Heart Rate Variability as a Mental Workload Index

Shinji Miyake, Hiroyuki Kuraoka** and Chikamune Wada***

** School of Health Sciences*
University of Occupational and Environmental Health, Japan
Kitakyushu, 807-8555, JAPAN

*** Graduate School of Life Science and Systems Engineering*
Kyushu Institute of Technology
Kitakyushu, 808-0196, JAPAN

ABSTRACT

In this study, we investigated relationship between task characteristics such as sensory intake and cardiovascular responses. Nineteen male participants were asked to perform a mental arithmetic task (MA) and a computerized mirror tracing (MT) task for five minutes each. In the MA task, participants were instructed to respond within five seconds by pressing the left or right mouse button. Therefore, this task includes a high time pressure (temporal restriction). In the MT task, participants were required to trace a zigzag pathway displayed on a PC screen by using a mouse. The horizontal and vertical control elements of the mouse were exchanged with each other. This task contains a sensory intake characteristic which induces parasympathetic dominance resulting in bradycardia. ECG and arterial blood pressure were continuously recorded during the two task blocks and before (PRE) and after (POST) resting periods of five minutes each. Heart rate variability indexes such as low frequency (LF) component, high frequency (HF) component and LF/HF ratio were derived. In the results, heart rate (HR) was considerably larger in the MA compared to PRE. On the contrary, the HR change was small in the MT, suggesting that the physiological response in MT is a pattern 2 type which is typically induced by a sensory intake task, although no significant difference was found between the two tasks. Systolic blood pressure (SBP) and Diastolic blood pressure (DBP) were higher in the MT than MA, but there was no significant difference between them. Both SBP and DBP were significantly higher in the task periods than resting periods. Significant differences were found only between PRE and MT, and PRE and POST in LF/HF which showed the highest value in POST, suggesting that the LF/HF ratio is not a reliable mental workload index.

Keywords: LF/HF ratio, Blood Pressure, Mirror Trace, Mental Arithmetic

INTRODUCTION

Cardiovascular responses evoked by a mental task are influenced by the nature of the task and/or individual response style. The responses to mental arithmetic task include increases in heart rate, systolic blood pressure, and forearm vasodilation. In contrast, the responses to more passive sensory intake tasks have been shown to be associated with forearm vasoconstriction resulting bradycardia (Schneiderman & McCabe 1989). The latter is described as pattern 2 response (Williams 1986), where vagal tone is increased. Mirror tracing (MT) tasks require visual-motor (hand-eye) feedback. Therefore, MT seems to be a typical sensory intake task. Kasprowics et al (1990) demonstrated significant increase in total peripheral resistance as well as significant decrease in pre-ejection period and no change in heart rate from baseline during MT using a simple six-pointed star, suggesting MT is a strong vascular stimulus.

Heart rate variability (HRV) spectral indexes, especially LF (low frequency component around 0.1Hz) and/or LF/HF (the ratio of LF to high frequency (HF: 0.15-0.40Hz) component) is frequently used to evaluate mental workload (MWL) and also in many other research fields. Many researchers have reported that a decrease in the LF or 0.1Hz component during mental tasks, indicating the inhibition of parasympathetic nervous system (PNS) by the tasks. However, if some mental task, e.g., MT as described above, contains sensory intake characteristics, HF (and LF) may increase. LF/HF is a fraction number of two components and both of them are mediated by PNS. Therefore, when PNS is inhibited by a mental task or activated by some specific task like MT, and sympathetic nervous system (SNS) activity does not change, changes in LF/HF may be bidirectional and unpredictable, resulting in a larger deviation among participants. This study investigated these HRV spectral indexes and blood pressure responses induced by two different mental tasks, including a MT task.

METHOD

Participants

Nineteen healthy males participated in this study. Each participant was paid 2,000 yen ($20) for his time. They provided written informed consent, and the study was approved by the Ethics Committee of University of Occupational and Environmental Health. Four participants were removed from the analysis due to a data recording failure in some blocks. The blood pressure sensor is very sensitive to hand movement causing a sudden shift in the waveform. To obtain reliable results, three more participants whose blood pressure waveforms included such artefacts were excluded by a visual inspection. Therefore, totally twelve participants (age: 19.1-24.4 years, mean/SD = 22.1/1.35 years) were submitted to analysis. All were right-handed.

Physiological Measures

ECG from CM_5 lead and arterial blood pressure from the left wrist (radial artery) using the tonometry method (BP608, Colin) were measured continuously throughout the experiment. They were sampled at 1kHz and stored in a PC disk. HRV indices (LF: 0.05-0.15Hz, HF: 0.15-0.40Hz, LF/HF ratio, total power (TP), coefficient of variation of RR intervals (CV-RR)) and HR were calculated from the ECG signals. The autoregressive power spectral component analysis was used after regularly sampled interpolation. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were derived at beat by beat timing. Then mean blood pressure (MBP) was calculated as MBP = DBP + (SBP -DBP) / 3.

Experimental Tasks

A computerized MT task was used. Participants were required to trace a zigzag pathway displayed on a PC screen by using a mouse. The horizontal (X) and vertical (Y) control elements of the mouse were exchanged with each other. Therefore, for example, when the mouse is moved to the left, the mouse cursor moves upward. Participants were not notified of such a mechanism and just instructed to trace the pathway as precisely as possible for five minutes. Previous studies that used this MT showed no heart rate change and an increase in LF/HF ratio during the MT task compared to a resting period, suggesting this MT task induced a pattern 2 response (Sato et al, 1998; Sato & Miyake, 2004).

In the mental arithmetic (MA) task, the MATH algorithm (Turner et al, 1986) was used. The MA contains 5 levels of difficulty: level one comprises 2-digit + 1-digit problems; level two 2-digit - 1-digit problems; level three 2-digit +/- 2-digit problems; level four 3-digit + 2-digit problems; and level five 3-digit - 2-digit problems. All subtractions yield positive answers. A problem appears on a 17 inch PC screen for 2 s, followed by the word 'EQUALS' for 1.5 s. An answer then appears; half of the presented answers are correct and half incorrect. The participants are required to press the left button of a mouse if the presented answer is correct, and the right button if it is incorrect. The presented answer remains on the screen for up to 1.5 s, during which time the participants must respond. Even if a participant responds quicker than 1.5 s, the next problem is presented after 1.5 s. Therefore, problems appear every 5 s. The first problem presented is always the third level of difficulty. From then on, the level of the problem presented depends entirely on the participants' responses: an appropriate response raises the level of difficulty of the next problem by one step, while an inappropriate response or no response within the time limit lowers it by one step. Appropriate responses to level five problems and inappropriate responses to level one problems do not alter the level of the next problem presented. These are slightly modified from the original MATH contents, and this task is a machine-paced task including a high time pressure (temporal restriction). The task duration was 5 min. Therefore the participants responded to sixty problems.

Procedure

The participants were given general information about the experiment when they arrived. After attaching the sensors and electrodes, the participants were instructed to rest quietly for about ten minutes to adapt to the experimental environment. Following a 5-minute resting period (PRE) in a sitting position, the participants performed two tasks in the fixed order, i.e., from MA to MT, then they took a rest for five minutes (POST) again. All the procedures were done in a sound-proof and electrically shielded room.

Statistical Analysis

Each parameter was standardized among four blocks for each participant. A repeated-measures ANOVA was used to test the main effect of block (four levels) using Greenhouse-Geisser correction of the degrees of freedom. A post-hoc analysis (Student-Newman-Keuls multiple comparisons) was applied when the main effect was significant ($p<0.05$).

RESULTS

The HR was considerably larger in the MA compared to PRE. Although no significant difference was found between the two tasks, The HR change from the baseline (PRE) in MT was smaller than in the MA (Figure 1a). LF significantly decreased from baseline in the MA. No significant difference was found between PRE and MT, indicating that the LF was almost the same level as the baseline in the MT (Figure 1b). HF significantly decreased from the baseline in both tasks (Figure 1c). LF/HF ratio showed higher values in both tasks than baseline, but the difference was significant only in the MT, and there was no significant difference between the two tasks (Figure 1d). The responses in TP and CV-RR were similar to those in HF because CV-RR is equivalent to TP (Figures 1e and f).

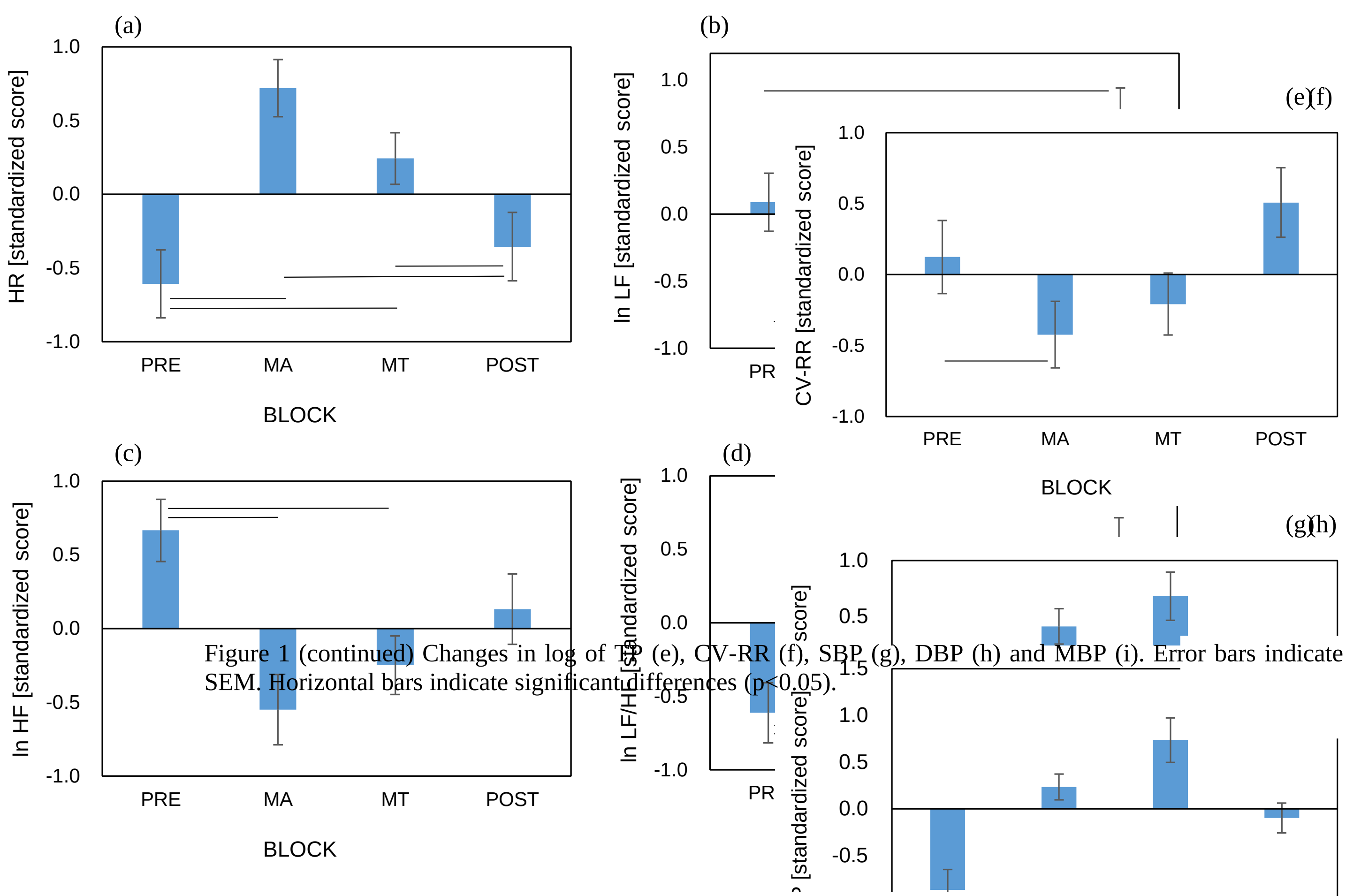

Figure 1 (continued) Changes in log of TP (e), CV-RR (f), SBP (g), DBP (h) and MBP (i). Error bars indicate SEM. Horizontal bars indicate significant differences ($p<0.05$).

Figure1 Changes in HR (a), log of LF (b), log of HF (c) and log of LF/HF ratio (d). Error bars indicate SEM. Horizontal bars indicate significant differences ($p<0.05$).

SBP, DBP and MBP were higher in MT than in MA, but there was no significant difference between the two tasks. They were significantly higher in the task periods than PRE (Figures 1g, h and i).

DISCUSSION

The physiological response in the MT might have been pattern 2 type, in which increased peripheral resistance induces blood pressure increase and compensatory heart rate decrease. In this study, a significant difference between the two tasks was found only in the LF, and HR significantly increased in the MT also. Therefore, no bradycardia was clearly observed in the MT. Unfortunately, we did not take any subjective mental workload evaluation for the two tasks. Teshima and Miyake (2003) used the same task combination to assess the effect of music and nature sounds, reporting that no significant difference was found between MA and MT in NASA-TLX WWL scores, suggesting overall workload levels for them are identical.

For many years, LF and LF/HF ratio have been believed to be indexes of sympathetic nervous system activity and sympatho-vagal valance, respectively. Recently, interpretations of them are being reconsidered (Billman, 2013; Goldstein et al, 2011; Reyes del Paso et al, 2013). Regardless of the interpretation of LF and LF/HF ratio, the fact that (1) no significant difference was found between baseline and MA in LF/HF ratio although HR showed very large increase in MA from the baseline; and (2) LF and LF/HF ratio showed the highest value during the resting period after the tasks, indicate that there is no relationship at least between these two HRV parameters (LF and LF/HF ratio) and MWL.

Blood pressure may be more sensitive to MWL. However, it is difficult to monitor blood pressure continuously without a high restriction of the hand movement. The establishment of a reliable blood pressure estimation method using, e.g., pulse transit time (Gesche et al, 2012) is expected to use MWL evaluation by physiological measures. As indicated in this study, physiological responses induced by mental tasks alter according to the task characteristics, even if the subjective MWL scores are identical. If discrimination of such differences among tasks is necessary, one single index is not enough and a multi-dimensional assessment using a multivariate statistical analysis including several physiological measures may be useful (Miyake, 2001; Miyake et al, 2006).

CONCLUSIONS

As indicated in the results, LF/HF is not a suitable index for MWL evaluation. Blood pressure may be more sensitive to MWL, but it is difficult to measure SBP and DBP continuously without severe restriction of hand motion. A reliable non-restricted SBP estimation method should be developed.

REFERENCES

Billman, G.E. (2013), "*The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance*", Frontiers in Phsyiology, Volume 4, 1-5

Gesche, H., Grosskurth. D., Küchler, G., Patzak, A. (2012), "*Continuous blood pressure measurement by using the pulse transit time: comparison to a cuff-based method*", European Journal of Applied Physiology, 112 (1), 309-15.

Goldstein, D.S., Bentho, O., Park, M., Sharabi, Y. (2011), "*LF power of heart rate variability is not a measure of cardiac sympathetic tone but may be a measure of modulation of cardiac autonomic outflows by baroreflexes*", Experimental Psychology, 96(12), 1255-1261

Kasprowicz, A.L., Manuak, S.B., Malkoff, S.B., Krantz, D.S. (1990). "*Individual differences in behaviorally evoked cardiovascular response: Temporal stability and hemodynamic patterning*", Psychophysiology 27 (6), 605-619

Miyake, S. (2001), "*Multivariate workload evaluation combining physiological and subjective measures*", International Journal of Psychophysiology, 40, 233-238

Miyake, S., Yamada, S., Shoji, T., Takae, Y., Kuge, N., Yamamura, T. (2006), "*Multi-dimensional evaluation of physiological responses induced by mental tasks*", Proceedings of Human Interface Symposium 2006, pp.267-272 (*in Japanese*)

Reyes del Paso, G.A., Langewitz, W., Mulder, L.J.M., Roon, A.V., Duschek, S. (2013), "*The utility if low frequency heart rate variability as an index of sympathetic cardiac tone: A review with emphasis on a reanalysis of previous studies*", Psychophysiology, 50, 477-487

Sato, N., Kamada, T., Miyake, S., Akatsu, J., Kumashiro, M., Kume, Y. (1998), "*Power spectral analysis of heart rate variability in Type A females during a psychomotor task*", Journal of Psychosomatic Research, 45, 159-169

Sato, N., Miyake, S. (2004), "*Cardiovascular reactivity to mental stress: relationship with menstrual cycle and gender*", Journal of Physiological Anthropology and Applied Human Science, 23, 215-223

Schneiderman, N. and McCabe, M. (1989), "*Psychophysiologic strategies in laboratory research*", in: Handbook of research method in cardiovascular behavioral medicine, Neil Schneiderman, Stephen M. Weiss, Peter G. Kaufmann (Eds.). Plenum Press, pp.349-364

Teshima, M., Miyake, S. (2003), "*Effects of favorite music and nature sound on mood, task performance and physiological indices*", Proceedings of the XVth Triennial Congress of the International Ergonomics Association and the 7th Joint Conference of Ergonomics Society of Korea / Japan Ergonomics Society, Volume 4, pp.141-144

Turner, J. R., Heiwitt, J. K., Morgan, R.K., Sims, J., Carrol, D. , Kelly, K. A. (1986), "*Graded Mental Arithmetic as an Active Psychological Challenge*", International Journal of Psychophysiology, 3, 307-309

Williams, R.B. (1986), "*Patterns of reactivity and stress*", in: Handbook of stress, reactivity, and cardiovascular disease, Karen A. Matthews, Stephen M. Weiss, Thomas Detre, Theodore M. Dembroski , Bonita Falkner, Stephen B. Manuck, and Redford B. Williams, Jr. (Eds.). Wiley, pp.109-125