Driver Vigilance Monitoring – Impact of the Long Tunnels

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Abstract: - This paper studied the vigilance level of a fatigued driver in a long tunnel. The vigilance of the driver is monitored using Electroencephalography (EEG) in a driving simulator under different scenarios namely Normal road and Tunnel road. The hypnagogic, relaxation and vigilant phase of each driver is analyzed from their EEG data. The experiments projected a negative impact on driver vigilance in long tunnels. A comparative study on the driver vigilance inside the tunnel and to that of a normal road is presented. In addition, the impact of colored tunnel to that of a regular tunnel was also studied and results are presented.

Key-Words: - Vigilance, Micro sleeps, Tunnel driving, EEG analysis, Driving simulator, Tunnel design

1 Introduction

The occurrences of a traffic accident seem to be increasing. This could be because of technical failures and as well as due to the human factors. Possible reasons of human failures could be fatigue, aggressive driving, impaired driving due to taking alcohol, etc. Fatigue is a common phase, which every human undergoes. But it is considered extremely dangerous if it is in a tunnel. It can cause extensive damage starting from a few lives in the immediate vicinity to the entire occupants of the tunnel and heavy damage to property. If fatigue is the cause for many accidents on road then, fatigue and monotony could be a main cause for many disastrous accidents in long tunnels.

A tunnel is missing the regular engagements and distractions that are available on a normal highway/normal road. A tunnel is quite simple to drive because it has a plain road with a constant speed. Hence, this would push them to a boring drive. When fatigue drivers feel bored, he/she tends to lose their vigilance levels. A driver should always be in a wakeful state and better is to be in a vigilant state. When the driver is driving continuously for about 10 hours their vigilance levels seems to dip. He/she will mostly move to the next stage of being relaxed and then hypnagogic state and finally to the micro sleep stage. A driver should always be in a wakeful state and better is to be in a vigilant state. When the driver is driving continuously for about 10 hours their vigilance levels seems to dip. He/she will mostly move to the next stage of being relaxed and then hypnagogic state and finally to the micro sleep stage.

The driver's behavior is to be studied in different scenarios namely on normal road, regular tunnel and color tunnel. Each driver's hypnagogic phases and relaxation phases should be studied. Then a comparative study on the behavior of the driver in the three different scenarios must be performed. Driver's behavior is assessed using Electroencephalography (EEG). The drivers drove the advanced driving simulator at Simulator laboratory DSRG [1,2,3] of Faculty of transportation Sciences, CTU in Prague.

2 Simulations and Measurements

The suitable simulations were discussed and accomplished. The simulation has two tasks creation and then implementation. A moderate density of traffic is set in all the scenarios. Three scenarios were created.

2.1 Normal Road

This scenario is a simple two-lane road with two-way traffic. The road is located on the countryside. The simulation would start from a railway station and would run for about 5.3km. There is a level crossing in the middle and about 2 traffic signals (see Fig.1). The 5.3km stretch is made as a loop. It tends to infinity, one has to start and stop only based on instructions during the measurement. This simulation was used for some other projects as well [2]. Henceforth in this document, this particular road simulation will be referred as "normal road".

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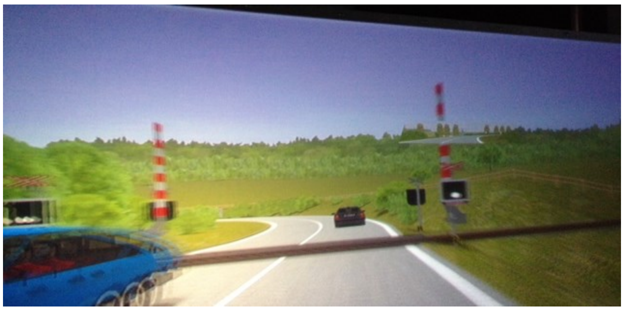

Fig.1: The Normal road simulation

2.2 Tunnel Road

In this scenario the road is located in a hilly region. The tunnel is constructed like a loop. The simulation starts with a petrol bunk on the exit of a highway then, it joins a two-lane road. This road leads to the tunnel. The tunnel and the highway is a two-lane road with one-way traffic. The length of the tunnel is 19 915,5m (20km) and the highway connecting the ends of the tunnel is of the length 1620m (1.6km). The interior of the tunnel is very simple, very much like a regular tunnel with grey wall, signals at regular intervals and emergency cabin (see Fig.2). Henceforth in this document, this particular road simulation will be referred as "tunnel" or even as "regular tunnel".

Fig.2: Inside the tunnel

2.3 Color Tunnel Road

In terms of construction this scenario is a replica of the previously discussed tunnel simulation. The tunnel is constructed like a loop with the same length. The only difference would be in terms of its interior wall coloring (see Fig.3). The color spectrum starting from lime yellow, fluorescent till turquoise and dark blue were used inside the tunnel. The whole tunnel tube is colored the same way. The colors such as red, chrome, orange and pink were purposely eliminated as it might introduce sense of fear called the "Wall Effect". Wall Effect - A sense of fear that the driver experiences when he/she enters a tunnel. This could occur because of some experience or by just imagining negatively. The studies revealed that the colors such as red, yellow and orange could increase the fear or even induce fear in some cases [4]. Henceforth in this document, this particular road simulation will be referred as "color tunnel".

Fig.3: Inside the color tunnel

2.4 Prerequisites for the measurement

Since this experiment work requires fatigue drivers, the participants were requested to follow some conditions before the measurement.

- The last sleep should have been 10-15 hours before.
- No coffee and alcohol should be consumed during these 10-15 hours.

The participants were advised to do something tiring during these 10-15 hours. All the drivers followed the above-mentioned conditions before the measurements.

2.5 Measurements:

The EEG for each driver is made. There is also a video recording the behavior of the driver on the road. The video records a side profile of the driver and how he/she travels in the road. The EEG recording is made and markers are used to mark the entering into tunnel, stopping, crash and etc. The driver drives for about 15-20 minutes in each scenario. After the experiment a questionnaire was to be filled by each of them. The answers to the questionnaire were hand written by the drivers to get the accurate opinion from them.

3 Analysis

The EEG analysis is essence of this experiment, as this would clear the assumptions and reveal the reality. TruScan explorer software is used for analyses. The main function of this program is to review the EEG data obtained by the TruScan acquisition software. [5] This program offers the possibility to apply different filters and settings in order to inspect the data.

The data is first analyzed for the artifacts. The artifacts were removed manually. The major artifacts were due to yawning. This was found using the video. The video and EEG were synchronized to find the artifacts as well as the "eyes drooping" phase. Since the camera doesn't look directly on the driver, it is difficult to spot the eyes drooping scenario. Hence it is co-related with the driving condition and it is understood that during eyes drooping, one doesn't drive the vehicle according to the required road condition.

3.1 Terminology

The following are the terms, which would be used further in this document.

- Eyes closed scenario – The phase recorded just before the driving could start.
- Eyes Drooping scenario – The sagging of upper eyelids due to drowsiness (sleepy).
- Vigilance – The ability to maintain attention and alertness over a prolonged period of time.
- Wakefulness – A state of consciousness in which the individual responds appropriately to the turns, traffic signal, maintains speed and etc.
- Relaxation – A state of being free from tension and anxiety. Relaxation and hypnagogic phase are the two possible phases between wakefulness and sleep. [6]
- Hypnagogic phase – A state were the driver approaches sleep. It is immediately before falling asleep, when α / δ is less than one. [6]
- Micro-sleep – It is a temporary episode of sleep, which may last for a fraction of second or even up to 30 seconds. The driver fails to respond to the road.

3.2 Fundamental Frequency of the Brain

The frequency range is divided into different band, δ (0.5 – 3.5 Hz → Sleep),θ (4 – 7 Hz → Drowsy, Meditative), α (8 – 13 Hz → Relaxed, calm, lucid, not thinking), β (14 – 30 Hz → Awake, conscious, calculating/working).

The EEG analysis for participants was analyzed and their inference is discussed in the further pages. The EEG analysis for each participant was made and a sample analysis of subject number 005 is shown.

3.3 EEG Analysis of subject Number 005

The subject is a healthy student. She has a basic alpha of about 9.8-10Hz and delta of about 2.5Hz during vigilance.

3.3.1 Normal road

She experiences relaxation and vigilance phases, but both don't stay for a long duration, only about 2or3 seconds and almost negligible percentages of hypnagogic phase. Otherwise all through the simulation she was wakeful. There is no occurrence of eyes drooping scenario.

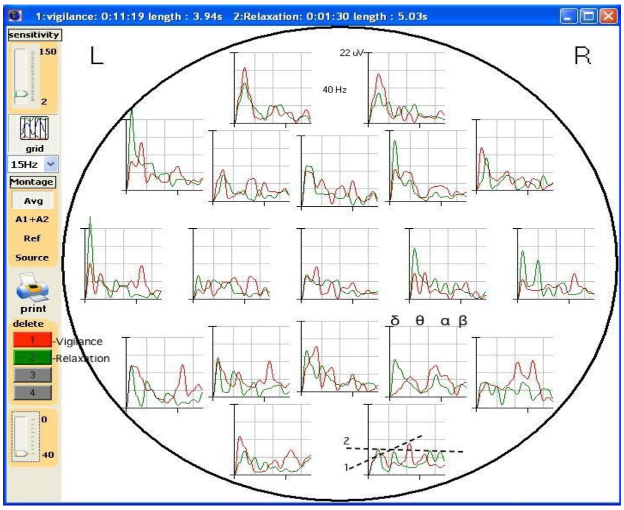

Fig.4: Spectrogram in Normal Road-005

The Fig.4 shows the spectrograms calculated according to FFT analysis from a notable relaxation phase and a vigilance phase. Two dotted lines (1&2) connect the apices of curves at the lower right occipital region; this represents energy in the alpha and delta bands. The line (1) shows the vigilance phase. The alpha is larger than delta with a very low theta. The line (2) shows the relaxation phase as the alpha/delta coefficient is in equilibrium (alpha/delta ≅ 1).

3.3.2 Tunnel Road:

The occurrence of eyes drooping scenario is very frequent. The eyes closed scenario differs from the eyes drooping scenario. From the frequency mapping, one can say that during the eyes drooping scenario (see Fig.5), Delta prevalently appears from the frontal left region to the center of the brain and the alpha increases in the occipital region to the center of the brain and theta is also present. Whereas in the eyes closed scenario the theta and delta is lower and alpha is almost the same, these are mentioned in comparison with eyes drooping scenario. There are about 7 incidents of hypnagogic phase, 6 incidents of eyes drooping scenario and one prevailing micro-sleep phase detected. The driver never lost the road or crashed. This phase took place after 10 minutes of driving in the tunnel.

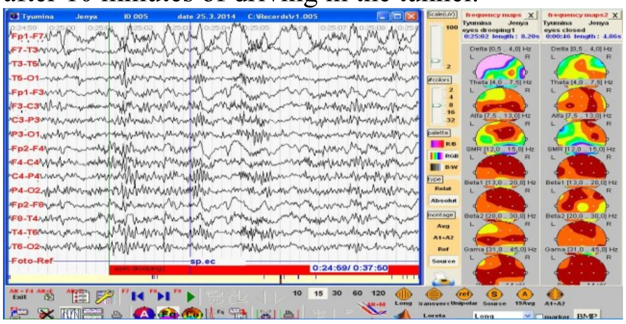

Fig.5: Frequency Mapping

The Fig.6 shows the spectrograms of 2 hypnagogic phases and 1 eyes drooping phase. A dotted line (1 & 2) connects the apices of curves at the lower right occipital region. In the spectrogram line (1) shows that the delta is predominately higher than the alpha. Hence the alpha/delta<1, the hypnagogic phase with slightly increasing theta.

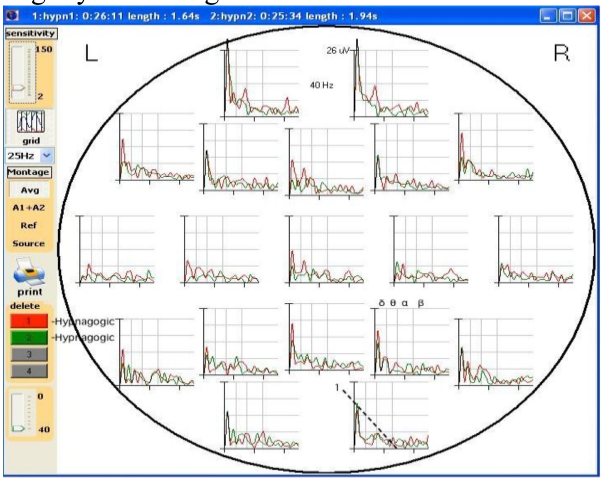

Fig.6: Spectrogram in Tunnel-005

3.3.3 Color Tunnel Road

The eyes drooping scenario occurs only once. There are about 2 incidents of hypnagogic phase and no micro-sleep phase detected. Her beta waves are much lower and overall she appears to be calm, throughout this simulation she appears to fluctuate between relaxation and vigilance. The Fig.7 shows the spectrograms of a hypnagogic, vigilance and a relaxation phase in the colored tunnel. Three dotted lines (1,2&3) connect the apices of curves at the lower right occipital region. The line (1) shows that the delta is predominately higher than alpha. It is a clear hypnagogic phase with alpha/delta<1. The line (2) shows the vigilance phase. The alpha is larger than delta with a very low theta. The line (3) shows relaxation phase as the alpha/delta coefficient is in equilibrium.

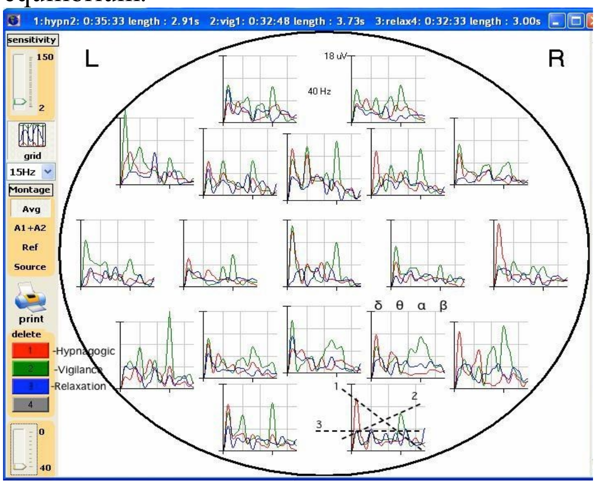

Fig.7: Spectrogram in Color Tunnel-005

4 Results and Their Inferences

The following are the inferences based on the results from analysis of the individual EEG as well as from the questionnaire.

4.1 Inference based on the EEG

One can say that since the normal road is distractive with a lot of movements hence, even after 10hours without sleep everybody drives attentively. All of them were in a wakeful state, responded properly to the traffic signals and speed limit. Most of them are relaxed and vigilant. In the tunnel scenario, the drivers seem to be very bored and restless. Most of them are drowsy in the tunnel.

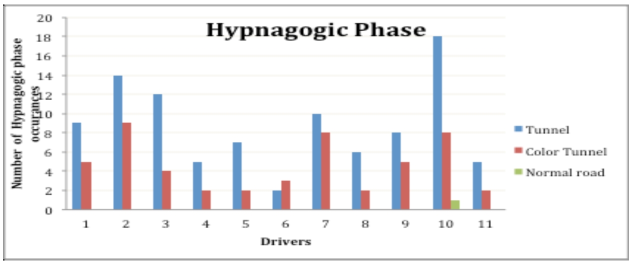

Fig.8: Number of hypnagogic phase occurrences for each driver

Above Fig.8 is set on number of hypnagogic phase occurred for each driver. One can see that in a tunnel, drivers experience many incidents of hypnagogic phase whereas, in the color tunnel drivers experience lesser incidents of hypnagogic phase. The 10^{th} driver was the one with most number of hypnagogic phases and hence he also experiences a hypnagogic phase in the normal road. One can say that the drivers with high susceptibility to sleep after long hours of drive amount to a great danger in the tunnel. Drivers 4,6 and 11 are the ones with very low hypnagogic phase. They seemed to be very relaxed and vigilant in the normal road and experience hypnagogic phase only in last 5 minutes of the tunnel.

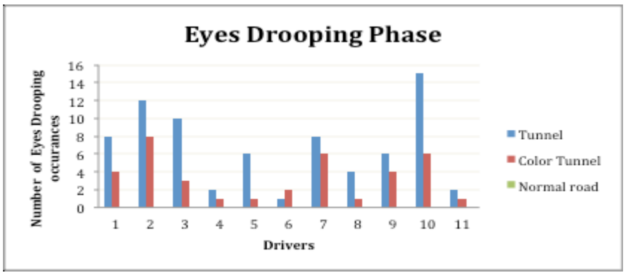

Fig.9: Number of Eyes drooping phase occurrences for each driver.

The number of eyes drooping phase (see Fig.9) experienced by each driver seems to be lower than that of the hypnagogic phase experienced. The drivers 4, 6 and 11 are the ones with least number of eyes drooping phase. They can be described as attentive drivers. But even the attentive drivers experienced eyes drooping in tunnels. Similarly the micro sleep experienced also seems to be lower than that of the hypnagogic and eyes drooping phase. The attentive drivers didn't experience micro sleep (see Fig.10). The 10th and 2nd drivers are the ones with most number of micro-sleep. They can be described as drowsy drivers.

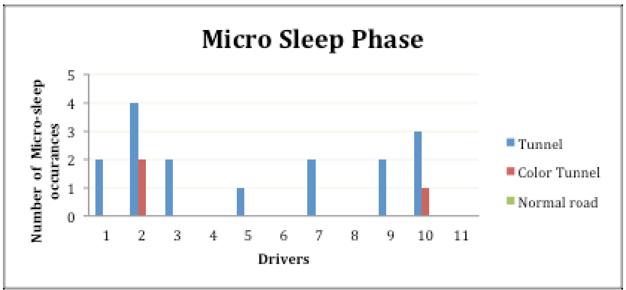

Fig.10: Number of Micro-sleep phase occurrences for each driver

4.2 Comparison of scenarios

Based on all scenarios normal roads don't hold big danger when compared to the tunnels. The very attentive are able to drive for about one hour on all roads without micro-sleep. But the drowsy drivers find it difficult on the tunnels. The drowsy drivers will be a threat if they drive without sleep for about 10 hours or so.

When tunnel and colored tunnel is taken for a comparison, number of incidents of hypnagogic phase and eyes drooping phase are lesser in the color tunnel.

The color tunnel distracts the drivers for a longer time. In the first 5-minute drive inside a normal tunnel, the 10th driver encounters his first hypnagogic phase but the same driver encounters his first hypnagogic phase only after driving 10-minutes in the color tunnel. Similarly the attentive drivers encounter their first hypnagogic phase only in last 5-minutes of drive in the color tunnel. All drivers experience the hypnagogic phase in color tunnel after some time but it just delayed and the intensity is reduced. The fact is that, they get used to the interiors hence it becomes all the same after 10 minutes in the color tunnel.

4.3 Inference based on the questionnaires

The drivers answered the questionnaire immediately after the experiment. They were provided a rating scale from 1 to 5 (least-1, less-2, medium-3, more-4, the most-5) to access their level of attentiveness and the drowsiness on the normal road, tunnel and the color tunnel.

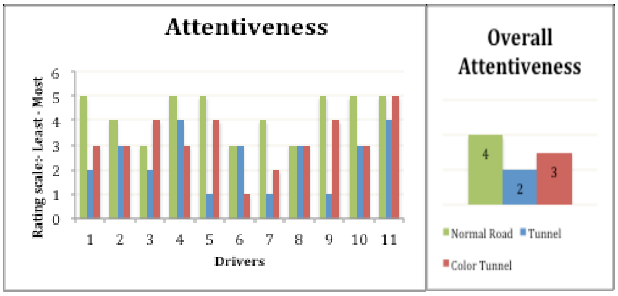

Fig.11: Level of attentiveness in each scenario given by the drivers

Above presented chart (Fig.11) is the level of attentiveness. The second is an average calculated from this data. On an average, drivers are most attentive in the normal road, medium level of attentiveness in the color tunnel and lesser attentive in the tunnel. One can infer that normal road is the safest to drive after 10 hours without sleep, the color tunnel is the next, and then the least safe would be the tunnel.

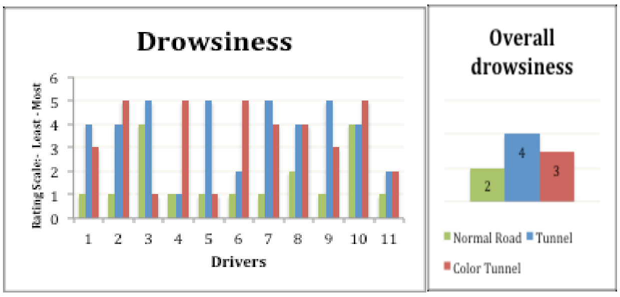

Fig.12: Level of Drowsiness in each scenario given by the drivers

Above presented chart (Fig.12) is the level of drowsiness. The second is an average calculated from this data. On an average, drivers are most drowsy in the tunnel, medium level of drowsiness in color tunnel and lesser drowsy normal road. One can infer that normal road is the safest after 10hour without sleep drive, the color tunnel is the next, and then the least safe would be the tunnel.

Six of them like the concept of color tunnel to that of the regular tunnel. When asked whether driving in tunnel is better than driving on a road, nine of them prefer driving on a normal road to that of the tunnels. An interesting fact here would be that, in the simulator of normal road scenario there are no feedbacks from the simulator hence few people felt nausea. These people didn't feel that in the tunnel hence, the felt comfortable in the tunnel. A specific question was triggered asking if they felt drowsy in the tunnel, about ten of them said that they felt drowsy. Comparing with the results from

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the EEG almost everybody felt drowsy in the tunnels.

The attributes of discomfort in the regular tunnel were monotony, darkness, and low speed limit so easy to get drowsy. The attributes of discomfort in the color tunnel were that, after sometime it becomes monotonous, hypnotic impacts and they felt as if they have lost the dimensions of the tunnel's walls. The most important inference made is that, the chances for the driver to enter to micro sleep is more vulnerable in a tunnel when compared to a normal road. Hence, interiors of the tunnel must be improved to break the monotony.

5 Discussion

Tunnels longer than 15km must have something for the drivers to break the monotony in the tunnel. The following suggestion could make the drivers much attentive.

5.1 Intermittent feature walls

If the walls were painted with a pattern or some colors then, the daily commuters would get used to the walls. Hence, the best way is to project something on the wall.

The feature walls must be painted white. Projectors can be set at the kerb to project on the sides as well as the roof of the tunnel. The projections mustn't be dreamy like clouds, snow, etc. The intermittent walls projections cannot be made for the entire stretch of the tunnel. Hence, depending on the total distance it can be divided into sections of either 5km or 10km stretch. Both of these should go hand in hand. This suggestion has a lot of scope of innovations. This can be explored so that the long tunnels can be made very safe.

4 Conclusion

Driver vigilance monitoring in long tunnels has been successfully carried out. The EEG measurements on the human brain of various drivers have been obtained. The hypnagogic phases, relaxation phases and micro-sleep phases were analyzed for each individual.

Analysis reveals that, the chances for a driver to enter to micro sleep are more vulnerable in a long tunnel when compared to a normal road. Even the most attentive drivers encounter hypnagogic phase and eyes drooping phase after a certain period of driving in the tunnel. Micro sleep is a state of substantial decrease in vigilance and attention; this poses a threat to the driver as well as to the other commuters on the road. Such micro sleeps would increase severity when it comes to a tunnel. About 10 years ago studies were conducted to show that some drivers experience fear inside the tunnel. Hence, interiors of tunnels were modified such that the fear factor is eliminated. Now this project calls in for a similar redesigning of the interiors not only for the fear factor but also for the removal of micro sleep occurrences in the fatigued drivers. The tunnels must be designed to break the monotony.

This experiment was carried out with 11 drivers has proved that the risk of micro sleep in the tunnel is more. If this experiment were carried out on a larger scale, with an extended sample size, and also employing interesting tunnel design, it would fortify the conclusions of this project.

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