SENSITIVITY ANALYSIS OF LANE POSITION AND STEERING MEASUREMENTS TO FATIGUED DRIVING

Hui Zhang¹,²
¹Intelligent Transportation Systems Research Center
Wuhan University of Technology
Wuhan, Hubei, China 430063
Tel: 86-18062033810, Fax: 86-27-86582280; Email: zhanghuits@qq.com
²Department of Civil and Environmental Engineering
University of Alberta, 4-110D NREF
Edmonton, Alberta, Canada T6G 2W2
Tel: 1-780-885-1291, Fax: 1-780-492-0249; Email: hui2@ualberta.ca

Chaozhong Wu¹,², Corresponding Author
Professor
¹Intelligent Transportation Systems Research Center,
Wuhan University of Technology
Wuhan, Hubei, China 430063
Tel: 86-27-86582280, Fax: 86-27-86582280; Email: wucz@whut.edu.cn
²National Engineering Research Center for Water Transportation Safety,
Wuhan University of Technology
Wuhan, Hubei, China 430063
Tel: 86-27-86582280, Fax: 86-27-86582280; Email: wucz@whut.edu.cn

Xinping Yan¹,²
Professor
¹Intelligent Transportation Systems Research Center,
Wuhan University of Technology
Wuhan, Hubei, China 430063
Tel: 86-27-86582280, Fax: 86-27-86582280; Email: xpyan@whut.edu.cn
²National Engineering Research Center for Water Transportation Safety,
Wuhan University of Technology
Wuhan, Hubei, China 430063
Tel: 86-27-86582280, Fax: 86-27-86582280; Email: xpyan@whut.edu.cn

Tony. Z. Qiu¹,²
Associate Professor
¹Department of Civil and Environmental Engineering
University of Alberta, 6-271 Donadeo Innovation Centre for Engineering
Edmonton, Alberta, Canada T6G 1H9
Tel: 1-780-492-1906, Fax: 1-780-492-0249; Email: zhijunj@ualberta.ca
²Intelligent Transport Systems Research Center
Wuhan University of Technology
Wuhan, Hubei, China 430063

Word count: 4,716 words text + 10 tables/figures x 250 words (each) = 7,216 words
Submission Date: November 11, 2015
ABSTRACT

The parameter value chosen for measuring driving performance impacts the accuracy of fatigue level estimation. Therefore, methods to analyze the sensitivity of these parameter values are proposed in this study. Both the measurement of Standard Deviation of Lane Position (SDLP) and Steering Reversal Rate (SRR) are considered for assessing fatigue, and the sensitivity of the parameters from the time domain and value domain is analyzed. Thirty-six male drivers participate in a field test, and in addition to the lane position and steering wheel angle data, their self-reported fatigue level according to the Karolinska Sleepiness Scale is also recorded. Regarding the SDLP, the results indicate that the maximum average coefficient with fatigue level reached 0.11, with a unified statistical interval of 202 seconds when the consecutive analysis method is used, and for the maximum analysis method, the maximum average coefficient is 0.12 with a unified interval of 120 seconds. In terms of the results of SRR, 6 degrees of steering angle difference is the most sensitive threshold for the drivers’ fatigue level and has an average correlation coefficient of 0.42. This demonstrates that the SRR is more reliable than the SDLP when monitoring fatigue level. By using the optimal parameter value, the variation results of SDLP and SRR at each fatigue level are examined, and the results show that driving ability is impaired with an increase of fatigue level. Therefore, the methods and results of this study can be used as a future reference for fatigued or drowsy driving analysis.

Keywords: Traffic Safety, Fatigued Driving, Standard Deviation of Lane Position, Steering Reversal Rate, Sensitivity Analysis, Optimization Method
INTRODUCTION
The objective of this study is to present the results on the sensitivity of lane position and steering changes in response to fatigue level. The motivation of this study is that fatigued driving is one major reason for traffic accidents, especially those involving serious injuries or fatalities \( (1) \). Therefore, many methods have been proposed in studies on monitoring or quantifying drivers’ status in terms of drowsiness or fatigue. The findings of some of these studies revealed that an electroencephalogram is one feasible measurement that is sensitive to the indication of sleepiness \( (2,3,4) \). Meanwhile, eye \( (5,6) \) or head movement \( (7) \) are measurements also proposed in other studies. Compared with those measurements of the drivers’ physiological status, there is no direct interference with drivers for the objective driving performance measurements, by which only focus on drivers’ operation \( (1,8) \) or vehicles’ movements \( (1,9) \).

As a result, the methods based on objective performance have been widely tested and implemented inside vehicles to monitor fatigued driving. However, one limitation concerns individual differences and each individual’s sensitivity to fatigue for these driving performance parameters. Proper adjustment of the parameters for lane position or steering based fatigue monitoring can improve the sensitivity to drowsiness. Therefore, in order to estimate the most sensitive parameter value of the measurement of lane position and steering, a field driving test was conducted to propose the optimal parameter value.

The rest of this paper is organized as follows. The literature review of measurements used for fatigued driving studies is first discussed. The experimental design and the sensitivity analysis methods and parameters used in this study are then introduced. After obtaining the experimental data, the results showing the correlation between fatigue level and different parameter values are presented, and finally is the conclusion of the sensitivity analysis.

LITERATURE REVIEW
Lane Position or Steering Measurements for Monitoring Fatigue
Drivers’ operation and vehicles’ movements are two commonly used objective indicators for monitoring the physiological status when drivers are under the influence of fatigue, distraction, alcohol or medicine. Many of these studies have indicated that measurements of steering and lane-keeping are considered the most reliable for monitoring fatigue, and the related parameters used include Standard Deviation of Lane Position (SDLP) \( (10) \), Steering Reversal Rate (SRR) \( (11) \), frequency of steering error \( (12) \) or steering exceeding the threshold \( (13) \), etc. In summary, the steering reversal rate is the parameter used to measure the frequency at which steering exceeds the threshold of the wheel angle. Thus, SRR can reflect drivers’ ability to maintain stable control of the wheel. The SDLP is the parameter used to detect the swerving of vehicles when moving inside the lane. The SDLP can reflect the ability of drivers to maintain driving at a safe position to avoid unintentional lane departure or lane crossing.

Field tests and simulated driving tests are two main approaches used for exploring the effect of driver fatigue on driving performance; the methods, dependent measurements and parameters used in these studies have been summarized in Table 1. The results indicated that the statistical time interval used for SDLP varies in different studies, ranging from 1 minute (min) to 480 minutes, which demonstrates that the parameters in the time domain are a sensitive measurement of lane position. The main parameters used for steering are the threshold of wheel angle, and the parameter value ranges from 6 to 10 degrees. In conclusion, it can be easily seen from Table 1 that for different studies, the parameters adopted are not the same; the value
adjustment for all these parameters will impact the accuracy of monitoring fatigued driving. The sensitivity of these parameter values to fatigue level is still unknown.

**TABLE 1** Summary of the Parameter Values Used for the Fatigued Driving Study Based on Steering and Lane Position

<table>
<thead>
<tr>
<th>Study</th>
<th>Dependent Measurement</th>
<th>Parameters Used</th>
<th>Fatigue Reference</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gastaldi, et al. (2014)</strong>[10]</td>
<td>SDLP &amp; Mean of Absolute Steering Error</td>
<td>4 min for SDLP</td>
<td>SSS¹</td>
<td>Sim²</td>
</tr>
<tr>
<td><strong>Zhang, et al. (2014)</strong>[9]</td>
<td>SDLP &amp; SRR</td>
<td>5 min for SDLP 6 degrees for SRR</td>
<td>KSS³</td>
<td>On road</td>
</tr>
<tr>
<td><strong>Merat and Janson (2013)</strong>[14]</td>
<td>SDLP &amp; High Frequency Steering</td>
<td>Not mentioned</td>
<td>PERCLOS⁴ &amp; Scale</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Rossi, et al. (2011)</strong>[12]</td>
<td>SDLP &amp; Standard Deviation of Steering Error</td>
<td>1 min</td>
<td>Not Mentioned</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Tal, et al. (2008)</strong>[11]</td>
<td>SDLP &amp; SRR &amp; Average Lane Position</td>
<td>120 min for SDLP</td>
<td>Swedish Occupational Fatigue Inventory-20</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Ting, et al. (2008)</strong>[15]</td>
<td>SDLP, Frequency of Extremely Large SWM⁵</td>
<td>10 min for SDLP 10 degrees for Large SWM</td>
<td>SSS &amp; RT⁶</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Altmüller (2007)</strong>[16]</td>
<td>SDLP, SRR, TTC, Spectrum of Steering</td>
<td>3 min for SDLP 6 degrees for SRR</td>
<td>PERCLOS &amp; Video Rating</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Morris, et al. (2015)</strong>[17]</td>
<td>Deviation of Lane Position</td>
<td>150 min</td>
<td>RT &amp; VAS⁷</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Philip, et al. (2005)</strong>[18]</td>
<td>Inappropriate Lane Crossing</td>
<td>105 min</td>
<td>KSS</td>
<td>On road</td>
</tr>
<tr>
<td><strong>Davenne, et al. (2012)</strong>[19]</td>
<td>Inappropriate Lane Crossing</td>
<td>60 min to 480 min</td>
<td>VAS &amp; KSS</td>
<td>Sim &amp; On road</td>
</tr>
<tr>
<td><strong>Brown, et al. (2009)</strong>[20]</td>
<td>Lane Excursions</td>
<td>Less than 45 min</td>
<td>Obstructive Sleep Apnea Level</td>
<td>Sim</td>
</tr>
<tr>
<td><strong>Thiffault, et al. (2003)</strong>[13]</td>
<td>Mean Amplitude of SWM &amp; Frequency of large SWM</td>
<td>6-10 degrees for Large SWM</td>
<td>Time-on-task</td>
<td>Sim</td>
</tr>
</tbody>
</table>

¹ SSS: Stanford Sleepiness Scale; ² Sim: Simulator; ³ KSS: Karolinska Sleepiness Scale; ⁴ PERCLOS: PERcentage of eye CLOSure; ⁵ SWM: Steering Wheel Movement; ⁶ RT: Reaction Time; ⁷ VAS: Visual Analog Scale.

**Sensitivity Analysis for SDLP and SRR Parameters**

Several studies have proposed methods to address this problem of a sensitivity analysis of measurements in response to fatigued driving. The methods to optimize the parameters for improving fatigue level estimation accuracy are discussed. The sensitivity analysis results of one simulator-based study reveal that 6 degrees is the most sensitive threshold for SRR, for which SRR has the strongest correlation with PERCLOS. The SDLP every five minutes is most sensitive for fatigue level (16). Also, the calculation results of SDLP using retrospective six-minute moving averages and one-minute intervals were considered most sensitive to the measurements of an
Zhang, Wu, Yan, Qiu

electroencephalogram, which was used to represent the level of fatigue (21). Thus, adjusting the 1 time interval for SDLP and the gap of the steering angle for SRR will influence the fatigue 2 monitoring accuracy. Sensitivity analysis results of these parameters need to be further discussed. 3

In summary, the literature review results found that in different fatigued driving studies, 4 the parameter values used for lane position or steering based methods were not consistent. The 5 value impacts the estimation accuracy. Regarding the SDLP, the parameter value was related to 6 the time interval, and regarding the SRR, the parameter was related to the gap or threshold. 7 Although a few studies examined the sensitivity of these parameters, the experimental data from 8 driving simulators have limitations and lack detailed discussion. Therefore, the purpose of this 9 study is to systematically analyze the sensitivity of the time interval for SDLP and the threshold 10 for SRR by conducting a field driving test.

METHODS

Experimental Design
Thirty-six professional taxi drivers with an average age of 48.3 and a standard deviation of 8.1 14 were recruited to participate in this field driving test. In addition, they were determined to be free 16 from any sleeping disorders. Each participant was required to drive the test vehicle (shown in 17 Figure 1 (a)) along the G70 (Han-Shi) Expressway from Wuhan to Xiangyang, which takes drivers 18 more than six hours to complete a round trip. A laptop computer was used to acquire the lane 19 positioning and steering angle data in real time. Measurements of lane position were collected 20 using the Mobileye C2-270, as shown in Figure 1 (b), with a resolution of 0.1 meters and sampling 21 frequency of 8 Hz. The steering angle sensors were integrated with the vehicle’s steering axle, 22 with a resolution of 0.1 degrees and a sampling frequency of 10 Hz, as shown in Figure 1 (c). 23 During the drive, participants were surveyed every five minutes by an observer in the passenger 24 seat and were required to self-report their fatigue level based on the Karolinska Sleepiness Scale 25 (KSS) (22). The KSS is a fatigue level survey scale that ranges from 1 to 9; a score of 1 is extremely 26 alert, and a score of 9 is extremely sleepy, with great effort required to remain alert. The higher 27 the score, the more fatigued the driver is. Other factors such as the ambient temperature and noise 28 were also controlled in this study.

Sensitivity Analysis Procedures and Parameters
The purpose of this study, as discussed previously, is to optimize the parameter values, according 37 to which are the most sensitive to the fatigue level. The parameters that need to be analyzed are 39 introduced in Figure 2. The statistics on the time interval for lane position are used to calculate the
SDLP, and the threshold is used to calculate the SRR. Then the SDLP and SRR are compared with the KSS to test the correlation coefficient. The consecutive SDLP analysis only focuses on the continuous correlation with fatigue level, but the SDLP may not continue to increase at every time interval; therefore, in order to overcome this shortcoming of consecutive analysis methods, the maximum SDLP method is also proposed. The idea of maximum methods is for different time intervals, only the maximum SDLP for this time interval within every five minutes was used to represent the error or impairment under the influence of fatigue, and then analyze the correlation with fatigue level. For instance, if the time interval used is 50 seconds for SDLP, then the consecutive SDLP analysis methods will have six samples for each five-minute interval, as shown in the blue rectangle box in Figure 2. After obtaining six SDLP data samples, the correlation analysis will be conducted by comparing the SDLP with the synchronized KSS. If the time for SDLP is located between two KSS data samples, then the second KSS will be used in this study. The maximum SDLP analysis methods will use only one maximum SDLP among all six samples every five minutes, as in the green rectangle box shown in Figure 2, and then calculate the coefficient. The sample size for each individual will depend on the time interval for the consecutive method, and will depend on the sample size of valid KSS measures for the maximum method.

![Figure 2 Sample data for sensitivity analysis of SDLP and SRR.](image)

**Sensitivity Analysis Model**

As discussed in the study by Koh (23), the linear model was established between the fatigue levels and driver performance in terms of lateral acceleration obtained from a gyroscope sensor. Also, one combination linear model was established between the drowsiness level and driving performance measurement (12). In addition, the regression analysis results show the strong correlation existing between the SDLP and drowsiness rating (24). Therefore, it was assumed that a linear regression model exists between fatigue level and driving performance in terms of the SRR and SDLP. Thus, the method for the sensitivity analysis is expressed as Equation 1; the objective
function is to maximize the Pearson correlation coefficient $R$ between the driving performance measurement and fatigue level indicator.

$$
R = \frac{\sum_{i=1}^{N} r_i}{N}
$$

(1)

Where, $N$ is the sample size of participants (36 in this study); $R$ is the average Pearson correlation coefficient; $r_i$ is the Pearson correlation coefficient between $X_i$ and $Y_i$ for the $i_{th}$ parameter value; here, $X_i$ is the driving performance in terms of SDLP or SRR; $Y_i$ is the fatigue level in terms of KSS; and $n$ is the valid sample size of driver performance or fatigue level.

Because the interval of KSS data collection is five minutes in this study, the SDLP parameter time interval is constrained from 1 second to 300 seconds. During data processing, the calculation step used for the SDLP sensitivity test is 1 second. Therefore, regarding the SDLP, this study will have 300 correlation coefficient test results for both the consecutive and maximum methods. Meanwhile, the threshold used in this study is from 1-10 degrees for the SRR; preliminary test results in this study also found that when the threshold was set greater than 10 degrees, no SRR was found for several participants. The SDLP and SRR are also filtered using the criteria mentioned in (12) before the sensitive analysis.

RESULTS AND DISCUSSION

Sensitivity Analysis Results of SDLP

SDLP sensitivity analysis results for both the consecutive and maximum methods are presented in Figure 3, and the average Pearson coefficient followed the same variation trend as the increase of the time interval when the time interval used was less than 100 seconds for both methods. Regarding the consecutive method, when the time interval was greater than 100 seconds, no significant effect on correlation coefficient was found for different time intervals ($F_{199,7000}=0.085$, $p=1.000>0.05$), and the maximum average coefficient was reached when the time interval was 202 seconds. Different from the consecutive method, the average coefficient reached peak value when the time interval was in the range of 100 seconds to 150 seconds, and the maximum coefficient was 0.12 at the time interval of 120 seconds, which is higher in comparison to 0.11 at 202 seconds for the consecutive method. However, no significant difference ($F_{1,21598}=0.025$, $p=0.874>0.05$) was found between these two methods regarding the sensitivity of SDLP to fatigue level.

The distribution of the coefficient for the consecutive and maximum methods is presented in Figure 4 (a) and Figure 4 (b) respectively. It can be seen from the boxplot analysis results that the deviation of the coefficient was greater when large time intervals were used, which means that if the time interval is larger, individual differences would be more significant than with lower time intervals. Another finding in Figure 4 (a) is that the median coefficient followed the same trend as the average coefficient for the consecutive method, which was not found for the maximum method. In general, for the same time interval, the maximum method had higher deviation than the consecutive method.
The distribution analysis results reveal that individual differences exist, which may impact the accuracy of the correlation coefficient with fatigue level. Significant differences among individual participants were also found for both the consecutive ($F_{35,10764}=1076.356, p<0.01$) and maximum ($F_{35,10764}=1385.668, p<0.01$) sensitivity analysis methods in this study. Therefore, the analysis of
the mean and maximum coefficient for each individual using both methods is further tested in this study. The results of the average coefficient for 300 time intervals for individual participants are presented in Figure 5. Twenty-six of the participants (72%) showed a positive correlation with fatigue level using the consecutive method, and 19 of them (53%) were a positive correlation using the maximum method. The maximum coefficient for both the consecutive and maximum sensitivity analysis methods indicated that only one or two participants had a negative correlation with the increase of fatigue level respectively. These maximum coefficient analysis results reveal that the parameter values for SDLP based fatigue monitoring can be optimized for each individual after data training. Since most of the participants showed a positive correlation, then the SDLP was reliable for evaluating drivers’ physiological status.

![Graph showing comparison of average and maximum Pearson coefficient for each individual participant regarding both consecutive and maximum SDLP analysis methods.](image)

**Figure 5** Comparison of the average and maximum Pearson coefficient for each individual participant regarding both consecutive and maximum SDLP analysis methods.

The maximum coefficient for each time interval in both methods is presented in Figure 6. Although it could be found that, compared with the consecutive method, the maximum method had a higher maximum coefficient, this finding could be from only one individual driver whose lane position performance had a strong correlation with fatigue level. Therefore, it could not be used to prove that the maximum method is more accurate than the consecutive method in fatigue monitoring. It also can be seen from Figure 6 that a greater time interval will have a higher coefficient, which demonstrated that a greater time interval will be more sensitive to fatigue level for both the consecutive and maximum methods.
Figure 6  The maximum coefficient of each time interval for both SDLP analysis methods.

Besides the statistical test, the analysis of SDLP for each KSS-based fatigue rating level was also conducted using the most sensitive time intervals for the consecutive and maximum methods; the results are presented in Figure 7 (a) and Figure 7 (b), respectively. The results show that the SDLP increases with the KSS for both methods, which leads to the following sensitivity analysis results: 120 seconds for the maximum method and a 204-second time interval for the consecutive method were evaluated as reliable in this study. The results indicated that the fatigue level has a significant effect on the SDLP using the optimal time interval extracted by the consecutive ($F_{7, 3685} = 4.275, p < 0.01$) and maximum ($F_{7, 2586} = 2.836, p < 0.01$) methods.
Figure 7 The SDLP at each fatigue level (KSS) for both consecutive and maximum sensitivity analysis methods using the optimal time interval: (a) consecutive SDLP sensitivity analysis method; (b) maximum SDLP sensitivity analysis method.
**Sensitivity Analysis Results of SRR**

Different from the sensitivity analysis of SDLP, the time interval was set to five minutes for the SRR in this study. The correlation coefficient was built between the steering reversal frequency and fatigue level at different thresholds of the steering reversal angle. The sensitivity analysis results for each SRR threshold are presented in Figure 8. The results indicated that 6 degrees of steering wheel gap is the most sensitive for detecting the steering error frequency. The coefficient reached 0.42 for SRR, showing a stronger correlation with fatigue level than the SDLP. These results mean the SRR could be effectively used for evaluating drivers’ steering reliability.

![Figure 8 The sensitivity analysis results for the measurement of SRR regarding the threshold.](image)

By using the most sensitive threshold of 6 degrees, the SRR at each fatigue level was used to further test the reliability of this most sensitive parameter value. The results indicated that when drivers are alert (KSS < 5), their steering reversal rate (Mean SRR=16 / 5 minutes) is less than when they are asleep (Mean SRR= 23 / 5 minutes for KSS=7) or deeply asleep (Mean SRR=38 / 5 minutes for KSS=8), as presented in Figure 9. This result means the sensitivity analysis results of SRR in this study can also demonstrate that when drivers are under the influence of fatigue, their steering stability is impaired and more steering errors are found, which is consistent with the findings in other studies (16). Also, there are significant ($F_{7,2479}=2.671, p<0.01$) effects of fatigue level on the SRR.
CONCLUSION

The literature review results revealed that the time intervals for the SDLP and the steering angle threshold for SRR are two important parameters and that both of these measurements will impact the accuracy of fatigue level estimation. Therefore, the purpose of this study was to evaluate the sensitivity of change in these parameters to fatigue level. A field driving test was conducted to collect driving performance measurements for analysis, and 36 professional taxi drivers were recruited to participate in this driving test. Their driving performance, including the fatigue level according to the KSS, the lane position and steering wheel angle were measured for further analysis. Two methods were proposed to access the sensitivity of SDLP parameters; the first one was based on the consecutive SDLP samples, and the other one was by using the maximum SDLP of all samples to represent the driving performance variation within every five minutes. The results indicated that because of the individual differences, no unified time interval was found to have a strong correlation with fatigue level, even for both SDLP analysis methods. The maximum correlation coefficient was only 0.11 for the consecutive method and 0.12 for the maximum method. However, one interesting finding in this study was that if the time interval used for both methods is less than 100 seconds for obtaining the SDLP, the coefficient is very low. Although no unified parameter value could be found in this study to be acceptable for both methods, if the independent optimal parameter value could be generated for each driver after data training, then this independent value could significantly increase the coefficient with fatigue level, which will be more reliable than using the unified value. In comparison to SDLP, the sensitivity analysis of the steering focuses only on the threshold of wheel angle difference. The threshold of 6 degrees for SRR has a higher coefficient than that of the SDLP sensitivity analysis results, and the correlation coefficient reached 0.42, which was also found by Altmüller (16) in his thesis. Based on this finding, this paper considers the measurement of steering more reliable than the

Figure 9 SRR at each fatigue level (KSS) using the optimal threshold of 6 degrees.
measurement of lane position for monitoring fatigued driving. Finally, all of these optimal
measurement values for SDLP or SRR were examined by evaluating driving performance under
different fatigue levels. The results all demonstrated that both of these performance measures
indicated higher impairment when the driver’s fatigue level increased, which is consistent with the
conclusion by Yan (25). This finding also proved that the methods used in this study are feasible.

The field driving test conducted in this study could overcome the limitation of driving
simulator studies regarding the data accuracy; however, the raw data filtering criterion used may
influence the sensitivity analysis results. Another shortcoming of this study is that all these
sensitivity analyses are based on the assumption that there exists a linear correlation between
fatigue level and driving performance regarding the SDLP and SRR. Fortunately, the driving
performance was confirmed at each fatigue level (KSS), showing a consistent variation trend with
other studies. In addition, the effect of other demographic factors like gender, age, etc. are not
considered in this study. The last but not least important limitation of this study is that fatigued
driving accidents are more severe when they involve trucks and coaches (which are driven by
commercial drivers). However, due to limited funds and a lack of available participants who are
commercial truck and bus drivers, this study was based on data from professional taxi drivers. The
methods used in this study can be a reference to conduct a sensitive analysis for truck or bus drivers
in the future.

The sensitivity analysis regarding driving performance explored the optimal parameter
value. The results of this study could be used as a reference for future fatigued driving studies,
which could improve the accuracy of fatigue monitoring. Meanwhile, based on the results of this
study, if the optimal measurement parameter value could be obtained after data training for each
driver, the fatigue level of each could be effectively estimated. The maximum coefficient results
for each participant could enhance the confidence by using the objective driving performance
measurement to monitor driver fatigue. On the other hand, if the results of these tests could find
one unified parameter value that has a reliable coefficient with the fatigue level, then the findings
of this study could be an important reference for further fatigued driving performance studies or
for the development of fatigue monitoring devices.

ACKNOWLEDGEMENT

This study is supported by the National Nature Science Foundation of China (51178364) and
National Key Projects in the Science & Technology of China (2014BAG01B03). The authors
would like to thank the professional drivers for participating in the experiment, and the researchers
and students at Wuhan University of Technology for their technical assistance.

REFERENCES

Drowsiness Monitoring System. Publication FMCSA-RRR-12-008. Federal Motor Carrier
2. Makeig, Scott and T. P. Jung, Tonic, Phasic, and Transient EEG Correlates of Auditory
pp. 15–25.
3. Lin, C. T., K. C. Huang, et al. Tonic and Phasic EEG and Behavioral Changes Induced By


