The effect of cardiac detection upon heart rate control: An extension

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The present study is an attempt to determine whether the subject's effort to put her own cardiac activity into entrainment with artificial extrinsic feedforward signals, as target response, facilitates learned cardiac control. During the initial six sessions, subjects were trained to press key simultaneously with feedback signals in order to facilitate their interoceptive detection of cardiac activity. During the latter four sessions, which were provided for the period of control training, these same subjects were required to bi-directionally control their cardiac activity, under conditions of entrainment effort to extrinsic feedforward signals as target response for two sessions and under conditions of no such signals for two sessions. Results replicated and extended our previous findings on interoceptive detection and cardiac control, i.e., the two experimental groups showed significantly better cardiac control than the control group, lending support to the notion that entrainment effort may serve as a behavioral strategy for developing self-control on cardiac activity.

Key words: cardiac control, entrainment, artificial extrinsic feedforward signals, target response, interoceptive detection.

The present study is an extension of a preceding one by Hamano (1980), which investigated the relation of interoceptive detection to self-control in cardiac activity without mechanical aids. The results seemed to suggest some kind of substantial relation, but the detection of interoceptive signals did not have so great an effect on controllability as expected. In this respect one possible reason was proposed. According to Pribram's (1976) theoretical account, the development of self-control as such requires the formation of feedforward organization which leads to the responding toward an appropriate direction by some form of self-produced programme. A similar scheme has also been proposed by Brener (1974, 1977). The physiological substrate for this notion is apparently the interoceptive detection of the response to be controlled. At early primitive levels in the development of feedforward organization, feedback signals presented through the biofeedback technique act to render discriminable interoceptive events which are related to the occurrence of target response. The con-

ditions for and means of attaining this ability to discriminate are discovered blindly, or by the intuitive way. At the same time, because of the development of such response strategies, the image construction occurs. At later stages of development, when the image becomes sufficiently complex and is endowed with memory, it begins to acquire the characteristic of feedforward organization that reproduces the target response following the withdrawal of the feedback signal. The outline of this general model for self-control appears to be relatively easy to discern. However, in practice this general notion seems to involve coping with some difficulties. It seems plausible that one potential source of them may stem in part from intersubject variability in such intrinsic autonomic responding as noted by the accumulating literature relating to the individual characteristics of the subjects's physiology (Gatchel, 1974; Bell & Schwartz, 1975; Stephens, Harris, Brady, & Shaffer, 1975; McCanne & Sandman, 1976; Roberts, 1977). What is being proposed here is the total dependence of

autonomic compliance with the directional requirement upon such intrinsic responding. Thereby, as Katkin and Shapiro (1979) point out, the attenuation of the treatment effect may be caused by inter-subject variability. It is assumed, therefore, that training over a prolonged period is necessary to develop sufficient feedforward organization in conformity with this notion.

In the present study, as one way to circumvent this objection, the author attempted to require subjects to entrain their cardiac activity to artificial extrinsic feedforward signals employed as target responding. Although there has been little experimental basis available for such an approach through entrainment, we can empirically enumerate several entrainment phenomena: instances of a psychologically exalted feeling due to quick musical tempo, or reverse cases of entrainment function in the nervous system, as perceived in the inducement of tranquility. The author's conception for the introduction of a substitute process by means of a kind of modeling as target responding is based on such empirical instances as have been mentioned.

Method

Subjects

Twenty-four female undergraduates with an age range of 19–23 years at Notre Dame Seishin University served as subjects. None had any personal histories of cardiovascular disease nor any prior experience with experiments of this kind.

Recording and Apparatus

In the experiment, the heart beat (HB) with concomitant respiration measurement was recorded. HB was obtained from subject's right and left arms by ECG electrodes. Respiration was measured in the standard manner using a strain gage mounted on a rubber chest strap. The physiological recording devices were iden-

tical to those used in the previous study (Hamano, 1977). An amplified ECG signal was also fed to a feedback and artificial feedforward signal administration equipment set via an output jack of a cardiometer. The equipment set was used to generate a pulse frequency equal to the subject's HB. A sequence of tactile signals which were triggered by the set was delivered to the subject's right middle fingertip through a vibrator. The basic procedure of the initial sessions in the present study required the subject to press a microswitch button every time she felt her HB. The level of HB detection was assessed by examining the distribution of latencies from HBs to button presses. Thus, logic modules were programmed so as to record the time interval occurring between each button press and the HB which immediately preceded it. These latencies were recorded in 100 ms interval categories. Latencies longer than 1 000 ms were not recorded. Electromagnetic counters also recorded the frequency of various sequences of button presses and HBs. One counter recorded the number of HBs which followed a HB, another counter tallied the number of HB-button press latencies within a range of 0–100 ms, and a third one determined the number of HB-button press latencies within a range of 400–600 ms.

Procedure

Twenty-four subjects were divided into three groups each containing eight subjects. The experiment consisted of 10 sessions which comprised a total of 46 trials, each 10 seconds in duration.

In the initial six sessions (the BP sessions), the procedure was identical to that described by Hamano (1980). Each session was composed of five trials. On the first four trials for each of the BP sessions, all the subjects of the two experimental groups (FF and FF-K groups) were asked to calibrate extrinsic HB feedback signals with the intrinsic sensations that are con-

sequent upon their cardiac activity. This lasted throughout the button press effort in synchrony to each of the signals. On the other hand, all the subjects of the control group (C group) were required to perform a button press in response to each of forty artificial pulses per minute given as tactile signals. On the last trial, the 5th for all groups, no tactile signal was presented to the subject's right middle fingertip. The subjects of the FF and FF-K groups were instructed to press a button as soon as the signal is given, in response to each of the intrinsic HB feedback signals. Those of the C group were requested to reproduce the periodicity of these pulse sequences experienced on the preceding four trials by performing button presses.

The latter four sessions were for the bi-directional control of HB increase and decrease. Each of these sessions consisted of four trials and HB control was assessed employing the same procedure for all groups. In the first two sessions (the FW sessions), the artificial extrinsic feedforward signals were delivered to the subject's right middle fingertip through a vibrator as target responding, and all subjects were instructed to put their HBs into entrainment with those signals. Ninety artificial pulses per minute were employed as an extrinsic target responding for the HB increase trial, and forty per minute for the decrease trial. In the remaining two sessions (the NFW sessions), subjects were asked to attempt to increase or decrease their HBs without artificial aid. They were also required not to engage in any abnormal breathing and to refrain from bodily movement or any other maneuver involving muscular tension in which they could affect control of their HBs. In neither the FW nor NFW sessions were button presses performed. The directional requirement in HB control was verbally given alternately towards increase and decrease, immediately prior to the onset of each trial. Finally, the only treatment in which the groups were different, was

that in the FF-K group the knowledge of the results was given following each trial throughout all the sessions, whereas the other two groups did not receive that knowledge.

Results and Discussion

Figure 1 shows the percentage of correct response frequency for each 5th trial of the 1st and 6th BP session. In this presentation the correct response frequency as a basic dependent variable was determined in the manner described in the Hamano study (1980). As with the initial investigation, the button press events with a latency range of 100 ms to 400 ms between HB and button press were regarded as correct responses and they were used for an analysis of the results, as a measure of the successful detection of the intrinsic HB. Although the 5th trial-frequencies for the 1st BP session were different, the differences among these medians were not statistically significant, indicating that the groups did not differ in the initial frequency. An inspection of the histogram in Fig. 1 shows that there was an improvement in interoceptive detection from the 1st to the 6th BP sessions for the two experimental groups, while the C group displayed poor detection. An analysis of variance of these data confirmed that a significant group effect, $F(2/42)=5.241$, $p<.01$, was obtained. In the 5th trial-

Fig. 1. Median percent of correct responses.

frequencies of the 6th BP session the results of the t tests were significantly different between the FF and C groups, $t(42)=2.998$, $p<.01$, and between the FF-K and C groups, $t(42)=2.563$, $.01<p<.05$. This observation is interpreted as evidence that the training with cardiac-motor coupling led to successful HB detection for the two experimental groups. Further evidence in support of this contention is contained in the significant sessions effect, $F(1/42)=4.082$, $.01<p<.05$. This finding may make us consider the possibility of the periodicity that the subjects of the FF and FF-K groups learned to press the button at a frequency approximating their HBs. However, such a possibility could hardly be supported because confirmation of the negative view of the issue of periodicity had been obtained in some previous exploratory work (Miyake & Hamano, 1978; Hamano, 1980). In the preceding one of this series, the Experimental and Control groups were run under the same conditions as those of the BP sessions in the present study except that extrinsic signals connected with the subject's own HBs were fed back also to the Control group. The only difference between those groups lies in the fact that the Experimental group received instruction emphasising the calibration of extrinsic feedback signals with intrinsic HBs, whereas the Control group did not. The results showed that the latency distribution of the Experimental

group had the tendency to converge toward one of HB-button press latencies within a range of 100–400 ms over the course of the training. This tendency is not observed in the Control group. The differences in the correct response frequency were significant at beyond the .02 level. Thus, it is proposed that those data, though not conclusive, provide evidence that Experimental subject's button presses were being timed with respect to the occurrence of her intrinsic HBs.

The mean change scores in HB control of the three groups during both the FW and NFW sessions are depicted in Fig. 2. Each histogram in this figure presents a difference in HB between the two increase and decrease trials for its respective session. As evident in Fig. 2, the FF and FF-K groups demonstrated better HB control than the C group over both the FW and NFW sessions. The degree of controllability in the two experimental groups was, on the average, approximately 45% superior to that of the Experimental group in the earlier research (Hamano, 1980). On the other hand, the controllability of the C group was as inferior as in the earlier experiment. According to an analysis of variance, the groups effect, $F(2/84)=30.046$, $p<.01$, and the sessions effect, $F(1/84)=4.837$, $.01<p<.05$, were significant. The groups comparison revealed that HB control differed significantly between the FF and C groups,

Fig. 2. Mean differences in HB between increase and decrease trials.

$t(84)=6.339$, $p<.01$, and between the FF-K and C groups, $t(84)=7.035$, $p<.01$.

Consequently, the following particulars can be pointed out by comparison with the Hamano (1980) findings and the statistical analyses of the above results. Namely, it can be seen that the requirement of an effort to entrain to target responding by the application of artificial feedforward signals would have a tendency to elevate such controllability and help to form feedforward organization into a central system. As evidence for the use of those extrinsic signals to better facilitate the organization formation, the present data demonstrate that the attenuation of the treatment effect as observed in the author's previous experiment is not repeated in the controllability of the two experimental groups for the NFW sessions in Fig. 2. Furthermore, an inspection of Fig. 2 suggests the interpretation that the training for interoceptive detection during the BP sessions may have contributed to the differences in controllability among the two experimental and C groups. In connection with this point, the rank-difference correlation was finally conducted by determining the relationship between correct response frequency during the BP sessions and the mean change in HB control during the FW and NFW sessions for each subject of the FF group. The analysis failed to present a significant correlation coefficient between them, although their comparisons approached a significant level, $r_s=0.666$, $.1>p>.05$. Moreover, according to the figure, decrement tendency in controllability, the same as in the FF group for the initial NFW session, does not occur in the FF-K group which was informed of the control results after every trial. Nonetheless, the difference was not generally significant between the FF and FF-K groups, so the effectiveness of the knowledge in this case as in that of Diekhoff (1976), can not be positively supported. Lastly, as to respiration which was simultaneously recorded no

conspicuous change presumably associated with HB control was found for both the FF and FF-K groups. This is the same as in the conventional experiments.

In conclusion, the major finding of this experiment was that Experimental subjects demonstrated significantly greater HB controllability than Control ones. This finding is of substantial interest because it is evidence that entrainment effort of the type employed here may serve as a behavioral strategy in order to establish an information-processing feedforward organization for cardiac self-control. And also the finding that the cardiac-motor coupling procedure was related to successful HB detection partially supports Hamano's (1980) assertion that such interoceptive detection facilitates subsequent learned cardiac control. At the present time when positive experimental data regarding the self-control as described above remain scant, the present proposal of a control model for the establishment of feedforward organization may provide a viable source of knowledge concerning the development of cardiac self-control.

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