The Psychophysiology of Driver Fatigue/Drowsiness: Electroencephalography, Electro-oculogram, Electrocardiogram and Psychological Effects

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Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

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Preface

The research reported in this thesis was conducted at the University of Technology (UTS), Sydney, in the Department of Health Science. The author was granted an Australian Postgraduate Award Scholarship to complete the degree of Doctor of Philosophy in Science. The author was a part-time lecturer/tutor at UTS and also completed an internship program in education during the course of the doctoral research and was awarded the Graduate Certificate of Higher Education in 2000. During the period of the doctorate, the author was also an active member of the Academic Board and was also a member of the review panel of the Academic Board at UTS. Towards the end of the PhD, the author attracted a National Health and Medical Research Council (NHMRC) fellowship, 2001 (Australian Clinical Research Fellowship) for further research in fatigue with Professor Ashley Craig as co-investigator. Some of the reviews and research presented in this thesis have been published, accepted for publication or submitted for publication in the following journals.

Manuscripts

Lal, SKL and Craig, A (2001). A critical review of the psychophysiology of driver fatigue. Biological Psychology, 55: 173-194.

Lal, SKL and Craig, A. (2000). Electroencephalography activity associated with driver fatigue: implications for a fatigue countermeasure device. Journal of Psychophysiology (submitted).

Lal, SKL and Craig, A (2000). Driver Fatigue: electroencephalography and psychological assessment. Psychophysiology (submitted).

Conference Papers and abstracts

Lal SKL, Craig A. Psychophysiology of driver fatigue. Proceedings of the Fourth International Conference on Fatigue and Transportation. Transportation Research, (2000).

Lal SKL, Craig A. Psychophysiological effects associated with drowsiness: driver fatigue and electroencephalography. International J Psychophysiology 35: 39 (2000).

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Manuals

Lal SKL (2000) A fatigue questionnaire for assessing physical and mental fatigue (Modified from Wessely and Powell, 1989). Sydney, UTS.

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Abstract

Driver fatigue is a major cause of road accidents and has implications for road safety. Investigating the psychophysiological links to fatigue can enhance our understanding and management of fatigue in the transport industry. A variety of psychophysiological parameters have been identified as indicators of fatigue, with electroencephalography (EEG) perhaps being the most promising. Therefore, monitoring EEG during driver fatigue may be a promising variable for use in fatigue countermeasure devices. However, most previous fatigue-based studies have suffered from methodological shortcomings such as insufficient sample numbers, lack of a controlled testing environment, inadequate study design and statistical analysis. Furthermore, a thorough psychophysiological assessment of fatigue was found to be lacking in the literature. Therefore, the aims of the present doctoral research were to: 1) Assess the EEG and electro-occulogram (EOG) changes during driver fatigue in a 'state of the art' experimentally controlled study. 2) Identify psychological associations with fatigue. 3) Assess the changes in autonomic nervous system activity during fatigue. 4) Investigate the differences in the physiological changes that occur during fatigue in professional versus non-professional drivers. 5) Identify the reproducibility of physiological changes that occur during fatigue. 6) Examine the changes in EEG coherence during fatigue. 7) Utilise the physiological findings in this research for the development of EEG based software to detect fatigue.

The results showed significant increases in delta and theta during driver fatigue. The conventional high amplitude blinks during alertness was replaced with slow, low amplitude blinks during fatigue. Reduced Fatigue-Inertia and decreased Vigour-Activity (which are mood sub-scales) and increased anxiety levels were associated with fatigue. There was an increase in parasympathetic activity during fatigue. Non-professional drivers showed greater increases in the EEG of fatigue compared to professional drivers. The EEG changes associated with fatigue were shown to be reproducible. The changes in EEG coherence were not found to be significant during fatigue. The EEG changes during fatigue were used for the development of an algorithm for a fatigue-countermeasure device and was shown to reliably detect fatigue.

In summary, this research has provided important information on the psychophysiology of driver fatigue clarifying some of the findings of prior research.

Significant changes were found to occur in EEG, EOG and parasympathetic activity during fatigue. From this research it may also be suggested that psychological status of the driver may influence fatigue status. Furthermore, the EEG changes during fatigue are consistent and reliable, which can be utilised to detect fatigue in a EEG-based fatigue countermeasure device. The results are discussed in the light of direction for future driver fatigue studies and fatigue management.

Definition of Technical Terms

Coherence analysis (spectral correlation): The coherence function measures the correlation between two signals as a function of the frequency components which they contain. Thus, the coherence function is a correlation spectrum and also known as spectral correlation. The coherence function is a statistical measure used to determine the likelihood of two stochastic signals arising from some common generator process, and the frequency band in which this occurs. Therefore, the coherence measure is conducted on sample epochs of the signals of interest and is therefore a statistical estimate of the true relationship between the signals.

Electrocardiogram (ECG): The ECG is the measure of the electrical activity of the heart.

Electroencephalography (EEG): The EEG or 'brain wave' is a measure of the electrical activity present in the brain. There are four major types of brain waves which are delta, theta, alpha and beta (refer to 'Electroencephalography frequency bands). The changes in EEG amplitude and magnitude are two common descriptors of EEG activity.

> ***Amplitude:*** The amplitude of EEG waves is measured in microvolts (μV, millionths of a volt). It is determined by measuring the total vertical distance of a wave. Amplitude is the maximum or peak spectral amplitude within a band's frequency range.
>
> ***Magnitude:*** The magnitude of EEG waves is measured in microvolts (μV). Magnitude is the sum of all the amplitude in a band's frequency range.

Electroencephalography frequency bands:

> ***Delta***: These are slow waves between 0.5 and 4 Hz in a range of 20-200 μV. Delta waves are present during the deep sleep stage of normal EEG, that is, synchronised sleep indented by faster spindle waves. Delta activity is also present during various stages of drowsiness.
>
> ***Theta:*** The theta rhythm is an activity within the frequency range of 4-8 Hz, at an amplitude ranging from 20-100 μV. Theta occurs during drowsiness.

Theta has been associated with conditions of low levels of alertness and sleep deprivation and has such been associated with decreased information processing.

Alpha: The alpha rhythm has a frequency range of 8-12 Hz at a magnitude of about 20-60 μV, occurs during wakefulness particularly over the occipital cortex, appears at eye closure and disappears at eyes opening. The classical view of alpha has been that it represents a relaxed state and will be disrupted with any kind of mental work.

Beta: Beta is an irregular wave that occurs at a frequency of 13-50 Hz with an amplitude of approximately 2-20 μV. It is common during increased alertness such as during mental or physical activity.

Electro-occulogram (EOG): The EOG is the measure of changes in electrical potential that occurs when the eyes move.

Heart rate variability: is a spectral measure of changes in ECG and has the potential value of being a non-invasive measure of autonomic nervous system activity. The two main spectral regions of interest are (1) a low frequency (LF) component and (2) a high frequency (HF) component. The higher frequencies are believed to reflect parasympathetic activity, and lower frequencies are believed to be sympathetic activity (Baharav, et al. 1995). The parasympathetic origins of high frequency fluctuations are generally accepted. The interpretation of changes in lower frequencies is controversial. Some believe that LF activity is a composite of parasympathetic and sympathetic influence (Baharav, et al. 1995). Since the neuroautonomic influence at the low end of the spectrum is complex, a useful way to study the autonomic activity by means of spectral analysis is to define a sympathovagal balance or a sympathetic index. The sympathovagal balance or sympathetic index is derived by dividing the LF activity by either the HF activity or total spectral activity, that is, LF:HF or LF: total spectrum (Baharav, et al. 1995; Jaffe et al. 1993).

LF: The lower frequencies are believed to be sympathetic activity.

HF: The higher frequencies are believed to reflect parasympathetic activity.

LF:HF or LF: total spectral activity: The sympathovagal balance or sympathetic index is derived by dividing the LF activity by either the HF activity or total spectral activity, that is, LF:HF or LF: total spectrum.

Fatigue Phases: Fatigue may be divided into transitional, transitional to post-transitional and post-transitional periods as defined below, and the EEG features of each can be presented separately.

Transitional: The transitional phase occurs between awake alpha and absence of alpha, that is, a few to 10 seconds preceding alpha disappearance, during which the EEG changes in frequency, distribution, or amplitude of the dominant activity.

Transitional-post transitional: The transitional and post-transitional phase refers to both or either of the transitional or post-transitional periods.

Post-transitional: The post-transitional phase consists of the first EEG section after alpha disappearance comprising early Stage 1 of sleep.