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SUITABILITY OF HEART RATE RECORDING AS PHYSIOLOGICAL MEASURES TOOL TO DETERMINE DRIVERS' PERFORMANCE IMPAIRMENT: A PRELIMINARY STUDY

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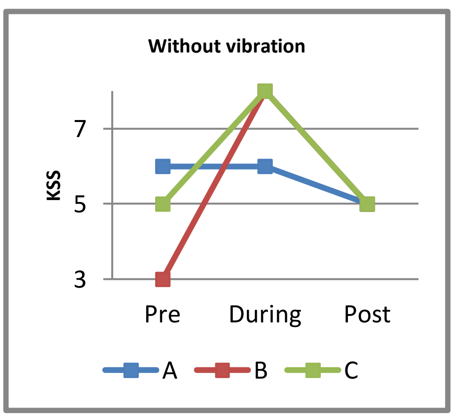
Graphical abstract



Abstract

Performance impairment may occur if the driver feels fatigue while driving. This study investigated the drivers' condition while performing one hour driving simulation in a controlled environment. The aim of this study was to evaluate whether heart rate measures can be used to detect impaired driver performance as well as reduced alertness. There are two different experiments conducted among the subjects; (i) without vibration and (ii) with vibration. A monotonous driving simulation scenario with low demand of traffic flow was utilized to detect drivers' performance impairment. Heart rate (HR) was recorded over the entire experiment; (i) 30 minutes before driving, (ii) one hour during driving and (iii) 30 minutes after driving in the morning before lunch break. The baseline measurement was recorded when the subject has performed his daily routine in the same hours of experiment, which is about three hours. HR measures were derived and correlated to variation of lane deviation (VLD), a driving performance measure, and to the driver's state, which was estimated by the Karolinska Sleepiness Scale (KSS). Experimental result shows all subjects' HR data were lower at the end of the driving task, particularly when driving in the simulator without vibration. Based on KSS evaluation, subjects tend to feel sleepy during driving and become less sleepy when they reach the destination. In term of VLD, all subjects tend xto cross the lane, which means they were not focused to the task. In conclusion, HR can be used as a tool to detect drivers' performance and it is a useful indicator of physiological adaptation and intensity of effort.

Keywords: Heart rate, driver, vibration, fatigue, performance, sleepiness, simulator

Abstrak

Kemerosotan prestasi pemanduan boleh berlaku apabila pemandu berasa lesu ketika memandu. Kajian ini mengkaji keadaan pemandu apabila memandu selama satu jam di dalam persekitaran yang terkawal. Objektif kajian ini ialah untuk menilai sama ada pengukuran kadar degupan jantung dapat digunakan untuk mengesan kemerosotan prestasi pemandu dan juga kecerdasan pemandu. Satu senario simulasi memandu dengan aliran trafik yang rendah digunakan untuk mengesan kemerosotan prestasi pemandu. Kadar degupan jantung direkodkan sepanjang eksperimen, 30 minit sebelum memandu, satu jam semasa memandu dan 30 minit selepas memandu pada waktu pagi sebelum rehat tengah hari. Selain itu, pengukuran rujukan direkodkan apabila subjek telah melakukan rutin hariannya dalam waktu yang sama dengan waktu eksperimen. Nilai kadar degupan jantung diperoleh dan dikaitkan dengan perubahan sisihan lorong, ukuran prestasi pemanduan, dan juga penilaian subjektif menggunakan *Karolinska Sleepiness Scale* (KSS). Hasil eksperimen menunjukkan data HR subjek adalah lebih rendah ketika di akhir pemanduan, terutamanya ketika memandu di simulator tanpa getaran. Berdasarkan pada penilaian KSS, peserta kajian cenderung untuk berasa mengantuk semasa memandu dan menjadi kurang mengantuk apabila mereka sampai ke destinasi. Dari segi perubahan sisihan lorong, peserta cenderung untuk menyeberangi lorong, yang bermakna mereka tidak memberi tumpuan kepada tugas. Kesimpulannya, kadar degupan jantung boleh digunakan sebagai alat untuk mengesan prestasi pemandu dan ia adalah petunjuk yang berguna dengan adaptasi fisiologi dan penentuan itensiti usaha.

Kata kunci: Kadar degupan jantung, pemandu, getaran, kelesuan, prestasi, mengantuk, simulator

1.0 INTRODUCTION

Driver fatigue has long been identified as a major cause for road accidents due to reduced driving performance [1-2]. In the past, cardiac measurement has been the most popular physiological techniques to assess the mental fatigue, including ECG, blood pressures (BP) and blood volume measurement [3-5]. Several relevant indicators were used in mental workload evaluation related to heart activity, such as: Heart Rate (HR), and the Heart Rate Variability (HRV)[6-7].

HR is a good index of evaluating mental stress, workload and fatigue. HR is easily obtained in real time and is more resistant to the effects of outliers than the measures of HRV [8]. In the past, HR data has been used in many areas and has been associated with many parameters in clinical setting and practice. In addition, HR also had been used to study the driver focus when performing secondary task under two different age groups. Reimer et al. had compared middle age and younger adult performance when dealing with hand free phone demands [9]. Findings show that the late middle age subjects did not demonstrate heart rate acceleration in response to the phone conversation that was seen in younger subjects. In addition, the older subjects drove car more slowly compared to younger subjects.

In general, HR is a particularly attractive measure for real-time driver state detection. Even though physiological indicators were found to be related with the increase in driving mental fatigue, the relative insensitivity and inability of accurately detecting the fatigue is still very challenging for the variety of driving behaviours. This paper presents the results from an experiment using HR recording and subjective evaluation by using Karolinska Sleepiness Scale (KSS) and self-report questionnaire. In addition, video recording, variation of lane deviation (VLD) and speed recording had been taken in the experiment. The findings of this study might be applied to inhibit fatigue in actual driving through cultivating on certain elements of the driving task such as the design of seat and steering wheel in which some sort of stimuli can be added.

2.0 METHODOLOGY

2.1 Subjects

Three male subjects from three different age (27, 32 and 40 years) were recruited to perform the experiments. All subjects are healthy and without a history of heart failure and without pacemakers. All subjects were familiar with the simulator operation due to their task as researcher and have more than five years of driving experience.

2.2 Apparatus and Data Acquisition

The Wahoo Fitness TICKR sensor as shown in Figure 1 was used to record the HR data. The sensors measuring heart rate, steering variability and speed was fed directly into the logger which stored the data and provided a measure of time for each data sample. At the end of a trip, the data and time information were downloaded to a PC.

Figure 1 HR equipment

Driving simulator which consist of car frame with a built in steering wheel, accelerator and brake pedals are used in this simulator. The large white screen was arranged in a semi-circle and positioned with a distance of about 200 cm in front of the simulator. The screen provided a 220 degree field-of-view at any one time. A rear-view mirror was displayed on the central monitor, and side-view mirrors were displayed on the outer monitors. The screen showed the road environment and the subject can see the current speed through the customized dashboard in the car simulator. The system also produced simulated engine noise. The simulated route and traffic signs were standardized according to national traffic law.

2.3 Experimental Design by Using Simulator

There were two experimental sessions required to be performed by each subject. Each subject was required to drive the car simulator without (WOV) and with vibration (WV) conditions (with 5 millimetres amplitude and 5-10 Hz frequency). The philosophy behind these experiments is to investigate whether there is any effect on the vibration to the drivers' state. As mentioned by Wu et al., the influence of whole-body vertical vibration of 1-10 Hz on the dynamic human–seat interface could induce fatigue [10]. Therefore, in this case, the variation of HR value may indicate the drivers' condition and performance. Both of the conditions were conducted at two different days but at the similar time slot, which is from 9 am to 10 am. In each experiment, the subject was instructed to drive and obey road rules for one hour. The driving task was reduced to a lane keeping task to induce task monotony: no traffic, driving consisted in following a lane (no itinerary involved) with minimum speed 80 kilometres per hour, without having to stop the car (no red traffic lights, stops) or having the need for frequent breaking intervals (no T inter-sections or perpendicular turns), or having the necessities for gear and lane changings, as well as turn signals activation. Laboratory temperature was controlled at 18 degrees. In addition, highway scene was selected for this experiment. The simulated driving task was designed with the following requirements: the route was simple so that the drivers could complete the task as easily as possible, there were few scenery changes, there was no inclination on driving route to reduce outside stimuli, and a very light curvature was chosen so that drivers should pay attention.

2.4 HR Recording and Monitoring

Each subject was required to record the HR data for two days activity, which are during daily activity and during driving activity in the simulator on the next day. They wore the HR monitor and completed the routine for at least 3 hours at the same duration for both days. For example, if the subject is required to drive the car simulator at 9 am to 10 am, he should record the HR from 8 am to 11 am continuously. Daily activity (DA) would be referred as the baseline measurement. Each subject was performed his daily activities (eg: working in the office) within the same duration before the experiment day.

2.5 Subjective Assessment and Performance Evaluation

All subjects were required to fill in the self-report questionnaire regarding their age, weight, height, caffeine intake, food intake and sleep duration. In addition, all subjects were required to respond to Karolinska Sleepiness Scale (KSS) to measure the subject's drowsiness before, during (after 30 minutes of driving) and after driving. KSS is frequently used to investigate the driver's focus and performance [11-12]. It is helpful in monitoring the changes in response to environmental factors, circadian rhythm, and effects of drugs [13]. KSS has used 9-point scale which are: 1 = extremely alert, 2=very alert, 3 = alert, 4=rather alert, 5 = neither alert nor sleepy, 6=some signs of sleepiness, 7 = sleepy, but having no difficulty remaining awake, 8=sleepy but having some difficulty to keep awake, and 9 = extremely sleepy, having great difficulty to keep awake, fighting sleep.

In addition, video recording was also performed during the experiment in order to observe the driving behaviours, such as yawning, movement of the body and eye by using mobile phone. Therefore, the subject may know the end time of the driving, by looking at the recorded video. Moreover, the VLD was recorded during driving activity. The VLD is referred on the steering wheel movement and the data was recorded to the computer during the whole experiment when the subject started driving the car simulator.

3.0 RESULTS AND DISCUSSION

3.1 Background Information

Based on Table 1, there are three different volunteers from three different groups, which are Subject A (under 30), Subject B (under 40) and Subject C (under 50). Subject A and B preferred to take coffee every morning and sleep well for 8 hours before the experiment. Both of them are under normal weight. Meanwhile, Subject C preferred to take the milk and light meal for his breakfast. He was having difficulty to sleep for long hours before the first experiment (WOV) and categorised under overweight group.

Table 1 Background information

Subjects information	Condition	Caffeine intake	Food intake	Sleep duration
A (age=27, BMI=20.5)	WOV	Coffee	Light meal (cereal)	8 hours
	WV	Coffee	No meal	8 hours
B (age=32, BMI=24.5)	WOV	Coffee	Light meal (snack bar)	7 hours
	WV	Coffee	Light meal (cereal)	7 hours
C (age=40, BMI=29.7)	WOV	No caffeine (milk only)	Light meal (bread and cheese)	3 hours
	WV	No caffeine (milk only)	Light meal (bread and cheese)	8 hours

3.2 KSS and Video Recording

With regards to Figure 2 (a) and Figure 2 (b), all subjects feel sleepy during driving and the scale was reduced at the end of the driving activity. According to the video recording, they were yawning and moving their head occasionally during the driving task. In addition, based on the feedback from the subject, they got difficulties in concentrating their attention on the driving task and sometimes feel boredom. All subjects thought that the above-mentioned feeling might appear approximately after 30 minutes of driving and getting worst with increasing driving time. However, it was reduced at about five minutes before the completion time because they know the experiment was over. According to them, it was similar to their feeling when you have reached your final destination, all your boredom and sleepiness is lesser due to your pleasure by reaching your target.

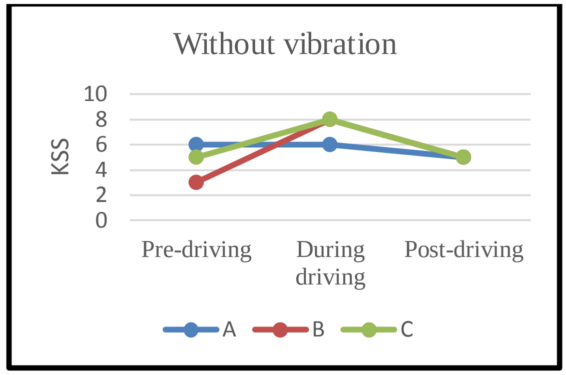


Figure 2(a) KSS result for WOV

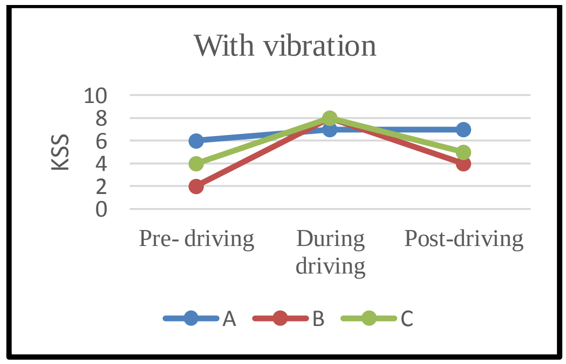


Figure 2(b) KSS result for WV

3.3 HR Analysis

Table 2 shows the HR result based on the activities performed by the subject. Based on the HR data for daily activity which is referred as a baseline, subject C has the highest recorded HR, while subject B has the lowest HR in average. It might be related to daily routine by doing some exercise and age of the subject. The normal resting adult human heart rate ranges from 60 to 100 beat per minute (bpm). Based on the Table 2, comparison of the HR data without and with vibration has been made. HR of all subjects when undergoing the experiment WOV was reduced from the start to the end of the driving task. For example, HR of the subject A at the start is 92 bpm, and end at 80 bpm. It is in line with previous studies which indicated the HR will be reduced at the end of driving journey [14-15]. On the other hand, experiment with vibration illustrates different results. Only subject C shows a reduction of HR while subject A and B shows an increment. It possibly due to the physical condition of the subject, which is under overweight category. In another study conducted by Jiao et al., different vibration frequencies may induce different levels of mental stress and fatigue among drivers [16].

3.4 Performance Analysis

VLD is recorded based on a right handed coordinate system, which means the left side of VLD value has positive value in this system. Based on the average VLD, subject B and C tend to cross the lane to the left, while subject A tend to cross the lane to the right. In addition, most of the time, subject B tends to cross the lane. In average, all subjects managed to control the speed in between 70 to 90 km/h. Table 3 shows the average, maximum, minimum value of VLD and speed for the first half and the second half of driving task.

In term of correlation of the HR and VLD, there is no strong correlation between both of these parameters. In addition, there is also a weak correlation between speed of the car and the HR of the subject. However, KSS evaluation shows a good correlation with the HR data, where the HR data reduced and subjects feel less alert at the end of the journey compared to when they start the journey.

Overall, there are some limitations in this study. One of it is that participants were not asked to avoid drinking beverages containing caffeine before the study. Caffeine is known as one of the stimulant to alleviate sleepiness and maintain alertness [17-18]. As mentioned by Friswell, & Williamson, controlling caffeine consumption is one of the strategy in fatigue management[19]. Based on past studies, food intake and caffeine intake may influence the drivers' performance when driving [20-22]. Moreover, in some studies, caffeine and food consumption has been controlled prior to experiment [23-24]. In the future, it is suggested to control caffeine and food intake as well to ensure it will not affected the experiment. For example, roughly in this study, based on the KSS pattern, the caffeine and food intake might be the factors that influenced the subject. Therefore, controlling the food and caffeine intake possibly provide different data in the future study.

Table 2 HR result based on activities of the subject

Conditions / Subjects			Start-end HR (bpm)	Ave. HR (bpm)	Max HR (bpm)	Min HR (bpm)
DA	A		69-69	71	97	59
	B		49-48	52	87	40
	C		81-109	90	110	90
WOV	A	Pre	72-95	88	110	72
		First half	92-75	74	92	65
		Second half	75-80	78	89	68
		Post	80-72	81	108	67
	B	Pre	42-51	50	84	39
		First half	51-46	45	52	39
		Second half	46-44	45	57	39
		Post	43-40	55	89	38
	C	Pre	86-69	73	97	48
		First half	69-69	64	79	53
		Second half	69-68	64	83	50
		Post	68-66	65	86	48
WV	**A**	Pre	77-80	83	103	65
		First half	80-71	71	86	62
		Second half	70-97	69	97	62
		Post	98-82	78	107	63
	B	Pre	44-44	56	86	40
		First half	44-49	48	67	41
		Second half	50-61	48	69	43
		Post	72-41	57	94	41
	C	Pre	75-79	82	94	68
		First half	79-71	70	88	63
		Second half	71-71	71	92	62
		Post	72-74	74	103	59

Table 3 VLD and speed result based on subjects' driving task

Conditions / Subject			Ave. VLD	Max VLD	Min VLD	Ave. speed (km/h)	Max. speed (km/h)
WOV	A	First half	0.122	1.872	-5.918	85	91
		Second half	0.093	1.044	-0.907	84	91
	B	First half	-0.178	4.328	-6.055	83	99
		Second half	-0.069	1.847	-2.061	74	94
	C	First half	-0.33	1.497	-4.569	76	112
		Second half	-0.316	1.765	-1.855	83	95
WV	A	First half	-0.028	3.317	-6.146	67	98
		Second half	0.38	1.12	-0.56	81	87
	B	First half	-0.197	3.547	-6.648	82	117
		Second half	-0.289	1.6699	-2.788	79	99
	C	First half	-0.197	3.547	-6.648	82	117
		Second half	-0.289	1.67	-2.788	79	99

4.0 CONCLUSION

Continuous HR recordings enable us to identify those periods of work which are most stressful and hence optimal targets for ergonomics interventions. Despite some limitations, there are considerable strengths in this study. The proposed method can be adopted for evaluating fatigue level with combination of other measurement tools. Compared with other indications of performance, HR is easy to monitor, is relatively cheap and can be used in most situations. Instead of HR recording, subjective evaluation such as KSS and self-reported questionnaire are useful tools to be integrated with the HR data. Based on the experimental and subjective evaluation findings, all subjects feel less alert and quite sleepy during driving task. However, the situation is different when the subjects had completed the driving task. Overall, this study should be improved in the future, as it is only preliminary study to understand the HR trend and its affects in determining drivers' performance.

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References

[1] Connor, J., G. Whitlock, R. Norton, and R. Jackson. 2001. The Role of Driver Sleepiness in Car Crashes: A Systematic Review of Epidemiological Studies. *Accident Analysis and Prevention*. 33: 31-41.

[2] Horne, J., and L. Reyner. 1999. Vehicle Accidents Related to Sleep: A Review. *Occupational and Environmental Medicine*. 56(5): 289-294

[3] Kramer, A. F. 1991. Physiological Metrics of Mental Workload : A Review of Recent Progress. *Multiple-task Performance*. 279-328.

[4] Wierwille, W. and F. Eggemeier. 1993. Recommendations for Mental Workload Measurement in a Test and Evaluation Environment. *Human Factors.* 35(2): 263-281

[5] Rowe, D., J. Sibert, and D. Irwin. 1998. Heart Rate Variability: Indicator of User State as an Aid to Human-Computer Interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM Press/Addison-Wesley Publishing Co.

[6] Orsila, R., M. Virtanen, T. Luukkaala, M. Tarvainen, P. Karjalainen, J. Viik, M. Savinainen and C. H. Nygard. 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*. 14: 275-283.

[7] Fu, R., Y. Guo, Y. Chen, W. Yuan, Y. Ma, J. Peng, C. Wang. 2011. Research on Heart Rate and Eye Movement as Indicators of Drivers' Mental Workload. *3rd International Conference on Road Safety and Simulation*. Indianapolis, USA. 14-16 September 2011. 1-20.

[8] Li, Z., K. Jiao, M. Chen and C. Wang. 2004. Reducing the Effects of Driving Fatigue with Magnitopuncture Stimulation. *Accident Analysis and Prevention*. 36(4): 501-505.

[9] Reimer, B., B. Mehler, J. F. Coughlin, N. Roy, and J. A. Dusek. 2011. The Impact of a Naturalistic Hands-free Cellular Phone Task on Heart Rate and Simulated Driving Performance in Two Age Groups. *Transportation Research Part F: Traffic Psychology and Behaviour.* 14(1): 13–25.

[10] Wu X., S. Rakheja S, P. É. Boileau. 1998. Study of Human-Seat Interface Pressure Distribution under Vertical Vibration. *International Journal of Industrial Ergonomics.* 21: 433-449.

[11] Shahid, A, K. Wilkinson, S. Marcu, and C. M. Shapiro. 2012. *STOP, THAT and One Hundred Other Sleep Scales, Chapter 91: Stanford Sleepiness Scale*, Springer Science & Business Media. 369-370.

[12] Kecklund, G., T. Åkerstedt. 1993. Sleepiness in Long Distance Truck Driving: An Ambulatory EEG Study of Night Driving. *Ergonomics*. 36 (9): 1007–1017.

[13] Shahid, A, K. Wilkinson, S. Marcu, and C. M. Shapiro. 2012. *STOP, THAT and One Hundred Other Sleep Scales, Chapter 31: FACES (Fatigue, Anergy, Consciousness, Energy, and Sleepiness).* Springer Science & Business Media. 155-156.

[14] Gibson, J., D. J. Mascord, and G. A. Starmer. 1995. The Effects of Caffeine on the Development of Fatigue in a Prolonged Driving Related Task Measurements during the Fatigue Trial. *Proceedings Internalnational Council Alcohol Drugs Traffic Safety Conference.* 92–97.

[15] Jagannath, M., and V. Balasubramanian. 2014. Assessment of Early Onset of Driver Fatigue using Multimodal Fatigue Measures in a Static Simulator. *Applied Ergonomics.* 45(4): 1140-1147.

[16] Jiao, K., Z. Li, M. Chen, C. Wang, and S. Qi. 2004. Effect of Different Vibration Frequencies on Heart Rate Variability and Driving Fatigue in Healthy Drivers. *International Archives of Occupational and Environmental Health.* 77(3): 205-212.

[17] Dorrian J, N. Lamond, and D. Dawson. 2000. The Ability to Self-monitor Performance when Fatigued. *Journal of Sleep Research*. 9(2):137-144.

[18] Hartzler, B. M. 2014. Fatigue on the Flight Deck: The Consequences of Sleep Loss and the Benefits of Napping. *Accident Analysis and Prevention*. 62: 309–318.

[19] Friswell, R. and A. Williamson. 2013. Comparison of the Fatigue Experiences of Short Haul Light and Long Distance Heavy Vehicle Drivers. *Safety Science*. 57: 203–213.

[20] Horne J. A, and L. A. Reyner. 1996. Counteracting Driver Sleepiness: Effects of Napping, Caffeine, and Placebo. *Psychophysiology.* 33 (3): 306-309.

[21] Biggs, S. N., A. Smith, J. Dorrian, K. Reid, D. Dawson, C. Van den Heuvel, and S. Baulk. 2007. Perception of Simulated Driving Performance After Sleep Restriction and Caffeine. *Journal of Psychosomatic Research*. 63(6): 573–7.

[22] Dawson, D., A. K. Searle, and J. L. Paterson, J.L. 2014. Look Before you (S)leep: Evaluating the Use of Fatigue Detection Technologies Within a Fatigue Risk Management System for the Road Transport Industry. *Sleep Medicine Reviews*. 18(2): 141-152.

[23] Jap, B. T., s. Lal, P. Fischer, and E. Bekiaris. 2009. Using EEG Spectral Components to Assess Algorithms for Detecting Fatigue. *Expert Systems with Applications*. 36(2): 2352–2359.

[24] Larue, G. S., A. Rakotonirainy, and A. N. Pettitt. 2011. Driving Performance Impairments due to Hypovigilance on Monotonous roads. *Accident Analysis and Prevention*. 43(6): 2037-2046.