PHYSIOLOGICAL EFFECT OF RUMBLE STRIPS INSTALLED ON THE HIGHWAY SHOULDER

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Abstract : Korea Highway Corporation, a South Korea government agency, installed rumble strips on 2 miles of Second Joong-Bu highway from 338.0 kilometer to 336.0 kilometer section in 2001. The purpose of installing rumble strips is to decrease the number of accidents caused by drowsy drivers. Researchers have not dealt with the estimation of rumble strip's effectiveness on the driver's alertness, and most researches have presented only the before-and-after analysis of the accidents. In this study, the effectiveness of the rumble strips on the driver's alertness was estimated by measuring the bio-signal transmitted from the driver. The bio-signal data was obtained from five experimental subjects with average driving experience of 13.4 years and average age of 31.6 years. The experimental results revealed that the alpha and theta waves as measured from the driver's head while in the rumble strip section differed from those while in non-rumbled section; 38 and 74 percent increase in alpha and theta wave value, respectively. This fact finding could mean that the driver's alertness increased from 38 percent to 74 percent while in the rumble strip section of the road. In all five trials of driving experiments on the rumble strip section, all the drivers showed the best alertness as measured by the alpha and theta waves in the first driving trial.

Key Words : physiology, rumble strips, highway, signal, EEG

1. OVERVIEW

The history of Korea highway began with the opening of Kyung-In and Kyung-Bu Highways in 1969. As of the end of 2002, there are presently 23 highway lines with a total length of 2,660 kilometers throughout Korea. Most highways are 4-lanes on each direction and are designed with the speed limit at or over 100 kilometers/hour. Currently, the speed limit for passenger vehicles are set between 100 and 110 kilometers/hour. The number of traffic accidents showed

steadily increasing trend due to extension and expansion of national highways in the past. However, since the year of 2000, it has been showing a deceasing trend due to the national efforts to improve on the safety facility, geometric configuration of the roads layout, and other safety measures targeted on frequent accident-prone areas. <Table 1> shows the classification of the traffic accidents on Korea highway by the accident types. It shows that the accident of the vehicle breaking away (drifting away) from the traffic lane to collide with surrounding objects on the side of the road numbered 1,972 incidents and accounted for 54.2% of the total. These traffic accidents can be caused by many factors, but they can be attributed mainly due to the inattentive behaviors of the drivers.

Table 1. Classification of the Traffic Accidents on Korea Highway by the Types

Classification	Total	alone	collision	rear-end	contact	car-obstacle	car-human	fire	miscellany
Number of Incidents	3,638	681	91	683	15	1,972	70	44	82

* 2001 Statistics on Highway Traffic Accidents, Korea Highway Corporation, 2002

In case of the United States, Pennsylvania Turnpike Commission reported 1%-60% reduction in the number of drift-off road accidents by installing rumble strips.
Korea Highway Corporation is a government agency responsible for the construction and maintenance of the highways in Korea, and it initiated an experimental installation of 2 kilometers rumble strips on the shoulder of the Second Joong-Bu Highway in December of 2000 in order to reduce or prevent drift-off road accidents caused by inattention of the drivers. Nevertheless, it should be pointed out that a long-term evaluation of the accidents data is needed indeed for a valid evaluation of the effectiveness of such a road safety facility. In fact, the United States spent more than a year in evaluating its effectiveness before and after the installation. Korea Highway Corporation was required of devising a method to evaluate the effectiveness of the safety facility in a relatively short time with respect to its large-scale induction. The Human Factor research team of the Transportation Research Division suggested a method to evaluate the effectiveness of road safety facilities by analyzing the change in driver's mental workloads as measured by the bio-signal transmitted from the driver.

2. Literature Review

There are several methods such as subjective assessment, observed assessment and measured assessment in obtaining the driver's mental workload. This research selected bio-signal analysis method for its objective measured values and repeatability.
Bio-signal is the term used to denote the measured change in the electric voltage, which is generated whenever a human thinks and acts. Various studies performed since the 1970's especially in the United States demonstrated that alertness of a driver can be explained by the driver's bio-signal. Kecklund and Akersted found that the alpha and theta waves in the central lobe area of the drivers increased significantly during long-distance driving in their study of 28 truck drivers. Alpha wave and theta wave are larger while in non-driving state and are known to increase when the driver gets drowsy or falls into the sleeping state.(1993, Kecklund, G.) O'Hanlon et al. investigated the change in physiological response of the drivers during long period of night driving. They found that the EEG (ElectroEncephaloGram) showed an increase in the activity of the delta and theta wave as the driving time increased. Thus, they showed that long driving can cause a driving in a drowsy state with experimental objective measurements.

Lee et al. reported that beta wave increased while the driving speed increased from safe speed of 70 kilometers/hour to average highway speed of 100-110 kilometers/hour in their study of a driver's response to an increased speed. Cristi et al. claimed that the complexity of surrounding stimuli effects the activity of the alpha wave reversely as well influencing the cognizance. As the stimuli gets larger and complex, the activity of the alpha wave, which is known to increase in easing the tension, gets decreased whereas the activity of the beta wave, which is related to alertness, increases. Brookhuis et al. asserted that a long period of driving decreased the driver's driving performance and could be shown as the increased activity of theta and alpha waves in the brain wave spectrum.(1993, Brookhuis) Akerstedt et al. reported that under-workload phenomenon during highway driving could be traced to the road section sharply curved to the right. They demonstrated that this phenomenon caused a decrease in driving performance by an investigation relating the driving performance to physiological phenomenon. Beatty et al. stated that the lowered driving performance related to lowed cognizance level, which in turn related to increased activity of theta wave.(1974, Beatty) Furthermore, Park et al. analyzed the alpha and beta waves during long highway driving experiment of over 2 hours and reported that the driver's cognizance level decreased after 60 minutes of driving with upper limit of 90 minutes.(1998, Seong-kwan Mark Lee) Additionally, Chung et al. carried out an analysis of the drivers' behavior in relation to highway design factors to be considered. They cautioned against the increased risk of drowsiness in a continuously stretched-out straight highway section as well as collecting and analyzing the beta wave activity in both right and left frontal lobes and the occipital lobe. Their analysis result demonstrated that the continuously straight road did not effect the drivers up to 30 times of the design speed.(2001, Bong-Jo Chung)

3. Rumble Strips

Rumble strips are a form of pavement with grooves and/or a raised surface level on the traffic lane and/or the shoulder of the roadway as shown in <Figure 2> and <Figure 3>. It creates a noise and vibration upon the contact with the tires of a vehicle so as to alert the drivers to a change in road conditions. The drivers can then redirect their attention to safe driving. It is known as a very effective facility to reduce or prevent drift-off accidents caused by a driving under a drowsy condition or vision impairment due to rain, fog and night driving as well as unusual weather. In the United States, this facility has undergone various tests in many states including Pennsylvania and New York and is widely used in state roads.

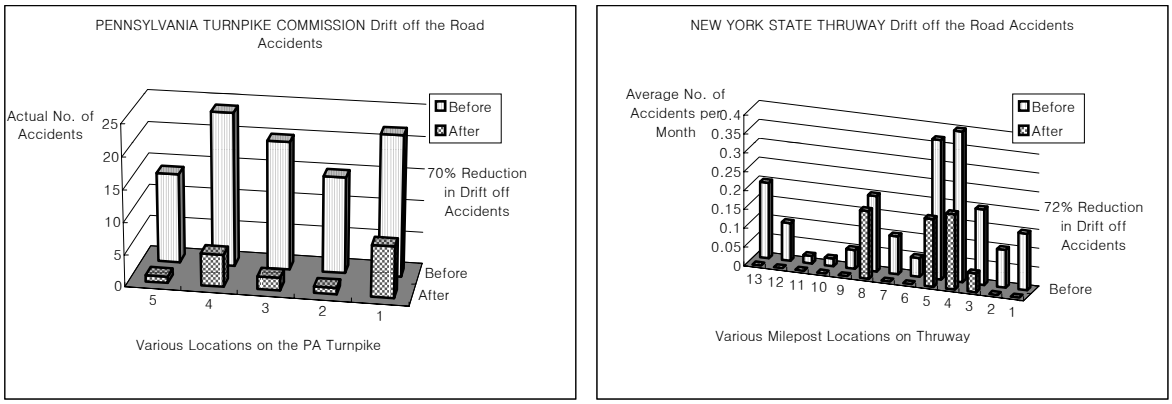

Figure 1. Effective Cases of Rumble Strip Installation (Pennsylvania, New York)
*http://www.rumblestrips.com (Massachusetts Turnpike Authority, Press Release, 1994)

Rumble strips were first experimentally installed in approximately 2 kilometers section of the Second Joong-Bu Highway between 338.0 kilometers - 336.0 kilometers location (south bound). <Figure 2> depicts the specification for the installation of the rumble strips. The installation method used a pavement cutting machine, and the installation specification was 400mm in breadth, 160-180mm in width, 300mm of the distance between centers of the grooves, and 9-15mm in depth of the groove.

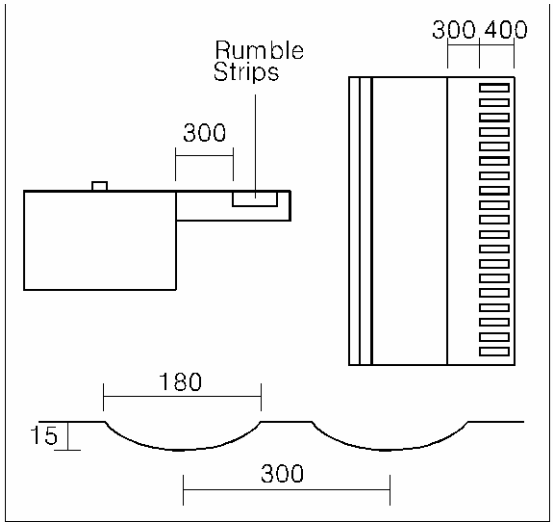

Figure 2. Installation Specification for Rumble Strips

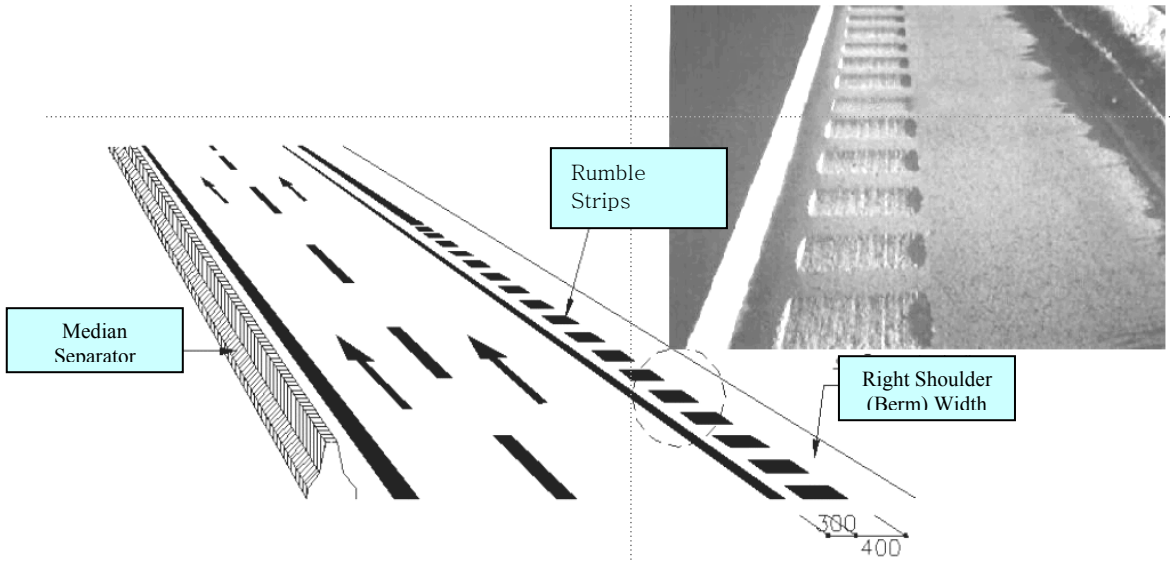

Figure 3. Installation Location and a Case Photo of Rumble Strips (Korea)

4. Field Investigation

4.1 Selection of Highway Sections for Data Collection

The selection of the experimental site for data collection regarding rumble strips was based on the following conditions, and a field investigation was carried out to ensure that no artifacts except normal driving conditions would influence the drivers.

- road section where no influence on the driver's cognizance is expected
- road section where there is no excessive road signs and there is no frequent accidents
- road section where there is no change in the number of lanes
- exclude cloudy, rainy, snowy days from the field investigation

Based on these conditions, the 2 kilometers section between 338.0 kilometers - 336.0 kilometers (south bound) of the Second Joong-Bu Highway was selected for the field investigation site of rumble strips. The regular non-rumbled highway for comparison was to be of straight road section within 1% gradient and was chosen to be around 350.0 kilometers location of the same highway. The characteristics of the field investigation sites are summarized in <Table2>. The field investigation of the rumble strips section was carried out by repetitive driving of the experimental subjects. The subjects were instructed to drift off to the rumble strips five times in one passing through driving. Thus. repetitive driving data was collected. The data were collected for one second from the time that the right (passenger) side tires contact the rumble strip to create the noise and vibration. This duration was chosen to equalize any unsuspected artifacts taking place in the highway section compared as the control. These artifacts are also removed by the filtering reprocess as well as by the experimental design aforementioned.

Table 2. Characteristics of the Field Investigation Sites

Classification	Starting point (kilometer)	Ending point (kilometer)	Speed limit (kilom-eters/h)	Road Characteristics
Regular Non-rumbled Section (control)	Second Joong-Bu Highway 360.0	Second Joong-Bu Highway 340.0	110	-2 lanes on each direction -Horizontal road shape : Linear -Vertical road shape : within 1% gradient
Rumble Stripped Section	Second Joong-Bu Highway 333.8	Second Joong-Bu Highway 333.6	-	-2 lanes on each direction (shoulder area) -Horizontal and vertical road shape : Linear, uphill/downhill, curved to the left or right

Notes) Data on the rumble strips section were collected at straight road section with low gradient.

4.2 Experimental Subjects

The formation of the experimental subjects was facilitated by applying 'Within subject composition method' to find out the differences in the experimental subjects through comparison of their behavior at rumble stripped section and at regular non-rumbled section. The five subjects in total were subjected to driving experiment at rumble stripped section and regular non-rumbled section (control) for the comparison analysis. In composing the subjects, more experienced drivers were preferred although factors such as the age, gender, and driving history were not regarded as important. The experiments were performed on a sunny weekday between 10:00-11:00 am. As shown in <Table 3>, the average age of these subjects was 31.6 years, and their average driving experience was 13.4 years. They were normally-developed and healthy adults

with no history of hospitalization or treatment due to brain disorder or heart disease. Their visions were also normal without color-blindness or color-weakness (achromatopsia). They were instructed to refrain from taking medicine, smoking, drinking coffee or alcoholic beverages and to get adequate rest before the experiment.

Table 3. Characteristics of Experimental Subjects

	age	gender	Height (cm)	Weight (kg)	Driving Experience (years)
Subject1	31	male	176	72	4
Subject2	27	female	173	53	4
Subject3	34	male	169	64	8
Subject4	36	male	170	56	10
Subject5	30	male	170	74	11
Average	31.6	-	171.6	63.8	13.4

4.3 Experimental Method and Collected Data Description

The experimental subjects had a brief orientation period in which important safety precaution and their tasks were explained. Sensors to gather the data were then attached to them. They were given enough rest period not to have any negative resistance feelings toward the testing. After the subjects were rested, they were asked whether they were ready to take the test. Upon confirming their readiness, their bio-signals were collected for over minutes during this non-driving, normal, relaxed state. These data were to serve as the base line and would be used in the Normalization analysis to avoid any individual differences (idiosyncrasies).

The experiment for data gathering was carried out by having the subjects drive their vehicle so that their right (passenger) side tires would make a contact with the rumble strips. This contact was to be repeated five times during one pass-through driving. The testing vehicle was driven around 90 kilometers/hour. From <Figure 4> to <Figure 7> depicts the photos of the testing vehicle (Driver's Response Detecting Vehicle, DBDV), the interior of the testing vehicle showing the testing equipments, and an experimental subject.

Figure 4. Experimental Vehicle

Figure 5. Interior of the Vehicle (Monitors for Bio-signal)

Figure 6. Acquisition System of Bio-signal

Figure 7. Subject Wired for an Experiment

During the experiment, the alpha and theta wave as measured from the central lobe of the central nervous system (CNS), the speed of the testing vehicle, and the surrounding environmental data were collected. The central lobe of the brain is known as the comprehensive information processing area of a human and, thus, was chosen to collect the data for an overall evaluation of the driver's cognizance level.(1980, Cooper, R.)

4.4 Analysis Method

For each brain wave frequencies, a relative power spectrum value was obtained from FFT (Fast Fourier Transform) as in (Equation 1). Then, the values of theta and alpha wave, known for their close relation to drowsiness (or alertness), were analyzed mainly. The parameters of the analysis were obtained by normalizing the values of relative power spectrum analysis (Equation 2). An imported device from the United States, Mp100 of Biopac company, was used to reduce the noise in the bio-signal generated mainly by the vibration of the testing vehicle as well as equipping the testing vehicle with vibration and shock absorbing devices. A noise filtering process to eliminate the extreme maximum and minimum values was also included in the analysis.

$$R_{power} = \frac{E_{power}}{\sum(A_{power})} \qquad \text{(Equation 1)}$$

Here, R_{power} = relative power spectrum value
E_{power} = specific power spectrum value
A_{power} = all power spectrum value

$$N_p = \frac{P_{driving}}{P_{resting}} \qquad \text{(Equation 2)}$$

Here, N_p = Normalized value
$P_{driving}$ = Bio-signal value while driving
$P_{resting}$ = Bio-signal value while resting

5. Analysis

5.1 Comparison Analysis of Rumble Stripped Highway Section and Regular non-rumbled Highway Section

The result of the comparison analysis of the average bio-signal values of all 5 experimental subjects, which were measured at rumble stripped section and regular non-rumbled section is shown in <Figure 8>. The result of the analysis showed that the alpha wave of the central lobe decreased by 0.2871 from 0.746 at regular non-rumbled section to 0.4593 at rumble stripped section. This indicates that the rumble strips increased the alertness by approximately 38% compared with regular non-rumbled section. However, this finding was not statistically significant.

The theta wave of the central lobe also exhibited a decrease in value by 0.462 from 0.6194 at regular non-rumbled section to 0.1573 at rumble stripped section. This fact also indicates that there was an increase in the alertness level at rumble stripped section compared with that at regular non-rumbled section by approximately 74%. This finding was statistically significant, and the statistical analysis result is presented in <Table 4>.

It can be inferred that the drivers experience a change in their alertness (or cognizance level) while driving into rumble stripped section from regular non-rumbled section. The significant decrease in theta wave, which is closely related to drowsiness or sleeping, further supports the effectiveness of rumble strips in increasing the alertness of the driver.

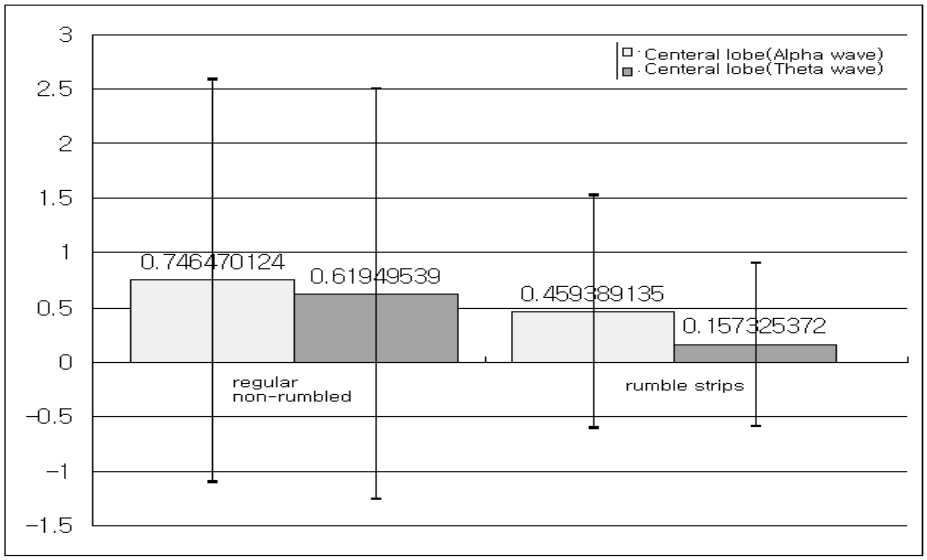

Figure 8. Cognizance Level Change at the Rumble Stripped Section and Regular Non-rumbled Section (control for the comparison analysis)

Table 4. Statistical Result of the Comparison (central lobe, theta wave)

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	5.998	1.4995	4.13	0.0134**
Error	20	7.263	0.3631	-	-
Total	24	13.612	-	-	-

5.2 Analysis of Repetitive Driving Behavior on the Rumble Stripped Highway

The driver's alertness increased by 74 percent while driving at rumble stripped section compared with that while driving at regular non-rumbled section. An analysis of the driver's alertness change in response to a repetitive driving condition at the rumble stripped section was carried out in order to investigate the change in further detail based on the order of driving onto the rumble stripped section.

Data on the repetitive driving onto the rumble stripped section were collected sequentially. The alpha and theta wave measured at the central lobe were then compared and analyzed based on the order of entry to the rumble stripped section. From <Figure 9> to <Figure 10> shows the analysis result based on the average value of all five experimental subjects.

It showed that the change in alertness level of the driver was most noticeably observed upon the first entry onto the rumble striped section. The average alpha wave was measured at approximately 0.13, showing about 82% increase in the alertness level. Likewise, the same trend of increased alertness at rumble stripped section compared with that at regular non-rumbled section was observed for the theta wave. The average values of alpha wave were measured at 0.38, 0.41, 0.30 upon the third, fourth, and fifth entry onto the rumble stripped section, again attesting to the increased level of alertness compared with that at regular non-rumbled section. Likewise, the same trend of a decrease were observed for the average values of theta wave, making it possible to evaluate that the alertness of the drivers increased significantly overall upon entry onto the rumble stripped section. The average values of alpha and theta wave were noticeably larger upon the second entry onto the rumble stripped section compared to other entries, and this seemed rather peculiar. In order to explain this peculiar result, many variables to the experimental result such as possible nearby traffic accidents as recorded in a traffic logbook and the traffic flow volume were investigated. However, no significant explanations were found. However, one of the five experimental subjects reported on the post-experiment subjective questionnaire that he/she experienced a rather comfortable driving upon the second entry onto the rumble stripped section. This report was evidenced by larger values of alpha and theta wave than the expected upon his/her second entry onto the rumble stripped section, thus influencing their average. However, no other noticeable explanation regarding the driving conditions was found, and this peculiarity was attributed to a subjective element of an experiment such as an unexpected change in the subjective mental mood of the human experimental subject. The researchers of this study could not come up with any other more detailed and plausible explanation with the current data at hand.

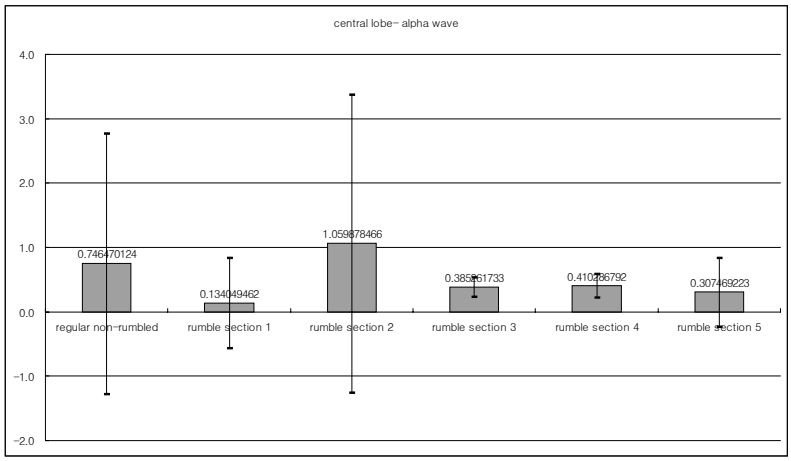

Figure 9. Changes in the Driver's Alertness Level by Repetitive Entries onto the Rumble Stripped Section(graph depicts the alpha wave measurements)

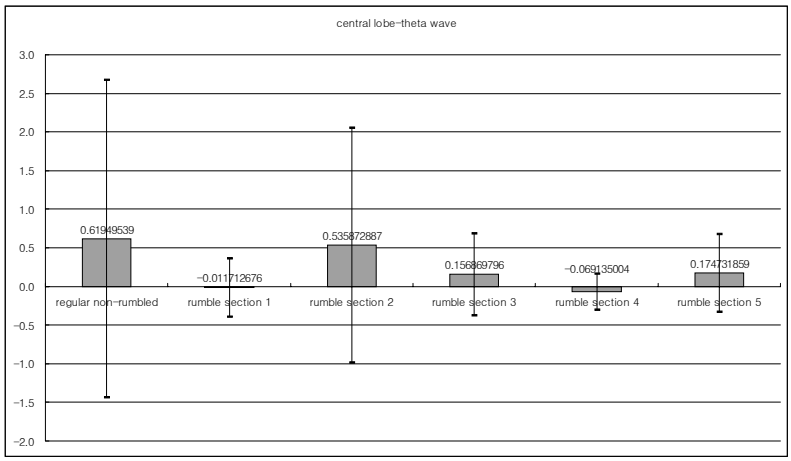

Figure 10. Changes in the Driver's Alertness Level by Repetitive Entries onto the Rumble Stripped Section(graph depicts the theta wave measurements.)

7. Conclusion

As a method to decrease drift-off accidents significantly, Korea Highway Corporation has the intention and plan to install rumble strips on all major highways at the national level. Before this grand-scale implementation, an evaluation on the effectiveness of the rumble strips was carried out with the aspect of human factors. Especially, the change in alpha wave and theta wave transmitted at the central lobe was measured and analyzed as an indicative of the change in the driver's alertness level because of the previous physiological research findings relating these waves to drowsiness or sleepiness. This research method was adopted due to the necessity to evaluate the effectiveness of this facility in a relatively short time period given for the implementation of this urgent and important project.
The findings on the effectiveness evaluation of the rumble strips are as follows. :

Firstly, the comparison of driving experiment on the rumble stripped section and regular non-rumbled section revealed that the average value of the alpha wave decreased by 0.2871 upon entry onto the rumble stripped section although it was not statistically significant. However, the decreased change in the average value of the theta wave by 74% upon entry onto the rumble stripped section was statistically significant. Thus, it can be shown that rumble strips are effective in increasing the alertness level of the drivers.

Secondly, the activity of the alpha and theta waves at the central lobe is known to be an indicative of the alertness (or drowsiness for the matter) and was measured to decrease, indicating an increase in the subject's alertness by approximately from 74% to 82% upon entry onto the rumble stripped section compared to that while driving on the regular non-rumbled section.

This research investigated the effectiveness of the installation of rumble strips on the highway from the perspective of the drivers. The research method chosen for this research, which employed human factor aspect of the bio-signals, was found to be objective and effective as an instrument of evaluating the installation effectiveness in a relatively short period of time.
With the cost and time permitting, increasing the number of experimental subjects and employing more representative experimental sample subjects can greatly contribute to more significant and valid research findings in evaluating the effectiveness of a road safety facility installation.

ACKNOWLEDGEMENT

This research of Korea Highway & Transportation Technology Institute is the result of an internally developed/performed investigation and the funding by Korea Highway Corporation in the year of 2002. The assistance and cooperation by the Road Maintenance Department and Design Department of Korea Highway Corporation are greatly appreciated.

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