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# Effect of Secondary Tasks in Touchscreen In-Vehicle Information System Operation on Driving Distraction

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## ABSTRACT

With the rapid development of the automotive industry and the advancement of mobile communication technology, In-Vehicle Information System shifted from traditional button to touchscreen. However, while enriching the drivers' driving experience, there are also certain potential driving distractions when operating touchscreen IVIS during the driving process. This study takes the operation of touchscreen IVIS by the driver as secondary driving task, and designs a simulated driving experiment to explore the impact of the operation of secondary tasks on driving safety from driving performance, secondary task performance and EEG. Research has shown that low load operation tasks can easily cause drivers to be distracted, while high load operation tasks can affect drivers' judgment ability and occupy too much action resources. And when the difficulty level increases, drivers develop a compensation mechanism to complete secondary tasks through self-regulation.

**Keywords:** Driving distraction, Touchscreen in-vehicle information system, Secondary tasks, Driving performance, EEG

## INTRODUCTION

In recent years, with the transformation of the automotive industry and the development of intelligence, increasingly intelligent connected vehicles have emerged in the public's view and their demand is showing a growing trend (McKinsey). In order to quickly respond to market demand, car enterprises have increased their research and development efforts on the key aspect of In-Vehicle Information System (IVIS) in intelligent connected vehicles (Kim et al., 2016), aiming to improve the driver experience and Intellectualization the basic functions of the car. Therefore, IVIS is increasingly developing towards complexity and large screens, and is transitioning from traditional button based IVIS to touch screen based IVIS. However, while enriching the drivers' driving experience, interactive touchscreen IVIS poses certain driving distraction.

Touchscreen IVIS blindly reduces mechanical buttons and integrates button functions into various menus in the interactive interface, which also increases the complexity of driver operations and leads to driving distraction. When using touchscreen IVIS, a large number of touch controls are required, such as radio frequency modulation, navigation settings, and music playback (Gupte and Askhedkar, 2018, Marinkov et al., 2022), which can distract drivers and lead to traffic accidents (Zahabi, 2017). According to official media reports, in 2017, more than 3 million traffic accidents occurred due to driver distraction, accounting for almost half of the total traffic accidents. Among them, 36% of traffic accidents were caused by drivers actively operating secondary tasks (Kenneth et al., 2008), and distraction caused by operating secondary tasks has become an important cause of traffic safety accidents. Therefore, it is urgent to study the effect of secondary tasks in touchscreen IVIS operation on Driving distraction.

At present, the indicators of driving safety mainly focus on driving performance, secondary task performance and EEG signal. In terms of driving performance indicators, they mainly include steering rate, steering angle speed, lateral vehicle movement, lane lateral deviation standard deviation, longitudinal acceleration standard deviation, and other indicators (Kim and Yang, 2018, Tarabay and AbouZeid, 2018a). In terms of secondary task performance indicators, secondary task response time and secondary task accuracy are widely used, and the use of IVIS can reduce the drivers' response ability (Yan et al., 2015). In terms of EEG indicators, they are commonly used to analyze driving safety issues (Chung et al., 2001), and they are found that as the difficulty of driving tasks increases $\beta$ enhanced wave activity, $\alpha$ weakened wave activity (Smith et al., 2001).

Therefore, in order to make car enterprises pay attention to the importance of touchscreen IVIS interaction design while meeting user needs, this paper focuses on the effect of touchscreen IVIS operation on driving distraction. Firstly, design a simulation experiment on the difficulty of three driving operations under touch interaction state. Secondly, process and analyze data on driving performance indicators, reaction indicators, and EEG signal indicators. Finally, the relationship between the difficulty of touch interaction tasks and the driver's driving behavior was obtained. This study aims to improve the safety and convenience of touchscreen IVIS, while also providing development direction for car enterprises in presenting and designing information on touchscreen IVIS, and helping them have more competitive advantages in the market.

## Method

### Participant

30 participants aged between 23 and 60 were recruited from the surrounding com-munity, including 7 females and 23 males, as shown in the Table 1. All participants are in good physical condition, have sufficient sleep, and need to wash their hair before the experiment to ensure that their scalp and hair are dry before starting the experiment.

**Table 1.** Age distribution and proportion of subjects.

| age distribution | number | proportion |
|---|---|---|
| 20-29 | 11 | 36.67% |
| 30–39 | 14 | 46.67% |
| 40–49 | 4 | 13.33% |
| over 50 | 1 | 3.33% |

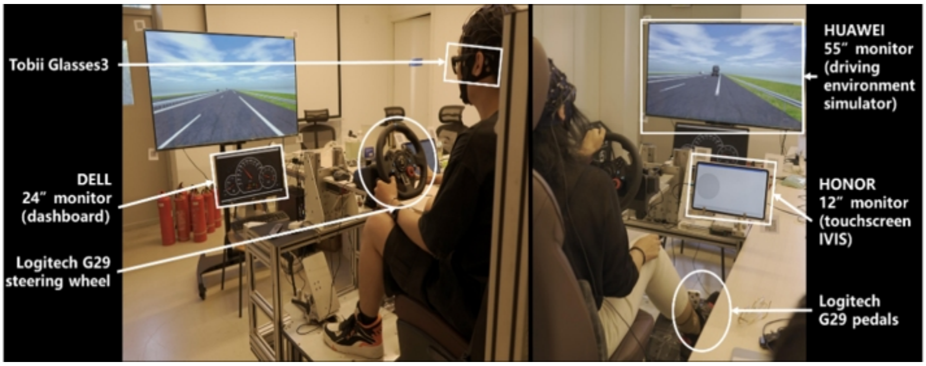



**Figure 1:** Experiment apparatus.

**Apparatus and Driving Environment**

This thesis uses a simulated driving experiment, and the equipment of the experiment is divided into two parts, which are the driving simulation system and the data acquisition system, as shown in Figure 1. The main equipment of the driving simulation system consists of a Logitech G29 steering wheel and foot pedals, a HUAWEI 55″ monitor, a Dell 24″ monitor, and an HONOR 12″ Android pad. The data acquisition system is mainly divided into collecting driving performance data and EEG signal data. And the experimental scenario is a two-way four lane fully enclosed road simulated using SCANeR Studio 2021, with a flat road surface and clear weather.

**Experimental Design**

A typical dual-task design was chosen for the experiment type. The primary task was a simulated driving task, which required the driver to drive in a straight line in the right lane on a city road and to control the speed at 40-60km/h to perform a normal following driving task. The secondary task is the operating task, which requires the driver to perform corresponding gestures (drag / click) on the touchscreen IVIS according to voice instructions, as shown in Figure 2. During the driver's driving process, the touchscreen IVIS of the car issued specific instructions, namely "Please drag the button to the other side" and "Please click the central button", and the subjects completed the task according to the instructions. The task was divided into three difficulty levels, from easy to difficult, as shown in Table 2, and the total duration of the experiment was 6 minutes.

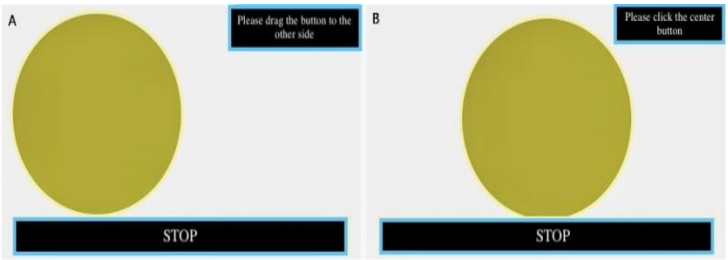



**Figure 2**: Operation distraction experiment interface (left: dragging button operation interface; right: clicking button operation interface).

**Table 2**. Operation distraction difficulty parameter setting table.

| Operation secondary task difficulty | Command release interval (s) | Hit judgment time limit (s) | Operation frequency (times/min) |
|---|---|---|---|
| 1 | 2 | 2 | 15 |
| 2 | 1 | 2 | 20 |
| 3 | 0.5 | 0.5 | 30 |

### Procedure

The experimental process includes three parts: experimental preparation, training stage, and formal experiment, with the specific steps as follows.

Experimental preparation. Introduce the purpose and content of the experiment to the participants, and wear relevant experimental equipment.

Training stage. Participants are trained to familiarize themselves with experimental tasks and equipment.

Formal experiment. The subjects completed the secondary task while driving at a speed of 40–60 km/h. Among them, take a 1-minute break between tasks at different difficulty levels.

### Dependent Variables

The dependent variables in this study can be divided into driving performance, secondary task performance and EEG signals. Driving performance indicators are divided into horizontal and vertical: horizontal indicators are the standard deviation of vehicle lateral position (SDLP) and steering wheel angle standard deviation (SASTD) (average, standard deviation, 95% confidence interval). The SDLP and SASTD reflect the driver's lane-keeping ability and visually represent the driver's ability to maneuver the vehicle laterally. Vertical indicators are the standard deviation of acceleration (ASTD) (average, standard deviation, 95% confidence interval). The ASTD is the parameter that most directly reflects the state of the vehicle movement and is closely related to driving efficiency and safety. The two secondary task performance indicators were secondary task reaction and secondary task correct rate. Secondary task response time is the period between a stimulus's presentation and a reaction's onset. The secondary task correct rate is the degree to which the driver is correct in completing the secondary task and reflects.

They reflect the speed of the driver's reaction to a secondary task scenario and how well the driver reacts to the operational task. The EEG signal indicators were beta and theta. They are often used as indicators to identify distracted and fatigued drivers.

### Performance of Driving and Secondary Tasks Data Pre-Processing

The data are obtained from the simulated driver. During the experiment, changes in the environment, the operational stability of the experimental equipment, and driver operation errors may cause data anomalies. Therefore, the outliers in the experimental data need to be removed before further research is conducted. Comparing each method of handling outliers, the Pauta criterion method ($3\sigma$) was selected as the solution for managing outliers in experimental data. This method mainly processes driving performance indicators and secondary task reaction times. Secondary task correctness requires manual rejection of abnormal user data.

### EEG Pre-Processing

Because EEG signals are susceptible to environmental interference, randomness, low signal-to-noise ratio, instability, and nonlinearity, they are prone to artifacts. Usually, common EEG signal artifacts and interferences include ocular artifacts, ECG artifacts, EMG artifacts, cardiac artifacts, and power frequency interference, so it is necessary to pre-process the EEG signal before analysis. The following are the steps of EEG signal processing for artifacts and interferences: Firstly, delete those subjects who did not achieve complete recording by the naked eye and those whose data were misrepresented due to the movement of the EEG signal collector caused. Determine the channel locations, and the sampling rate for this experiment is still 500 Hz. The next step is to filter the data. For the presence of power frequency interference, a 50 Hz notch filter can be used to filter it out. A 1 Hz high-pass filter and a 40 Hz low-pass filter are used. The EEG data recorded throughout the experiment is segmented according to the time of the task. After segmentation, independent component analysis (ICA) was performed to eliminate oculomotor interference and EMG artifacts. The frequency structure of the signal is decomposed using the fast Fourier transform, using a Hanning window with an overlap of 50%. The power values of each band are calculated in the ranges of theta (4 to 7.5 Hz) and beta (14 to 30 Hz).

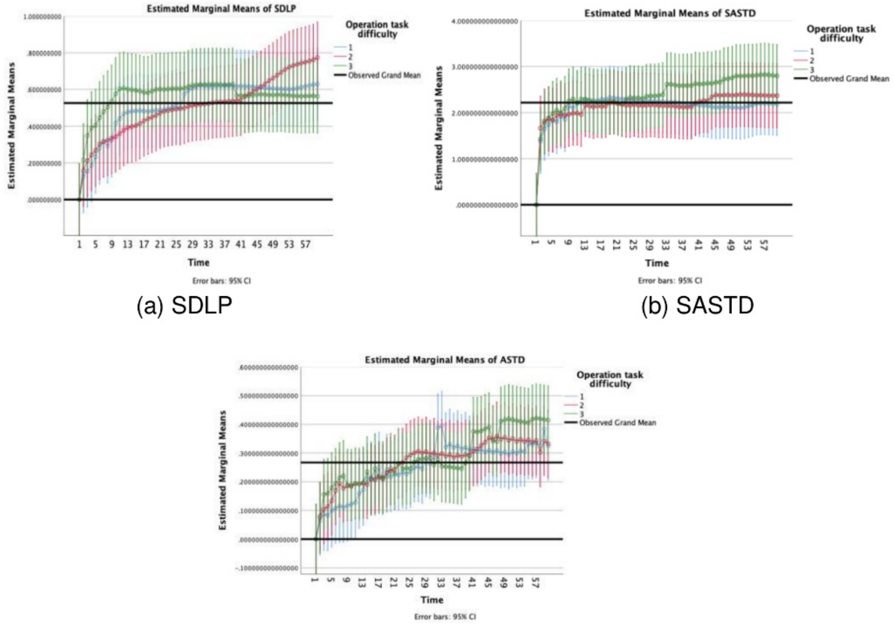
## Results

### Driving Performance

A one-way ANOVA was first conducted on these indicators to confirm that difficulty levels of secondary tasks would affect these indicators. If there is a significant effect, then the LSD method is further used to determine whether there is a significant difference between operation tasks of different difficulty levels. Table 3 shows the mean, standard deviation and 95% confidence interval of the driver's driving performance in completing three different difficulty levels of operation and the ANOVA results. Figure 3 offers the driving performance results.

**Table 3.** Driving performance result.

| Indicator | Level of Difficulty | Average | Standard deviation | 95% confidence interval | P |
|---|---|---|---|---|---|
| SDLP | 1 | 0.52 | 0.47 | 0.49-0.54 | 0.01 |
| | 2 | 0.51 | 0.49 | 0.48-0.53 | |
| | 3 | 0.56 | 0.62 | 0.53-0.59 | |
| SASTD | 1 | 2.12 | 1.97 | 2.02-2.21 | 0.04 |
| | 2 | 2.14 | 1.76 | 2.06-2.23 | |
| | 3 | 2.4 | 1.88 | 2.31-2.49 | |
| ASTD | 1 | 0.25 | 0.32 | 0.23-0.27 | 0.016 |
| | 2 | 0.27 | 0.34 | 0.25-0.28 | |
| | 3 | 0.28 | 0.3 | 0.27-0.30 | |




(a) SDLP (b) SASTD

(c) ASTD

**Figure 3:** The result of driving performance.

The results of the one-way ANOVA revealed a significant difference in the standard deviation of lane lateral position by different levels of the operational task ($p = 0.01 < 0.05$). A post hoc test LSD method obtained that there was a significant difference between difficulty one and three ($P = 0.02 < 0.05$), a significant difference between difficulty two and three ($P = 0.005 < 0.05$), and no significant difference between difficulty one and two ($P = 0.628 > 0.05$). A one-way ANOVA on the steering wheel corner standard deviation yielded a significant effect of different levels of touch interaction operations on the steering wheel corner standard deviation ($P = 0.004 < 0.05$), a significant difference between difficulty one and three ($P = 0 < 0.05$), a significant difference between difficulty two and three ($P = 0 < 0.05$), and no significant difference between difficulty one and two ($P = 0.696 > 0.05$). A one-way ANOVA on the standard deviation of longitudinal acceleration yielded that the secondary task difficulty level of the operation would have a significant difference in the standard deviation of longitudinal acceleration ($P = 0.016 < 0.05$). Further, it was obtained that there was a significant difference between difficulty one and three ($P = 0.003 < 0.05$), no significant difference between difficulty one and two ($P = 0.168 > 0.05$), and no significant difference between difficulty two and three ($P = 0.110 > 0.05$).

**Secondary Task Performance**

A one-way ANOVA yielded a significant difference in secondary task reaction time by the difficulty level of the touch interaction operation secondary task ($p = 0 < 0.05$). The LSD method delivered significant differences between difficulty one and difficulty two ($P = 0.005 < 0.05$), difficulty one and difficulty three ($P = 0 < 0.05$), and difficulty two and difficulty three ($P = 0.001 < 0.05$). An ANOVA test was performed on the secondary correctness, and it was obtained that the difficulty level of the touch interaction operation significantly affected the secondary task correctness ($P = 0.004 < 0.05$). The LSD got that there was no significant difference between difficulty one and difficulty two ($P = 0.644 > 0.05$); there was a significant difference between difficulty one and difficulty three ($P = 0.008 < 0.05$) and between difficulty two and difficulty three. ($P = 0.002 < 0.05$). Table 4 shows the mean, standard deviation and 95% confidence interval of the driver's secondary task performance in completing three different difficulty levels of operation and the ANOVA results. Figure 4 offers the secondary task performance results.

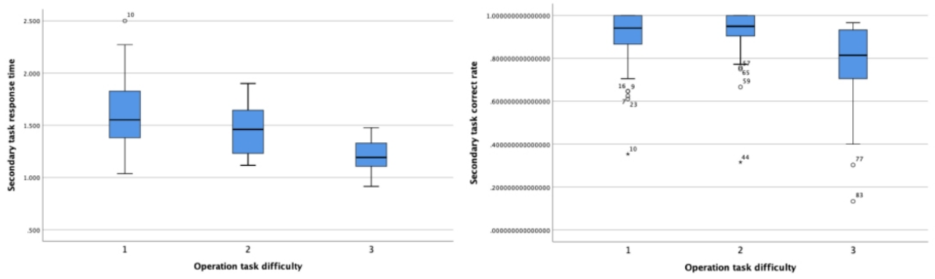
**EEG**

The Shapiro-Wilk test was performed on the power of $\theta$ and $\beta$ at the three operational secondary task levels, and it was determined that there was no normality in either of the two bands of the EEG signal ($P < 0.05$). The independent samples Kruskal-Wallis test was then performed for nonparametric analysis of both waves. Table 5 shows the mean, standard deviation and 95% confidence interval of the driver's EEG in completing three different difficulty levels of operation and the ANOVA results. Figure 5 offers the EEG results.

The results showed that operational secondary tasks of difficulty levels were significantly different for $\beta$ ($P = 0.011 < 0.05$) and also

**Table 4.** Secondary task performance result.

| Indicator | Level of Difficulty | Average | Standard deviation | 95% confidence interval | P |
|---|---|---|---|---|---|
| Secondary task response time | 1 | 1.61 | 0.55 | 1.56-1.66 | 0.00 |
| | 2 | 1.44 | 0.39 | 1.41-1.47 | |
| | 3 | 1.20 | 0.22 | 1.18-1.22 | |
| Secondary task correct rate | 1 | 0.89 | 0.16 | 0.83-0.94 | 0.004 |
| | 2 | 0.91 | 0.14 | 0.86-0.96 | |
| | 3 | 0.77 | 0.20 | 0.70-0.85 | |

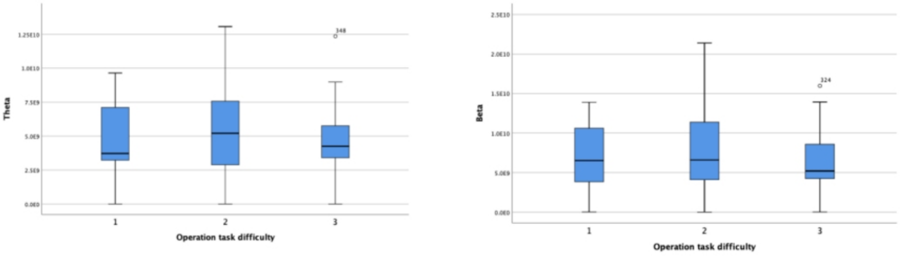



(a)Secondary task response time (b) Secondary task correct rate

**Figure 4**: The result of secondary task performance.

**Table 5.** EEG data result.

| Indicator | Level of Difficulty | Average | Standard deviation | 95% confidence interval | P |
|---|---|---|---|---|---|
| $\theta$ | 1 | 4.53 | 0.23 | 4.06-4.99 | 0.011 |
| $*10^9$ | 2 | 5.53 | 0.29 | 4.95-6.12 | |
| $(\mu v^2)$ | 3 | 4.49 | 0.21 | 4.08-4.91 | |
| $\beta$ | 1 | 6.78 | 0.36 | 6.06-7.50 | 0.044 |
| $*10^9$ | 2 | 7.50 | 0.42 | 6.67-8.33 | |
| $(\mu v^2)$ | 3 | 5.96 | 0.32 | 5.33-6.59 | |




(a) $\theta$ (b) $\beta$

**Figure 5**: The result of EEG.

for $\theta$ (P = 0.044<0.05). Further analysis yielded that $\theta$ was significantly different between difficulty one and difficulty two operational secondary tasks (P = 0.022<0.05), difficulty two and difficulty three operational secondary tasks (P = 0.044<0.05), and not at difficulty one and difficulty three (P = 0.785>0.05). $\beta$ was significantly different only at difficulty two and difficulty three (P = 0.003< 0.05), and no significant differences existed in all other levels (P>0.05).

## DISCUSSION AND CONCLUSION

This study investigated the effects of three difficult operational secondary tasks on driving performance, secondary task performance, and EEG.

Regarding driving performance indicators, there was no significant difference in the standard deviation of lane position, steering wheel angle and acceleration when the driver completed the touch operation task between difficulties one and two. On the contrary, there was a significant increase in these indicators in difficulty level three. Although there was no significant difference between difficulty levels one and two in the early stage, in the second half of the experiment, the standard deviation of lane lateral position increased, the standard deviation of steering wheel angle also increased, and the driver's ability to control the car weakened. This means that when there is a secondary task load, although, in the short term, the driver does not experience much change in lane control. But when the duration becomes longer, the adverse effects of operating the secondary task become more severe, neglecting the main task of driving and thus reducing the ability to control the vehicle. The insignificant difference in the pre-task between difficulty one and two can be explained by the compensatory concept of driver presence. The driver's additional operational resources are used to cope with the increased difficulty of the secondary task and instinctively keep regulating the time spent on the secondary task engagement. The driver's compensatory adjustment behavior manifests as small changes in the vehicle's longitudinal and lateral control metrics (standard deviation of lane position lateral excursions, etc.). However, as demonstrated in much of the literature, the resources available to control the driving task may be depleted over time, leading to impaired driving performance (Tarabay and Abou-Zeid, 2018b).

In terms of the secondary task performance, the driver's secondary task response time showed a decrease as the operation difficulty increased. However, the operation task difficulty two had the highest secondary task correctness, followed by difficulty one, and finally, difficulty three, and the secondary task correctness rate for difficulty three was much lower than that of difficulty one and two. It can be inferred from the results that the download of difficulty level one makes the driver less attentive and alert. In contrast, the high burden of difficulty level three makes the driver overly distracted and unable to process information, so the driver pays attention to the primary mission. Regarding the highest correctness in level two, it can be concluded that the driver is trying to allocate their cognitive resources or energy. This confirms the self-regulatory behavior explored in the driving performance indicators above, inferring that the driver adopts a compensatory mechanism.

The theta band is often used to judge whether a driver is distracted (Lin et al., 2008). Theta band power is highest at difficult two due to the increased brain workload and the additional operational resources the driver needs to take up to complete the secondary task compared to the difficult one. The decrease in theta wave power for rank three is caused by the driver focusing on the primary driving task.

Compared to the tasks of operation levels one and two, the beta power increases, and the driver is more focused when completing difficulty two.

When reaching operation task level three, the beta power decreases. The driver is too mentally stressed because the brain's cognitive resources occupied by the operation distraction task are more than the driver can bear. The driver needs to spend more time digesting and processing the information.

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## REFERENCES

Chung, B. J., RESEARCHER, C., CENTER, H., CORPORATION, K. H., Keumto-Dong & Sujeong (2001), "Limit Length Evaluation of Tangent on Freeway according to Driver's Physiological Response", TRB ID, 01–3166.

Gupte, S. & Askhedkar, A. R. (2018) An Innovative Wireless Design for a Car Infotainment System. 2018 Second International Conference on Intelligent Computing and Control Systems (ICICCS). Madurai, India.

Kenneth, M., Jæger, M. G., Skov, M. B. & Thomassen, N. G. (2008), "You can touch, but you can't look: interacting with in-vehicle systems", in Annual SIGCHI conference On Human factors in computing systems, pp.

Kim, J. R., Shin, S., Choi, S. & Yoo, Y. (2016), "Multimodal Interaction on Automultiscopic Content with Mobile Surface Haptics", Etri Journal, Vol. 38 No. 6, pp. 1085–1094.

Kim, S. L. & Yang, J. H. (2018), "Evaluation of the Effects of Driver Distraction Part 1: Based on Simulator Experiments", in 2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC), pp.

Lin, C. T., Lin, H. Z., Chiu, T. W., Chao, C. F. & KO, L. W. (2008), "Distraction-related EEG dynamics in virtual reality driving simulation", in IEEE International Symposium on Circuits & Systems.

Marinkov, S., Mihajlovic, R., Kenjic, D. & Antic, M. (2022), "One Solu-tion of a Communication Manager for Connecting Advanced Driver Assistance Sys-tems with In-Vehicle Infotainment Systems", in 45th Jubilee International Conven-tion on Information, Communication and Electronic Technology, MIPRO 2022, May 23, 2022 - May 27, 2022, Institute of Electrical and Electronics Engineers Inc., Opatija, Croatia, pp. 1399–1403.

Mckinsey McKinsey's electric vehicle index [EB/OL]. (2019-10-31) [2021-05-01].

Smith, M. E., Gevins, A., Brown, H., Karnik, A. & Du, R. (2001), "Monitor-ing Task Loading with Multivariate EEG Measures during Complex Forms of Human-Computer Interaction", Human Factors, Vol. 43.

Tarabay, R. & Abou-Zeid, M. (2018a), "Assessing the effects of auditory-vocal distraction on driving performance and physiological measures using a driving simulator", Transportation Research Part F Traffic Psychology and Behaviour, Vol. 58 No. OCT., pp. 351–364.

Tarabay, R. & Abou-Zeid, M. (2018b), "Assessing the effects of auditory-vocal distraction on driving performance and physiological measures using a driving simulator", Transportation Research Part F Traffic Psychology and Behaviour, Vol. 58 No. OCT., pp. 351–364.

Yan, W., Wong, S. C., Li, Y. C., Sze, N. N. & Yan, X. (2015), "Young driver distraction by text messaging: A comparison of the effects of reading and typing text messages in Chinese versus English", Transportation Research Part F: Psychology & Behaviour, Vol. 3187–98.

Zahabi, M. (2017), "Analysis and Redesign of Police Vehicle Mobile Computer Terminal for Minimizing Officer Driving Distraction."