Role of Feedback Signal in Voluntary Heart Rate Control

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SUMMARY

The role of feedback was reviewed by examining our previous experiments on biofeedback-aided voluntary heart rate (HR) control. The task of first experiment was ordinary HR increase or HR decrease during 12-days. The results of this experiment showed that the subject's awareness of the measured variables, required task, meaning of feedback, and the relationships among these was crucial in determining his or her performance. The task using the rest four experiments was a kind of tracking task where subject was required to keep one's HR or HR-like motor response in the target area as much as possible. The independent variable in those experiments was feedback delay, or time lag, between response and the presentation of feedback signal. The series of results obtained suggest that in the tasks such as HR-tracking, a mechanism similar to that of motor-learning is at work, and that even a slight delay in feedback can disturb the performance. These observations suggest when the feedback signal was fit for the required task, the performance complies with the theories of closed-loop feedback control in which case the effects of biofeedback are maximized.

Key Words: heart rate, feedback delay, motor skills

The term "biofeedback" simply refers to a technique to feeding back physiological responses which are transformed into some perceptible and measurable variables. It seems to me that the term became well established as a result of efforts to recognize biofeedback in the framework of clinical applications and general control theories, rather than as a topic of learning theories in psychology. The greatest difference between the studies of operant conditioning of autonomic responses and those on biofeedback applications lies in the treatment of mediator and of the subject's knowledge, or awareness, of the experiment situation, particularly the significance of response and feedback. In the former, mediators are considered something to be removed, and the awareness of the situation on the part of the subject is regarded unnecessary. In contrast, in the latter, that is, in the applications of biofeedback, the mediators are something to be positively employed, and the awareness is considered vital in successfully performing the task.

In our first experiment, a subject took part in a 12-day HR control. After the pre-trial baseline was measured for 30 seconds, the subject was told to either increase or decrease his HR for 30 seconds. The type of feedback was an analog HR meter. After each trials, the results were given to subjects on a digital counter as a "reward". Subjects could not control their HR too well for the first
four days when they were not told about the nature of responses and the reinforcer. On the fifth day, the experimenter gave instructions on the experimental situations, such as, the meaning of response and feedback. Immediately after that, the subjects were able to increase their HR quite well, first by changing their respiratory frequency. When the subjects were then told to keep the respiratory frequency constant, they were still able to increase HR, this time, by varying the respiratory amplitude. However, when the respiratory amplitude had to be sustained constant, they could no longer control their HR. Moreover, while the subjects could increase their HR by using respiration, they could not decrease it at all even when the respiratory frequency was found lower than the pre-trial baseline. These simple results suggest that in the HR voluntary control: (1) the awareness of the situation is necessary, (2) HR-increase and HR-decrease are different processes, (3) respiratory mediator is effective in increasing HR, but not in decreasing it, and (4) there are separate, respective effects of respiratory frequency and respiratory amplitude.

In the second experiment (Inamori, 1993), the task was to keep one's HR in the target area as much as possible. It was a kind of tracking task using HR, in which the subjects were required to horizontally advance in 100 beats, through the target, which was a cycle triangle wave of 40-msec vertical width, and HR feedback was presented on the computer display. Subjects were told that they were free to do anything for their task execution, provided that it did not disturb the HR measurement. This task was more like motor-learning tasks, because the feedback information was indispensable for executing the task and worked as a negative feedback by showing the degree of error from the target. Since most of other experiments of voluntary HR control required subjects to increase or decrease their HR as much as possible, without providing them with a clear target, feedback did not work as negative feedback in those cases.

An independent variable employed in this experiment was feedback delay, or time lag, between response and the presentation of feedback signal. In a closed-circuit negative feedback system, the delay in feedback is crucial. In the experiment, 1-beat delayed feedback (1D) and 3-beat delayed feedback (3D) were compared immediate feedback (IM). In the IM condition, HR tracked the target fairly well, but the tracking performances were clearly disturbed in the delayed conditions of merely a few seconds. Particularly large oscillation of HR was observed in the 3D condition where the feedback signal had failed to serve as negative feedback. This is a phenomenon observable also in the data on mechanical and motor learning.

Mean scores, or the beats within the target per trial, for all 14 subjects indicated a progressive decrease in the order of IM, 1D, and 3D. The system, which is affected by such short delays must be a closed-circuit negative feedback system with a short loop transfer time and rapid feedforward stream of information. It is therefore highly likely that it is the parasympathetic nervous system that is at work in generating such a rapid reply in the cardiac system.

So far, we have seen that the tracking task by HR control exhibited effects in the variables that were similar to those in motor learning. Our next task was to consider which type of motor learning this particular task resembles.

Since HR consists of discrete beats, we designed several variation of the task, in which a series of discrete signals were produced as motor activity. The newly established feedback conditions were as follows: immediate (IM), 1/2-beat constant delay (1/2CD), 1/2-beat variable delay (1/2VD), and 1-beat delay (1D). Under the IM condition, the newest R-R interval was fed back as soon as R-wave was detected. In 1/2CD, the feedback was delayed for a period equivalent to one-half of the average R-R interval obtained in the pre-trial. Under this condition, upon detection of R-wave, the feedback was given with a delay equivalent to one-half the average R-R interval computed in the pre-trial. In 1/2VD, while the newest information on R-R intervals was given as feedback, the timing of feedback was determined on the basis of EKG record of the subject or 4.6 seconds ago. The length of delay varied within 1 beat from R-wave, but they averaged out to 1/2 beat in the end. Since the feedback was displayed according to EKG of a short while ago, there was no unnaturalness in the procedure. 1/2CD and 1/2VD conditions were prepared to examine whether or not the synchronization between feedback timing and R-wave was necessary in the HR control based on biofeedback. While the delay time was about 400 msec in either of the conditions, it was assumed that 1/2CD was synchronized with R-wave, and that the feedback timing in 1/2VD was not synchronized with R-wave.

When an HR control task was performed under these conditions, the number of HR within the target progressively decreased as the delay time increased.
demonstrating the effect of feedback delay (Fig. 1-A). As seen in the figure 1-B, the oscillation phenomenon caused by delay was observable also in the frequency analysis. For 1D, the peak of the power was found in the low-frequency range. Between 1/2CD and 1/2VD, there was absolutely no difference, either in the number of HR within the target or in the power spectrum. In addition, both the score and the distribution of power spectra for these two conditions were found halfway between those for IM and 1D. Whether the delay of feedback from R-wave was constant or varied, in other words, whether the feedback was synchronized with R-wave or not, did not matter. The scores and the power spectra were affected only by the length of delay time, perhaps due to the difficulty of clearly perceiving one’s own heart beat.

Three kinds of motor skill tasks similar to the previous HR control task were designed. As in the HR control task, the intervals of 100 beats of discrete signals were adopted as responses, and a triangle-wave which rose or lowered from the 800 msec baseline was employed as the target.

Tapping movement was used in the first task. Instead of heartbeat, the subjects had to tap their finger on a plate. In this task, the subjects were fully aware of when they tapped their fingers. The results showed that the score drastically deteriorated in the 1/2VD condition. This was because the subject’s time assessment was disturbed by the varied delay of the feedback. As for the frequency analysis no power peak could be observed, as if it were a spectrum of white noise.

In designing the second task, we tried to find a motor task in which the timing of beats could not be known to the subject. One such task we found was the turning of fishing reel. The actual rotation of the reel does not coincide with the number of turns made by hand. A single complete rotation of the reel is equivalent to 0.42 rotation by hand. The time required for a rotation was detected by a photo-interrupter and was processed in the same way as the R-R intervals of EKG. This task differed from the first task, in that the subject could not perceive at what point a response was sampled as a discrete response. The scores for each conditions were different from those of either the HR task or the tapping task. In the power spectrum, the large powers in high frequencies reflect rotation by hand: the speed of the movement decreased as the hand moved upward, and increased as it moved downward.

The third and last motor response was also reel turning, but the method adopted to measure response was more intricate. In previous task, the duration of a single reel-turning was directly counted as a response. In this task, an integral factor was also considered, and each sampled time, minus 800 msec was integrated to the previous value. 800 msec is equivalent to 75 bpm, which is a normal heart rate. And, the integrated values were adopted as controlled interval. It was found that successive HRs, that is, successive R-R intervals, were not independent but they were highly correlated each other. The effects of all of the devised conditions exhibited in the
results of this experiment, were consistent with those of the HR task, in both tracking performance (Fig. 2-A) and power spectra (Fig. 2-B). In the delayed conditions, oscillation occurred just as it did in the HR task. These observations appear to suggest that the reel-turning task do have considerable similarities with the HR-control task.

To test whether there are same type of integral elements in the HR control system, differences of successive R-R intervals were analyzed. By assuming that there are integral elements involved, the input elements of the HR control system were examined. In Fig. 3, the power spectrum densities in this series of differences, were very much like those of respiration in the mid-frequency range. In fact, the spectrum patterns for the four conditions almost exactly overlap with those for respiration. This indicates that in mid-frequency range, that is, within the rage of normal respiration frequency of 10 to 20 per minute, the effects of respiration are clearly exhibited in the sequence of HR, and, this represents what is referred to as respiratory sinus arrhythmia. Furthermore, while this is still a speculation, there is a possibility that when the effects of respiration on HR are integrated, they extend to a frequency range lower than the range of respiratory frequency. The idea is consistent with some of the previous reports which said that the HR level is affected by respiratory amplitude, but not by frequency.
The series of results obtained suggest that in the tasks such as HR-tracking, a mechanism similar to that of motor-learning is at work, and that even a slight delay in feedback can disturb the performance. Also, the results indicated the possibility that respiration, which is one of the effective input elements in HR-control, affects the basic HR control after going through some kind of conversion, such as, integration, for instance.

Now, I would like to propose a model for voluntary control of autonomic responses. First of all, we need awareness of the situation. It is this awareness that enables the subject to find effective mediators and test their effectiveness by feedback information. It may be sometimes necessary for the experimenter to investigate the relationship between the target response and its possible mediators, and suggest the subject to use a mediator which is more effective.

As for the type of feedback, there are many possibilities, such as binary, or yes-no feedback, analog real-time feedback, stored feedback which gives a bundle of information for over a certain period of time, and so on.

As for the nature of task, there are director-oriented tasks in which the direction is fixed and the subjects is asked to modify his or her response as much as possible, and there are also direction- and amount-oriented tasks which require the subject to make a fixed amount of change in the responses as well as in the direction. Once we find the most suitable combination between the type of feedback and the nature of task, we should be able to fully extract the effects of biofeedback.

Finally, in order to effectively apply biofeedback, we should consider it not as something peculiar and special, but in the same way as we consider machine control or motor skills.

Reference