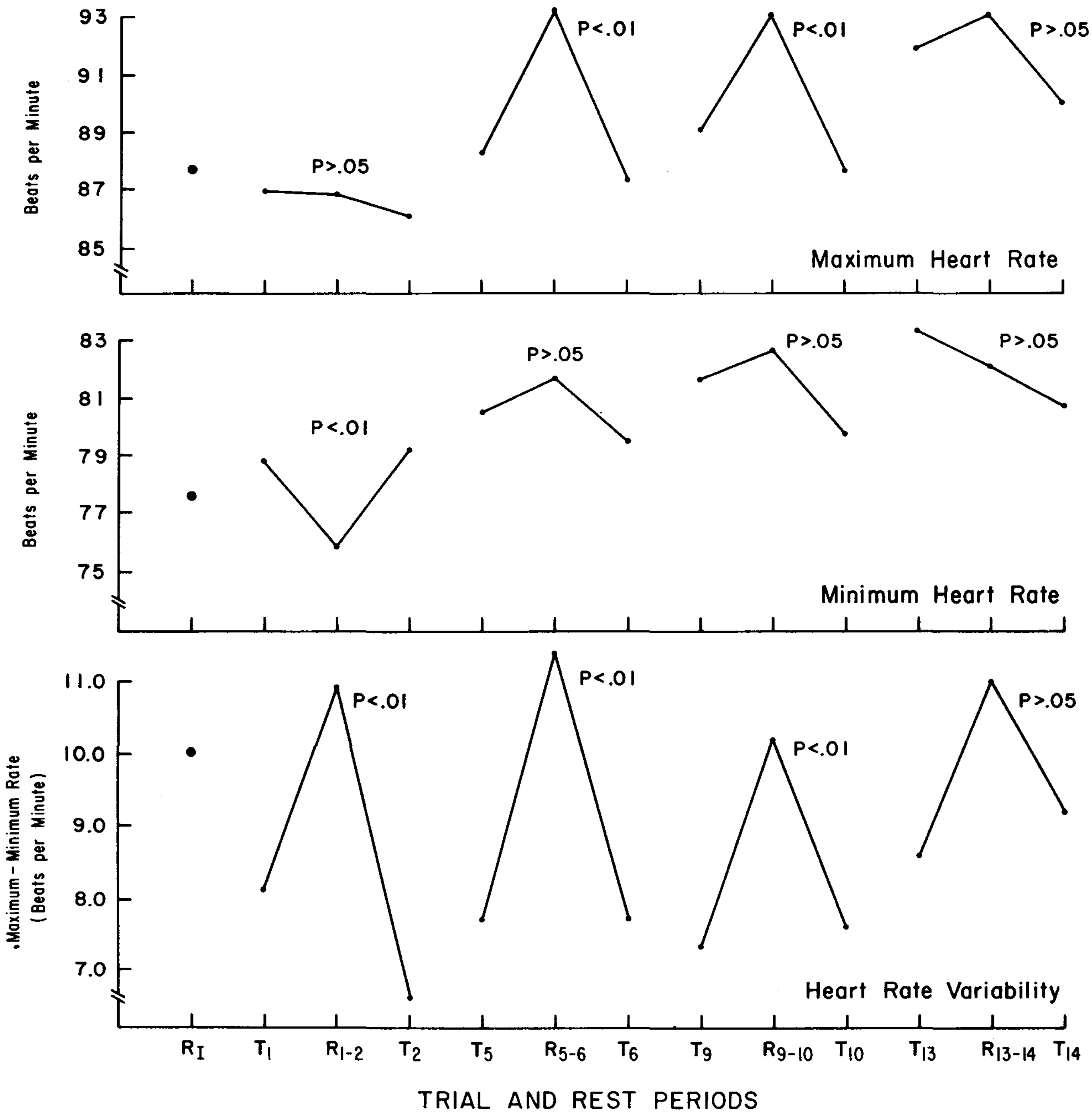

FIGURE 4. Maximum heart rate, minimum heart rate, and heart rate variability for the rest period prior to trial 1 and for the four trial-intertrial blocks.

figure (as well as the subsequent ones) adjacent to the curve for each block. The patterns for minimum heart rate parallel those for maximum heart rate in blocks 2 and 3, but only the analysis of variance conducted on block 1, which shows an interesting reversal of trend, was significant. The data for heart rate variability clearly reveal the greatest sensitivity in differentiating between the trial and intertrial periods. As indicated in the figure, the analyses of variance were significant for three out of the four blocks.

Figure 5 shows the data for respiration rate, respiration period variability, and respiration amplitude variability. Both respiration rate and respiration period variability reveal consistent within-block patterns. Relative to the intertrial periods, the corresponding trial periods show an increase in rate, with a reduction in period vari-

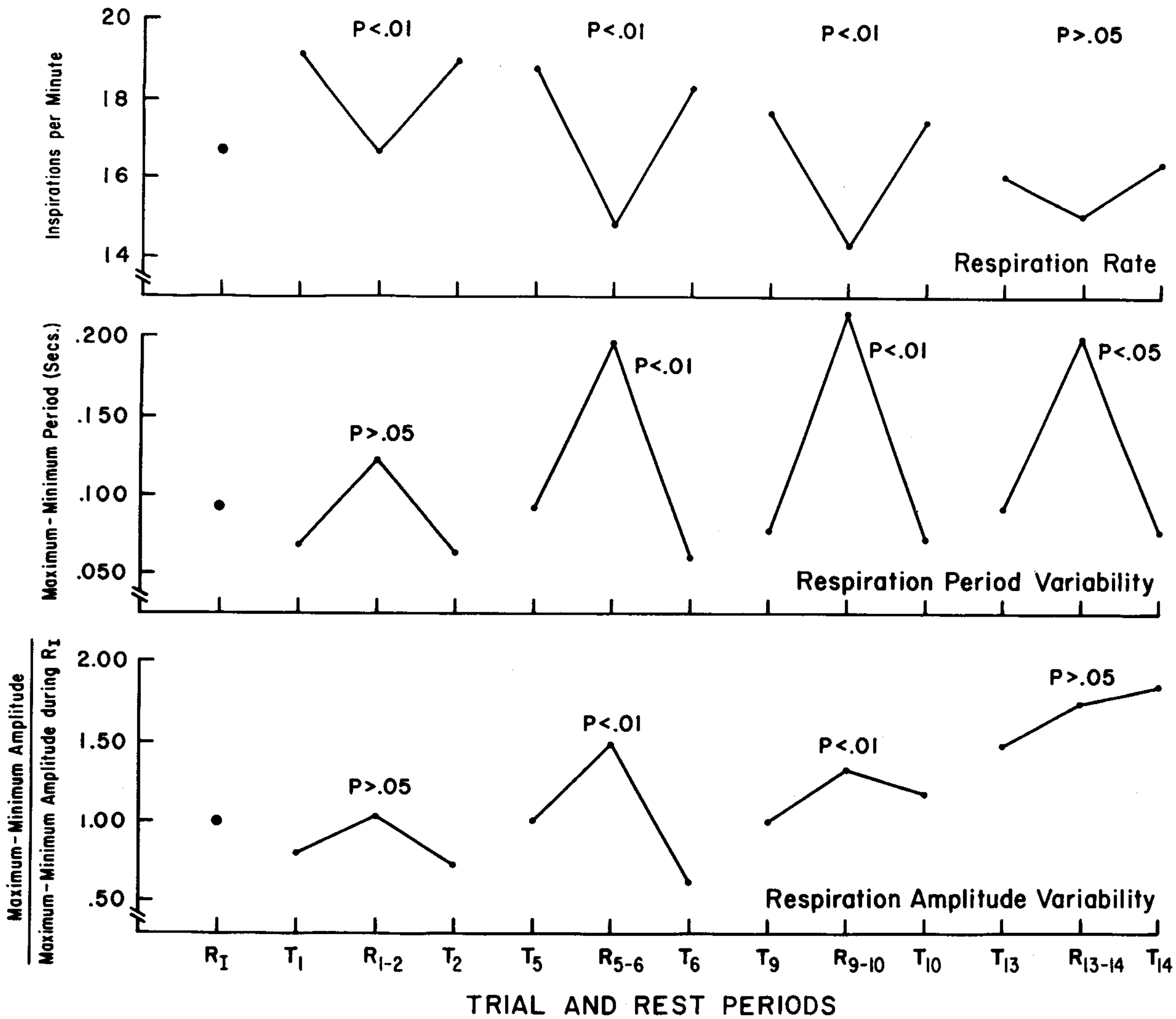

FIGURE 5. Respiration rate, respiration period variability, and respiration amplitude variability for the rest period prior to trial 1 and for the four trial-interial blocks.

ability. As noted in the figure, blocks 1, 2, and 3 were significant for respiration rate, while for respiration period variability, blocks 2, 3, and 4 were significant. Like period variability, amplitude of respiration also tended to be less variable during the trials than during the intertrials. However, the within-block changes were significant for only two of the four blocks. It should be noted that, while the curves shown for respiration rate were plotted from mean values and parametric analyses of variance conducted, those for both period and amplitude variability were plotted from median values because of the general lack of normality of the distributions. Because of the non-normality, Friedman nonparametric analyses of variance[13] were employed for these variables, and the p-values shown refer to the results obtained using this test.

Figure 6 shows the mean values for cumulative respiration amplitude, blink rate, and conductance level. Cumulative respiration amplitude reveals no consistent within-block trends and none of the analyses of variance were significant. Blink rate and conductance level were quite consistent, however, with blink rate being considerably depressed during the trial periods relative to the intertrials. Analyses of variance indicated the trends within all four blocks to be highly significant. Conductance level was found to be higher during the intertrial period than during the preceding trial period, and continued to increase during the subsequent trial. Analyses of

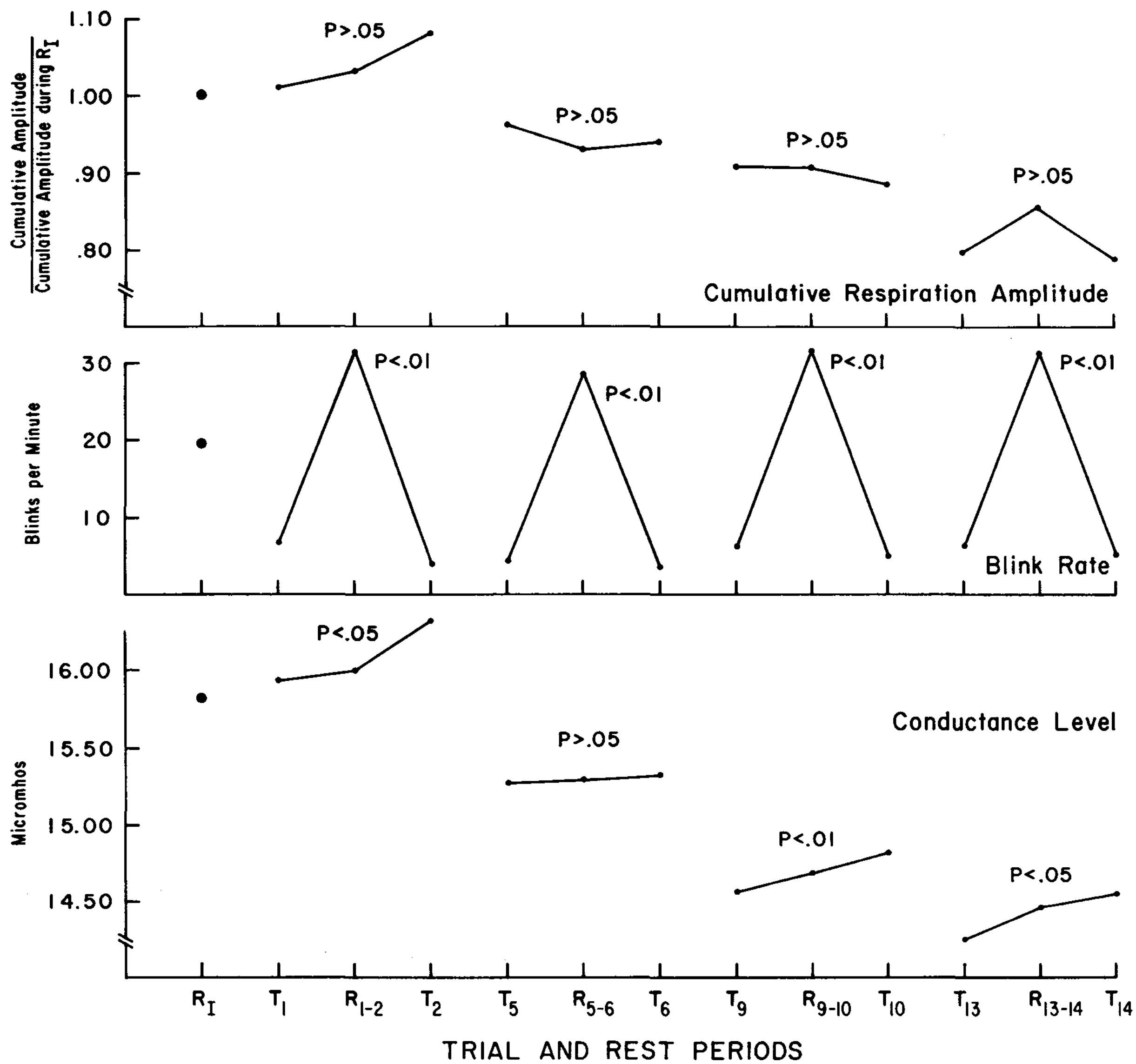

FIGURE 6. Cumulative respiration amplitude, blink rate, and conductance level for the rest period prior to trial 1 and for the four trial-intertrial blocks.

variance yielded significant effects in three out of the four blocks.

Since changes in physiological activity during the trial periods were evaluated and expressed in terms of their respective intertrial rest values, it seemed of interest to examine possible differences and/or progressive effects among the rest periods. Consequently, comparisons were made of the five rest periods (the four intertrial periods and R_I) for each variable with the exception of cumulative respiration amplitude and respiration amplitude variability. These two variables could only be examined for the four intertrial periods due to the values being expressed as ratios of R_I. Except for the necessity of conducting Friedman tests on the two respiration variability measures, all of the comparisons were tested by analyses of variance.

The analyses for three of the variables (cumulative respiration amplitude, respiration amplitude variability, and heart rate variability) revealed no significant differences among any of the rest periods ($p>.05$), while all of the remaining comparisons yielded significant differences ($p=.05$ or less). Examination of Figures 3 and 4 indicates that the significant differences for respiration rate and conductance level reflect a declining trend as the learning session progresses. Figure 2, however, reveals that the significant differences for both maximum and minimum heart rate reflect an increase in rate, relative to the R_I level, during the intertrial periods of the last three blocks. A similar pattern is shown in Figure 3 for respiration period variability. Examination of Figure 4 suggests that the significant difference found for blink rate is the result of the markedly low R_I value relative to the other four intertrial values. An orthogonal comparison[16] confirmed this impression by yielding a significant difference ($p<.01$) between the R_I level and the combined intertrial levels for all four of the blocks.

IV. Discussion.

The results of the present study revealed that heart rate variability, respiration rate, respiration period variability, and blink rate were the most consistent in clearly differentiating between the trial and intertrial periods. For each of these, the trial-intertrial patterns were significant in at least three out of the four blocks studied. Relative to the intertrial periods, the trial periods revealed decreased heart rate variability, respiration period variability, and blink rate, while respiration rate increased. With the exception of blink rate, the data suggest that the learning of a complex perceptual-motor task is accompanied by physiological changes during the trial and intertrial periods which are similar to those found for these same variables in simpler situations calling for passive attention to auditory or visual stimuli.[4,10] In a recently presented paper, Welford[15] has reported findings which further support those of the present study. He found reduced heart rate variability to accompany performance on both reaction time and tracking tasks with a marked increase in variability during the subsequent rest periods.

The consistency with which blink rate differentiated the trial-intertrial periods is quite interesting. Blink rate is known to be inhibited during performance on visual-motor tasks,[9] and this inhibition appears to be related to the attentional process. Thus, several studies have demonstrated that frequency of blinking is inversely related to the difficulty level of visual tasks.[2,17] Because the range of blink rate during the trial periods in the present study was quite small, with some *S*s showing no blinks, the sensitivity of this measure as a possible index of attention, however, may not be as great as some of the others employed, especially in terms of differentiating between individuals.

Of the two heart rate measures, maximum rate was superior to minimum rate in differentiating the trial and intertrial periods, although neither measure was as consistent as variability of heart rate. The greater sensitivity of heart rate variability over heart rate itself was an unexpected finding. However, Obrist, *et al.*[11] also found heart rate variability to be superior to heart rate in differentiating rest periods from task periods during mirror tracing performance.

Respiration amplitude variability was diminished during the trial periods relative to the intertrials, although this pattern, like that for maximum heart rate, was significant in only two of the four blocks. Cumulative respiration amplitude showed no consistent or significant trial-intertrial pattern. This suggests that no significant changes in tidal volume accompanied the other changes in respiration within the trial-intertrial blocks. As noted earlier, though, changes in chest girth may be quite inadequate in reflecting changes in tidal volume, and this finding should be interpreted with considerable caution.

Conductance level revealed a consistent pattern in three out of the four blocks, but one which differed from the general pattern displayed by most of the other variables. The question of why conductance increased during the intertrial period and continued to increase during the initial period of the subsequent trial is difficult to answer. Lack of correspondence, however, between the direction of change in conductance level and the direction of change in other indices of sympathetic activity, such as heart rate, has been previously found by Lacey[5,6] and others[1,10] to accompany attentive observation. Lacey[5] has referred to this general phenomenon as "directional fractionation" of response.

Directional fractionation was also shown in the rest period trends during the training session. Thus, the patterns of within-block change for some of the variables appeared to be superimposed upon levels which suggested declining sympathetic-like activity (i.e., conductance level and respiration rate), while the patterns for other variables, such as maximum heart rate, were superimposed upon levels which suggested increasing sympathetic activity. Respiration period variability likewise increased from the initial rest level, although it is not known whether or not this would imply an increase in sympathetic activity. Heart rate variability, respiration amplitude variability, and blink rate showed no progressive changes in the intertrial rest levels which were significant, although the intertrial blink rate levels were significantly elevated over the initial rest level.

It is interesting to speculate on the possible significance of these divergent trends during the learning session. Post-experimental inquiries indicated that many *S*s felt increasingly drowsy, fatigued, and restless, especially toward the end of the session. Such factors may have lessened attention to the task or acted as distracting influences, and could have contributed to the increased between-trial variability in tracking performance found beginning with trial 11. Thus, it seems entirely possible that the progressive decline in conductance level and respiration rate reflected this increasing drowsiness and fatigue, while the general increase in heart rate may have resulted from an attempt to compensate for these detrimental influences. Such an explanation has also been offered by Eason, Beardshall, and Jaffee[3] to account for declining conductance level with a corresponding increase in muscle tension during the course of a prolonged vigilance situation.

The possibility that attention to the task declined or fluctuated more toward the end of the session could also account for the fact that there were fewer variables showing significant within-block patterns of change in block 4 than in any other block. While this may indicate that some of the variables were more sensitive than others in detecting changes in attention, further research is clearly needed in which a variety of cardiac and respiratory variables, as well as perhaps blink rate, are studied as a function of declining (or increasing) attention to perceptual-motor or vigilance tasks to determine which are most sensitive to such changes.

Finally, Lacey[5,6] has proposed, and reviewed the evidence for, a mechanism whereby cardiac deceleration can facilitate sensory input via baroreceptor feedback to the central nervous system. While such a feedback system undoubtedly contributes to the attentional process, the data obtained here, as well as in studies referred to earlier, suggest that heart rate reduction may be only one aspect of a more extensive central process which exerts a suppressive or regulatory influence on the cardiac, respiratory, and somatic systems (at least as reflected in blink rate) during attention, with a consequent release of this suppression or regulation during rest periods. Suppression of eyeblinks during visual attention should facilitate information intake.[8] Whether the increased respiration rate, along with reduced amplitude and rate variability, also contributes directly to information intake is not clearly understood. Oswald,[12] however, has reviewed the results of a few early studies which suggest a relationship between fluctuations in attention and respiratory rhythm.

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