Original research paper

Driver's Stress Condition on Highway Lane Changing

Jianbang Du[1], Fengxiang Qiao[1, 2] , Qing Li[1] , Junqing Shi[1]

[1]*Texas Southern University, 3100 Cleburne St, Houston, Texas77004, USA*

[2] *Professor of Department of Transportation Study, Texas Southern University, 3100 Cleburne St, Houston, Texas77004, USA*

Abstract

As the growing complexity of the traffic environment, including the increasing vehicle quantities on road, diversity drivers' driving habit, and more complex road layout, driver's stresses increase while completing various everyday driving tasks. Especially while driving on the highway, based on the prior research, as of 2013, about one-quarter of all vehicle miles driven in the country use the highway system. There is an inevitable action while driving on the highway-- lane changes. Lane changes are required no matter taking on and exiting the highway or trying to surpass other vehicles. While changing the lanes, drivers would meet some emotional changes caused by the traffic, and those emotional changes could influence the drivers' health and physical reactions. Among those emotional changes, rising of stress is one of the most significant one. In this research, Heart Rate Variability is used to analyze the stress of the tests drivers. Three time domain index was used to monitor the Heart Rate Variability: RMSSD, R-R interval, SDNN, calculation equations will be given. Heart rate data is collected by a ECG Holter monitor, and analyzed by Microsoft Excel. At the conclusion part of this paper, the relationship between the stress of drivers and the number of lane changing and traffic situation will be discussed.

Keywords:

lane change; heart rate variability; RMSSD; SDNN; R-R interval;

*Corresponding author. Tel.:+1 979 2291555.
E-mail: dujianbang@gmail.com.

1 Introduction

Based on the international traffic accidents statistics, one of the major causes of severe traffic accidents is drivers' stressfulness (Yuan et al., 2014). Stress is an emotional and physical response that affects person's feeling, thinking, behavior and the way how the body works. Stress is usually a response to an environmental situation which is new, unpredictable or makes one feels challenged to solve. According to Yerkes-Dodson Law, different levels of stress tend to have significant effects on behavior (Andreassi, 2000). One of the levels of stress is moderate level, which tend to be beneficial in maintaining attention, keeping driver motivated and providing sensitive responses to the driving environment. In the meantime, low levels of stress can result in low motivation to face tasks, boredom and errors, on the other hand high levels of stress can cause tension, irritability, lower concentration, low self-confidence, problems with decision making and solving and accompany with a variety of physical symptoms that include headache and irregular fast heartbeat (Brookhuis and Waard, 1993). When driving with high levels of stress, drivers tend to have a declined driving performance, also panic and frustration as a result the driver will meet increased risk of traffic rule violation and accidents or eventually give up driving (Yuan et al., 2014). Driving is a regulated activity between different drivers, thus when one driver has high levels of stress, other drivers often can be affected by the stress reaction like frightening, dangerous and difficult to control situations (Veltman and Gaillard, 1998).

As the growing complexity of the traffic environment, including the increasing vehicle quantity on road, diversity drivers' driving habit, and more complex road layout, driver's stresses increase while completing various everyday driving tasks (Waard, 1996). The US highway system is more than 46000 miles long and the highway network has since been extended, as of 2013, about one-quarter of all vehicle miles driven in the country use the highway system (Lin et al., 2013). There arises an issue: how the driver's stress fluctuates while they are driving on the highway. Based on the prior researches, some of the most important reasons that would affect derivers performances are nervousness, unfamiliarity vehicle, strange area and busy traffic conditions (Hu et al., 2011). Many researchers took different methods and experiments to find out the relationship between driver's stress to traffic condition, for example, the driver's stress can be influence by the speed of the vehicle they are driving, the speed of other vehicles on the road, and the climate condition while driving (Wu et al., 2010). However, there is an important issue which is needed to be address: how does the change lane impact on driver's stressfulness. While a driver attempt to take a ramp to merge on or off on a highway, they need to take at least one lane change. That means under normal driving conditions, a driver need to take at least two lane changes for driving on and off a highway (Wang et al., 2013). Other than that, normal highways have equal or more than two lanes, the left most lane is designed to use as a overtaking lane, so when a driver needs to take one or two lane changes in order to overtake other vehicles (Dong et al., 2010). That's the reason why researches on the driver's stress while they are changing lanes on highway is so important.

The primary objective of this paper is to develop reproducible and flexible methods for studying the relationships between driver's stress and the number of lane changes and driving conditions (Gerald et al., 1998). This includes the comparison of driver's stress between taking lane changes on a highway in light, medium and heavy traffic conditions (Brenner and Selzer, 1969); the comparison of driver's stress between taking 1 lane change and 2 lane changes. It is hoped that the researches on how the stressfulness changes when the drivers take lane changes under real-world driving conditions would help the future researchers to identify ways to reduce or avoid stressfulness while driving.

2 Methodology

Autonomic nervous function disorders happen while people in stress situation, the main symptom is hypersympathicotonus, this will influence the blood pressure stability (Gullian et al., 1989). The heart rate variability is an index for autonomic nervous function, which is wildly used in measure the depth of anesthesia. Heart rate variability (HRV) is the physiological phenomenon of variation in the time interval between heartbeats (Gullian et al., 1990). It is measured by the variation in the beat-to-beat interval like heart rate but heart rate variability is more sensitivity than hear rate. Before the analyzing of the heart rate variability data, all abnormal heartbeats and artifacts need to be removed from consideration before calculation (Gullian et al., 1989). In this study three time-domain parameters are calculated for recordings which are Mean Heart Rate, SDNN (standard deviation of normal to normal RR intervals) RMSSD (root mean square of successive NN interval differences) (Lizawati and Desok, 2006). The time-domain parameters are associated mostly with overall variability of HR over the time of recording, except RMSSD, which is associated with fast (parasympathetic) variability (Sonal et al., 2010). In HRV analysis, SDNN, HRV index, RMSSD are all positively related to each other where the relation index is greater than 0.85 (Tanja et al., 2000). Based on the prior researches, the normal SDNN for an adult in age range 18- 29 should be 169.92± 41.01(128.91- 210.93); the normal RMSSD range for an adult in age range 18- 29 should be 72.39± 47.10(25.29- 119.49). The calculation equation of SDNN and RMSSD is (Elmar et al., 2001):

$$MRR(mean\ of\ RR\ intervals) = \bar{I} = \frac{1}{N-1}\sum_{n=2}^{N}[I(n)] \quad (1)$$

$$SDNN = \sqrt{\frac{1}{N-1}\sum_{n=2}^{N}[I(n)-\bar{I}]^2} \quad (2)$$

$$RMSSD = \sqrt{\frac{1}{N-2}\sum_{n=3}^{n}[I(n)-I(n-1)]^2} \quad (3)$$

where N is Total Heart Beats (THB).

On the RR interval side, the heart rate variability point was shown on a Poincaré Plot. SD1 and SD2 is calculated to reveal the relationship with the HRV and stress (Nis et al., 2004). SD1 is the standard deviation of the Poincaré plot perpendicular to the line-of-identity, describes short-term variability caused by respiratory sinus arrhythmia (Luciano et al., 2000). Low value indicates high stress. SD2 indicate the standard deviation of the Poincaré plot along the line-of-identity, describes long-term variability. Low value indicates high stress (Paolo et al., 2011). SD1 and SD2 can be calculated as:

$$SD1 = \sqrt{Var(1/\sqrt{2})(RR_n - RR_{n+1})} = \left(\frac{1}{2}\right) * SDSD^2 \quad (4)$$

$$SD2 = 2 * SDRR^2 - \frac{1}{2} * SDSD^2 \quad (5)$$

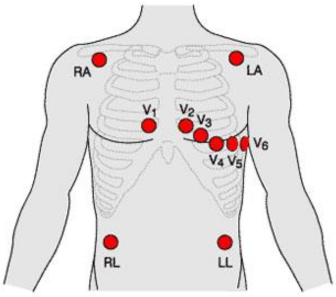
where $SDRR$ is standard deviation of the RR intervals, $SDSD$ is standard deviation of the successive differences in the RR intervals.

3 Test Plan and Data Collection

3.1 Test Equipment

The vehicle used in this test is a TOYOTA Camry (displacement: 2.5L, power: 178hp). Three dash cameras (Fig. 1 a) is used to record the driving status including how many lanes is changed for a certain period and what is the traffic status. One ECG Holter monitor (Fig. 2 b) is used to collect heart rate data.

(a) Dash camera **(b) Holter monitor to collect ECG data**



(c) ECG body positions

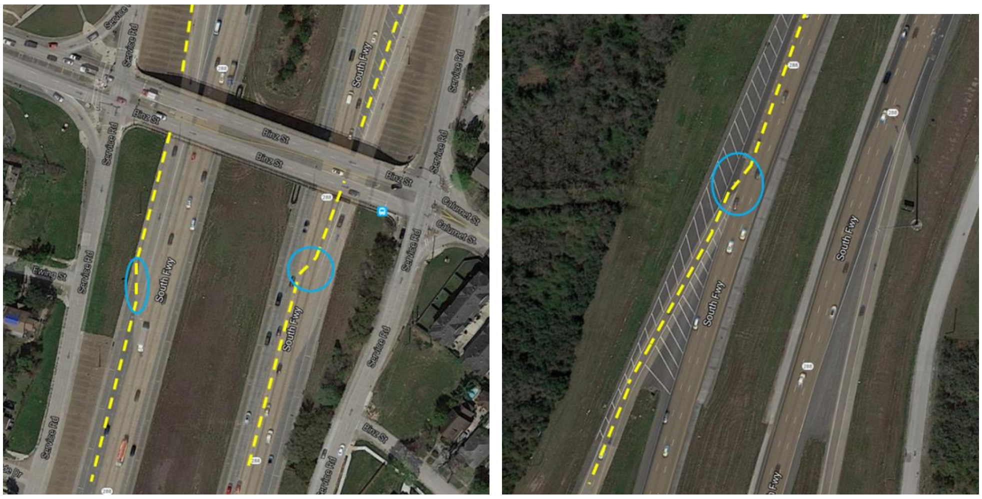
Fig. 1 Test devices and ECG body position

3.2 Equipment Installation

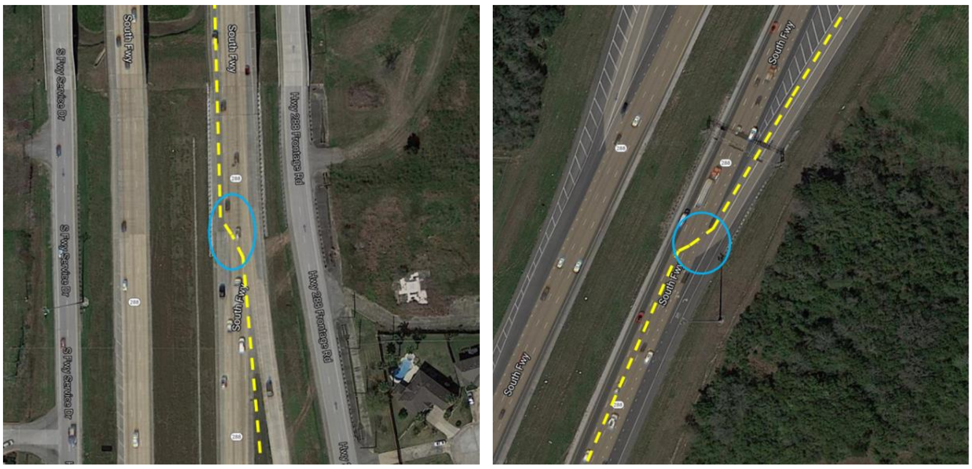
The 3 dash cameras were installed in the car hanged on three separate windows by rubber suckers. One dash camera was installed on front windshield, other two dash cameras was installed on driver side window and passenger side window. The camera on windshield was used to record how many lanes was changed while driving, the cameras on the side windows was used to record traffic status. The ECG Holter monitor have 6 pouches, installed on the testing person's body (Eberhard et al., 2007). The position on the body for ECG Holter monitor's pouches is shown in Fig. 2 c (positions LA, RA, V1, V2, RL, LL).

3.3 Test Locations and Scenarios

For the tests, this research designed 6 scenarios in different traffic situations, light, medium and heavy. Test locations are mainly on highway 288, Houston, Texas. First location is the intersection of South Fwy 288 to Binz St with total distance of 1223ft. Second location is exit 468 of South Fwy 288 with total distance of 1345ft. Third location is the entrance to South Fwy 288 from frontage road with total distance of 2064ft. Forth location is exit 425 of South Fwy 288 with total distance of 1982ft. (Fig.2, Table 1)



(a) One lane change **(b) One lane change**



(c) Two lane change **(d) Two lane change**

Fig. 1 Test location

Table 1 Scenario description

Scenario	Number of Lane Change	Traffic
S1	1	Light
S2	2	Light
S3	1	Medium
S4	2	Medium
S5	1	Heavy
S6	2	Heavy

3.4 Test procedure

A total of 6 personal was attended the test procedure, 4 males and 2 females, age from 20 to 40, no heart disease. Tests total evolved 7 days, from 7 am. to 5 pm. to catch the traffic rush time of the highway (6:30 am. to 10:00am., 3:00 pm. to 7:00 pm.) and the idle time of the highway (10:00 am. to 3:00 pm.). It takes approximately 1.5 hour per round to cover all test locations. For each test, one driver and one co-driver worked together, drivers' duty was focus on the road and drive the test vehicle and collect the heart rate data, co-drivers' duty was mention the test route to the driver and check the working situation of the ECG Holter monitor as well as the dash cameras. All the data collected was analyzed by Microsoft Excel after the on-road tests.

4 Results and Discussions

Normal healthy people's Heart Rate should be in a range of 60-100 beats/min (Luciano et al., 2000). From the data collected and analyzed, it can be seen that the high frequency range of heart rate is 71-100 beats/min (Fig. 3) which is within the normal Heart Rate range.

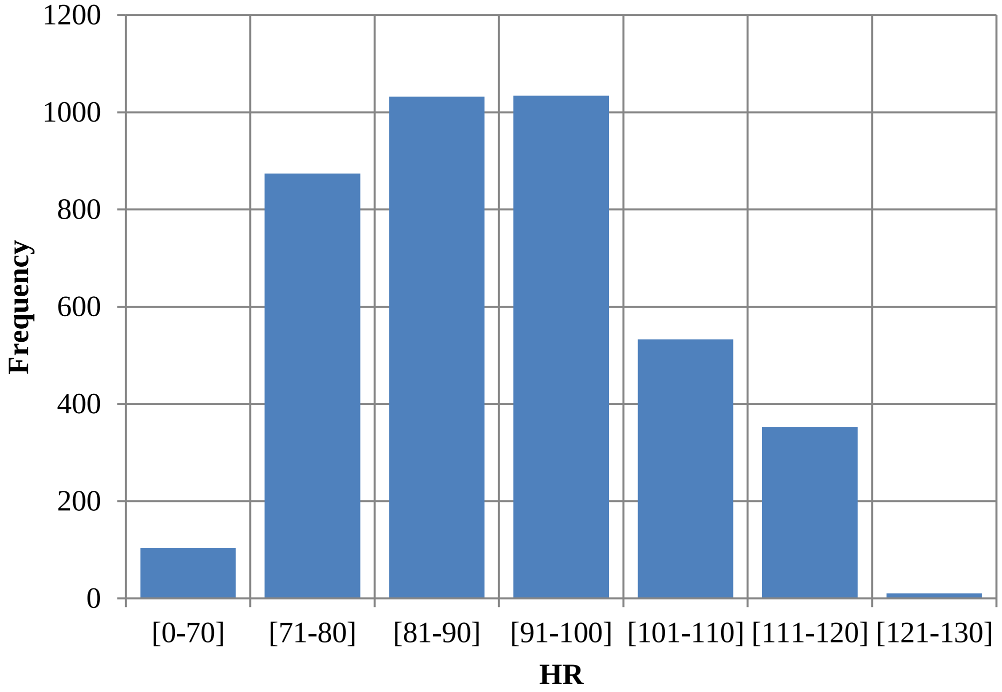


Fig. 3 Heart rate distribution on lane change

However, in the results the percentage of the Heart Rate out of the healthy range (<60 or >100 beats/min) is 22.74% where all of them are all above 100 beats/min. As the tests drivers are healthy people, it means that the higher Heart Rate is probably related to mental stress. When healthy people are in stress, a rapid heartbeat occurs (Michael et al., 2000). Only the heart beats reregulation is not sufficient to determine the pressure status, further data analysis is required.

4.1 RMSSD Analysis

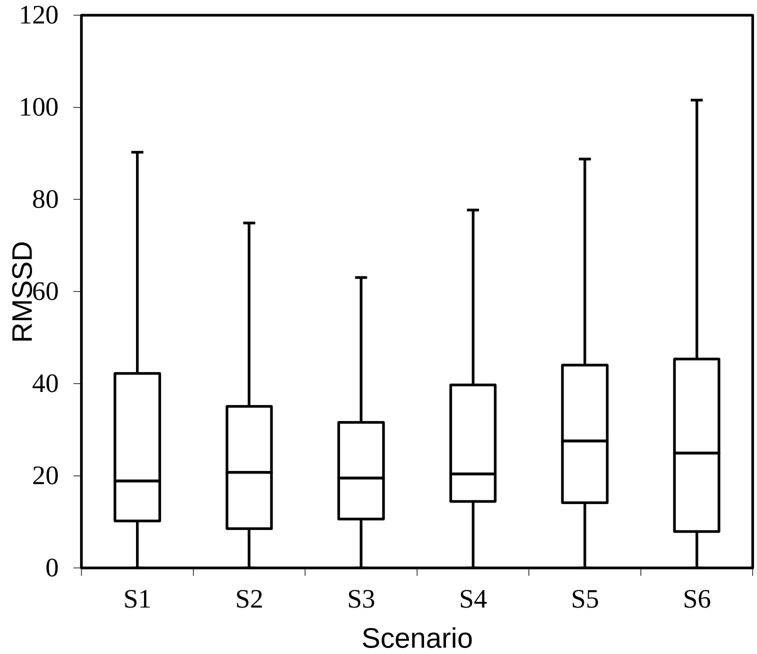
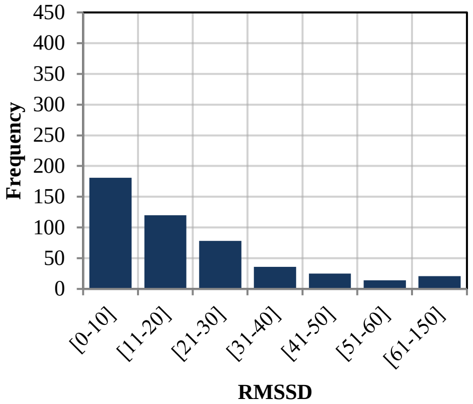
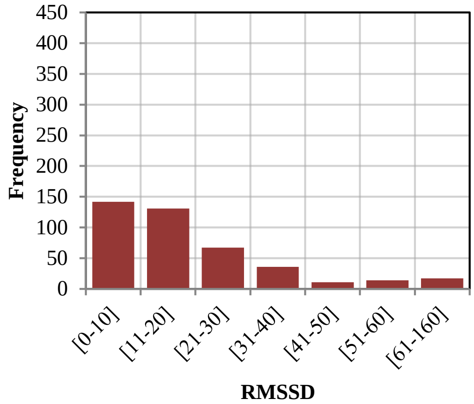


Fig. 4 RMSSD distribution on each scenario

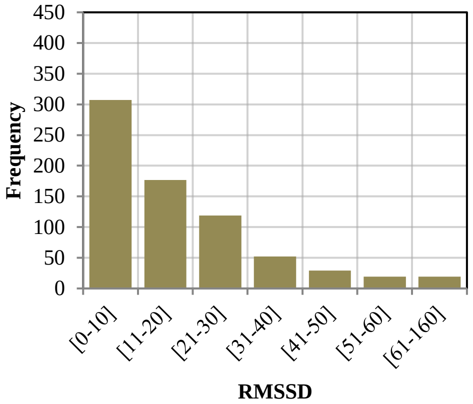
Fig. 4 is the box plot of RMSSD value of all test samples on each scenario. For difference scenario, the RMSSD value have no significant difference. This means different number of lane change and different traffic situation doesn't influence the RMSSD by large scale. However, there is some trends from the plot. In the box plot, lower RMSSD value happens in S6, S2, S6 is change 2 lanes in heavy traffic, S2 is change 2 lanes in light traffic. Above RMSSD value of Heart Rate Variability indicate driver have higher stress when they take 2 lanes change. Driver need to do more complicate observations and decisions when they take 2 lanes change compared to 1 lane change, this is consistent with the real traffic circumstances (Andreassi, 2000).



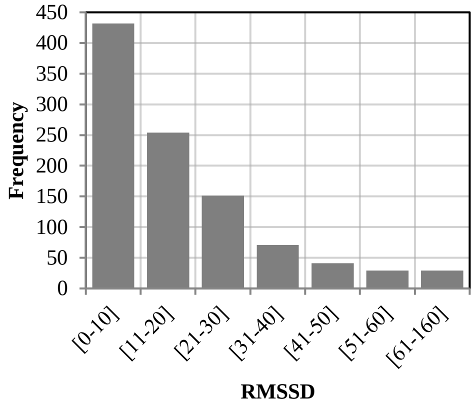
(a) S1 Change 1 Lane in Light Traffic



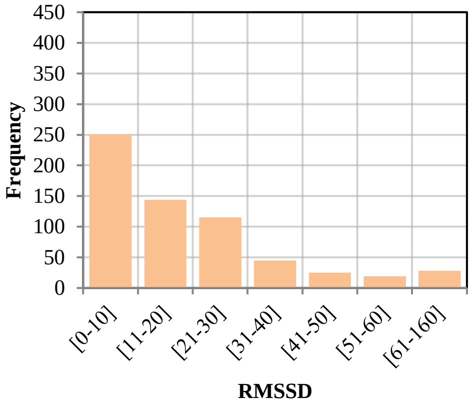
(b) S2 Change 2 Lane in Light Traffic



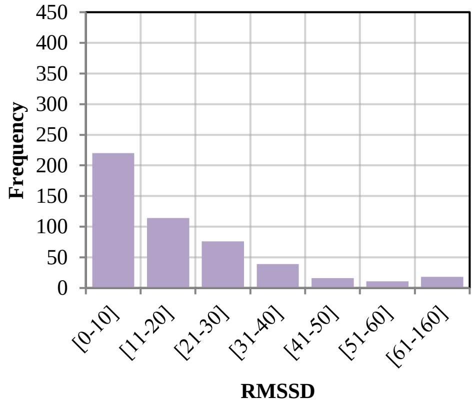
(c) S3 Change 1 Lane in Medium Traffic



(d) S4 Change 2 Lane in Medium Traffic



(e) S5 Change 1 Lane in Heavy Traffic



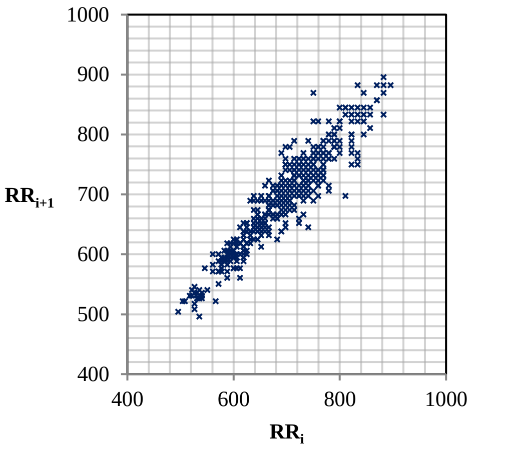
(f) S6 Change 2 Lane in Heavy Traffic

Fig. 5 Impact of the number of lane change on RMSSD

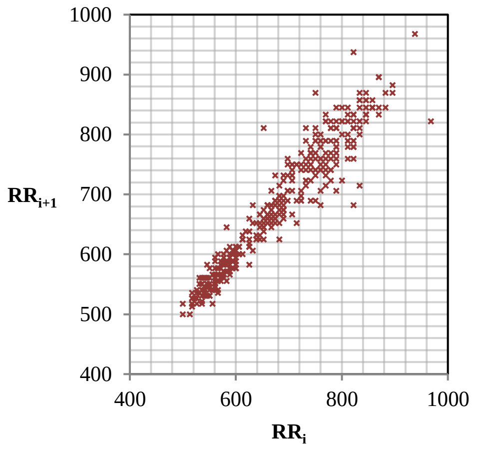
Fig. 5 is the distribution plot for different scenario, from the plots, the lower RMSSD value have the highest frequency. From Fig. 6, for all scenarios, RMSSD between 0 to 10 has the highest frequency, then 11 to 20. RMSSD between 41 to 60 has the least frequency, these data shows HRV under stress, means the driver might in stress situation. Scenario 2 has the relatively highest portion of higher RMSSD values, the sequence by higher portion of high RMSSD value is: S2> S1> S5> S6> S3> S4. This result can be interpreted as for most occupation, drivers have the RMSSD value that shows lower stress when change 1 lane than Change 2 lanes; in medium traffic situation, the driver have the most stress RMSSD value and least stress RMSSD value in light traffic (Matti et al., 2015).

4.2 R-R Interval Analysis

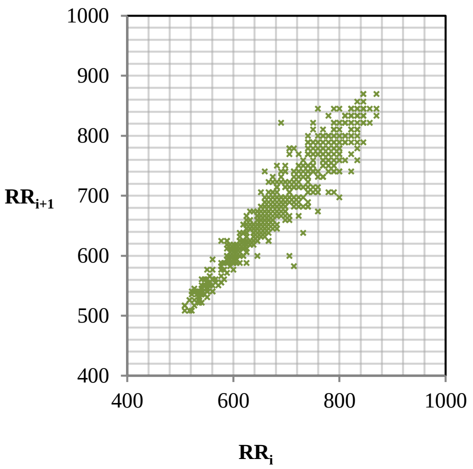
Fig. 6 is the Poincaré Plot of RR intervals for each scenario. Below is the SD1 value and SD2 value derived from each plot (Matti et al., 2015).

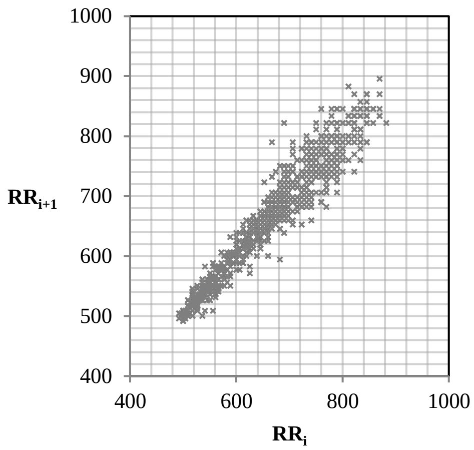


(a) S1 Change 1 Lane in Light Traffic

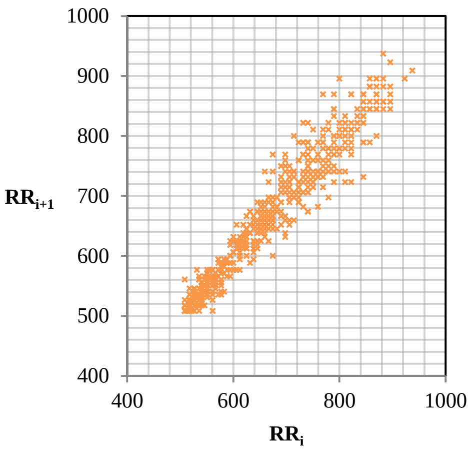


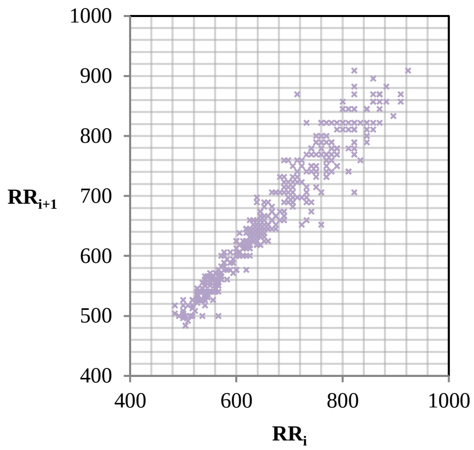
(b) S2 Change 2 Lane in Light Traffic





(c) S3 Change 1 Lane in Medium Traffic **(d) S4 Change 2 Lane in Medium Traffic**





(e) S5 Change 1 Lane in Heavy Traffic **(f) S6 Change 2 Lane in Heavy Traffic**

Fig. 6 Impact of lane change on long-term and short-term driving stress (RR-interval)

From the table 2, she short term stress of scenario S2, S1, S5 is higher, the long term stress of S2, S5, S6 is higher (Luciano et al., 2000). Due to the test is relatively short term (less than 24 hours), so only short term stress is used to analyze. The SD1 values indicate driver have higher stress when change 2 lanes in light traffic and change 1 lane in light and heavy traffic. While drive in light traffic, the vehicle speed is higher, then drivers need to pay more attention to the traffic situation; while change 2 lanes, drivers used to already familiar to the traffic before they make the first lane change, so they may have less stress, this is consistence with the reality.

Table 2 SD1, SD2 value of each scenario

	S1	S2	S3	S4	S5	S6
SD1	26.842	28.4418	24.6373	24.1735	26.6534	25.1969
SD2	158.0828	203.699	163.785	182.1	206.631	196.918

4.3 SDNN Analysis

Table 3 Impact of traffic on SDNN

scenario code	S1	S2	S3	S4	S5	S6
SDNN	143.1469	234.3848	145.9244	125.1802	143.8536	164.964

The result of SDNN is more straightforward: the lower the SDNN value, the more stress the drivers are (Lin et al., 2013).

Based on the data collected and analyzed, the stress sequence is: S4> S1> S5> S3> S6> S2. This means drivers have the highest stress while change 2 lanes in light traffic, and have higher stress while change 2 lanes in heavy traffic. This result is consistence with the results of RMSSD analysis.

5 Conclusions

Base on the analysis above, the integrated results from R-R interval, RMSSD, SDNN value shows the trend: 1. When the traffic situations are the same, drivers change 1 lane have lower stress than change 2 lanes; 2. The drivers have the lowest stress when drive in the medium traffic situation. The first trend is easy to explain: the rear-view mirror can help driver to determine the traffic situation of the lane next to the drivers' current driving lane, however when drivers need to change two lanes continuously, it is hard to observe the traffic situation of the second lane, the unpredictable situation could rise the drivers' stress. And it is felt dangerous when changing lanes that do not have a good view even in a light traffic, this unsafe feeling could rise the stress of drivers

The second trend could be explained reasonable as: while drivers' driving in light traffic situation, the speed on freeway is usually quite fast (50-70 mph in these tests), so drivers need to pay more attention of the traffic while change the lanes. And the faster speed give the drivers more unsafe feeling as the same time, so driver's stress could rise when changing lanes in light traffic. When driving in heavy traffic, the emotional change like anxiety and annoyance caused by the traffic jam or other changing lanes vehicles could rise the stress reaction of the divers. Thus, based on this research, it is the least stress for a driver when change only 1 lane each time in medium traffic situation.

Reference

Arthur, W. A., Jr., Strong, M. H., & Williamson, J., 1994. validation of a visual attention test as a predictor of driving accident involvement. Journal of Occupational and Organizational Psychology, 67, 173–182.

Andreassi. J., 2000. Psychophysiology: Human Behaviour and physiological response (4th Edition). Lawrence Erlbaum Associates.

Brenner, B. & Selzer, M. L., 1969. Risk of causing a fatal accident associated with alcoholism: Psychopathology and stress: Further analysis of previous data. Behavioral Science, 14, 490–495.

Brookhuis, K. A., Waard D., 1993. The use of psychophysiology to assess driver status. Ergonomics, 36(9):1099-1110.

Dong, Z., Sun, S., Wu, Q., 2010. Study of correlation between heart rate variability and driving fatigue. Journal of Zhejiang University. 44(1): 46-50.

Eberhard, B., Jan, L., Gerard, D., 2007. Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals — A review. Physiology & Behavior. 92(3): 293-316.

Elmar, M., Jan, L., Gerd, N., 2001. Heart rate variability: A noninvasive approach to measure stress in calves and cows. Physiology & Behavior. 75(1-2): 251-259.

Gerald, M., Lisa, D., Thomas, W., 1998. Driver stress and performance on a driving simulator. Human Factors: The Journal of the Human Factors and Ergonomics Society. 40(1).

Gulian, E., Debney, L. M., Glendon, A. I., Davies, D. R., & Matthews, G., 1989. Coping with driver stress. In M. G. McGuigan & W. E. Sime (Eds.), Stress and tension control, Vol. 3, pp. 173–186.

Gulian, E., Glendon, A. I., Matthews, G., Davies, D. R., & Debney, L. M., 1990. The stress of driving: A diary study. Work and Stress, 4, 7–16.

Gulian, E., Matthews, G., Glendon, A. I., Davies, D. R., & Debney, L. M., 1989. Dimensions of driver stress. Ergonomics, 32, 585–602.

Hu, J., Li, A., Wang, W., 2011. Analysis on driver's driving workload in different weather conditions. Journal of Beijing Polytechnic University. 37(4): 529-532.

Lizawati, S., Desok, K., 2006. Detection of Acute Stress by Heart Rate Variability (HRV) Using a Prototype Mobile ECG Sensor. Information and Communications University, Korea.

Lin, S., Liu, J., Yan, Y., 2013. Safety evaluation model of long-steep downgrade section for montage highway based on driving workload. Journal of Traffic and Transportation Engineering. 13(6): 99-106.

Luciano, B., Joanna, W., Cinzia, V., Stefano, C., 2000. Effects of controlled breathing, mental activity and mental stress with or without verbalization on heart rate variability. Journal of the American College of Cardiology. 35(6).

Matti, V., Tiina, L., Mika, T., 2015. 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. 24(3): 275-283.

Michael, B., Marimuthu, P., Peter, K., 2000. Poincaré plot interpretation using a physiological model of HRV based on a network of oscillators. American Journal of Physiology. 283(5): 1873-1886.

Nis, H., Dag, R., Anne, K., Nils, F., 2004. The effect of mental stress on heart rate variability and blood pressure during computer work. European Journal of Applied Physiology. 92(1): 84-89.

Paolo, M., Marcello, B., Leandro, P., 2011. Nonlinear Heart Rate Variability features for real-life stress detection. Case study: students under stress due to university examination. BioMedical Engineering OnLine.

Rosangela, A., H., Carlos, M., Luiz, C., 2013. Poincaré plot indexes of heart rate variability: Relationships with other nonlinear variables. Autonomic Neuroscience. 177(2): 271-274.

Sonal, A., Nick, S., Debra, N., 2010. The impact of stress on surgical performance: A systematic review of the literature. Surgery. 147(3): 318-330.

Tanja G. M. Vrijkotte, Lorenz J. P. van Doornen, Eco J. C. de Geus, 2000. Effects of Work Stress on Ambulatory Blood Pressure, Heart Rate, and Heart Rate Variability. Hypertension. 35(4).

Veltman, J., A., Gaillard, A., 1998. Physiological workload reactions to increasing levels of task difficulty. Ergonomics, 41(5): 656-669.

Waard, D., 1996. The measurement of drivers' mental workload. University of Groningen.

Wang, L., Li, S., Zhou, R., 2013. Impact of roadside landscape color on driver mean heart rate. Journal of Jilin University. 43(1): 74-80.

Wu, X., Zhang, L., Lu, H., 2010. A driver workload approach to a study on highway geometric consistency evaluating method. Road Traffic and Safety. 10(5): 30-33.

Yuan, W., Guo, Y., Fu, R., Chen, Y., 2014. Influence of urban road section types on drivers' workload. Journal of Chang' an University, 35(5): 1177–1185.