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Assessment of early onset of driver fatigue using multimodal fatigue measures in a static simulator

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ABSTRACT

Driver fatigue is an important contributor to road accidents. This paper reports a study that evaluated driver fatigue using multimodal fatigue measures, i.e., surface electromyography (sEMG), electroencephalography (EEG), seat interface pressure, blood pressure, heart rate and oxygen saturation level. Twenty male participants volunteered in this study by performing 60 min of driving on a static simulator. Results from sEMG showed significant physical fatigue ($\rho < 0.05$) in back and shoulder muscle groups. EEG showed significant ($\rho < 0.05$) increase of alpha and theta activities and a significant decrease of beta activity during monotonous driving. Results also showed significant change in bilateral pressure distribution on thigh and buttocks region during the study. These findings demonstrate the use of multimodal measures to assess early onset of fatigue. This will help us understand the influence of physical and mental fatigue on driver during monotonous driving.

1. Introduction

In the current globally networked economy more and more people tend work in multiple time zones resulting in almost 24 h running of organizations and increasingly longer "voluntary" working hours, which is akin to long-shift hours (Dorrian et al., 2011). In addition to this, mobility of human, goods and services is another implicit requirement to cater this growing global economy. Road transportation networks play as one of the critical facilitator for short and medium haul of people and goods thereby helping the mobility. However the down side of this mode of transportation is the number of accidents which appears as large owing to the volume of traffic.

India, a major emerging economy driven by this globalization, road networks are a key in-land linkage. According to a report by National Crime Records Bureau, road accidents in 2009 reported 35.5% death rate in India (Government of India, 2010). It is argued that up to 40% of the accidents in road transportation system worldwide is due to driver error which may be a result of fatigue (Connor et al., 2002; Horne and Reyner, 1995; Roads and Traffic Authority, NSW, 2011). The National Transportation Safety Board (2010) has reported driver fatigue as a probable cause for road accidents that result in financial losses, injuries and even fatalities.

It has been demonstrated that people engaged in long shift-work have a circadian disruption, i.e., changes in sleep patterns, which often leads to sleep deprivation and its associated ailments (Åkerstedt et al., 1987; Darwent et al., 2012; Rosekind et al., 1994). Disruptions in circadian rhythms and sleep pattern results in decreased alertness, impaired activity, tiredness and possibly fatigue (Bonnet, 1985). These impediments manifest itself broadly as fatigue disrupting several activities of daily living, one of which is for vehicle drivers.

Fatigue decreases an individual's ability to operate vehicles safely and reduces situation alertness. There are many factors that may cause the driver to be fatigued. It results from the complex interaction of various factors (Kecklund and Åkerstedt, 1993; Young et al., 2006), of which mainly: 1. Environmental factors such as road surface irregularities, low density traffic, time of day, rain, fog, etc, 2. Biological factors such as inadequate sleep, circadian rhythms, health, age, etc, 3. Socio-economical activities such as long work-shifts, increased work load, alcohol, drugs, etc and 4. Vehicle factors such as noise, vibration and postural stress that are created by the vehicle itself, poor suspension, seat and vehicle design, demands on both physical and mental processes. Detection of driver fatigue is a major concern in vehicle design, road safety and transportation research. However a serious impediment to address

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driver fatigue is the difficulty and most times the inability to detect it.

Several papers have suggested methods for quantifying driver fatigue based on subjective and objective measurements. Subjective measurements are based on self-rating tests by means of questionnaires (Caldwell et al., 2003). One of the major drawbacks of this method is that it is either conducted before and/or after the event. This can probably lead to drivers forgetting important issues that they perceived or experienced during the course of driving. Objective measurements of driver fatigue are categorized as: *vehicle parameters* such as change in the steering wheel rotation, acceleration, speed of the vehicle, braking and lane tracking etc (Apostoloff and Zelinsky, 2003) and *physical movements* such as eye closure and blink rates, tracking of facial expression, etc by using video imaging techniques (Zhu and Ji, 2004). Major problems with these approaches are their sensitivity to external factors such as luminance and vibration that the driver experiences in the real driving scenario. Moreover, they could detect only the outcomes of fatigue and they do not predict the occurrence of fatigue before. There are some blood biochemical parameters that are also used for evaluating driver fatigue. However such testing often is invasive and disadvantageous in analysis. Similarly the disadvantage of psychological tests is that they often make heavy demands on the subjects, which will raise the level of cerebral activity. The above issues can be overcome by appropriate indices of driver fatigue which would be some sort of physiological measures to quantify both physical and mental skills associated with driving performance.

Different physiological and psychophysiological parameters are contributed for the fluctuations of alertness, activation and performance degradation. It is of particular importance to isolate them precisely in order to understand their contribution to human functioning system. To better understand the driver fatigue and train the key stakeholders in the road transportation, simulations and simulators are extensively used (Waller, 1992; Young et al., 2006). Several advantages like safety, security, exposure to high-hazard and cost-effectiveness are there in using simulators in lieu of on-road training. Increasingly, driving simulators that represent realistic environment with force feedback and motion platform are now popularly used to examine driver behaviour, performance and attention (Eoh et al., 2005; Land and Horwood, 1995).

The reliability of driving simulators coupled with ease of experimentation has prompted us to use a static simulator with force feedback in steering to study the physical and mental aspects of driver fatigue during monotonous driving. Since driver fatigue has multiple causal pathways and early symptoms, we decided to adopt a multimodal monitoring of the driver performance. We have used surface electromyography (sEMG) to understand the muscle activity, electroencephalogram (EEG) to understand brain activity, seat pressure distribution and other measures of physical exertion like blood pressure such as heart rate, oxygen saturation level to quantify driver fatigue during monotonous simulated driving. Hence a multimodal technique of detecting driver's status/condition can provide reliable results in terms of both physical and mental fatigue.

2. Methods and materials

2.1. Participants

Twenty male participants volunteered for this study. Their mean age, weight, heights were 23 $\pm$ 4.40 years, 64.5 $\pm$ 10.70 kg and 1.76 $\pm$ 0.08 m respectively. All participants had light motor vehicle (LMV) license and had more than two years of driving experience. The study protocol was clearly explained to each participant and the possible risks associated with the study. A written informed consent was taken from the volunteers to enrol as participants in the study. All experimental procedures were performed using a static driving simulator in a controlled environment of the laboratory.

2.2. Simulation task

The static driving simulator comprises of steering wheel with force feedback, gear shift lever, foot pedals and a projection of the driving environment for visual feedback (Fig. 1). A commercially available ('Need for Speed', Electronic Arts 2010) driving environment was used for the study. The driving environment selected for this study was a highway with low traffic density. All participants were allowed approximately 30 min of driving practice session to get accustomed to the controls used in the simulator. After the practice session, participants were given a break of 20 min away from the simulator and were allowed to have unconstrained movement within the laboratory. Participants were then required to sit on the driver's seat in their comfortable driving postures. The angle between the thigh and the trunk was between 110° to 120°. Then they commenced their 60 min of testing after a quick check of all instrumentation.

2.3. Multimodal physiological signal analysis

It was found essential to determine both physical and mental aspects of fatigue in order to accurately validate the driver's level of alertness. Hence, simultaneous recording of the following multimodal signals were obtained during the monotonous driving session.

2.3.1. Surface electromyographic analysis

Extensor carpi radialis (ECR), biceps brachii (BB), medial deltoid (MD), trapezius medial (TM), sternocleldomastoid (S), latissimus dorsi medial (LDM) and erector spinae (ES) muscle-groups were evaluated bilaterally for this study. Muscle-groups were chosen based on preliminary studies for implication in driving, intensity of signal generated and accessibility of muscle for electrode application. Before placing the measurement electrodes, the placement site were identified, shaved, and cleaned with ethanol to avoid impedance mismatch and movement artifacts. sEMG signals were acquired using 16 channel EMG machine (Wireless Myomonitor IV, Delsys Inc., Boston, MA) at a sampling rate of 1000 Hz. Raw sEMG

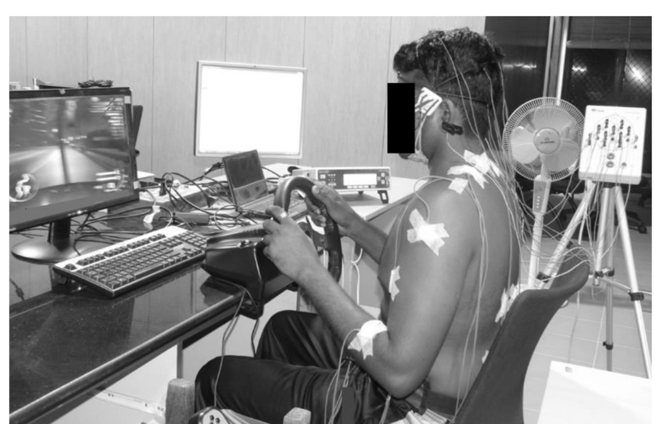

Fig. 1. Experimental setup includes driving simulator, data acquisition systems for surface electromyographic and electroencephalographic signals, seat interface pressure mapping system and photoplythesmography unit for heart rate and blood pressure monitoring.

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