Effects of a sensory intake task on heart rate and heart rate variability

Hiroyuki Kuraoka\(^a\), Kazuki Tsuruhara\(^b\), Chikamune Wada\(^a\) and Shinji Miyake\(^b\)

\(^a\)Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Kitakyushu, Fukuoka, JAPAN; \(^b\)School of Health Sciences, University of Occupational and Environmental Health, Kitakyushu, Fukuoka, JAPAN

This study investigated the effects of a sensory intake task on heart rate and heart rate variability (HRV). Twenty-one female participants were asked to perform a mental arithmetic (MA) task and a mirror tracing (MT) task for 5 min each. A previous study indicated that MT task has the characteristic of sensory intake and induces Pattern 2 responses, which evoke vasoconstriction and the resulting bradycardia. In this experiment, participants were instructed to perform “without hurrying” and “as precisely as possible” during the MT task. Electrocardiogram (ECG) was recorded during the MA, MT, and resting period before and after each task. High frequency components (HF), low frequency components (LF), LF/HF ratio of HRV, and the coefficient of variations of RR intervals were derived from the ECGs. Subjective mental workload assessment by NASA task load index (TLX) was evaluated after each task. The MT task was found to induce Pattern 2 response in which HR significantly decreased from the before-task baseline, although no significant difference was found in HF. These results differ from those of our earlier experiments and past findings in which there was no significant change in HR from the baseline during MT task when the instructions “as quickly as possible” were given. This suggested that instruction contents might affect physiological responses. The NASA-TLX temporal demand was significantly higher in the MA task than in the MT task. Conversely, physical demand was higher in the MT task than in the MA task. Consequently, the weighted average scores were identical for these two tasks. Therefore, physiological responses induced by mental tasks vary according to task characteristics, although average mental workload scores are identical.

Practitioner Summary: Sensory intake task such as a mirror tracing task facilitates parasympathetic nervous system and reduces heart rate. On the other hand, heart rate and HRV responses depend on the content of instruction to participants. Task characteristic should be carefully considered in mental workload evaluation using HRV indices.

Keywords: mirror-tracing task, sensory intake, Pattern 2 response, heart rate, heart rate variability

1. Introduction

Research on the relationship between mental workload and heart rate variability (HRV) has shown that decreases in low frequency component around 0.1 Hz (LF) and high frequency component (HF: 0.15-0.40 Hz) during a mental task indicate inhibition of the parasympathetic nervous system (PNS) activity by the task (Boucsein and Backs, 2000). In contrast, a few report on the facilitation of PNS activities by mental tasks has been found (Berntson et al, 1996). Both LF and HF are mediated by PNS activities. Increases in heart rate (HR) and systolic blood pressure and vasodilation of peripheral vessels are evoked by sensory-rejection tasks such as the MA task. In contrast, during a sensory-intake task such as the MT task, HR decreases. The former is described as Pattern 1 response, and the latter is described as Pattern 2 response (Schneiderman and McCabe, 1989). Some studies indicated a significant HR increase and HF decrease in the MT task compared with the baseline (Kasprowics et al, 1990; Miyake et al, 2014). These results suggested that even in a sensory intake task when the participants are instructed to perform “as quickly as possible,” their physiological responses might resemble Pattern 1 responses. Therefore, we investigated the effects of task characteristics including a sensory intake on HR and HRV by carefully instructing “without hurrying” and “as precisely as possible” to subjects performing the MT task, comparing this performance with that of the MA task, which includes time urgency.
2. **Method**

2.1. **Participants**

A total of one hundred five participants of both genders, were recruited, including around ten healthy participants of ages ranging from 20 to 60. However, here we report the results of the twenty-one younger female participants only (age: 20.4-35.1, mean/SD = 26.9/6.16 years) to exclude the effects of gender differences and age. All participants were confirmed to have no cardiovascular disease and provided written informed consent. This study was approved by the Ethics Committee of University of Occupational and Environmental Health.

2.2. **Procedures**

Upon arriving at the laboratory, participants were given instructions for the experiment. Subsequently, they were asked to practice two mental tasks briefly and confirm their informed consent. After attaching electrodes, participants took a 5-min pre-test rest (PRE) in a sitting position. Next, they were instructed to perform the MA and MT tasks for 5 min each. The order of the tasks was counterbalanced. After conducting these two mental tasks, they took a 5-min post-test rest (POST) again.

2.3. **Experimental tasks**

The MA task was based on the MATH algorithm proposed by Turner et al (1986). In this task, first, a problem appeared on a PC screen for 2 s. Following the word “EQUALS” for 1.5 s, an answer appeared for 1.5 s. Therefore, a problem appeared every 5 s. Participants were required to press the left button of a mouse if the presented answer was correct and the right button if it was incorrect. Participants had to respond quickly within 1.5 s. The MA task contained five levels of difficulty: level one, level two, level three, level four, and level five comprises 2-digit + 1-digit, 2-digit - 1-digit, 2-digit ±/− 2-digit, 3-digit + 2-digit problems, and 3-digit - 2-digit problems, respectively. All subtractions yielded positive answers. The first problem presented was always at level 3. Thereafter, the levels of the subsequent problems depended on the participant’s responses. When the participant’s response was correct, the level of the next problem increased by one. If an incorrect response or no response was given within the time limit, the level went down. For correct responses to level five problems and incorrect responses to level one problems, the level of the next problem remained the same. The task lasted 5 min. Therefore, participants responded to 60 problems. In the MT task, participants were asked to trace a zig-zag pathway on a PC screen “as precisely as possible” by using a mouse whose horizontal and vertical control elements were interchanged. During the practice session, participants were notified that when the mouse is moved to the right, the trajectory goes down as an example. They were urged not to do this task “as quickly as possible”. Previous studies using this MT tasks suggested that they induced Pattern 2 response (Sato and Miyake, 2004; Miyake et al, 2014).

2.4. **Physiological Measurement**

Electrocardiogram (ECG) from lead II was recorded during tasks and resting. HF, LF, LF/HF ratio, coefficient of variations of RR intervals (CV-RR), and HR were obtained. Arrhythmia frequently appeared in some blocks in two participants, and the data of another participant included unexplained artefacts. Therefore, three participants were excluded from the analysis and a total of eighteen participants were analysed.

2.5. **Subjective Assessment**

Subjective mental workload scores were obtained by the NASA Task Load Index (TLX). This index contains six subscales, i.e., Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Own Performance (OP), Effort (EF) and Frustration (FR). The weighted mean (Adaptive Weighted Workload: AWWL) of these six subscales was calculated; the AWWL is a weighted average score of the six subscales calculated using the weighting coefficients defined by the rank order of the raw scores without the paired-comparisons (Miyake and Kumashiro, 1993).
2.6. **Statistical Analysis**

All physiological indices were standardized among four blocks (PRE, MA, MT, and POST) in each participant. A repeated-measures ANOVA was used to determine significant differences among blocks and Greenhouse-Geisser correction of the degrees of freedom was applied. A post-hoc analysis (Student-Newman-Keuls multiple comparisons) was used when the main effect was significant ($p < 0.05$). Paired t-tests were applied to test the difference in subjective MWL scores between the MA and MT tasks.

3. **Results**

HR in the MT task significantly decreased from PRE. However, no significant HR change from PRE was found in the MA task (Figure 1A). LF was significantly smaller in the MA task than in POST (Figure 1B). No significant main effects were found in HF and LF/HF (Figure 1C, D). CV-RR was significantly larger in the MT task than in the MA task (Figure 1E).

In the results of the NASA-TLX, TD was significantly higher in the MA task than in the MT task (Figure 2). There were no significant differences in average workload score (AWWL).

![Graphs](A, B, C, D, E)

Figure 1. Changes in HR (A), LF (B), HF (C), LF/HF ratio (D) and CV-RR (E). Error bars indicate SE (* $p < 0.05$). (continues)
4. Discussion

Pattern 2 response including decreased HR during the MT task was clearly observed in this experiment, as expected. Our previous study showed that HR increased significantly during MT task (Miyake et al., 2014). This could be because the instructions we gave included “as quickly as possible.” Therefore, these results suggested that the contents of instruction, i.e., “as quickly as possible” vs “without hurrying,” affected the physiological responses even if the task performed was identical. Gendolla and Richter (2005) showed that physiological responses were more affected by instructions related to “ego involvement,” that is, the condition in which participants were asked to perform tasks with a strong requirement for the mobilization of mental effort. In their results, the HR increase was marginally significantly stronger in the self-paced ego involvement condition than in the self-paced no-ego involvement condition. Even if it was suggested that
instructions related to accuracy such as “as precisely as possible” and “without hurrying” affected the decrease of HR in this experiment, further experiments would be required to verify the effects of the instructions on HR more definitively.

Although the average mental workload scores were identical for the two tasks, physiological responses induced by mental tasks varied according to the task characteristics. In particular, HR was more affected by task characteristics than other indices such as HRV parameters. In either case, one index is insufficient for evaluating mental workload. Therefore, multi-dimensional assessment using a multivariate statistical analysis proposed by Miyake (2001) may be useful.

5. Conclusion
Pattern 2 response, in which heart rate decreased during the MT task, were observed more clearly when the instructions “as precisely as possible” and “without hurrying” were given. Further studies are needed to verify the effects of these instructions on physiological responses more clearly by comparing these two instructions in a randomized, experimental design.

References