The Effect of Static Magnetic Field Exposure to Drivers Cognitive Ability

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Abstract—**Distraction driving is a key traffic and public safety issue; this paper examines the cognitive ability of drivers in the presence of static magnetic field (SMF) in electric vehicles (EVs). Lane Change Test (LCT) was adopted for the distraction driving evaluation and the driver's Electroencephalography (EEG) patterns during the experiments were recorded. Paired *t*-test was used to examine the LCT score and to examine the EEG data for correlating the cognitive ability. Statistical results have indicated that there is no considerable effect observed in the drivers' cognition by LCT, while there is a significant changes in the EEG with the significant level of $P<0.05$.**

Keywords— static magnetic field (SMF); electric vehicles; lane change test (LCT); distraction driving

I. INTRODUCTION

Distraction driving refers to the attention of the drivers is distracted away from the road, which has been concluded as the contributing factor that leads to why most of the collisions and near misses occur [1]. The inducement for distraction driving comes from four factors — visual, auditory, bio-mechanical, and cognitive factors [2]; some of the aspects may be affected by electromagnetic fields (EMFs). The brain as the central nervous organ of human beings, is responsible for emotions, thinking, and body movements [3], all of which are determined by neural signals transmitted at the millivolt-level between neurons [4]. Previous studies have verified that the EMF, or specifically static magnetic field (SMF), would affect human neuro-psychology in some aspects, *e.g.* short-term memory and attention [5], eye–hand coordination and the visual function [6], temporary psychomotor and visuosensory behaviors [7].

With the large-scale adoption of the electric vehicles (EVs), drivers and passengers are exposed to long-term EMF or/and SMF inside the vehicles. A survey of SMFs from existing EVs have been conducted [8]–[14]; SMFs measured inside EVs under driving mode are generally larger [8], [9], [12], [13]. Although many studies indicated that the EMFs measured or estimated from driving EVs are in compliance with the related human exposure standards [8], [9], [12], [14], some studies [10], [11] revealed that the EMFs may exceed the reference level prescribed in the international recommendations [15]–[17]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is considered for the protection of human safety from preventing the potential hazards, including the heating effects to body tissues [15] and the electro-stimulations to the transient nervous system responses [17]. SMFs could result in distraction driving by affecting the cognition ability or causing transient nervous system responses, leading to a threat of traffic safety.

The linkage between the human neuro activities and the cognitive activity has been established [18]; the hypothesis is that the induced EMFs could adversely affect human cognition, leading to distraction driving performances for the EVs drivers are yet to be determined.

In this pilot study, the potential effect of SMFs to distraction driving is examined with Lane Change Test (LCT). The EEGs of the drivers were also recorded during the experiment for the indication of their brain activities for a correlation with the LCT.

II. METHODOLOGY

A. Lane Change Test

Lane Change Test (LCT), designed for distraction driving evaluation[19], was applied in this study. It requires subjects to keep driving the car in the lane central along a normative path, the actual driving path by the subjects was recorded and compared to the normative path. Their distraction driving performance is quantified by calculating the mean lateral deviation between the actual path driven by the driver and the normative path.

In the experiment, the driving simulator including a computer with driving simulation software named OpenDS 4.0, and a steering wheel, were formed in compliance with the requirements in [19], on which participants were required to drive.

The test track of a 3 km straight three-lane road with 18 lane-changing signs was provided, as illustrated in Fig 1(a). Each sign is about 150 meters apart at two sides of the road, and is popped 40 meters before the car in order to indicate to which lane the participant should turn. Subjects were required to implement lane-change manoeuvres while maintaining a constant speed of 60 km/hour. The whole test lasts for about 3 minutes.

Mean lateral deviation is calculated as the difference of the area between the actual path and the reference path, and then divided by the total driving length.

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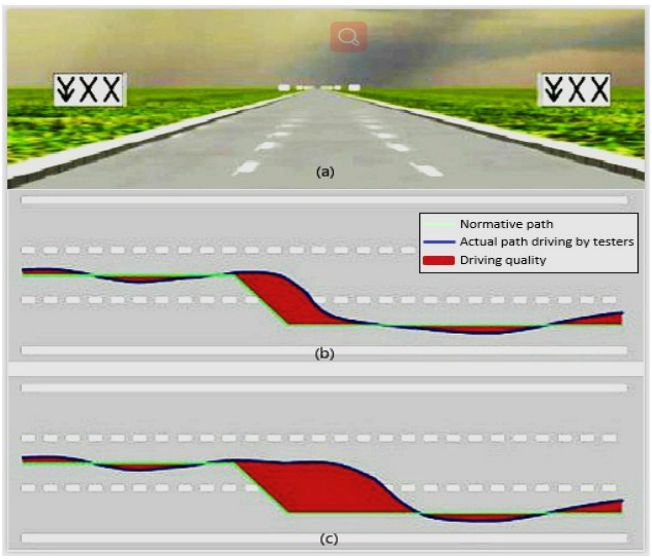

Fig. 1. (a) illustrates the sereen view of LCT. (b), (c) illustrates the difference in area (red) between the normative path (green line) and actual path(blue line) for a quick perception adapted from [19]. The area in (b) is smaller than that in (c), which demostrates the performance of lateral positioning in (b) is greater than that in (c).

B. Subject Selection

17 students from the City University of Hong Kong volunteered in the experiment, in accordance with the approval of human ethics review by the Human Subjects Ethics Sub-Committee of City University of Hong Kong (H000622). Previous driving experience was not compulsory. They were asked to have enough sleep the day before the experiment and to avoid any substances affecting mental health, *e.g.* psychotropic drugs, sedatives or alcohol, 24 hours before the experiment.

All of the participants were fully informed of the background of the experiment, and they then signed a declaration form in accordance with their sufficient understanding of the content and risks of the experiment, as is common practice with human subjects.

C. Source of Exposure

Previous literature has carried out that the intensity level of SMF inside EVs are up to 300μT summarized from various types of identified sources of EVs [13]. Thus in this study, SMF with averaged intensity value of 350μT was adopted, which is 16.7% higher than the maximum value in the previous study [13] while approximate 0.1% of the limit value given in ICNIRP [16].

A two-layer solenoidal coil with a diameter of 25 cm was fabricated for generating a required SMF. Each layer consisted of 22 turns of copper wire 0.27 mm in diameter. Both layers were nested together in the same direction for the same identical level of SMF; their levels can be calculated directly by Biot-Savart Law:

$$d\vec{B} = \frac{\mu_0 NId\vec{L} \times \vec{l_r}}{4\pi r^2} \quad (1)$$

where $\mu_0 = 4\pi \times 10^{-7} H/m$. In our experimental setting up, a direct current of 1.5 A to the coil would provide the required SMF. The thermal effects of the nested layer structured coil have been considered, and it is verified that the temperature-rise with 1.5A current input only gradually raised to a maximum of 40°.

D. EEG Acquisition

EEGs were recorded throughout the experiment with eego™ sports system launched by ANT-neuro [20]. In accordance with some previous outcomes, the memory and the decision making functions are mainly charged by the area of the frontal lobe of human brain [21]–[23], thus the same electrode locations, the same as them selected in [23], was adopted in this study, as follows.

Seven electrodes - F3, F4, F7, F8, Fz, Pz and Cz in line with the International 10/20 Standard [24] were used for recording subjects' EEGs. GND and Cpz electrodes were set as ground point and reference level, respectively. Electric gel was injected between the electrode and scalp to reduce the impedance for ensuring EEGs collection. A frequency band between 0.3 Hz to 30 Hz was adopted for filtering noises. Fast Fourier transformation (FFT) was applied to the captured EEGs in order to convert them to the power spectrum density (PSD) in different brain wave sub-bands with ASA Lab™ [25], and the classified PSD data were accordingly analyzed with statistical methods.

In this experiment, Beta, Alpha, Theta and Delta waves were concerned in measurement. Gamma wave, which only exists under unconventional brain activities, was discarded.

E. Experiment Procedure

17 volunteers were invited in an EMC anechoic chamber in the Applied Electromagnetic Laboratory of the City University of Hong Kong, for an isolated electromagnetic controlled environment. The experiment was intended to be a single-blind test, which means that the subjects did not know when the exposure was present. Subjects were required to wear electrode caps after arriving at the lab, then took few minutes rest and got briefing of the whole experiment. They were then required to sign a declaration for consent for the experiment. Subjects were asked to perform LCT; they performed LCT twice with or without the 350μT SMF exposure in random order.

III. Results and Discussion

In this experiment, the statistical method of a paired *t*-test was applied for analyzing subjects' distraction driving performance changes, and PSD data of EEGs, with a confidence interval of 95% ($P < 0.05$).

Table 1 illustrates all subjects' overall performance in LCT. P-value of mean lateral deviation with and without SMF is 0.352, which indicates that the impact of SMF to the distraction driving performance is not significant. There are 6 subjects (35.3%) that scored even lower for their distraction

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driving when under SMF than under no SMF, which indicates that they concentrated more driving under SMF. For the percentage of their distraction driving score changes, the percentage of 3 subjects is less than 10%, the percentage of 2 subjects is between 10% and 20%, and the percentage of 1 subject is higher than 20%. 11 subjects (64.7%) scored higher when they under SMF exposure, which indicates that they are more distracted when driving under the exposure. Among them, for the percentage of their driving scoring changes, the percentages of 5 subjects are less than 10%; the percentages of 2 are between 10% and 20%; percentages of 2 are between 20% and 30%; the percentage of 1 is between 30% and 40%, and the percentage of 1 is higher than 40%.

TABLE I. TABLE OF OVERALL PERFORMANCE IN LCT

No.	Score without SMF(m)	Score with SMF (m)	Differences between two exposure	Percentage of Change
1	0.7875	0.8507	0.0632	8%
2	0.908	1.1161	0.2082	23%
3	0.9752	0.5881	-0.387	-40%
4	1.4474	1.1946	-0.2527	-17%
5	0.5611	0.7356	0.1745	31%
6	1.1007	1.186	0.0853	8%
7	0.5874	0.6198	0.0324	6%
8	0.7578	0.7143	-0.0435	-6%
9	1.0149	2.313	1.2982	128%
10	0.4433	0.4644	0.0211	5%
11	1.0799	0.9376	-0.1423	-13%
12	0.5667	0.6441	0.0774	14%
13	0.8337	0.819	-0.0147	-2%
14	0.6736	0.7307	0.0571	8%
15	1.0312	1.1733	0.1421	14%
16	0.5823	0.7084	0.1261	22%
17	0.7649	0.6981	-0.0669	-9%
***P*-value**	0.352			

Table 2 illustrates the results of paired *t*-test of averaged PSD of EEGs measured during LCT test. PSD data of 7 electrodes under different SMF exposure conditions are listed in the table. Noted that delta sub-band PSD data in the table is 0, for it is only obvious when humans fall asleep, thus, the P-value of Delta wave is not applicable. P-values of Theta sub-band at F3, F4, F8, Cz and Pz, and that of Alpha sub-band at F4, F7, F8, Cz are lower than 0.05 (P <0.05), as underlined in table II, demonstrating that the significant changes are observed mainly in Theta and Alpha sub-bands of frontal lobe. No significance observed in Beta sub-bands due to either of the *P*-value at each electrode point is lower than 0.05 (P <0.05).

This pilot study investigates the effect of SMF induced within driving EVs to drivers' distraction driving. Their electroencephalographs (EEGs), which were captured for analyzing their brain activities, are for correlating their brain activity. According to the results above, a summary could be concluded that the given SMF would not give significant effect on the subjects' distraction driving, which indicates that their driving performance may not be notably affected by the 350 μT SMF induced by EVs. On the other hand, 64.7% of the subjects scored worse after being exposed under the SMF, which could be deemed as a trend that the public may be more likely affected by the SMF by EVs. The trend, in any further study, need to be continuously investigated with a larger subject population and multiple repetition.

TABLE II. RESULTS OF PAIRED T TEST OF AVERAGED PSD OF EEGS MEASURED DURING LCT TEST

Sub-band	Con.	F7	F3	F4	F8	Cz	Pz
Delta	***No SMF***	0.00E +00	0.00E +00	0.00E +00	0.00E +00	0.00E +00	0.00E +00
	SMF	0.00E +00	0.00E +00	0.00E +00	0.00E +00	0.00E +00	0.00E +00
	P	N.A	N.A	N.A	N.A	N.A	N.A
Theta	***No SMF***	2.84E +04	2.56E +04	1.38E +04	2.86E +04	9.02E +03	1.22E +04
	SMF	3.12E +04	3.47E +04	1.74E +04	4.23E +04	7.13E +03	1.87E +04
	P	1.93E -01	5.36E -04	2.86E -02	2.89E -02	6.74E -03	2.32E -04
Alpha	***No SMF***	9.23E +03	1.44E +04	5.51E +03	9.93E +03	1.95E +03	7.30E +03
	SMF	1.54E +04	1.20E +04	1.00E +04	1.83E +04	1.51E +03	4.35E +03
	P	4.15E -03	1.00E -01	4.87E -02	3.92E -04	4.30E -03	3.58E -01
Beta	***No SMF***	4.90E +02	5.46E +02	4.83E +02	4.90E +02	7.58E +01	1.24E +03
	SMF	2.30E +01	1.78E +01	1.38E +01	2.81E +01	2.34E +00	7.81E +00
	P	3.37E -01	3.34E -01	3.34E -01	3.40E -01	3.30E -01	3.33E -01

("Con." refers to "exposure condition"; "*P*" refers to the "P-value" at each electrode in each sub-band; the *P*-values less that prescribed significance level are underlined)

In this study, Theta and Alpha sub-bands were observed to be active when subjects were driving and making driving responses, while on which the most considerable changes in our study are observed. It could indicate that the Theta and Alpha waves are more likely to be affected by the SMF induced by EVs. On the other hand, the EEGs in this study are mainly recorded from electrodes in the area of frontal lobe, which has been verified responsible for emotions, problem solving, and body movement [3]. Noted that the Theta and Alpha waves are associated with wakefulness, either cognitive arousal or drowsiness[26], which are the general statuses that could be easily observed while people in daily work, therefore the reasons for the significant changes in the two bands deserve further study. What's more, a narrow area including 7 electrodes covering a small region mainly at frontal lobe area were selected in this pilot study for the exploration of the possible effects of the SMF by EVs, a larger area with more electrodes in all frontal lobe locations, or in any other lobes, should be adopted for identification of the potential effect.

IV. CONCLUSION

In this study, 17 subjects participated in the drivers cognitive ability examination, and their EEGs analyzing results were correlated to their LCT performances. It thus could be concluded that there is no considerable effect of EMF induced by EVs on the drivers' cognition, while there is a

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significant impact on their brain activity. On the other hand, with the tendency of 64.7% subjects' altered driving performance under induced SMF by EVs, it may be implied that the public might be affected, which deserves further study with larger subject population and multiple repetition.

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