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# HUMAN INTERFACE FOR HEART RATE CONTROL DURING BICYCLE ERGOMETER EXERCISE

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***We propose a human interface enabling unconscious real-time self-perception and self-correction of physiological state. Movies and music are used as media to present physiological state. The preliminary experiment employed bicycle ergometer exercise, and considered the interface's applicability to driving a vehicle. The experiment evaluated ease of perceiving heart rate range using movies, and effect of heart rate control using music. Based on the results, we designed two prototype systems. One, presenting heart rate range during exercise, uses movies that are highly sport-oriented and suggestive of numerical values. The other, a system of heart rate control during exercise, dynamically changes the tempo of music according to the level of difference between heart rate during exercise and target heart rate.***

## 1. INTRODUCTION

Many devices currently fitted to vehicles present information describing the status of the vehicle itself rather than the status of the driver; for example: speedometer, fuel gauges, and navigation systems. At the same time, accidents are often caused by drivers themselves for reasons such as fatigue, drowsiness, or lack of concentration. Pursuit of a safer and more comfortable mobile lifestyle has therefore led to the development of new human interfaces that gather information on drivers themselves. In this context, we are researching a human interface that uses the driver's own physiological signals in order to maintain a good physiological state. A human interface designed to facilitate safe and comfortable driving must minimize information processing by the driver during operation and not hinder driving tasks. To this end, we conducted a feasibility study for an **unconscious human interface** requiring no conscious effort to recognize the information presented while driving (Birgegard and Sohlberg, 1999).

In the present study, prototype systems were designed to investigate the performance of unconscious human interfaces. In these systems, the two media of movies and music were controlled using physiological signals which reflect human states. Then, by evaluating ease of recognition and the effect of physiological control in these prototype systems, we examined the feasibility of designing an unconscious human interface. For basic research for a human interface design that could be applied to vehicles, we used a bicycle ergometer to design a prototype human interface for heart rate present and control during exercise: a system which allowed evaluation in the laboratory. A bicycle ergometer was used because its operation resembles driving tasks and because it is easy to change the physical workload, which affects the heart rate. The prototype systems allowed noninvasive, unrestrained measurement of heart rate. The efficacy of the prototype system as an unconscious human interface was evaluated based on perception of heart rate range and potential for heart rate control.

# 2. DESIGN OF HUMAN INTERFACE FOR HEART RATE CONTROL DURING EXERCISE

## 2.1 System Concept

The objective of our research was to bring a knowledge of biofeedback to bear on the realization of an unconscious human interface that would establish a suitable human-machine relationship without conscious effort. Biofeedback is a technology that measures physiological signals reflecting the internal state of an individual and allows feedback control of the body by presenting that information as a feedback signal in a form perceptible to the individual (see Figure 1).

Biofeedback used for mental or physical therapy or rehabilitation often presents numerical information to the individual (Andrasik *et al*, 1984), but the application of such a method requires prior instruction in maintaining target values, and creates a secondary task. Therefore application of biofeedback technology alone is not always appropriate for a vehicle system.

We thus explore the feasibility of an unconscious human interface as a more human-friendly system. We used movies and music, more familiar to humans than numbers, as media for presenting information, and investigated the effectiveness of these media on both perception of human status and biological control.

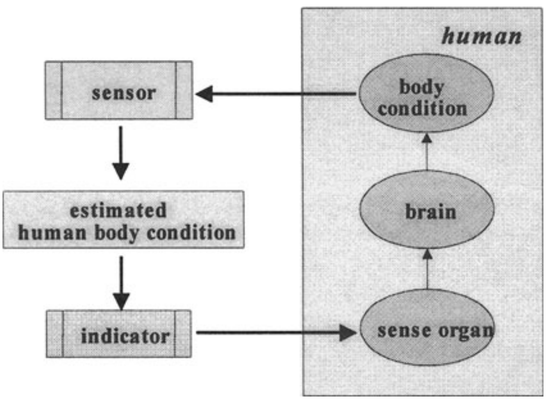



Figure 1 – Biofeedback system

### 2.2 Prototype Systems

Based on the concept described in Section 2.1, bicycle ergometers were used to design the two prototype systems shown below (Figure 2).

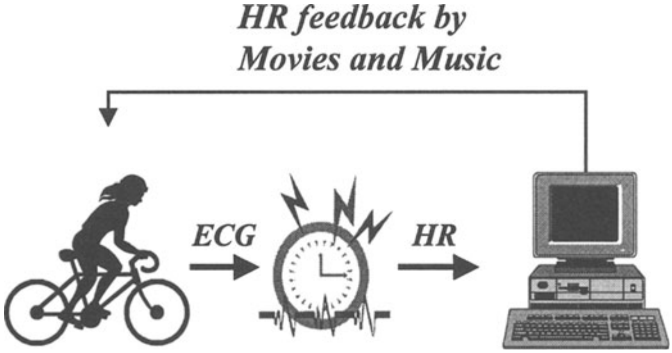



Figure 2 – The concept of an unconscious human interface

*(a) Movie-based Heart Rate Presentation System*
In this system, heart rate during bicycle ergometer exercise was divided into three heart rate ranges, and movies generated from computer graphics were used as a medium to represent the current heart rate range. Heart rate was measured at each beat using a portable heart rate monitor, and the measured heart rate data was input to a personal computer (PC) through its serial port. The mean heart rate was then calculated for 15-second intervals, and the calculated mean heart rate for each period was used to determine the heart rate range for that period. Finally, movies generated to represent the mean heart rate range thus determined were shown on the display screen of the PC. Bicycle ergometer exercise was performed while viewing the movie displayed on the PC display. The program for these systems was written using Visual BASIC.

*(b) Music-based Heart Rate Control System*
In this system, music was used as a medium, and heart rate during bicycle ergometer exercise was controlled so as to allow maintenance of a target heart rate. Heart rate was measured at each beat using a portable heart rate monitor, and the measured heart rate data were input to a PC through its serial port. Then, for the selected tune, the heart rate per beat was compared with a previously set target heart rate. If the heart rate was lower than the target, a higher tempo tune was selected, while if the heart rate was higher then the target, the tempo was decreased.

## 3. PROTOTYPING AND EVALUATION OF MOVIE-BASED HEART RATE PRESENTATION SYSTEM

This section discusses evaluation results for perception of movies created to communicate heart rate to the user during bicycle ergometer exercise.

### 3.1 Setting of Heart Rate Ranges

Heart rate was divided into three ranges, and movies corresponding to each range were decided. Three heart rate ranges: high, middle and low, are typically set according to Karvonen's formula (see below), in which the criteria are heart rate ranges indicating an appropriate quantity of exercise (Karvonen and Vuorimaa, 1988).

$$\text{Heart rate range} = (\text{HRmax} - \text{HRrest}) \times k + \text{HRrest} \qquad (1)$$

HRmax = 220 – age (beats/min)

HRrest: Heart rate during supine rest

| | | |
|---|---|---|
| Heart rate range: | High range | $k \geq 0.45$ |
| | Middle range | $0.3 \leq k < 0.45$ |
| | Low range | $0.3 > k$ |

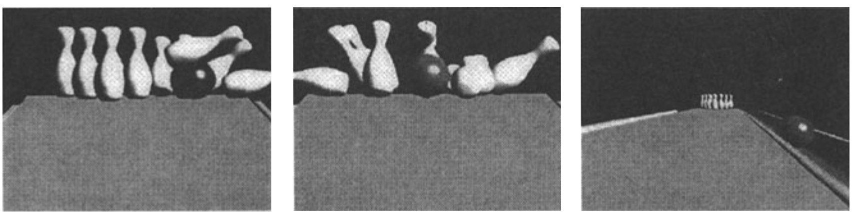
### 3.2 Movie Used in Heart Rate Range Presentation

Figure 3 shows an example of movies imaging three graduated heart rate ranges. In these movies, the number of bowling pins knocked over represents heart rate. In image (a), the low range, five pins are knocked over. In movie (b), the middle range, all 10 pins are knocked over. In movie (c), the high range, there is a gutter ball. The point of these movies is that they are both sports-orientated and directly suggestive of numerical values.

A second example movie consists of three scenes excerpted from the Disney movie *Toy Story*. The low range image presents a scene in which an escape rope dangles in front of a character out of reach. The middle range shows a scene where a car skillfully evades obstacles and escapes. The high range shows a scene in which a rocket ignites and powerfully blasts off. The point of these movies is that they are highly entertaining but not really suggestive of numerical information.

### 3.3 Evaluation of Heart Rate Perception by Media / Evaluation of Potential for Heart Rate Control

We evaluated the perception of the movies created to represent heart rate range to an individual during bicycle ergometer exercise. The subjects were 20 individuals in



(a) Low range (b) Middle range (c) High range

Figure 3 – Example of movies used to represent heart rate range

total, 10 healthy males and 10 healthy females aged 18 to 22 years, with no prior medical history relevant to the circulatory organs. The experiment was described to the subjects in advance, and subjects were prohibited from alcohol, tobacco, and caffeine consumption on the day preceding the experiment.

Figure 4 presents the experimental protocol. For two minutes following the start of the experiment the subjects remained in a state of quiet restfulness, in a sitting position with eyes closed. In Experiment 1, subjects were instructed to work at a level of intensity perceived as light "exercise", and a 5-minute exercise was performed. In Experiment 2, subjects were instructed to exercise for 5 minutes while viewing numbers depicting their instantaneous heart rate displayed on a heart rate monitor. Here the subjects were instructed to set their own target heart rate for the purpose of exercise only, and to try to maintain the target heart rate during the exercise. In Experiments 3 and 4, a 5-minute exercise was performed in each case while viewing movies corresponding to heart rate ranges, as described in Section 3.2.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Eyes closed, quiet rest 2 min | Experiment 1 (No display) 5 min | Rest | Experiment 2 (Numbers) 5 min | Rest | Experiment 3 (Toy Story) 5 min | Rest | Experiment 4 (Bowling) 5 min | Eyes closed, quiet rest 2 min |

Figure 4 – Experimental protocol

Experiment 3 used the movies excepted from *Toy Story,* and Experiment 4 used the bowling pin movies. In Experiments 3 and 4, movies were changed every 15 seconds. It was explained to the subjects that the movies were created to depict their heart rate during exercise, and the subjects were instructed to try to maintain their target heart rate, for the purpose of exercise only, by judging their current exercise levels from the images being presented. Enough rest time was provided between experiments for recovery to the original resting heart rate.

Figure 5 uses box-plots to show the distribution of mean heart rates at 5-minute intervals in each experiment. The lined area at the center of the boxes reveals the median of the distribution. The upper extreme of the boxes is a 75 percentile, and the lower extreme of the boxes is a 25 percentile. The upper extreme of the lines extending from the boxes is the maximum value, and the lower extreme is the minimum value, excluding outliers in each case. One asterisk (*) indicates observed significance in paired t-test results at a 5% level of significance, and two asterisks (**) indicate observed significance at a 1% level of significance. The results show a rise in mean heart rate when movies representing heart rate range were presented (Experiments 3, 4) versus exercise with no information presented (Experiment 1). This result illustrates that the movies presented had the effect of encouraging exercise and raising heart rate. In effect, control was implemented which raised heart rate during exercise as compared to the instance in which no information was presented.

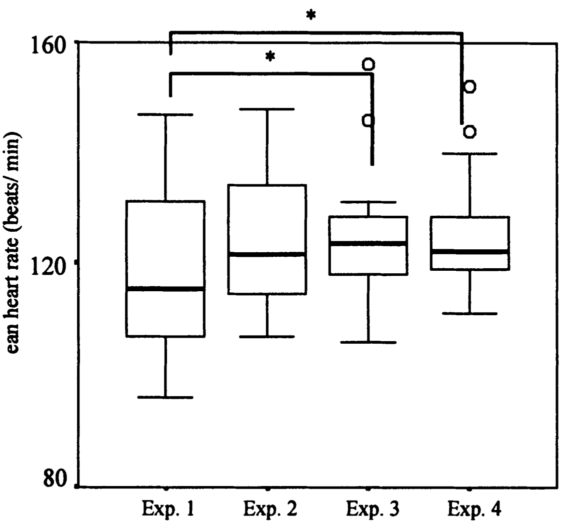



Figure 5 – Mean heart rate distribution: 20 subjects

Results from an F-test of distribution of mean heart rate dispersion at a 5% level of significance showed a smaller dispersion when bowling movies were presented (Experiment 4) than when no information was provided (Experiment 1). This result illustrates that the bowling movies had the effect of controlling heart rate during exercise. The observation of this effect also illustrates that a better perception of current heart rate was derived from the bowling movies.

Figure 6 shows the distribution of standard deviations of instantaneous heart rates at 5-minute intervals in each experiment. Standard deviations were larger when exercise was performed with no information presented (Experiment 1) or the movies excerpted from *Toy Story* were shown (Experiment 3) than when numerical information (Experiment 2) or the bowling movies were presented (Experiment 4). This result illustrates that a constant heart rate range was maintained more easily in Experiments 2 and 4 than in Experiments 1 and 3. The fact that a difference was seen in the results from Experiments 3 and 4 shows that when movies were used as a presentation medium, heart rate perception and the subsequent effect of heart rate control differed depending on the type of movies used.

Figure 7 shows the distribution of heart rate duration in the middle range. Middle range duration was longer in Experiment 4 than in Experiments 2 and 3. When numerical information was presented (Experiment 2), because of individual differences in the target heart rate set for each individual, it is difficult to maintain the target heart rate range for individuals. Similarly, it was deemed difficult to determine the target heart rate range when using the movies in Experiment 3. On the other hand, the movies used in Experiment 4 were deemed to have the potential to maintain the target heart rate range unconsciously.

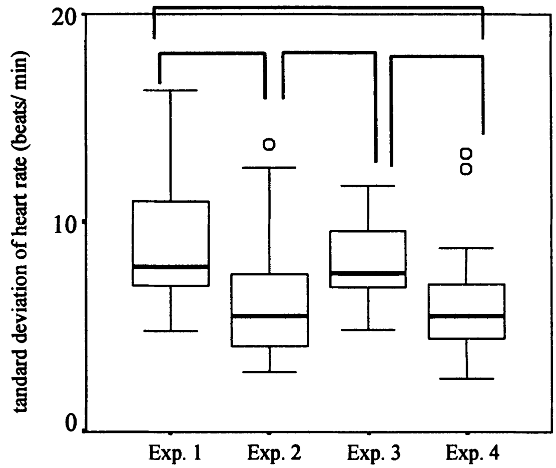



Figure 6 – Distribution of standard deviation of instantaneous heart rate at 5-minute intervals: 20 subjects

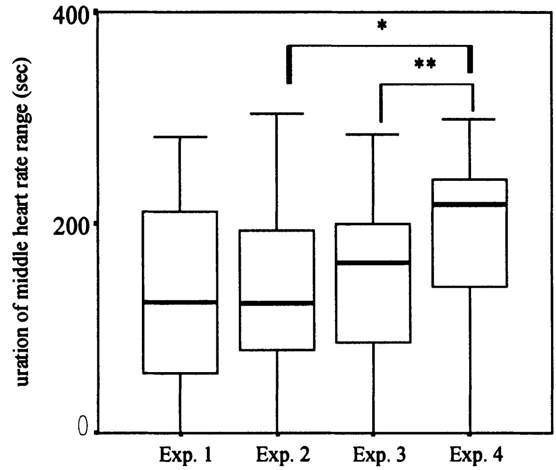



Figure 7 – Distribution of heart rate range during in the middle range: 20 subjects

### 3.4 Subjective Evaluation of Presentation Media

Figure 8 shows the results of the subjective evaluation during exercise viewing numbers (Experiment 2) and movies (Experiments 3, 4) concerning: 1) pleasantness, 2) relaxation level, 3) exercise-promoting effect, 4) exercise-hindering effect, and 5) perception of heart rate, all rated out of five. The results by paired t-test showed that at a 5% level of significance, pleasantness was significantly higher when movies were presented (Experiments 3 and 4) than when heart rate was presented numerically (Experiment 2). Presentation of the movies with story characteristics in Experiment 3 also led to significantly higher evaluations of relaxation level than in

Experiment 2 at a 5% level of significance. These results show that movies are highly pleasurable media.

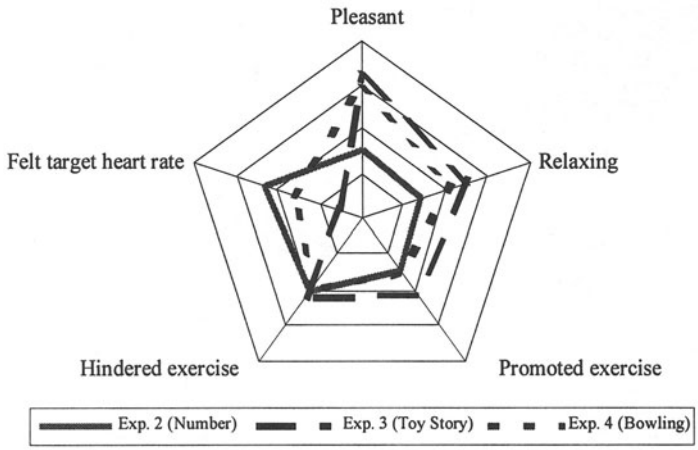



Figure 8 – Questionnaire evaluation results for presentation content

# 4. PROTOTYPING AND EVALUATION OF MUSIC-BASED HEART RATE CONTROL SYSTEM

This section discusses the feasibility of biological control through listening to music. Several different types of music with various tempos, dynamic patterns, and rhythms were employed to examine potential biological effects of music.

## 4.1 Investigation of Potential for Heart Rate Control During Exercise Using Music

There were a total of 20 subjects, 9 healthy males and 11 healthy females aged 18 to 22 years with no prior medical history relevant to the circulatory organs. The experiment was described to the subjects in advance, and subjects were prohibited from alcohol, tobacco, and caffeine consumption on the day preceding the experiment.

After two minutes of quiet rest in a sitting position, subjects were instructed to work at a level of exercise intensity perceived as "light exercise," and the bicycle ergometer was operated for 10 minutes without any information presented at all. The subjects then rested until they had recovered the original resting heart rate and then operated the bicycle ergometer while listening, for two minutes in each case, to the eight types of music listed in Table 1. The subjects were then instructed to exercise to the music.

The eight types of music selected differed in tempo, dynamic pattern, and rhythm, in ways deemed to have an exercise-promoting or -inhibiting effect. Table 1 lists the titles and characteristics of the music. The table also gives tempos numerically for music of constant tempo throughout the performance. *Change* indicates music of inconstant tempo and major changes during the performance. In terms of dynamics, under *Sig* (significance), O (yes) and × (no) indicate whether the music changes dynamically. Under *Per* (periodicity), O indicates periodic repetition of a dynamic pattern, and × indicates no periodic repetition. Under *Con* (continuity), O indicates smooth dynamic change, and × indicates the occurrence of sudden dynamic change. *Rhythm* designates music with (O) and without (×) a definite rhythm.

Table 1 – Eight types of music presented during exercise

| *Selection* | *Title* | *Remarks* | *Tempo* | *Dynamics* | | | *Rhythm* |
|---|---|---|---|---|---|---|---|
| | | | | *Sig* | *Per* | *Con* | |
| 1 | *Renjishi* | CD Anthology of poetry with Japanese music for celebrations (*samisen* music) | Change | O | × | × | × |
| 2 | Concret PH (1958) | CD Electronic music: Xenakis | Not fixed | × | × | O | × |
| 3 | Body Feels EXIT | CD 181920: Namie Amuro | 140 | × | × | O | 4 rhythms |
| 4 | *Aijo Monogatari* [Love Story] Prod: Takashi Takeuchi Arr: Toyoharu Kawamoto, Kazuhiro Kikuchi Perf: Hisao Sudo and the New Downbeat Orchestra | CD Let's Dance Waltz collection | 90 | ◇ | O | O | 3 rhythms |
| 5 | Theme From "A Summer Place" Percy Faith and His Orchestra | CD Best Oldies of the 60s | 62 | O | O | O | 4 rhythms |
| 6 | Ballet Mechanics (For 4 Pianos and Percussion) | CD Ensemble Modern Edition III | Not fixed | O | × | O | × |
| 7 | Heaven and Hell Comp: Offenbach Arr: Naoyoshi Ozawa Perf: Victor Orchestra | CD *Jitsuyo* Best Exercise group | 170 | × | × | O | 4 rhythms |
| 8 | The Well-Tempered Clavier Volume 1, No. 12 in E Minor | CD J.S. Bach, The Well-Tempered Clavier | 96 | × | × | O | 4 rhythms |

Music selections 3, 7, and 8 have the same dynamic patterns and rhythm; only the tempo was changed. Selection 1 is a song in which the tempo changes during the performance. Selection 2 is noise and has no tempo, rhythm, dynamics, or periodicity. Selection 4 is a waltz. Selection 5 is a song with a very slow tempo. Selection 6 is a fast tempo song but without rhythm. The eight songs described have differing characteristics in tempo, dynamic patterns, and rhythm, and these elements were selected to allow analysis of their effect on heart rate control. Between songs, the extent to which the music promoted or inhibited exercise was evaluated subjectively according to a 20-point rating method.

The music presentation method involved listening direct to music over headphones from a portable CD player so that extraneous sounds were inaudible. To eliminate any effects of differing volume, the maximum volume of each song was standardized using MIDI Software (*Pro Tools*), and the CD player volume was kept constant.

The distributions of mean heart rate in exercise while listening the eight types of music are shown in Figure 9. The scores were normalized by each subject. Table 2 shows the results for a paired t-test performed on differences in mean heart rate according to differences in music. Mean heart rate was significantly lower with Selection 1 than Selections 3–8, showing that Selection 1 had an exercise-inhibiting effect compared to Selections 3–8. Selection 1 is traditional Japanese *samisen* music characterized by tempo changes during the performance. In contrast, Selection 7 was associated with a significantly higher mean heart rate than the other music and was seen to raise heart rate during exercise. Selection 7 is fast tempo, pleasant music used in exercise classes and the like.

Table 2 – t-test results for difference in mean value of heart rate

| | S 1 | S 2 | S 3 | S 4 | S 5 | S 6 | S 7 | S 8 |
|---|---|---|---|---|---|---|---|---|
| S 1 | | × | ⊙↓ | O↓ | O↓ | ⊙↓ | ⊙↓ | ⊙↓ |
| S 2 | × | | ⊙↓ | × | × | ⊙↓ | ⊙↓ | O↓ |
| S 3 | ⊙↑ | ⊙↑ | | O↑ | × | × | ⊙↓ | × |
| S 4 | O↑ | × | O↓ | | × | O↓ | ⊙↓ | × |
| S 5 | O↑ | × | × | × | | O↓ | ⊙↓ | × |
| S 6 | ⊙↑ | ⊙↑ | × | O↑ | O↑ | | ⊙↓ | × |
| S 7 | ⊙↑ | ⊙↑ | ⊙↑ | ⊙↑ | ⊙↑ | ⊙↑ | | ⊙↑ |
| S 8 | ⊙↑ | O↑ | × | × | × | × | ⊙↓ | |

O: Significant differences $p<0.05$
⊙: Significant differences $p<0.01$
↑: Mean heart rate in column > mean heart rate in row
↓: Mean heart rate in column < mean heart rate in row

## 4.2 Subjective Evaluation of Exercise-Promoting Effect of Music Presented

Figure 10 shows the results of the exercise-promoting effect of various types of music presented to subjects according to a 20-point rating method, in which 10 indicates promotion and −10 indicates inhibition. Results from a t-test performed on the music evaluations showed that Selection 7 had an exercise-promoting effect compared to all other songs at a significance level of 1% and that Selection 3 had an exercise-promoting effect compared to all songs other than Selection 7 at a significance level of 1%. Selection 2 had an exercise-inhibiting effect compared to Selections 3, 5, 6, and 7 at a significance level of 1%. Selections 3 and 7, for which questionnaire survey results indicated an exercise-promoting effect, also returned results of a greater rise in heart rate during exercise than other songs, according to the heart

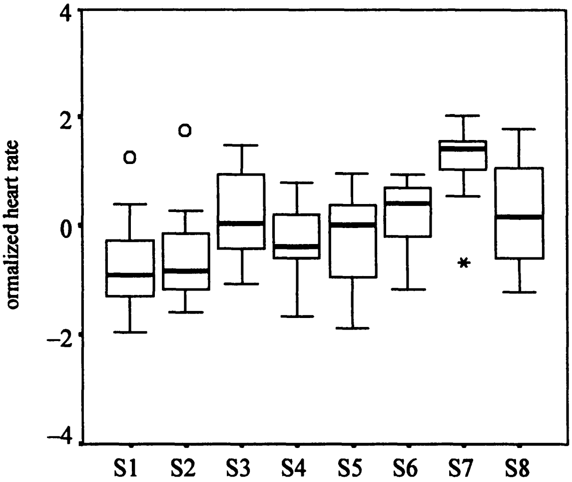



Figure 9 – Change in mean heart rate according to type of music

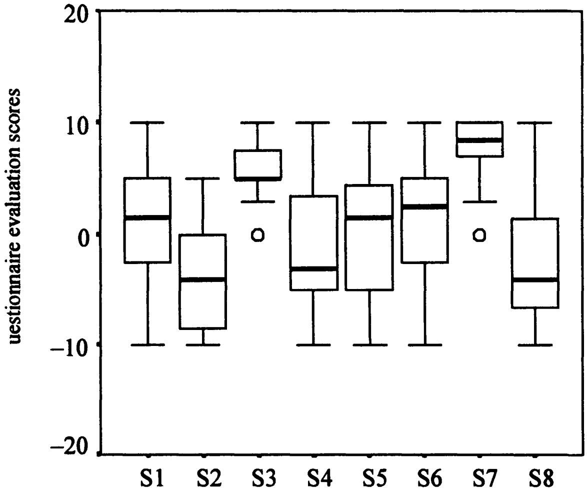



Figure 10 – Questionnaire evaluation results for exercise promoting/inhibiting effect

rate-based evaluation results discussed in Section 4.1. Selections 3 and 7 are similar in rhythm and dynamic pattern, with rhythmic changes in dynamics and a fast tempo.

These results show an exercise-promoting effect. Thus, changes in the tempo, dynamic pattern, and other characteristics of music presented during exercise alter exercise-promoting or -inhibiting effects and can be used for control of heart rate during exercise.

# 5. CONCLUSION

In this study we propose an unconscious human interface, which was designed to maintain good conditions for a driver at all times using the driver's own physiological signals. To study the feasibility of the concept, prototype human interfaces designed for perception of heart rate and the potential for heart rate control during bicycle ergometer exercise. The prototype system used movies and music as media for presentation of heart rate information during exercise. The system was used to evaluate movie-mediated perception of heart rate range during exercise, and the potential for music-based heart rate control during exercise.

The results showed that when movies were used as a presentation medium, selection of suitable movies allowed perception of heart rate during exercise. When numbers were used for presentation, setting of target levels required prior instruction concerning the relevant numbers, but when movies were used, target levels were successfully converted to images without prior instruction, which demonstrated the potential for their application in construction of an unconscious human interface. Movie-imaged presentation also embodied highly pleasant, relaxing, and otherwise pleasurable elements. Movies are thus suitable as a presentation means for commonplace human interfaces to be used wherever desired and on a long-term basis.

Presentation of music during exercise showed that the characteristics of the music presented produced observable differences in exercise-promoting and -inhibiting effect. Music of fast tempo and distinct dynamic rhythmic patterns promoted exercise. Experiments evaluating heart rate showed that music without a constant tempo inhibited exercise, and questionnaire surveys showed that non-musical noise inhibited exercise. These results illustrated a relationship between the characteristics of music and exercise promotion or inhibition as well as a heart rate-controlling effect of music, demonstrating the efficacy of music as a medium for presentation of an unconscious human interface. Music also embodies pleasurable elements and has the merit of not hindering tasks, allowing broad application including commonplace human interfaces or human interfaces for tasks.

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