Tonic and phasic changes in interbeat interval and ECG transit time during the foreperiod of a reaction time task

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Interbeat interval (IBI) and ECG transit time (ECG-TT) were measured during the foreperiod of a reaction time task. Thirty subjects received one of three different foreperiod durations (10, 20, or 40 beats). During longer foreperiods, warning tones sounded at 10-beat intervals. Regardless of foreperiod length, ECG-TT decreased prior to the "respond" signal. IBI showed the commonly reported biphasic changes during the 10-beat condition and in response to each presentation of the tone at longer foreperiod durations. With long foreperiods, idiosyncratic tonic changes in both IBI and ECG-TT also occurred, with half of the subjects showing consistent tonic decreases in both IBI and ECG-TT and the remainder showing tonic increases. The results have significance both for hypotheses concerning the preparatory nature of phasic cardiovascular changes and in their demonstration of individual differences in tonic conditioned response patterns.

During the foreperiod of the reaction time (RT) task, a biphasic change in heart rate is usually reported (e.g., Obrist, Webb, & Sutterer, 1969) consisting of an initial acceleration followed by a deceleration prior to "respond" signal onset. Since the magnitude of the cardiac deceleration has been found to be associated with the speed of the RT (Lacey, 1967; Webb & Obrist, 1970), the cardiac deceleration has been seen as part of a preparatory response. Lacey and his colleagues (e.g., Lacey, 1967) have argued that a decrease in heart rate reduces baroreceptor-mediated inhibition of the sensorimotor centers, thus allowing a faster RT, while others have suggested that the decreasing heart rate is a function of concomitant decreases in somatic activity (Obrist et al., 1969; Webb & Obrist, 1970).

Although the RT task continues to be widely used by psychologists to investigate phasic preparatory cardiovascular responses (e.g., Jennings, Schrot, & Wood, 1980), Obrist (1976) has argued that long-term or tonic responding may be of more interest than such phasic changes. Tonic changes are possibly of more significance to the organism than phasic responses, since they represent periods of sustained cardiac activity. Although the terms "tonic" and

"phasic" remain to be precisely defined, the distinction may prove useful in categorizing cardiac responses. For example, Obrist and his colleagues (Obrist, Gaebelin, Teller, Langer, Grignolo, Light, & McCubbin, 1978) demonstrated that tonic HR changes during a series of unsigned RT tasks differed from the phasic responses, in that they were of larger magnitude, were acceleratory rather than deceleratory, and were sympathetically, rather than vagally, determined.

However, investigations of tonic cardiovascular responding during a RT task have been limited to the presentation of blocks of unsigned RTs, so that the cardiovascular changes observed are averaged across foreperiod, buttonpress, and postresponse periods. Thus, the tonic changes cannot be regarded as preparatory responses in the same sense as the phasic cardiac deceleration in the foreperiod of a signaled RT task.

In the experiment to be reported here, the RT task was used to investigate tonic preparatory changes by greatly extending the duration of the foreperiod. The opportunity to use the foreperiod as preparatory was enhanced at long durations by the use of a countdown signal indicating the approach of the "respond" signal. If cardiac deceleration is the optimal preparatory response, then greater deceleration may be expected with increasing foreperiod length. A greater magnitude deceleration has been found with foreperiod durations up to 16 sec (Webb & Obrist, 1970), but durations of sufficient length to be regarded as generating tonic changes have not been investigated. In contrast, to the extent that the foreperiod is long enough to observe tonic changes, an

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overall sympathetically mediated cardiac acceleration might be expected.

In addition to cardiac rate, the time between the ECG signal and the arrival of the resulting pulse (ECG-TT) at the popliteal artery, behind the left knee, was measured. Changes in ECG-TT, which have been reported as reflecting changes in mean arterial pressure (Steptoe, Smulyan, & Gribbin, 1976), systolic blood pressure (Obrist, Light, McCubbin, Hutcheson, & Hoffer, 1979), and the pre-ejection period (PEP) (Newlin & Levenson, 1979), are particularly susceptible to changes in sympathetic activity to the heart (Obrist et al., 1979). Since the tonic changes in heart rate described by Obrist (1976) were sympathetically mediated, changes in a measure reflecting such activity is of particular interest with long foreperiod durations. In addition, ECG-TT has not previously been recorded within a RT task, yet its apparent relationship with systolic blood pressure may provide relevant information on other aspects of the preparatory cardiovascular response.

METHOD

Subjects

Thirty stage 1 psychology students volunteered to participate in the experiment.

Equipment and Physiological Recording Procedures

The presentation of stimuli and data collection were controlled by a Hewlett-Packard 9835B desktop computer. ECG-TT and interbeat interval (IBI) were recorded.

The pulse was transduced from behind the left knee using a Biocom piezo electric-pulse transducer (Model 1010). The ECG-signal was detected using Lead II with Beckman electrodes. All signals were ac coupled to a Beckman Offner Dynograph, Type S, for preamplifying and conditioning.

The popliteal pulse was passed through a Multimetrix AF-410 low-pass filter set at 30 Hz and then fed into a dual-channel Gould Advance Storage oscilloscope (OS 4000). Each sweep of the oscilloscope was initiated by the R wave of the ECG, and the sweep speed of the oscilloscope was set on 0.05 cm/sec. Each frame of the oscilloscope was digitized and output to the computer, which calculated ECG-TT from the ECG signal to the onset of the sharp upsweep of the popliteal pulse. ECG-TT was determined with millisecond accuracy.

IBI was measured between successive R waves of the ECG using a Hewlett-Packard counter-timer (Model 5328A) with millisecond accuracy.

Procedure

All subjects attended the laboratory for two 1-h sessions. Upon arrival at the laboratory on both days, the subject was comfortably seated in a temperature-controlled, sound-attenuated room. His or her left leg was extended in a horizontal position and supported under the heel. Microphones and electrodes for physiological recordings were attached, headphones through which music was played throughout the experiment were positioned, and the subject was instructed to relax. The subject was then left alone and data collection was begun.

On the first session, the subject received five habituation trials, each consisting of a 10-beat baseline period, four presentations of the 2-kHz tone that was to be the CS at 10-beat intervals, and a 40-beat recovery period. The experimenter then explained the RT task and presented 10 unsignaled practice trials. The subject was re-

quired to depress a button as fast as possible on detecting the "respond" signal. The "respond" signal was the onset of a red diode on the front of a Hewlett-Packard counter timer (5300B), which also provided feedback of millisecond accuracy on the speed of the reaction time response.

The rest of the procedure was identical for both sessions. The subjects were presented with 20 trials of signaled RTs. Each trial began with the collection of 10 beats of baseline data, and, following each RT response, 40 beats of postresponse data were collected and a variable intertrial interval ranging from 20 to 40 sec was programmed. The subjects were assigned randomly to one of the three experimental groups. The groups differed only in the length of the foreperiod prior to the "respond" signal, with one group receiving a 10-beat interval, a second group receiving a 20-beat interval, and the third group receiving a 40-beat interval. For the 10-beat group, the tone preceded the onset of the "respond" signal by 10 beats. The other two groups received the same tone at 10-beat intervals throughout the foreperiod.

RESULTS

For each subject, the median change from baseline on each beat of the foreperiod during Session 2 was calculated. Based on these data, the mean and standard errors across subjects were computed and are presented in Figures 1 (IBI) and 2 (ECG-TT). As IBI

Figure 1. Beat-by-beat changes in IBI (in milliseconds) during the foreperiod at 10-, 20-, and 40-beat durations: Mean response across subjects during the last 20 trials. Error bars represent plus and minus one standard error.

Figure 2. Beat-by-beat changes in ECG-TT (in milliseconds) during the foreperiod at 10-, 20-, and 40-beat durations: Mean response across subjects during the last 20 trials.

was recorded, the results will be discussed as heart period, the inverse of heart rate.

10-Beat Condition

IBI. A biphasic IBI response consisting of an initial decrease in IBI followed by increasing values prior to the "respond" signal. This response shape occurred consistently across subjects.

ECG-TT. A biphasic ECG-TT response was also evident with the four initial beats, showing a lengthening of transit time with a later marked decrease in transit time prior to the "respond" signal. This shape also occurred consistently across subjects.

20-Beat Condition

IBI. Overall, a tonic decrease in IBI was apparent, although the large standard errors are indicative of marked interindividual variation.

ECG-TT. A small initial lengthening of ECG-TT was followed by a period of decreasing transit time up until "respond" signal occurrence. Again, interindividual variation was marked.

40-Beat Condition

IBI. Both tonic and phasic changes in IBI were apparent. Following every tone, a decrease in IBI occurred, followed by a period of lengthening IBI. These phasic changes were superimposed on a tonic decrease in IBI. In the later beats of the foreperiod, between-subject variability was marked.

ECG-TT. Tonic and phasic changes in ECG-TT were also apparent. Following each tone, a rapid small increase in transit time is evident; this is followed by a period of decreasing transit time prior to the onset of the next tone or buttonpress. These phasic changes were superimposed on a tonic decrease in ECG-TT, and again considerable inter-subject variability was evident towards the end of the CS period.

Individual Tonic Response Patterns

The marked intersubject variability evident with increasing foreperiod length suggested that the grouped comparison was inappropriate. A closer examination of individual data indicated that in both the 40- and the 20-beat conditions two distinct patterns emerged, with subjects showing either a tonic lengthening or decrease in both IBI and ECG-TT. A post hoc analysis was performed in which subjects were grouped according to the direction of their tonic responses. For the 40-beat condition, five subjects showed a tonic increase and five, a decrease. A summary of this data is presented in Figure 3.

It is evident that subjects gave a consistent tonic response across all trials, and that those subjects who showed a tonic decrease in IBI also showed tonic decreases in ECG-TT. The remaining subjects showed a tonic increase in IBI towards "respond" signal onset concurrent with a slight lengthening of ECG-TT.

The groups were not differentiated either on the basis of mean RT or on absolute baseline IBI levels.

DISCUSSION

To summarize the findings, in the 10-beat condition an initial lengthening of ECG-TT was observed, followed by a decrease below baseline which persisted until "respond" signal onset. This form occurred in a similar manner for all foreperiod lengths. The commonly reported biphasic IBI response was observed in the 10-beat condition, and in the 40-beat condition this biphasic response occurred after every presentation of the tone. With lengthening foreperiod, the phasic response was accompanied by tonic changes. Individual differences in tonic responding were marked, with half of the subjects showing a reliable decrease in IBI and ECG-TT and the remainder showing lengthening IBI and little change, or a slight decrease, in ECG-TT.

These findings have several implications. First,

Figure 3. Alternative tonic response modes shown during the foreperiod in the 40-beat group, separately for each 10-trial block. Each point represents the mean of 10 beats, averaged across subjects.

they offer little support to the hypothesis that the lengthening of IBI from baseline observed in the 10-beat condition is preparatory for the following RT buttonpress. If the lengthening was advantageous, a greater increase from baseline would be expected with a longer preparatory interval. This was not observed. Furthermore, since faster RTs would be expected with a greater increase in IBI, RT speed should have been greater in the 10-beat condition. This did not occur. Also, those subjects showing tonic lengthening of IBI prior to the "respond" signal did not have faster RTs than those subjects who had shown a tonic decrease in IBI. In addition, the occurrence of a similar biphasic response to each tone presentation in the 40-beat condition suggests that this form, both the initial decrease and the later lengthening of IBI, is a function of tone presentation rather than of preparation for the RT response.

Second, the ECG-TT changes observed in this experiment are difficult to interpret within a hypothesis that views the cardiac deceleration as part of a preparatory response that results in a faster reaction speed by reducing baroreceptor-mediated inhibition of the sensorimotor centers. The Lacey hypothesis

predicts that, since baroreceptors are pressure sensitive, decreases in blood pressure should be observed prior to the "respond" signal. However, in this experiment, decreases in ECG-TT were found before the RT task at every foreperiod length, and these decreases are likely to reflect increases in systolic blood pressure (Obrist et al., 1979) and mean arterial pressure (Steptoe et al., 1976).

Third, the use of a long foreperiod does appear to have generated tonic responding. The decrease in IBI occurs concomitantly with the decreases in ECG-TT, which have been argued to reflect beta-adrenergic influences on the myocardium, reducing the duration of the PEP component. Thus, in the 40-beat condition, tonic changes occurred which may have been determined by an increase in sympathetic activity to the heart. Such tonic changes have been argued to be of considerably more interest to psychophysicists than the vagally determined phasic changes (Obrist, 1976).

The observation of tonic changes at long foreperiods also has implications for the analysis of phasic responding. In the 40-beat condition, the last warning tone has the same temporal relation to the "respond" signal as the tone in the 10-beat condition. The failure to find similar increases from baseline in IBI in the last 10 beats of the 40-beat condition suggests that the phasic cardiac deceleration below baseline observed with a short foreperiod is a function of constraints imposed by the procedure.

Further evidence of the dependence of the biphasic response upon the particular foreperiod used is provided by the inconsistent responding observed with a 20-beat interval. Although in the 40-beat condition clearly distinguishable phasic and tonic changes were occurring and with a 10-beat duration only phasic changes were visible, the 20-beat foreperiod would appear to be something of an intermediate interval. There was little evidence of a phasic response to the tone, and intersubject variability was large. There was some indication of the development of individual differences in tonic responding, but this was not as unequivocal as that observed for the 40-beat condition. This particular foreperiod duration thus appears to provide conditions optimal for the development of neither phasic nor tonic responding.

Finally, while all subjects behave similarly with a 10-beat interval, the use of longer foreperiods appears to permit idiosyncratic tonic responses to develop. Such individual differences may be interesting in relation to the development of essential hypertension, since they indicate that, within a conditioning paradigm, large-magnitude decreases in IBI and sustained decreases in ECG-TT may occur in some individuals but not in others. To the extent that such increases are sympathetically mediated, the individual differences observed may be particularly interesting, since it is frequently argued that it is an inap-

propriate increase in sympathetic activity which results in the development of essential hypertension (Julius & Esler, 1975).

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