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ORIGINAL ARTICLE

A STUDY ON THE USAGE OF BLOOD-VOLUME-PRESSURE AS A DRIVER'S MENTAL WORKLOAD EVALUATION TOOL

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ABSTRACT

Estimating a driver's mental workload level is challenging part nowadays. In this study, an experimental investigation was conducted to explore mental workload using blood-volume-pressure (BVP) and electrocardiogram (ECG) signals. Participants performed two secondary tasks at two levels of task difficulty and also in two types of traffic conditions. The results show that increasing task difficulty seems to increase heart rate (HR) and reduce the heart rate variability (HRV) data simultaneously. Especially, data for HR was high when the drivers were performing the most difficult task for the mathematical arithmetic task. Results from BVP and ECG also show that they correlate each other showing that BVP can be used as a potential candidate as a mental workload measurement tools. Potential applications of this research include developing a method to estimate a driver`s mental workload level through blood volume pressure as the main measurement for evaluation of mental workload as it is non-intrusive to drivers.

Keywords: *Driver, Mental Workload, Heart Rate, Heart Rate Variability, Blood Volume Pressure*

INTRODUCTION

Cognitive distraction while driving is known as contributing factors to traffic crashes. In a driving situation, the source of cognitive distractions could be found on the inside and outside of the vehicle. For example, drivers may experience a higher workload while manoeuvring a vehicle on a street with high traffic load condition. While the source of workload on the inside of a vehicle can be from the interaction with in-vehicle equipment such as conversation on car-phone or operating car navigation. While many researchers interested in investigating about the level of the internal source of workload or cognitive distraction, this study tried to combine these two contributing factors based on the belief that the combination of these two sources will further increase driver's mental workload. In a different level of difficulties of the mental workload from both external and internal sources of mental workload.

In recent years, studies on the estimation of mental workload state have been investigated with various devices. The most commonly used physiological indices are the heart rate and heart rate variability from electrocardiograph or blood volume pressure, respiration rate and galvanic reflex (Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2012; Brookhuis & de Waard, 2010; Kawakita, Itoh, & Oguri, 2010; Lean & Shan, 2012; Tokuda, Obinata, Palmer, & Chaparro, 2011; Wang, 2007). While it is also difficult to find an accurate measurement that indicates a high level of mental workload, it is also important to choose a tool which is non-intrusive to drivers. As an example, the data from EEG is said to be robust. However, attaching electrodes to drivers during driving will give restriction to drivers.

Acknowledging the importance to develop a method to detect the driver's mental workload state, blood volume pressure (BVP) sensor. BVP is a device that records blood pulse wave is a promising candidate because it is non-interfere to the driving manoeuvres. The usage of a BVP has been used in a driving situation to monitor a driver's blood pulse. Recently there is increasing interest to use this sensor to monitor drivers' condition. For example, this device located on the steering wheel is designed to predict heart attack while driving (Tokyo Web, 2013). The main advantage of using this device is that it is non-intrusive to drivers thus the data is robust.

BVP produce infrared light through tissue (skin) and measures the absorption of light by the blood flowing through the vessels. Using the BVP sensor from seat to measure a driver's condition. Despite the potential of using BVP to estimate a driver's mental workload because it is non-intrusive to drivers, there are few studies the use of blood pressure to determine workloads (Miller, 2001). Recent studies by the authors on Blood pressure shows that BVP can be used to differentiate the level of difficulties of the task. (Makhtar & Itoh, 2014).

Comparison between BVP and ECG were made from a different perspective while BVP also can be measured from HR and HRV. The ECG signal is mainly to evaluate the heart rate (HR) and heart rate variability (HRV). HR is detected by measuring the R-R peak interbeat interval in milliseconds (ms). ECG was selected as a measure of comparison because it is widely used to measure mental workload. HR is the speed of the heartbeat measured by the number of heartbeat per minute (Beat-Per-Minute, BPM). BioTrace software was used to analyse the HRV data. HRV data can be analysed by using time-domain and frequency domain. For this research, we used the frequency domain. First, the continuous BVP data were transformed to Inter-Beat-Interval (IBI) time series. Then by using Fast Fourier Transform (FFT) Spectral Analysis, IBI converted to the frequency domain of HRV Spectrum. From the HRV Spectrum, there are two bands of interest: High Frequency (HF) band (0.15Hz - 0.7Hz) and Low Frequency (LF) band (0.04 Hz - 0.15Hz)(Malliani, Pagani, Lombardi, & Cerutti, 1991; Pagani et al., 1986). We used the ratio of LF/HF as it can measure of Autonomic Nervous System balance. (Delaney & Brodie, 2000; Orsila *et al.*, 2008; Luft, Takase & Darby, 2009; Cinaz & Marca, 2010). However, most of the works were performed non-driving condition environment (Cinaz, Arnrich, La Marca, & Tröster, 2011; Cinaz, La Marca, & Arnrich, 2010),(Dussault, Jouanin, Philippe, & Guezennec, 2005). Studies have shown that mental workload has a clear indication of heart rate and heart rate variability (Ben Mulder, van der Veen, van Roon, Rüddel & Schächinger, 1993; de Waard, 1996). According to Mulder et al. (1993), the mental workload may increase the heart rate and reduce heart rate variability at the same time.

An experiment was designed to examine the sensitivity of BVP and ECG data to changes in workload and to evaluate the usage of BVP as a potential candidate as evaluation tools of mental workload. In spite of that, there is still a problem in determining the high mental workload state (Miao, Shimizu & Shimoyama, 2003). Hence the goal of this research was to find a standard value that indicates 'high' mental workload by using BVP.

METHODS

In order to collect the data, a fixed-base driving simulator developed by Mitsubishi Precision, Inc (Figure 2(a)). It consists of 4 screens (H120 x W160mm) been projected by projectors. The location of screen projectors as shown in Figure 2(b). BVP and ECG data were recorded from Nexus-10 MKII devices developed by MindMedia. BVP device attaches to finger of participants and ECG were recorded from electrodes attached to the chest pf participants.

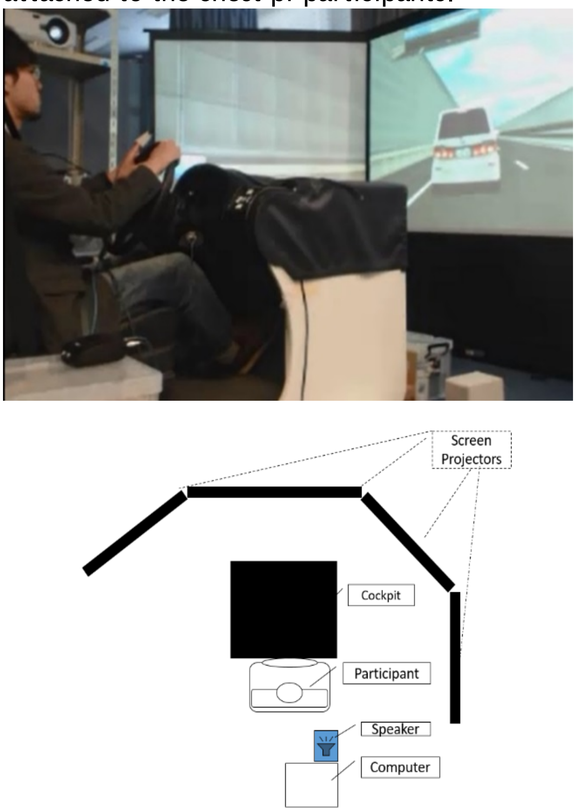

Figure 1. The driving simulator used in the study

Participants

Twenty-five male drivers with a mean age of 21.1 Years Old and Standard deviation of 1.3 participated in the experiment. Every participant holds a valid driver's license. The average driving experience was 2.3 years. Participants were explained that they had the option to end participation at any time during the experiment without any type of penalty.

Traffic Situation

The primary task was to drive safely in the left lane. The driving course was designed to be a straight 10km highway. There were four types of traffic conditions, a) Non-Driving Task, b) BD1&2: Baseline Driving first and the last run of the experiment. c) None Hazardous Conditions (NHC) and d) Hazardous Condition (HC).

a) BD1 & BD2

BD1 was 'Baseline Driving' where there was 'Non-Hazardous traffic condition and no secondary task have been imposed on the participants. There was no following vehicle behind the host vehicle.

b) Non-Hazardous Condition

Participants were told to keep a safe following distance and to be alert to sudden changes in the speed of both vehicles. If they meet with a crash during a trial, participants had to start a new trial all over again. This way, participants try their best for not involving with a crash. Figure 2 illustrates a scenario of an experiment in NHC driving condition. Participants were instructed to drive Host Vehicle (HV) in the left lane. Participants were asked to follow a lead vehicle (LV) and maintain a safe following distance at about 1 second Time Headway (THW). In order to maintain for not too far from the LV, the following vehicle was located in the behind of vehicle. In this traffic condition, both LV and FV were set to drive at a constant speed of 90km/h.

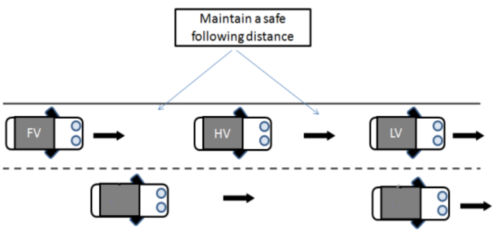

Figure 2. Non-Hazardous condition (HC)

Hazardous Condition (HC)

While under HC participants were also asked to maintain the distance between LV and aware of the speed of FV (Figure 3). Both LV and FV cruised between 55km/h and 100km/h. In a random way, with approximately twice the speed changes for each 400-meter run, LV and FV decelerate abruptly of 0.35g. After a while, LV and FV accelerate again. During 6-minutes of the trial, there were 16 braking tasks including 2 dummy braking. (Only stopping alarm of LV activated- this is to make them aware of the situation and not only rely on the stopping alarm of LV to make a deceleration)

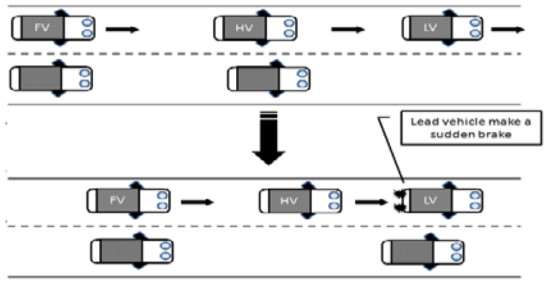

Figure 3. Hazardous condition (HC)

Secondary Task

For the secondary task participants were requested to carry out a two-minute Mathematical Arithmetic Task (MAT) in a 6-minute run. Figure 4 shows the location of MAT period in the 6 minutes of the run.

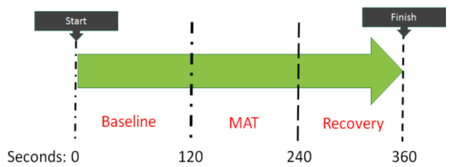

Figure 4. MAT period in a trial

MAT is a kind of so-called PASAT (Paced Auditory Serial Addition Test). It requires the participants to memorize the numbers presented before as well as solve the calculation. In order to increase demand for the mental task, MAT is divided into two levels of difficulties, namely the easy level (MAT1) and the difficult level (MAT2) tasks. In MAT1, participants were given one-digit numbers (from 1 to 9) in every three seconds through the speakers connected to a computer. Participants had to give the answer summation of last two numbers orally as in Figure 5. While in MAT2, participants were given two-digit numbers between 11 and 49 (Figure 6). As in MAT1, the participants were asked to provide the sum with the last two numbers orally.

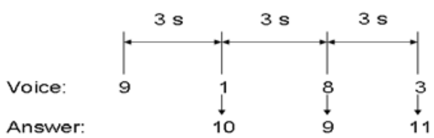

Figure 5. MAT1 (Easy Level)

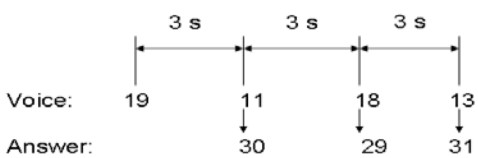

Figure 6. MAT2 (Difficult Level)

Experimental Design

In order to avoid order effects, the experimental procedure was arranged randomly between participants. Table 1 shows an experimental procedure for participants which combination of secondary task and traffic condition.

Table 1. Experimental procedure

No	Secondary Task	Traffic Condition	Driving Condition
1	NMAT	BD1	NMATBD1
2	NMAT	NHC	NMATNHC
3	MAT1	NHC	MAT1NHC
4	MAT2	NHC	MAT2NHC
5	NMAT	HC	NMATHC
6	MAT1	HC	MAT1HC
7	MAT2	HC	MAT2HC
8	NMAT	BD2	NMATBD2

***NMAT:** No Mathematical Arithmetic Task, **MAT1**: Arithmetic Task with one-digit numbers, **MAT2:** Arithmetic Task with two-digit numbers. **BD1**: Baseline Driving for the first time, **BD2:** Baseline Driving for the last time. **NHC:** Non-Hazardous Condition, **HC:** Hazardous Condition.

2.5 Procedure

Upon arriving at the venue, participants were explained about the general information of the experiment. They were also explained about participating in the experiment voluntary based and any time can cancel the participation without penalty. After that, they will have 5-10 minutes of training for both secondary task and traffic condition separately and 5 minutes for the training of combination with these two tasks. In order to make sure that they have been accustomed to the tasks, they were informed about the results of the percentage of the correct answer for the secondary task after completing the training trial. Prior to that, they were informed to try their best to get better results. After about 5 minutes, they will start the experiment. BVP device attached to the right-hand finger and ECG electrode attached to the chest of participants. After completing each trial, participants were asked to answer the questionnaire NASA-TLX as a subjective measurement to estimate the workload in each task.

3. Results

While performing a mathematical task, it was assumed that the demand for the mathematical task has remained unchanged during the 2-minute task. To know the mental workload of participants during the task period, the mean value of heart rate (HR) and heart rate variability (HRV) for that period were calculated. An alpha level of 0.05 was used for all statistical tests.

3.1 Heart rate (HR)

The mean value of HR data from BVP for the MAT intervals is displayed in Figure 7. As illustrated in the graphs, the highest value was found on MAT2NDT (M: 77.943, SD: 1.960) and NMATBD1 was the lowest of HR value with (M: 71.621, SD: 1.834). A repeated-measures ANOVA with a Greenhouse-Geisser correction was used as Mauchly's test of Sphericity been violated. The results determined that mean HR from BVP differed statistically significantly between driving conditions (F(3.878, 93.065)=13.527, $p<0.0005$, $\eta_p^2=0.360$).

While for ECG, the highest value was found on MAT2HC (M: 78.308, SD: 10.395) and NMATBD1 was the lowest of HR value with (M: 71.275, SD: 9.507). A repeated-measures ANOVA with a Greenhouse-Geisser correction determined that mean HR from ECG differed statistically significantly between driving conditions (F(4.334, 104.021)=14.791, $p<0.0005$, $\eta_p^2=0.381$).

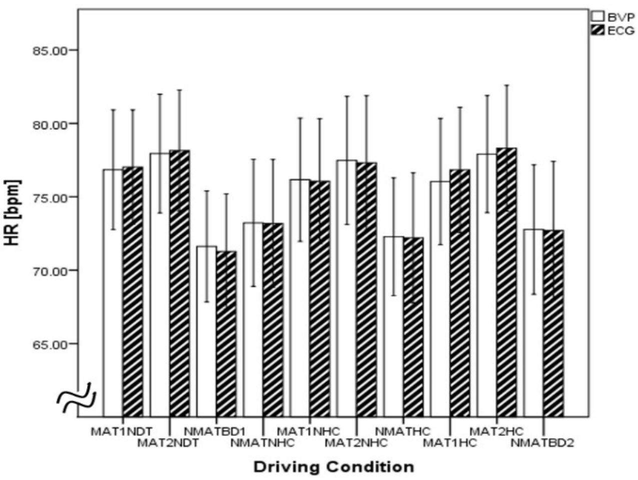

Figure 7: Mean Value of HR from ECG and BVP

To evaluate the usage of BVP as a tool to measure mental workload, a paired-samples t-test was conducted to compare HR data from BVP and ECG in driving conditions. The differences were not significant in every condition compared to data from ECG and BVP. HR BVP (M=104.41, SD=6.98) and HRV ECG (M=104.57, SD=6.70); t(249)=-0.630, p = 0.529.These results suggest that the data from BVP and ECG was the same.

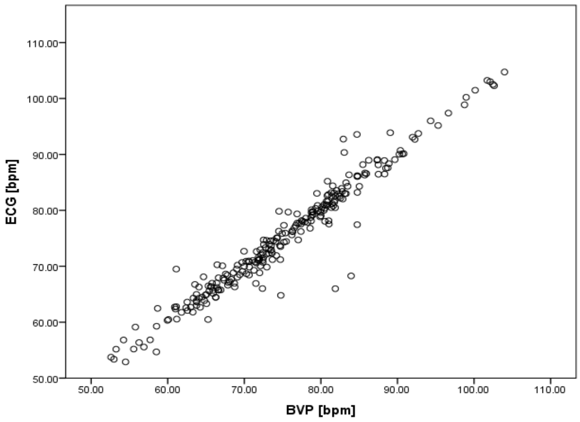

Figure 8: Scatterplot of ECG and BVP

A Pearson product-moment correlation coefficient was computed to assess the relationship between HR from BVP and ECG. There was a positive correlation between the two variables, $r=0.971$, $n=250$, $p<0.0005$. A scatterplot summarises the results (Figure 8). Overall, there was a strong positive correlation between HR from BVP and ECG. Increases in HR from ECG according to driving conditions were correlated with increases in HR from BVP.

3.2 Heart Rate Variability (HRV)

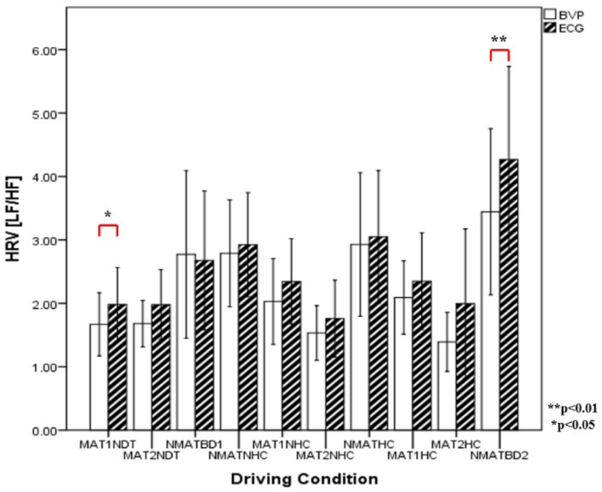

Figure 9: Mean value of HRV from ECG and BVP

As stated in the introduction of this paper, generally HRV will decrease when the mental workload increased, Figure 3 shows the results of HRV data collected from ECG and BVP for different driving conditions. The mean value of HRV data from BVP and ECG for the MAT intervals were shown in Figure 9. As illustrated in the graphs, For HRV from BVP data, the highest value was found on NMATBD2 (M: 3.44, SD: 0.635) and MAT2HC was the lowest of HRV value with (M: 1.392, SD: 0.226). A repeated-measures ANOVA with a Greenhouse-Geisser correction determined that mean HRV from BVP differed statistically significantly between driving conditions ($F(4.539, 108.932)=3.814$, $p=0.004$, $\eta_p^2=0.137$).

While for ECG, the highest value was found on NMATBD2 (M: 4.268, SD: 0.711) and MAT2NHC was the lowest of HRV value with (M: 1.760, SD: 0.294). A repeated-measures ANOVA with a Greenhouse-Geisser correction determined that mean HRV from ECG differed statistically significantly between driving conditions ($F(4.445, 106.688)=4.012$, $p<0.003$, $\eta_p^2=0.143$).

A paired-samples t-test was conducted to compare HRV data from BVP and ECG in each driving condition. There was a significant difference in the scores for HRV BVP (M=1.67, SD=1.20) and HRV ECG (M=1.98, SD=1.40) in MAT1NDT conditions; $t(24)=-2.449$, $p = 0.022$.There was also a significant difference in the scores for HRV BVP (M=3.44, SD=3.17) and HRV ECG (M=4.27, SD=3.56) in NMATBD2 conditions; $t(24)=-2.281$, $p = 0.009$.

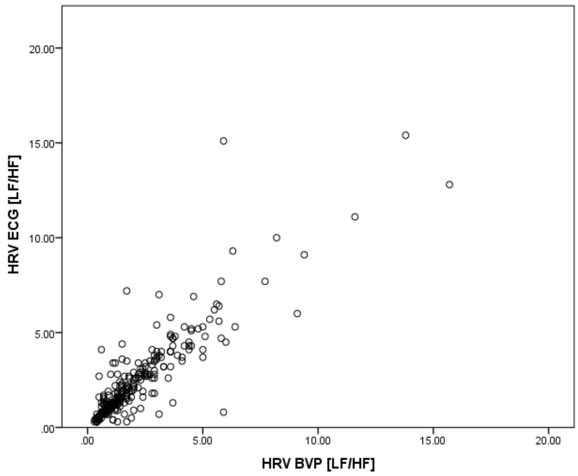

Figure 10: Scatterplot of ECG and BVP

A Pearson product-moment correlation coefficient was computed to assess the relationship between HRV from BVP and ECG. There was a positive correlation between the two variables, $r=0.875$, $n=250$, $p<0.0005$. A scatterplot summarises the results (Figure 10). Overall, there was a strong positive correlation between HRV from BVP and ECG. Increases in HRV from ECG according to driving conditions were correlated with increases in HRV from BVP.

3.3 Subjective Ratings

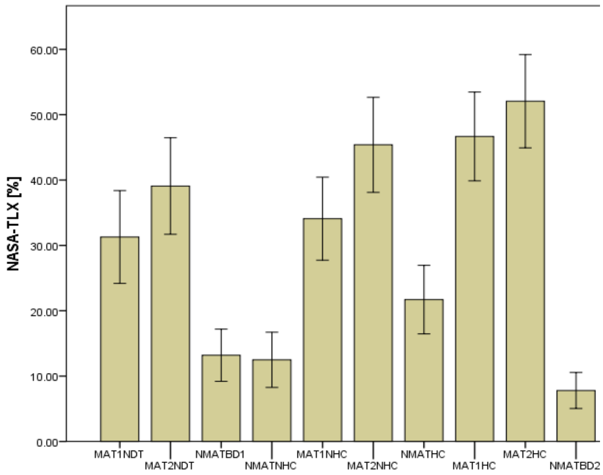

Figure 11: Mean value of NASA-TLX according to driving conditions

The mean value of NASA-TLX was shown in Figure 11. As illustrated in the graphs, the highest value was found on MAT2HC (M: 52.067, SD:3.456) and NMATBD2 was the lowest of NASA-TLX with (M: 7.80, SD:1.335). A repeated-measures ANOVA with a Greenhouse-Geisser correction determined that mean NASA-TLX differed statistically significantly between driving conditions ($F(3.808, 91.393)=45.939$, $p<0.0005$, $\eta_p^2=0.657$).

4. Discussion

4.1 **Regarding the level of difficulties of tasks.**

As our hypotheses were the more difficult level of the mental workload from secondary task and traffic condition, the higher value of HR is observed from data of BVP and ECG. In this experiment, MAT2HC was set as the most difficult task and predicted to give the highest level of mental workload to drivers. While for HRV, basically, the more difficult level of mental workload task, HRV will become lower. Based on the results of the experiment, data from NASA-TLX was tally with the hypotheses of the highest value came from MAT2HC. This subjective measurement will be the based comparison to predict the level of mental workload. Data of HR from BVP and ECG sources shows that the highest value came from MAT2HC as expected.

While for HRV, the lowest value was from MAT2HC from BVP data source. For ECG data, the lowest value was found on MAT2NHC, where participants accomplished the difficult level of the mental task under non-hazardous condition. These results show that using HR and HRV from data of ECG and BVP is appropriate to predict the level of driver's mental workload.

4.2 **Correlation between HR and HRV from ECG and BVP.**

The Evaluation of BVP to assess mental workload under different driving conditions. The results from HR correlate highly between BVP and ECG. Was the same, BVP and ECG. It has to be mentioned here about some of the limitations that could affect the finding. First, in this experiment, the only straight path was designed and this could reduce the noises from signals especially from BVP where it used a finger to collect the signal.

5. Conclusion

In this study, we found that:

1. MAT2HC was the highest mental workload with HR will give the highest value and HRV will give the lowest value. NMATBD will give the lowest value of mental workload.
2. BVP and ECG were the same data thus BVP can be used in the evaluation of mental workload.

COMPETING INTERESTS

There is no conflict of interest.

REFERENCES

1. Ben Mulder, H. V., van der Veen, F., van Roon, A., Rüddel, H., & Schächinger, H. (1993). On the effects of mental task performance on heart rate, blood pressure and its variability measures. *Blood Pressure and Heart Rate Variability: Computer analysis, modelling and clinical applications*, *4,* 153–166.

2. Borghini, G., Astolfi, L., Vecchiato, G., Mattia, D., & Babiloni, F. (2012). Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness. *Neuroscience and Biobehavioral Reviews*, 1–18. http://doi.org/10.1016/j.neubiorev.2012.10.003

3. Brookhuis, K. A., & de Waard, D. (2010). Monitoring drivers' mental workload in driving simulators using physiological measures. *Accident; Analysis and*

Prevention, *42*, 898–903. http://doi.org/10.1016/j.aap.2009.06.001

4. Cinaz, B., Arnrich, B., La Marca, R., & Tröster, G. (2011). Monitoring of mental workload levels during an everyday life office-work scenario. *Personal and Ubiquitous Computing*, *17*(2), 229–239. http://doi.org/10.1007/s00779-011-0466-1

5. Cinaz, B., & La Marca, R. (2010). Monitoring of mental workload levels. *Proceedings of IADIS …*, 189–193. Retrieved from http://www.researchgate.net/publication/235834315_Monitoring_of_Mental_Workload_Levels/file/d912f513f52a37ee39.pdf

6. Cinaz, B., La Marca, R., & Arnrich, B. (2010). Monitoring of mental workload levels. In *IADIS eHealth Conference* (pp. 189–193).

7. de Waard, D. (1996). The Measurement of Drivers ' Mental Workload. *PhD Dissertation*.University of Groningen

8. Delaney, J. P. A., & Brodie, D. A. (2000). Effects of short-term psychological stress on the time and frequency domains of heart-rate variability. Perceptual and motor skills, 91(2), 515-524.

9. Dussault, C., Jouanin, J., Philippe, M., & Guezennec, C. (2005). EEG and ECG Changes During Simulator Operation Reflect Mental Workload and Vigilance. *Aviat Space Environ Med*, *76*(4).

10. Kawakita, E., Itoh, M., & Oguri, K. (2010). Estimation of driver's mental workload using visual information and heart rate variability. *13th International IEEE Conference on Intelligent Transportation Systems*, 765–769. http://doi.org/10.1109/ITSC.2010.5625079

11. Lean, Y., & Shan, F. (2012). Brief Review on Physiological and Biochemical Evaluations of Human Mental Workload, *22*(3), 177–187. http://doi.org/10.1002/hfm

12. Luft, C. D. B., Takase, E., & Darby, D. (2009). Heart rate variability and cognitive function: Effects of physical effort. *Biological Psychology*, *82*(2), 196–201. http://doi.org/10.1016/j.biopsycho.2009.07.007

13. Makhtar, A. K., & Itoh, M. (2014). An Analysis of Ear Plethysmogram for Evaluation of Driver's Mental Workload Level. In *SICE Annual Conference 2014* (pp. 2025–2030).

14. Malliani, A., Pagani, M., Lombardi, F., & Cerutti, S. (1991). Cardiovascular neural regulation explored in the frequency domain. *Circulation*, *84*(2), 482–492. http://doi.org/10.1161/01.CIR.84.2.482

15. Miao, T., Shimizu, T., & Shimoyama, O. (2003). The Use of Chaotic Dynamics in Finger Photoplethysmography to Assess Driver Mental Workload. In *The Society of Automotive Engineers of Japan* (pp. 18–3, 1--3).

16. Miller, S. (2001). *Workload measures*. *National Advanced Driving Simulator Iowa City, United States*.

17. Orsila, R., Virtanen, M., Luukkaala, T., Tarvainen, M., Karjalainen, P., Viik, J., … Nygård, C.-H. (2008). Perceived mental stress and reactions in heart rate variability--a pilot study among employees of an electronics company. *International Journal of Occupational Safety and Ergonomics : JOSE*, *14*(3), 275–283. http://doi.org/10.1080/10803548.2008.11076767

18. Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., … Piccaluga, E. (1986). Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympathovagal interaction in man and conscious dog. *Circulation Research*, *59*(2), 178–193. http://doi.org/10.1161/01.RES.59.2.178

19. Tokuda, S., Obinata, G., Palmer, E., & Chaparro, A. (2011). Estimation of mental workload using saccadic eye movements in a free-viewing task. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference*, *2011*, 4523–9. http://doi.org/10.1109/IEMBS.2011.6091121

20. Tokyo Web. (2013). Electrocardiogram check by car handle that predict heart attack. *Tokyo Shinbun*. Tokyo.

21. Wang, L. (2007). A Composite Measure for the Evaluation of Mental Workload. In *Digital Human Modeling: Volume 4561 of the series Lecture Notes in Computer Science* (Vol. 4561, pp. 460–466). http://doi.org/10.1007/978-3-540-73321-8_53