STUDIES OF SELF-REGULATION OF INTERNAL ACTIVITY: THE INTEROCEPTIVE DETECTION AND CONTROL OF CARDIAC ACTIVITY VIA TRAINING PROCEDURE OF CARDIAC-MOTOR COUPLING

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The present study consists of two experiments, the first of which is an extension of a preceding study. To test a hypothesis that the possibility of interoceptively detecting cardiac activity is enhanced by increasing the strength of concentration, an attempt was made in Experiment I to train subjects for sustained concentration by combining biofeedback technique with a cardiac-motor coupling procedure. The results demonstrated that a significant improvement in interoceptive cardiac detection developed along with such training. Experiment II was designed to determine whether the interoceptive detection facilitates subsequent learned cardiac control. The Experimental group showed better cardiac control than the Control group. These findings were taken to suggest some substantial relationship between the detection and the control. However, the effect of detecting interoceptive signals upon the cardiac controllability was not so much powerful as expected. In this respect, the role of intrinsic effector-produced feedback as a possible factor was proposed and discussed.

The purpose of the present study was to see (a) whether feedback training with simultaneous button press effort assisted interoceptive cardiac detection enhances the probability of successful detection, and (b) whether the detection facilitates subsequent learned cardiac control.

In the preceding study of this series (Hamano, 1977), the findings were interpreted as supporting the probability of interoceptive detection of cardiac activity. However, some problems also remained unresolved. One of them was of a cue for detection, that is, there was the problem that more than half of the student subjects took their cues not from signals based on interoceptive cardiac activity, but, from a slight variability in the characteristics of the extrinsic feedback signals. In contrast, this tendency could not be observed in the group composed of Karate grade holders. The present author has proposed, therefore, that such a difference in a cue for detection is attributed to a difference in the strength of the concentration of attention activity. If this hypothesis is accepted, the solution of this problem may be sought in some minor procedural improvements for increasing the strength of concentration. Experiment I was planned to examine the validity of this hypothesis. To be concrete, the improvements could be focused upon two points: one, a way to let ordinary subjects maintain the concentration of attention to their cardiac activity and two, the training procedure enabling them to facilitate the interoceptive cardiac detection. From the practical point of view, these points entailed on the subject a task of performing a button press in synchrony with cardiac activity utilizing extrinsic feedback signals. No attempt

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2 The part of the study was read at the 42nd Annual Convention of Japanese Psychological Association (Miyake & Hamano, 1978).
to facilitate the interoceptive detection by such a cardiac-motor coupling has been made so far. Although the investigations by Kleinman (1970) and by McFarland (1975) may be cited as similar to the author's idea, those instructive experiments have no systematic training with cardiac-motor coupling. Related to this sort of training one question which raises is whether the promotion of interoceptive detection, if enhanced by such training, may arise simply from the learning of a periodic rhythm of button presses, not from the detection of intrinsic signals. The answer to this question was sought from Group III as mentioned below. In Experiment I, moreover, a gradual reduction in the presentation of extrinsic feedback signals was attempted in order to promote the more direct detection of intrinsic signals.

Another purpose of the present investigation is to determine whether there is a positive relationship between the interoceptive detection of cardiac activity and the self-control of such activity. As pointed out by Black, Cott, and Pavloski (1977), only a few researchers have devoted explicit attention to such a relationship, but as yet no clear decision has emerged (Clemens & MacDonald, 1976; Carroll, 1977; Gannon, 1977; Whitehead, Drescher, Heiman, & Blackwell, 1977). Against this mixed background, then, Experiment II was attempted to provide a clearer profile of the effect of interoceptive detection upon cardiac self-control within the context of a combination of biofeedback training with the coupling procedure employed in Experiment I.

**Experiment I**

**Method**

**Subjects.** Thirty 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 and any prior experience with experiments of this kind.

**Recording and apparatus.** In the experiment, the heart beat (HB) with concomitant respiration measurement was recorded. The physiological recordings and feedback equipment set were the same as those described by Hamano (1977).

The coupling procedure used in the present study required the subject to press a microswitch button every time she felt her HB. 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 1000 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.** Thirty subjects were divided into three groups each contained ten subjects. The experiment consisted of twelve sessions: two Pre-Training (PRE-T) and ten Training (T) ones. Each session was comprised of five successive 10-s trials. Subjects in Group I and II were instructed as to the significance of a sequence of vibratory tactile stimulus trains delivered to them which were in turn connected by their HBs and to associated the sequence with intrinsic cardiac signals. Instructions were given to subjects in Group III simply to concentrate their attention upon tactile stimuli and to memorize the rhythm of them. However, on the trials mentioned below, actual vibratory stimuli connected with the subject’s own HB were fed back also to Group III-subjects. In...
addition to these instructions, all subjects were shown how to hold the microswitch with their left hand and to press the button with the thumb. Immediately after these operations prior to the experiment proper the PRE-T and T sessions were initiated under the following conditions: On the first two trials in each session, all subjects were required to concentrate their attention upon a 10-s train of vibratory tactile stimuli in accordance with the instructions given. On the third and fourth trials, subjects in Group I and III were asked to perform a button press in response to each of the stimuli, extrinsic HB feedback signals. However, for the latter five seconds of the fourth trial, subjects of both groups were required to continue a button press without extrinsic feedback signals. For Group II the third and fourth trials were carried out under the same condition as with the first and second ones. On the fifth trial, no extrinsic feedback signals were presented. At the start sign, subjects in Group I and II pressed the button in response to each intrinsic HB signal based upon interoceptive detection, whereas Group III-subjects were requested, on the trial, to replicate the periodicities of these stimulus trains learned on the previous two trials by pressing the button. Inter-trial-interval ranged from 30 to 60 s at random. As pointed out initially, Group III was run as a control for the possibility that the interoceptive detection exhibited by Group I-subjects was attributable to the subjects having relied upon their memories of the periodicities. The above experimental procedure is summarized in Table 1.

Results and Discussion

The measure of interoceptive cardiac detection employed here was based on the distribution of HB-button press latencies. Only the button press responses showing a latency from 100 ms to 400 ms were regarded as correct responses produced under an adequate concentration of attention. This so-called latency was indicative of the successful detection of some sensory consequence of intrinsic HB as a cue for the button press.

Figure 1 shows the percent correct response frequency on the fifth trial of each session for each group, in blocks of two fifth trials. As is evident from Fig. 1, Group I alone displays an increase in the frequency as a function of the sessions. The response frequency for each fifth trial of the first PRE-T and the tenth T sessions for each subject was submitted to two factor analyses of variance. A significant groups effect was obtained ($F = 4.094$, $df = 2/54$, $0.01 < p < 0.05$) indicating that the fifth trial-frequency for the latter T session was significantly different between Group I and III ($t = 2.076$, $df = 54$, $0.02 < p < 0.05$). This is interpreted as evidence that the training with cardiac-motor coupling led to successful HB detection in Group I. Further evidence in support of this con-

4 The rationale underlying this modality detection index is based upon the assumption that the shortest interval between two successive HBs produced during each trial will be 600 ms, and consequently any inter-button press interval will have to be less than 600 ms. According to a time base, within a range of 0–500 ms, the inter-button press with a latency of 0–100 ms was discarded because of the possibility of half-cocked response. And the determination of a correct response was available from normative data on the simple reaction time. In general the reaction time lies between 100 and 300 ms although it differs in the same subject according to the direction of one's expectant attention. In the present experiment, different from those experimental conditions, subjects were required to continuously perform a button press in synchrony with each HB without foreperiod. This means that the expectant attention is exclusively addressed to the HB signal to be fed back. Thus it is assumed that the button press as successful detection can only begin after this HB signal has come in, and under this condition the response takes more time.

On the basis of this consideration, the inter-button press with a latency of 100–400 ms was taken as a reasonable correct response.
TABLE 1
Schematic presentation of procedure for Experiment I

<table>
<thead>
<tr>
<th>Group</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback type</td>
<td>Binary tactile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects informed of response</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Trial cycle 1-2</td>
<td>To attend to the FB &amp; associate it with the HB</td>
<td>To attend to the FB</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>To press the button (With FB)</td>
<td>To do the same as above</td>
<td>To press the button (With FB)</td>
</tr>
<tr>
<td>4</td>
<td>Initial half (With FB)</td>
<td>Latter half (Without FB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>To press the button</td>
<td>To do the same as above</td>
<td>To press the button</td>
</tr>
<tr>
<td>5</td>
<td>No feedback trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>To press the button as soon as the subject sensed the HB</td>
<td></td>
<td>To press the button so as to reproduce the temporal distribution of FB trains</td>
</tr>
</tbody>
</table>

Attention is contained in the significant groups by sessions interaction ($F = 3.651$, $df = 2/54$, $.01 < p < .05$).

Figure 2 indicates the percentage of HB-button press latencies falling into the modal category of the distribution for each session. Blocks of two fifth trials represent how the distribution gradually shifted through all the sessions. An inspection of the histogram in Fig. 2 suggests that the latency distribution of Group I has the tendency to converge toward one of such

![Bar Chart](image)

**Fig. 1.** Development of performance. Each session represents blocks of 2 fifth trials.
categories over the progress of the training. This tendency is not observed in Group III. Thus such a convergency process seems to reflect the fact that Group I-subject’s button presses were being timed with respect to the occurrence of her intrinsic HB. When the differences in the correct response frequency among the three groups were compared in each block by means of the chi-square technique, a significant difference was obtained in each block of the second, fourth, and fifth ($\chi^2 = 8.178, p < .01; \chi^2 = 15.417, p < .01; \chi^2 = 16.629, p < .01; df = 2$ respectively). In the second block only the frequencies between Group I and III displayed a statistically significant difference ($\chi^2 = 8.188, df = 1, p < .01$). The results of the chi-square in the fourth block showed that the differences between Group I and II and between Group I and III were highly reliable ($\chi^2 = 6.009, p < .01$; $\chi^2 = 14.923, p < .01; df = 1$, respectively). In the fifth block the comparisons in the frequency between the same two pairs of groups were also significant at less than 1% level ($\chi^2 = 13.819; \chi^2 = 10.251; df = 1$, respectively).

The present data indicates that the instructional set emphasizing the calibration of extrinsic feedback signals with intrinsic HB is important for the interoceptive cardiac detection, but, that compliance with instruction depends upon the effort of calibration. This is because a difference, with regard to the correct response frequency, took place between Group I and II during the latter half of the T sessions. As mentioned above, calibrations were performed without button press during four out of five trials in each session for Group II. Therefore, such a difference between the groups is interpreted as supporting the methodol-

![Graph](image)

**Fig. 2.** Distribution of latencies. Each session represents blocks of 2 fifth trials.
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ogical consideration—the need for training with the additional procedure for sustained concentration of attention activity upon the cardiac function—as pointed out at the beginning of this paper. This interpretation is confirmed also by the statistical analyses in the frequency obtained between Group I and III. Indeed, both groups performed a button press, but Group I-subjects were instructed to adjust button presses via extrinsic feedback signals to match their own HB, whereas the subjects of Group III were requested to perform a button press, without instruction of such requirement, simply in response to each of extrinsic vibratory signals. In other words, the results of Group III are accompanied by no calibration process in which the concentration of attention upon cardiac activity is required. Thus, the button press events of such parallel fashion as the type employed in Group III may be seen not to have led directly to a statistically reliable improvement in interoceptive cardiac detection.

The author concludes from these findings that the results of Experiment I support his hypothesis that, in order to insure more successful detection, it may be an important prerequisite to train the subject to enhance the strength of concentration by combining the biofeedback training with some additional procedure like the present coupling one. Finally, as for the promotion of direct cardiac detection by a gradual reduction of extrinsic feedback signals, its effectiveness is supported by the results of Group I, although the detailed experimental analyses are a subject for future study.

Experiment II

In Experiment II the author attempted to submit subjects who were trained to detect the intrinsic sensations of their cardiac activity to cardiac control training and determine whether or not the prior training for interoceptive detection facilitated their ability to control their cardiac activity.

Method

Subjects. A total of twenty female students with an age range of 19–22 years served as subjects. They had no previous experience with the experimental apparatus, procedures, or specific conditions of the experiment. They were assigned to each of two groups on the basis of the order of their appearance in the laboratory.

Recording and apparatus. The physiological recordings, feedback equipment set, and apparatus for the coupling procedure were the same as those described in Experiment I.

Procedure. Twenty subjects were divided into two groups, the Experimental and Control groups each constituted of ten subjects. The experiment consisted of ten sessions. In the initial six sessions (the BP sessions), a session was composed of five trials, each ten seconds in duration. On the first four trials for each of the BP sessions, all the subjects of the Experimental group were asked to calibrate extrinsic HB feedback signals with the intrinsic sensations that are consequent upon their cardiac activity. This lasted throughout the button press effort in synchrony mentioned in Experiment I. On the other hand, all the subjects of the Control group were required to perform a button press in response to each of sixty artificial pulses per minute given as tactile stimuli. On the last fifth trial for both groups no tactile stimulus was presented to the subject’s right middle fingertip.

The subjects of the Experimental group were instructed to press a button in response to each of intrinsic HB feedback signals, at the sign of start. Those of the Control 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-
TABLE 2  
Schematic presentation of procedure for Experiment II

<table>
<thead>
<tr>
<th>Group</th>
<th>Feedback type</th>
<th>Subjects informed of response</th>
<th>BP sessions (Trial cycle)</th>
<th>HB control sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1-4</td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>Binary tactile</td>
<td>Yes</td>
<td>Feedback-Button pressing</td>
<td>Alternate speeding &amp;</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>No</td>
<td>No artificial pulse trains-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Button pressing</td>
<td>slowing &amp; slowing HB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. of session</th>
<th>No. of session (Trials per session)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2 (4)</td>
</tr>
<tr>
<td>2 (4)</td>
<td></td>
</tr>
</tbody>
</table>

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 both groups. In the first two sessions (the FB sessions), extrinsic feedback signals coupled with HBs were fed back to both groups, and, in the remaining two sessions (the NF sessions), these extrinsic signals were unaccompanied. Incidentally, in neither the FB nor the NF sessions were button presses performed. Instructions of controlling the direction in HB were given alternately towards increase and decrease verbally immediately prior to the onset of each trial. The procedure described above is summarized in Table 2.

Following completion of the experiment, each subject was asked her introspection upon whether or not she thought she had carried out a control in accordance with the instruction.

Results

Figure 3 presents the percentage of correct response frequency on the fifth trial of the sixth BP session. As with Experiment I, 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 analysis of the results as a measure of successful detection of intrinsic HB. As shown in Fig. 3, the percentage frequency of the Experimental group was higher than that of the Control group. According to statistical analysis, the difference in the frequency between groups was also significant ($F=5.403, \text{df}=1/18, .01<p<.05$).

Figure 4 indicates the distributions of HB-button press latencies on the fifth trial of the sixth BP session. The distribution of the Experimental group presented a similar convergency to that of Group I shown in Fig. 2.

The results of HB control in the FB and NF sessions for both groups are depicted in Fig. 5. Each histogram in this figure displays a difference in HB between the two increase and decrease trials for its respective session. From Fig. 5 it can be seen that the change in HB control for

![Fig. 3. Median percent of correct responses.](image-url)
the Experimental group from the FB to the NF sessions was greater than for the Control group. Moreover, the Control group revealed a decrement tendency in HB control during the NF sessions, whereas the Experimental group exhibited the interesting phenomenon that change continued to exhibit the foregoing increment tendency. The results of the analysis of variance showed a statistically significant difference between these two groups ($F = 5.910, df = 1/76, .01 < p < .05$). As for respiration which was recorded simultaneously, no change as above mentioned corresponding with HB was found for either of these two groups.

To further analyze the effect of interoceptive detection upon HB control, the rank-difference correlation was finally conducted by determining the relationship between correct response frequency during the BP sessions and mean change in HB control during the FB and NF sessions for each subject of the experimental group. The analysis failed to present a significant correlation coefficient between them although their comparisons approached a significant level ($r_s = 0.567, .05 < p < .1$).

**Discussion**

To summarize, the results of Experiment II are considered to suggest the possibility that the effectiveness of interoceptive detection in facilitating the development of cardiac self-control may be a function of the procedures in which subjects have previously learned to detect their cardiac activity.

The finding that the Experimental group improved to a significantly greater extent in correct response frequency than the Control group on the fifth trial of the sixth BP session supports this contention partially. The results can be interpreted to demonstrate that a fairly high ability to detect intrinsic HB signals had been acquired by the subjects of the Experimental group on whom the effort of the calibration was imposed. Although 45.5% correct responses are observed even in the Control group, this finding should be attributed to the sixty artificial pulses per minute applied to the Control group for the following reasons: (1) No tactile stimuli were connected by the subject's own HB; (2) a reproduction of her pulsatile memory of tactile stimuli given during the preceding trials was requested on the fifth trial; and, (3) the median correct response frequency was 37.3% on the fifth corresponding trial of the first BP session. In summary, this can be judged to be responsible for the possibility of the subjects having relied upon their memories of the periodicity.

In addition, this is supported by the following two findings: First, the mean change in HB control of the Experimental group during the FB and NF sessions showed a significant difference from that of the Control group; and, secondly, a
tendency to suggest the considerable substantial relation of interoceptive detection to HB control might be recognized from the results of the Experimental group. As mentioned above, the experiment during the FB and NF sessions was carried out under the same procedure for both groups. The only difference between these two groups lies in that the Experimental group received training with cardiac-motor coupling for interoceiving before, whereas the Control group did not. For all the subjects of the Control group was HB control required through the calibration of extrinsic feedback signals with intrinsic HB ones only after the beginning of the FB session. Therefore, the foregoing experience in the training for facilitating such interoceptive detection can be assumed to have appeared predominantly in the Experimental group.

Furthermore, an inspection of Fig. 5 may support the interpretation that such difference in HB control is attributed to the effort of calibration. In fact, while HB controllability in the Experimental group continued showing a slightly but steadily increasing tendency with the progress of the training even during the NF sessions where no extrinsic feedback signal was presented, such an increasing tendency in the Control group could not be observed, or rather HB controllability decreased during the NF session. The downward tendency during the NF session for the Control group may be attributable to the inability of the subjects to detect intrinsic signals. However, no definite conclusion could be made since statistical analyses performed on the means for the Control group in the FB and NF sessions did not differ significantly. Inference then shall be pointed out only as one possibility.

Finally, though the present results affirmatively indicated the relationship of detection to control, the point that HB controllability was not so marked as expected remains unsolved. Many reasons may be stated for this finding, but the author would rather strongly prefer to attribute the cause of the above to the total dependence of the responding of the cardiac function towards adequate control directions upon intrinsic effector-produced feedback. This proposal makes us consider the probability that because of this dependency, an information-processing feedforward organization for self-control, which leads to the responding towards an appropriate direction by some form of self-produced programme, could not be so fully established and sufficient controllability was not obtained in Experiment II. As a descriptive generalization, the main reason for making this proposal is connected with the general argument regarding intersubject variability in such intrinsic autonomic responding (Gatchel, 1974; Bell & Schwartz, 1975; McCanne & Sandman, 1976; Roberts, 1977). These issues may after all be narrowed down to the point that certain subjects are inherently predisposed by physiological makeup to produce less HB controllability than are other subjects. Future study of this series will address itself to this question by attempting to develop cardiac self-control without mechanical aid.

References


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