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NARX Network based Driver Behavior Analysis and Prediction using Time-series modeling

Ling Wu[1], Haoxue Liu[2], Tong Zhu[2], Yueqi Hu[3]

[1] School of Vehicle Engineering, Xi'an Aeronautical University, Xi'an, Shaanxi, China
[2] Key Laboratory for Automotive Transportation Safety Enhancement Technology of the Ministry of Communication, Chang'an University, Xi'an, Shaanxi, China
[3] School of Automobiles, Chang'an University, Xi'an, Shaanxi, China

ABSTRACT
The objective of the current study was to examine how experienced and inexperienced driver behaviour changed (including heart rate and longitudinal speeds) when approaching and exiting highway tunnels. Simultaneously, the NARX neural network was used to predict real-time speed with the heart rate regarded as the input variable. The results indicated that familiarity with the experimental route did decrease drivers' mental stress but resulted in higher speed. The proposed NARX model could predict synchronous speed with high accuracy. These results of the present study concern how to establish the automated driver model in the simulation environment.

KEY WORDS: NARX network, Driver, Extra-long tunnels, Heart rate, Traffic psychology

1 INTRODUCTION

ROAD tunnels, as part of a particular structure in road networks, provide convenient connections in mountainous cities and space-constrained areas (Yeung and Wong, 2014; Van der Hoeven, 2011). In China, the largest number of tunnels has been constructed with the most complicated geological conditions. Furthermore, the quickest development is also expected in the future (Yan et al., 2017). Although surface roads have more elevated crash rates than road tunnels (Yeung and Wong, 2013; Ma et al., 2009; Amundsen and Ranes, 2000; Lemke, 2000), the consequences of tunnel crashes are much more catastrophic with prominently higher fatality rates (Kircher and Ahlstrom, 2012). Regarding different tunnel segments, the entrance zone resulted in a higher crash risk (Amundsen and Engebretsen, 2009; Nussbaumer, 2007) and pathologic discomfort (Yeung and Wong, 2014) than further into the tunnel. Because tunnels are dirty, dark and monotonous (Noizet and Ricard, 2004), accompanied by the high contrast of inside and outside driving environments, which could trigger rare, but severe accidents (Laureshyn et al., 2010), it is of critical importance to investigate the effects from the drivers perspective in terms of micro-behavior and understand how the driver's behavior changes when traveling through the tunnels.

The principal causes of traffic accidents have been extensively attributed to behavioral issues such as safe headway maintenance, speeding and lane keeping as well as the lack of vigilance, including fatigue, distraction, and inattention (Nussbaumer, 2007). Compared to open-road experiments, tunnel structures are found to cause increased attention, mental workload (Domenichini et al., 2017) and stress (Manseer and Riener, 2014), associated with lower driving speeds and differences in lateral deviations (distance to the tunnel wall) (Calvi et al., 2012). Other studies also examined the effects caused by different tunnel characteristics. Different tunnel lengths gave rise to differences in the proportion and distribution of fixation duration (He et al., 2010). A simulator study by Hirata et al. (2006) indicated that informing drivers of accidents ahead in a tunnel exerted a meaningful impact on safety. Previous literature has focused on the single aspects of potential workload (subjective evaluation), differences in attention distribution, speed or car-following behavior using either simulator tests or on-road tests. However, only a handful of field-operational studies provide thoughtful and comparative insight into both the variation of driver stress and speed when compared to open roads,

CONTACT Ling Wu lwzygj@163.com

specifically in extra-long highway tunnels with more obvious characteristics.

A growing body of literature was devoted to automated driving and tried to simulate driver behavior under different driving conditions (Smith and Starkey, 1995; Zeeb et al., 2015. In this special driving environment, driver mental activity and corresponding speed may be influenced by the change of visual pattern and the tunnel wall effect (Törnros, 2000), which could be embodied in the detailed description of the simulation model. ECG (Electrocardiogram) activity, regarded as parameter skin conductance, have a high correlation with the perceived stress levels of the subject (Manseer and Riener, 2014; Healey and Picard, 2005). Hence, the objective of this study was to examine experienced and inexperienced driver behavior (including HR (heart rate) and speed) in extra-long highway tunnels (longer than 3 km) using on-road tests. To remove the effects of geometric differences and inhomogeneity of the traffic flow, two typical extra-long tunnels were selected, and vehicles were driven in both directions in the tunnel (north to south and south to north). The mean value was adopted to characterize the variations in driver stress and speed. The reason why both experienced drivers (staff working in this experimental route) and inexperienced drivers were selected was to determine whether the familiarity with the tunnels would decrease driver stress and lead to a safer speed range. The correlations between heart rate and speed were experimentally verified. In the final part of the paper, the NARX neural network was adopted to predict their longitudinal speeds based on the heart rate while driving through the extra-long highway tunnels.

The specific research questions were as follows: How does an extra-long highway tunnel affect driver stress and speed in the entrance zone, the exit zone, and entire tunnel area? Did all drivers reduce speed and exhibit increased heart rate in this driving environment? Did the familiarity with the route safely impact driver speed and stress? Could the NARX model simulate driver’s real-time speeds with higher reliability and validity?

2 MATERIALS AND METHODS

2.1 Experiment Route

EXTRA-LONG tunnels on the Lan-Shang (Lantian - Shangluo) highway, situated in the Shaanxi Province, were selected as an experiment route. The Lan-Shang highway is bi-directional with four lanes, consisting of 226 bridges and 35 tunnels (the accumulated length of tunnels in a single direction was 37.13 km). There are two extra-long tunnels located on this highway (namely, the Lijiahe Tunnel 3# with 4259 m and the Qinling Tunnel with 4748 m). Both the Lijiahe Tunnel 3# and Qinling Tunnel are extra-long unidirectional tunnels with two lanes. The speed limit within the tunnel is 60 km/h, and on an open expressway, it is 80 km/h. This experiment route gives an overall reflection of the influence caused by tunnel environment on the drivers' ECG signals, because it runs through the Qinling mountains. On-site observation of hourly traffic volumes indicated that the experiment route is mainly in a free flow status. In other words, drivers control the speed freely based on their driving style, vehicle conditions, and road conditions, without being affected by traffic.

2.2 Subjects

There were several criteria for recruiting subjects due to the potential danger triggered by the tunnel environment. Subjects were asked to have no less than three driving years of driving practice and have no serious accident experience (no more than 10000 RMB economic losses or someone dying in the crash) before. In total, 60 male subjects (no female subjects) participated in this study, including 30 experienced drivers (staff responsible for the management of two tunnels) and 30 inexperienced drivers (no driving experience with this experiment route before). Experienced drivers had an average age of 35.7 years old with an average of 14.2 driving years. Simultaneously, inexperienced drivers had an average age of 39.2 years old with an average of 13.6 driving years. Thus, these two types of drivers were almost balanced in their age and driving years. The detailed information of all participants is listed in Table 1.

2.3 Apparatus

The real-time speed was collected using the OBD (on-board diagnostic) system and saved in the SCM (single-chip microcomputer) software. Synchronized ECG data from the subjects during the experiment were recorded using the MP150 (16-channel multi-functional physiological recorder produced by BIOPAC, a United States company). The ECG module (ECG100C amplifier) was used, and the obtained ECG data can be analyzed either online or offline via an additional software AcqKnowledge.

Table 1. Participants in this Study (Mean ± Standard Deviation).

Driver attribute	Age (years old)	Actual driving experience (years)	Driving distance/year (ten thousand kilometers)	Familiar with the experiment route or not
Experienced	35.7±9.8	14.2±9.7	4.8±2.6	Familiar
Inexperienced	39.2±11.3	13.6±12.0	1.9±0.9	Not familiar

2.4 Data Pre-processing

In accordance with the provisions in the Specification of Highway Route Design (JTG D20-2006) (Ministry of Transport of the People's Republic of China, 2006) on the road alignment, the lines outside the tunnel entrance should be well aligned with those inside. The plane lines outside the tunnel entrance within longer than 3s travel distance, and those inside the entrance within longer than 3s travel distance in design speed should be consistent, while the requirements for those vertical lines dictated that the traveling distance could be longer than 5s. Based on the fact that 80 km/h is the highest speed limit on an open expressway, the 3s travel distance and 5s travel distance were approximately 67 m and 111 m, respectively. In addition, the tunnel was divided into the entrance zone (within 250 m before and after the entrance), exit zone (within 250 m before and after the exit) and internal zone (the remaining area in the tunnel) when Yeung and Wong analyzed the road traffic accidents in Singapore expressway tunnels (Yeung and Wong, 2013).

Combined with the above mentioned specifications, the current study extended the scope to 300m outside the tunnel portal and divided each extra-long tunnel into entrance zone, internal zone, and exit zone. Specifically, the entrance zone consisted of 300m before the portal and 300m immediately after entering the tunnel. The exit zone was comprised of 300m before the tunnel exit and 300m after the exit of the tunnel. The remaining middle section was the internal zone.

To reflect the universality of the influence caused by the extra-long tunnel environment on the ECG signals, excluding the impact of certain factors such as the road shape and the safety facilities, both the selection of the typical tunnels and the data processing methods were adjusted. In detail, the entrance zone included both the Lijiahe Tunnel 3# and Qinling Tunnel in two directions (south direction and north direction). Similarly, the internal zone and exit zone in two directions of both the Lijiahe Tunnel 3# and Qinling tunnel were considered to generalize the ECG variation characteristics in the overall extra-long tunnel environment rather than a particular direction or condition. All subjects experienced a statistic before-experiment test to see if their heart rates were in a normal range for 60 to 100 beats per minute. The mean heart rate was presented since we adopted a within-subject measure (driving in both tunnels and open expressway).

We need to obtain the mean index to characterize the change at a specific position, because we obtained the data for both tunnels in both directions. Therefore, the method of cutting the traffic interval was proposed based on the above mentioned tunnel zone divisions. The entrance zone and the exit zone contain 12 traveling intervals with a range of 50m. In total, 20 consecutive points were selected to divide the internal zone into 19 traveling intervals with the same division rule adopted in an open expressway. Thus, in a way, the entire tunnel was composed of 43 intervals. Finally, the mean indicator for the same interval corresponding to both directions in both tunnels was calculated. Specifically, the mean value at an interval of 20m was obtained by Orthogonal Hermite Interpolation Method in the entrance zone and exit zone. The division diagram of tunnel zones and traveling intervals are presented in Figure 1.

3 RESULTS

3.1 Variation of Mean Heart Rate in the Entrance Zone

THE mean HR of experienced drivers varied during the process of passing the tunnel entrance zone. As shown in Figure 2, the mean HR variation could be divided into four stages. Considering that dark adaptation took more time than light adaptation, the ending point of dark adaption could be represented by the second mean HR dropping point or the first mean HR stable point occurring after the first dropping point when drivers entered the tunnel portal. It could be observed that the first mean HR dropping point occurred at 20m after the tunnel entrance, followed by the first mean HR stable point at 180m. Thus, the position ranges of the entrance zone with an impact on experienced drivers appeared from 300m before and 180m after the portal. Simultaneously, within the range of 20m before and after the portal, the mean HR had a staggering growth increase of 0.47%.

The mean HR variation for inexperienced drivers when they passed the entrance zone could also be distributed into four stages, seen in Figure 3. The mean HR exhibited the second drop at 220m after entering the tunnel portal. Hence, the impact of the entrance zone on the mean HR of inexperienced

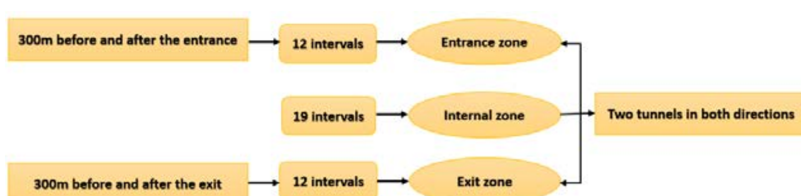


Figure 1. Division Diagram of Tunnel Zones and Traveling Intervals.

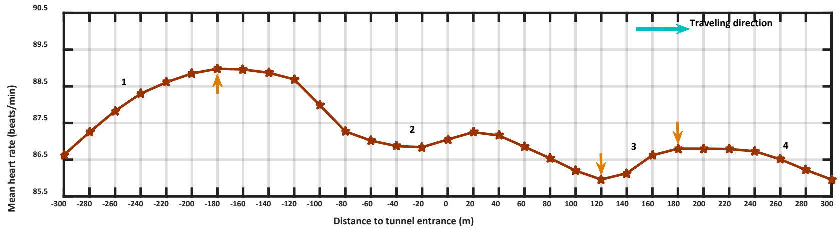


Figure 2. **Mean Heart Rate in the Tunnel Entrance Zone for Experienced Drivers.**

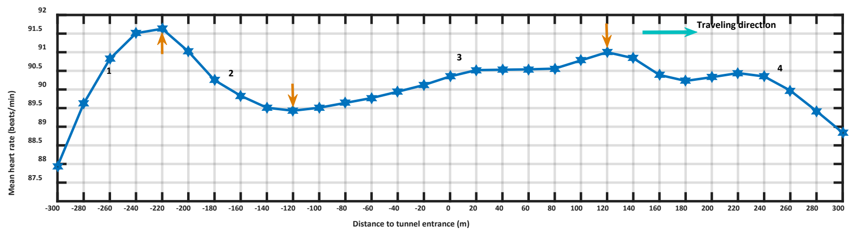


Figure 3. **Mean Heart Rate in the Tunnel Entrance Zone for Inexperienced Drivers.**

drivers mainly occurred from 300m before to 220m after the portal. Within the range of 120m before to 120m after the portal, the mean HR increased continuously by 1.76%.

3.2 Variation of Mean Heart Rate in the Exit Zone

The variation of the mean HR for experienced drivers in the exit zone could be divided into three stages, shown in Figure 4. Light adaptation is more rapid than dark adaptation. Therefore, the first mean HR dropping point occurred when drivers exited the tunnel, representing the end point of light adaptation. The impacting positions on the mean HR of experienced drivers appeared from 300m before the exit to 220m after the exit. Within the range of 80m before to 80m after the exit, the mean HR grew continuously by 1.94%.

The mean HR of inexperienced drivers when passing the exit zone could be distributed into four stages, seen in Figure 5. The mean HR of drivers fluctuated and increased due to the environment change exerted on their physiological index, although the mean HR slightly dropped between the 300m and 80m before the exit. Thus, the impacting range of the exit zone on the mean HR of inexperienced drivers apparently occurred from 300m before to 80m after the exit. Within the range of 80m before and after the exit, the mean HR went up continuously by 2.10%.

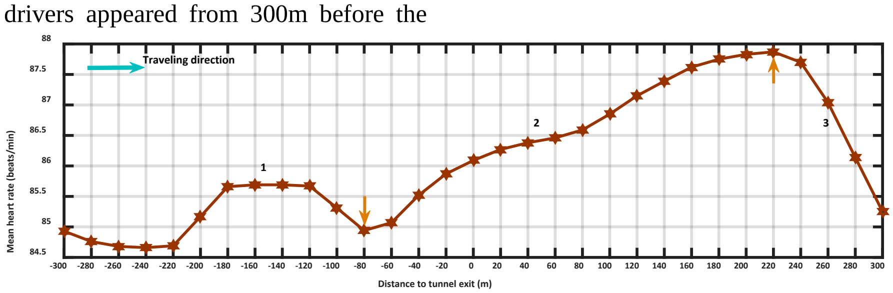


Figure 4. **Mean Heart Rate in the Tunnel Exit Zone for Experienced Drivers.**

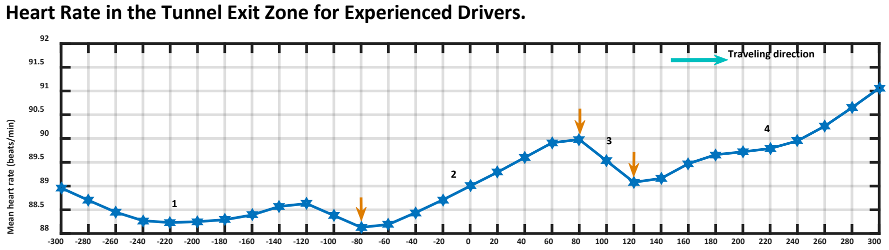


Figure 5. **Mean Heart Rate in the Tunnel Exit Zone for Inexperienced Drivers.**

3.3 Variation of Mean Heart Rate in Tunnels and Open Expressways

Figure 6 presents the mean HR variation for the two types of drivers when they passed through extra-long tunnels. Concerning the traveling direction, experienced drivers had a lower mean HR than that of inexperienced drivers at all intervals. In the process of entering and exiting the tunnel, the mean HR of both types of drivers began to increase farther from the entrance but closer to the exit. The curve of the mean HR for these two types of drivers presented a tendency of increase in the entrance zone, decreasing in the internal zone and again increasing in the exit zone. The mean HR had larger fluctuations in transition areas (entrance zone and exit zone) but mild fluctuations in the internal zone.

Due to their familiarity with the experimental route, experienced drivers had a lower mean HR than inexperienced drivers in all road sections, shown in Figure 7. Regarding tunnel sections, experienced drivers showed the highest mean HR in the entrance zone, while no apparent variation was found in the internal and exit zones. The mean HR of inexperienced drivers, however, who gradually adapted to the outside environment, was highest in the entrance zone and lowest in the exit zone. Both types of drivers were observed to have the highest mean HR in open expressways rather than in tunnels.

3.4 Variation of Mean Speed in the Entrance Zone

Figure 8 illustrates the mean speed variation at all entrance zone position points for experienced and inexperienced drivers. Little impact occurred in the range 100m from the entrance on the mean speed of experienced drivers, and the mean speed remained stable. From 100m to 20m before the portal, the mean speed increased by 6.20%; the mean speed remained steady from 20m before and 20m after the portal; and finally, the mean speed continued to increase. The mean speed variation for experienced drivers in the entrance zone showed a trend of increase-stable-increase.

Inexperienced drivers slowed down at a distance 300m to 80m before the portal, showing a drop of 5.61%; from 80m before to 120m after the portal, the mean speed remained stable; and then, the mean speed declined continuously by 4.10% until 220m after entering the tunnel. The mean speed variation for inexperienced drivers in the tunnel zone presented a trend of decrease-remain stable-decrease. The mean speed increased again once drivers were adapted to the tunnel environment, and this position point was defined as the ending point of dark adaptation. As a result, the impacting position of the entrance zone on the mean speed of inexperienced drivers occurred at the distance range from 300m before and 200m after the portal. Within the range of 20m before and after the portal, the mean speed dropped slightly. In the entrance zone, the variation of the mean speed of experienced drivers was twice than that of inexperienced drivers.

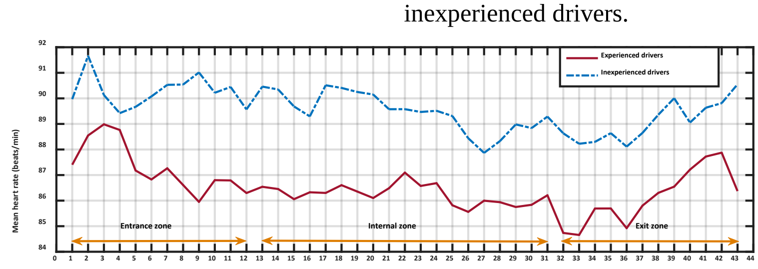


Figure 6. Mean Heart Rate in All Tunnel Intervals for Both Types of Drivers.

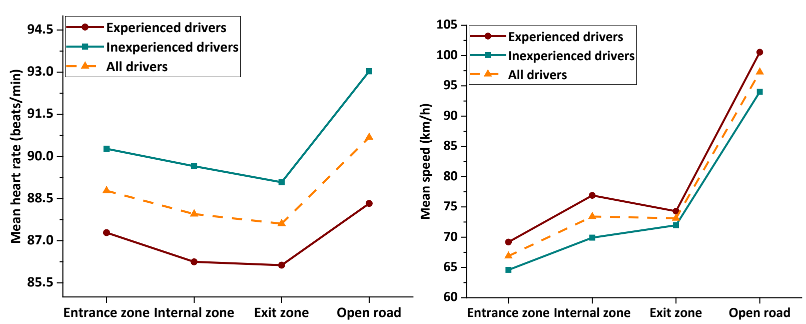


Figure 7. Comparison of the Mean heart Rate and Speed in Different Zones.

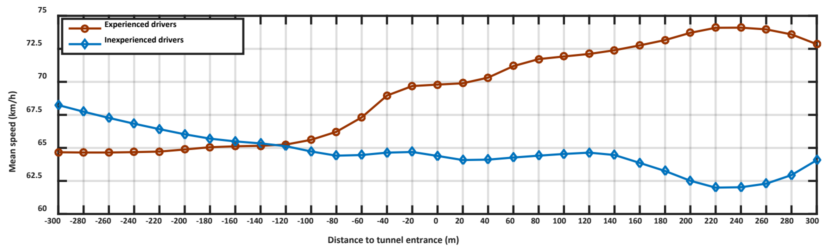


Figure 8. **Mean Speed in the Tunnel Entrance Zone for Both Types of Drivers.**

3.5 Variation of Mean Speed in the Exit Zone

As seen in Figure 9, during the process of approaching and leaving the tunnel exit, the mean speed of experienced drivers dropped slightly by 2.46%, and then, it dramatically and continuously declined by 16.00% at 20m from the exit until leaving the exit zone.

Inexperienced drivers within the range of 120m to the tunnel exit had a steady mean speed; from 120m before to 20m after the exit, the mean speed decreased steadily by 2.41%; and then, the mean speed plunged by 4.17% until 80m after the exit. Once drivers were adapted to the light, their mean speed began to increase markedly. The mean speed variation of inexperienced drivers in the exit zone showed a trend of decrease – plummet – increase. The ending point of the light adaptation process was represented by the position that witnessed a tendency of acceleration after the exit. As a result, the position ranges of the exit zone that impacted the mean speed of inexperienced drivers occurred at a distance from 120m before to 80m after the exit. Within the range of 20m before and after the exit, the mean speed of inexperienced drivers had a slight decline. In the entire exit zone, the mean speed variation for experienced drivers was twice of that of inexperienced drivers.

3.6 Variation of Mean Speed in Tunnels and Open Expressways

Figure 10 represents the mean speed of the two types of drivers in all tunnel intervals. With respect to the traveling direction, the mean speed of experienced drivers showed a trend of increase-stable-decrease. Inexperienced drivers, however, decelerated in the entrance zone, accelerated at a stable value in the internal zone, decelerated slightly in the exit zone, and accelerated again after exiting the tunnel. The mean speed of inexperienced drivers was lower than that of experienced drivers in each internal traveling zone interval.

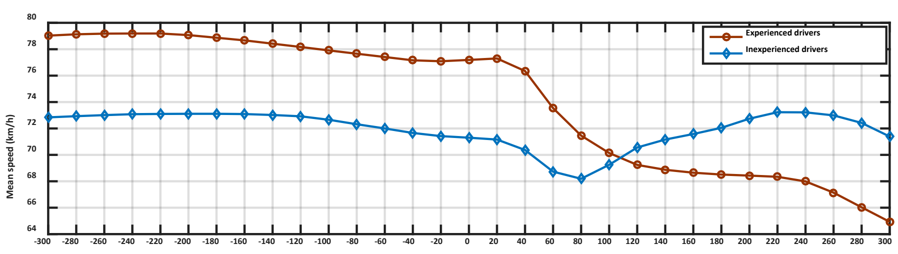


Figure 9. **Mean Speed in the Tunnel Exit Zone for Both Types of Drivers.**

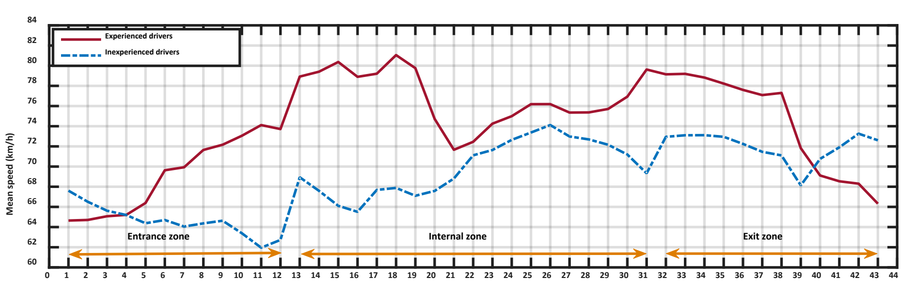


Figure 10. **Mean Speed in the Entire Tunnel for Both Types of Drivers.**

As seen in Figure 7, in the tunnel sections, all drivers had the minimum mean speed in the entrance zone, while experienced drivers showed the maximum mean speed in the internal zone, and inexperienced drivers showed the maximum mean speed in the exit zone. When compared to tunnels, open expressway drivers traveled at higher mean speeds.

3.7 Correlations between Heart Rate And Speed

There was no significant correlation between the driver's heart rate and speed when the data of all participants driving in tunnels and on highways were considered. However, the heart rate correlated negatively with speed (r = -0.109, $p < 0.01$) when only the tunnel data was considered. Still, no significant correlation was found in the highway data including both experienced and inexperienced drivers.

When drivers and road sections were taken into consideration separately, the heart rate of the experienced drivers in tunnels suggested a significantly negative correlation with speed (r = -0.115, p < 0.01). However, the heart rate of experienced drivers on highways correlated positively with speed (r = 0.275, $p < 0.01$). Also, the heart rate of inexperienced drivers on highways manifested a negative correlation with speed (r = -0.234, $p < 0.01$), although no significant correlation between these two indicators in tunnels was observed.

3.8 Speed Prediction Using NARX Models

NARX neural network describes a discrete nonlinear system by using past input and output data (Narendra and Parthasarathy, 1990; Nissinen et al., 1999). As seen in Figure 11, the expression is shown as follows:

$$y(t) = f\left[y(t-1), y(t-2), \cdots, y\left(t-n_y\right), x(t-1), x(t-2), \cdots, x(t-n_x)\right] \quad (1),$$

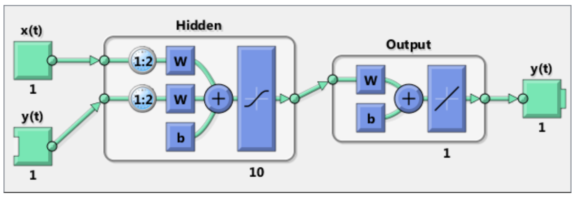


Figure 11. The Structure Diagram of the NARX Neural Network.

Where $x(t)$ and $y(t)$ represent the input and output values. 1:2 represents the time step of delay and W represents the link weights. b represents the threshold. That is to say, the next $y(t)$ value depends on the previous $y(t)$ and the previous $x(t)$.

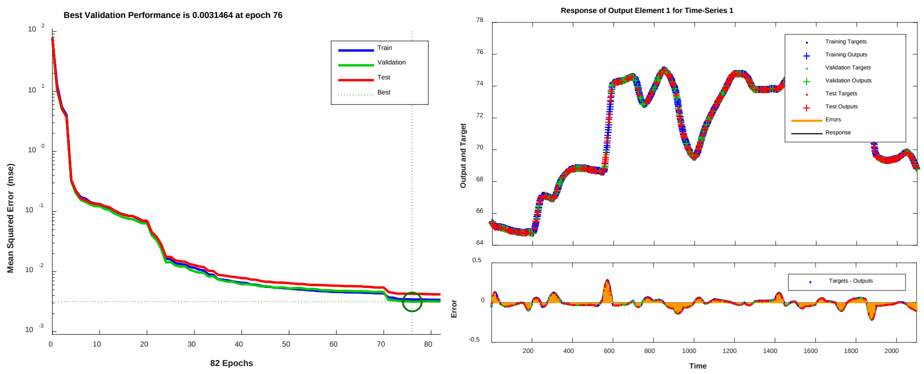
Regarding the data pre-processing, the mean heart rate and speed were all mean values originating from the traveling intervals. Thus, it was necessary to convert the spatial data into time series data. Because the original data was based on the high sampling rate, the value of heart rate and speed value at 1m interval could be obtained by Hermite interpolation. The heart rate correlated with the speed in tunnels based on the previous analysis, so the NARX model could be used to predict the driver's speed using the heart rate as the input variable.

The training effect of NARX neural network was shown in Figure 12. It can be seen from Figure 12(1) that the MSE (Mean Squared Error) started to increase after the 76 time-step, which proved that the training process could be ended and the error of the whole data set was 0.0031464. Figure 12(2) shows the time-series response for the target data and predicted data. The fitting coefficient of the training set, the validation set, the test set and the whole data set was R = 0.99986, R = 0.99987, R = 0.99983 and R = 0.99986 respectively. Therefore, it could be concluded that the NARX neural network model was effective in predicting the speed of the drivers when they drove through the tunnel section.

4 CONCLUSION

THE objective of this study was to use field-operational tests to determine whether a driver's behavior was affected when experienced drivers (familiar with the experimental route) and inexperienced drivers (unfamiliar with the experimental route) drove through extra-long highway tunnels and on open expressways. Two tunnels in both directions (north to south and south to north) were selected to conduct driving tests with real-time ECG signals, and driving speeds were synchronously collected. Finally, the mean indicator derived from traveling intervals was used to characterize the variation at specific positions.

Compared to experienced drivers, the impacting positions on inexperienced drivers were wider at the entrance zone but were narrower at the exit zone. In the process of entering and exiting the tunnel, the mean HR of both types of drivers began to increase at a distance far from the entrance but close to the exit, which demonstrated that the entrance and exit zones caused different impacting patterns on driver stress levels.



(1) Training Error **(2) Time-series Response**

Figure 12. The Training Results of NARX Neural Network.

The mean speed variation for experienced drivers in the entrance zone showed a trend of increase-stable-increase, which implied that drivers did not consider the entrance zone as a high-risk area and thus decelerate to avert any potential accident when familiar with the experimental route. Experienced drivers selected in the current study were staff in the tunnel management organization, so it was expected that the mean speed would increase when the depressed driving environment transitioned to the open expressway. However, the mean speed did not show such a trend. One possible reason was that experienced drivers might know about the hidden speed measurement devices installed at the exit zone.

Inexperienced drivers who were unfamiliar with the experimental route slowed down in advance at a distance farther from the tunnel entrance but closer to the exit. This psychological tension compensates for predicted risks. Simultaneously, in both the entrance and exit zones, the mean speed variation of experienced drivers was much more than that of the inexperienced drivers. Within the range of 20m before and after the portal (either at the entrance or the exit), inexperienced drivers decelerated slightly. In comparison with the entrance zone, the impacting area of the exit zone on the mean speed of inexperienced drivers was narrower; representing that light adaptation was faster than dark adaptation.

Experienced drivers who were familiar with road conditions showed a lower mean HR and a faster mean speed than inexperienced drivers in all road sections, which indicated that familiarity with the experimental route decreases mental stress, but results in higher speed. In terms of tunnel sections, both types of drivers showed the maximum mean HR but the lowest mean speed in the entrance zone, suggesting that the entrance zone was regarded as a dangerous area associated with high accident risk and stress based on the motivation model.

Inexperienced drivers, by contrast, who gradually adapted to the tunnel environment had a lower mean HR and drove faster in the exit zone than in the entrance and internal zones. All drivers showed the highest mean HR and the maximum mean speed on the open expressway, which may explain why the open expressway was thought to be safer but produces higher stress and behavioral risks. The results of Person’s correlation also revealed that both experienced and inexperienced drivers had different behavioral patterns between heart rate and speed on highways and in tunnels, which indicated that different drivers tended to respond to the two driving environments differently.

The NARX nonlinear neural network provides an efficient and innovative method for predicting driver’s speeds based on the heart rate. These conclusions were beneficial to delineate individual differences in driver behavior model under specific driving environment, providing a basis for constructing automated driving model or the development and design for more and more advanced in-vehicle technologies.

4.1 Acknowledgement

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5 REFERENCES

F. H. Amundsen & G. Ranes, (2000). Studies on traffic accidents in Norwegian road tunnels. Tunnelling and underground space technology, 15(1), 3-11.

F. H. Amundsen & A. Engebretsen, (2009). Studies on Norwegian Road Tunnels II: an analysis on traffic accidents in road tunnels 2001-2006.

A. Calvi, M. R. De Blasiis, and C. Guattari, (2012). An empirical study of the effects of road tunnel on driving performance. Procedia-Social and Behavioral Sciences, 53, 1098-1108.

L. Domenichini, F. La Torre, D. Vangi, A. Virga, and V. Branzi, (2017). Influence of the lighting system on the driver's behavior in road tunnels: a driving simulator study. Journal of Transportation Safety & Security, 9(2), 216-238.

C. He, B. Chen, J. Wang, and Y. Shi, (2010). Research on Allocation of the Driver's Attention on the Tunnel Sections of a Mountain Freeway. In ICCTP 2010: Integrated Transportation Systems: Green, Intelligent, Reliable (pp. 444-452).

J. A. Healey & R. W. Picard, (2005). Detecting stress during real-world driving tasks using physiological sensors. IEEE Transactions on intelligent transportation systems, 6(2), 156-166.

T. Hirata, T. Mahara, and Y. A. I. Tetsuo, (2006). Traffic safety analysis in an underground urban expressway using MOVIC-T4. Infrastructure Planning Review, 23, 797-804.

K. Kircher & C. Ahlstrom, (2012). The impact of tunnel design and lighting on the performance of attentive and visually distracted drivers. Accident Analysis & Prevention, 47, 153-161.

A. Laureshyn, Å. Svensson, and C. Hydén, (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. Accident Analysis & Prevention, 42(6), 1637-1646.

K. Lemke, (2000). Road safety in tunnels. Transportation Research Record: Journal of the Transportation Research Board, (1740), 170-174.

Z. L. Ma, C. F. Shao, and S. R. Zhang, (2009). Characteristics of traffic accidents in Chinese freeway tunnels. Tunnelling and underground space technology, 24(3), 350-355.

M. Manseer & A. Riener, (2014, September). Evaluation of Driver Stress while Transiting Road Tunnels. In Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 1-6). ACM.

Ministry of Transport of the People's Republic of China. Specification of Highway Route Design [S]. JTG D20-2006. Beijing: China Communications Press, 2006.

K. S. Narendra & K. Parthasarathy, (1990). Identification and control of dynamical systems using neural networks. IEEE Transactions on neural networks, 1(1), 4-27.

A. S. Nissinen, H. N. Koivo, and H. Koivisto, (1999). Optimization of neural network topologies using genetic algorithm. Intelligent Automation & Soft Computing, 5(3), 211-223.

A. Noizet & F. Ricard, (2004). The Acteurs project: results from the survey of drivers using the tunnels operated by the French alpine motorway companies. Computer software. London.

C. Nussbaumer, (2007, May). Comparative analysis of safety in tunnels. In Young Researchers Seminar (pp. 27-30).

D. E. Smith & J. M. Starkey, (1995). Effects of model complexity on the performance of automated vehicle steering controllers: Model development, validation and comparison. Vehicle System Dynamics, 24(2), 163-181.

J. Törnros, (2000). Effects of tunnel wall pattern on simulated driving behaviour. Statens väg-och transport forsknings institut., VTI EC research 9.

F. Van der Hoeven, (2011). A review of the impact of the RingRing study for multifunctional motorway tunnels in the Netherlands and beyond. Tunnelling and Underground Space Technology, 26(2), 292-309.

Y. Yan, X. Wang, L. Shi, and H. Liu, (2017). Influence of light zones on drivers' visual fixation characteristics and traffic safety in extra-long tunnels. Traffic injury prevention, 18(1), 102-110.

J. S. Yeung & Y. D. Wong, (2013). Road traffic accidents in Singapore expressway tunnels. Tunnelling and Underground Space Technology, 38, 534-541.

J. S. Yeung & Y. D. Wong, (2014). The effect of road tunnel environment on car following behaviour. Accident Analysis & Prevention, 70, 100-109.

K. Zeeb, A. Buchner, & M. Schrauf, (2015). What determines the take-over time? An integrated model approach of driver take-over after automated driving. Accident Analysis & Prevention, 78, 212-221.

6 DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

7 NOTES OF CONTRIBUTORS

Ling Wu is currently working towards a Ph.D. degree in Transportation Engineering (Vehicle Operation Engineering) at the School of Automobiles, Chang'an University, Xi'an, Shaanxi, China. She mainly focuses on driver behavior analysis and modelling, like driver distraction, and car-following behavior.

Haoxue Liu works as a research professor in Transportation Engineering (Vehicle Operation Engineering) at the School of Automobiles, Chang'an University, Xi'an, Shaanxi, China. His research interest mainly focuses on traffic safety and driver behavior.

Tong Zhu is now working as an associate professor in Transportation Engineering (Vehicle Operation Engineering) at the School of Automobiles, Chang'an University, Xi'an, Shaanxi, China. His research interest mainly concentrates on driver psychology and driver behavior analysis.

Yueqi Hu is working towards a Ph.D. degree in Transportation Engineering (Vehicle Operation Engineering) at the School of Automobiles, Chang'an University, Xi'an, Shaanxi, China. Her research interest is driver distraction.