Driver Fatigue: Psychological and Electroencephalography Assessment

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Abstract

Task performance during driving may be influenced by psychological factors since individuals differ in temperament and anxiety status. Fatigue has also been shown to be associated with changes in brain wave activity. However, research on psychophysiological associations with driver fatigue is scarce. Understanding the psychological links could provide information on fatigue management.

The aim was to identify the psychological associations during driver fatigue and the corresponding electroencephalography (EEG) changes. Thirty-five drivers were randomly assigned to the study. Subjects performed a driver simulator task until physical signs of fatigue were observed. Simultaneous nineteen channel EEG measures were obtained. Psychological factors assessed with validated questionnaires included anxiety, mood states and locus of control and self reported fatigue state.

The subjects were slightly fatigued before the study and moderately to extremely fatigued after the study. Delta activity was associated with increased anxiety ($r=0.42$, $p=0.01$), Vigor-Activity ($r=-0.44$, $p=0.009$), Fatigue Inertia ($r=0.39$). Theta activity was associated with Trait Anxiety and locus of control ($r=0.35$, $p=0.04$) and fatigue state ($r=0.44$, $p=0.009$). Alpha and beta were associated with Fatigue-Inertia ($r=0.36$, $p=0.03$ and $r=0.43$, $p=0.009$, respectively). Beta activity was also associated with fatigue state ($r=0.49$, $p=0.003$).

This research suggests psychological factors can influence fatigue status. It was found that increased anxiety, and negative mood states such as Tension-Anxiety and Fatigue-Inertia were associated with EEG indicators of fatigue such as increased delta and theta activity. This is the first study to show that various psychological factors may influence driver fatigue. To date no other study has investigated psychological and physiological changes simultaneously during driver fatigue. A future study with greater numbers and both professional and non-professional drivers will be required to confirm the current findings.

Keywords

fatigue, driver fatigue, anxiety, mood, electroencephalography, theta

Introduction

Fatigue and Psychological Effects

Electrophysiology in the form of recording the electrical potentials on the scalp using EEG has made possible the scientific investigation of the brain. Yet EEG is still relatively new in the area of investigating the psychology of fatigue. Few studies have investigated the psychological associations of mood states, anxiety levels and locus of control with fatigue. Investigating the psychological traits that are linked to fatigue may provide a better understanding of this complex functional state of the body and will hopefully lead to better driver fatigue management. Driver fatigue has been specifically defined as a state of reduced mental alertness that impairs performance of a range of cognitive and psychomotor tasks including driving (Williamson et al. (1)) It generally impairs human efficiency when individuals continue working after the onset of their fatigue state. However, task performance during driving may be influenced by psychological factors because individuals differ in attention and anxiety status (Broadbent et al. (2)). Fatigue is also associated with a change in the focus of attention. An early study of sustained performance in a flight simulator by Bartlett (3) showed that as performance time on task increased, changes in attention with an increase in errors occurred. Variable attention and anxiety status may possibly influence the ability to attend to a driving task. It has been suggested that fatigue could be experienced differently by drivers with different personality and temperament (Brown & Eng (4)). Lal et al. (5) have recently shown that mood and anxiety levels can influence task performance and outcomes. Other studies have indicated associations between brain activity and psychological factors such as anxiety (Heller et al. (6)). Although some studies have examined the neurophysiological concomitants of anxiety, firm conclusions about regional brain function associated with anxiety have been difficult to validate.

Are certain brain waves and psychological traits associated with better vigilance? Yamamoto and Matsuoka (7) suggested that when long lasting theta waves appear, a rest period should be considered before the subjects become fatigued. Deteriorated performance has been associated with increased theta and changes in alpha intensity while beta activity has also been shown to be altered (Townsend et al. (8)). Makeig and Jung (9) also found changes in theta and alpha waves related to fatigue. It has been suggested that in order to improve performance of people who are involved in long-term monitoring activities and monotonous tasks, such as drivers and operators, they should be taught to suppress theta (Andreassi (10)). Studies involving psychological factors, EEG and attention are scarce, but those that exist have produced interesting data. The question that needs further clarification is which psychological factors influence fatigue during a driving task. Understanding the psychological links to fatigue could provide useful insights for better fatigue management such as improving task performance and increasing attention levels in drivers. Therefore, the aim of the present study involved the investigations of the psychological associations during the transition from alertness to fatigue/drowsiness during a driver simulator task.

Methods

Subjects

Thirty-five subjects (26 males and 9 females) who were current non-professional drivers, aged 34 ± 21 years (range: 21-52), were recruited from a large tertiary institution and the local community and randomly assigned to the study. To qualify for the study, subjects had to have no contraindications such as severe concomitant disease, alcoholism, drug abuse and psychological or intellectual problems likely to limit compliance. This was assessed via interview and lifestyle questionnaires.

Study protocol

The study was conducted in a temperature-controlled laboratory (22-24º C) as the subjects performed a standardised sensory motor driver simulator task. The driving task consisted of 5 to 10 minutes of active driving to familiarise the subject with the driving equipment and video screen feedback. This was followed by driving for approximately two hours at a speed less than 80 km/hr till the subjects showed physical signs of fatigue. A video recording of the face provided an independent validation of fatigue.

Simultaneous EEG measures were obtained. Nineteen channel EEG was recorded according to the International 10-20 system (Fisch (11)). Anxiety, mood states and locus of control were evaluated immediately before the driving task. Trait anxiety and state anxiety were measured using the Spielberger State-Trait Anxiety Inventory (Spielberger et al. (12)). The Profile of Mood States provided a measure of six mood states: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia and confusion-bewilderment (McNair et al.(13)). Locus of control (LCB) of behaviour, a control efficacy measure, provided a measure of the subject's perception of the relation between events and their behaviour (Craig et al. (14)). The State Anxiety Inventory was re-administered immediately after the driving task. Fatigue levels immediately before and after the driving task were evaluated by a one item scale created specifically for this research study called the 'fatigue state question' which asked the subjects to respond to the following: 'Presently I feel fatigued (tired, drowsy)'. The choice of response ranged from 1-not at all, 2- slightly, 3-moderately and 4-markedly.

Statistical analysis

The EEG was defined in terms of frequency bands including delta (0-4 Hz), theta (4-8 Hz), alpha (8-13 Hz) and beta (13-20 Hz) (Fisch, B. J., 1991). For each band the average EEG magnitude (µV) and maximum amplitude (µV) were computed. The EEG data was compared for these phases to an alert baseline, which was identified from the video recording of the subject during the driving task. A sample size calculation provided a statistical power (1-?) of >0.9 based upon a moderate to large effect size of >0.9. The statistical power was therefore adequate for all comparisons performed. The score for each psychological measure was correlated to the average EEG change in each of the four bands during the transition to fatigue using Pearson's correlation. The site showing the maximum correlation with a psychological factor was reported. Multiple regression was then used to identify which of the psychological variables contributed significantly to the EEG variability associated with fatigue. The multiple regression was performed only with the EEG changes in the sites on the brain which showed significant correlation with the psychological variables. Since the psychological analysis in this study was exploratory, all significant results and trends to significance were identified. Since the investigation was exploratory, all p values <0.05 (non-conservative) are reported for the correlation. The significance level for the multiple regression was set at p<0.05.

Results

The subjects scored in the normal range for the psychological measures. The mean trait anxiety score was 36 ? 8.4, locus of control was 23 ? 8.6, and total mood score was 44 ? 24.4. The pre-study state anxiety of 32 ± 11.6 was not significantly different to the post-study state anxiety, which was 31 ? 9.1. The 'fatigue state question' identified subjects as slightly fatigued before the study and moderately to extremely fatigued after the study. The following correlation results are a typical representation for the entire brain. Table 1 shows all the individual psychological variables that significantly correlated with the EEG changes during transition to fatigue.

The following psychological associations were found with changes in EEG amplitude during transition to fatigue. Delta activity was associated with increased Trait Anxiety (r=0.40, p=0.02), post-study State Anxiety (r=0.42, p=0.01), Tension-Anxiety (r=0.40, p=0.02), Vigor-Activity (r=-0.44, p=0.009), Fatigue Inertia (r=0.39, p=0.02) and pre-study fatigue state (r=0.37, p=0.03). Theta activity was associated with Trait Anxiety and control efficacy (r=0.35, p=0.04 for both) and post-study fatigue state (r=0.44, p=0.009). Alpha and beta were associated with Fatigue-Inertia (r=0.36, p=0.03 and r=0.43, p=0.009, respectively). Beta activity was also significantly associated with pre-study fatigue state (r=0.49, p=0.003). For the magnitude changes, only delta showed trends of association. Delta activity was associated with Trait Anxiety (r=0.36, p=0.03), pre- and post-study State Anxiety, Tension-Anxiety, post-study fatigue state (r=0.40, p=0.02 for all four) and Vigor-Activity (r=-0.36, p=0.03). Figures 1 and 2 show examples of significant linear regression and correlation between some psychological factors and EEG activity during transition to fatigue.

Figure 1 A positive linear regression line of delta amplitude changes with Trait Anxiety

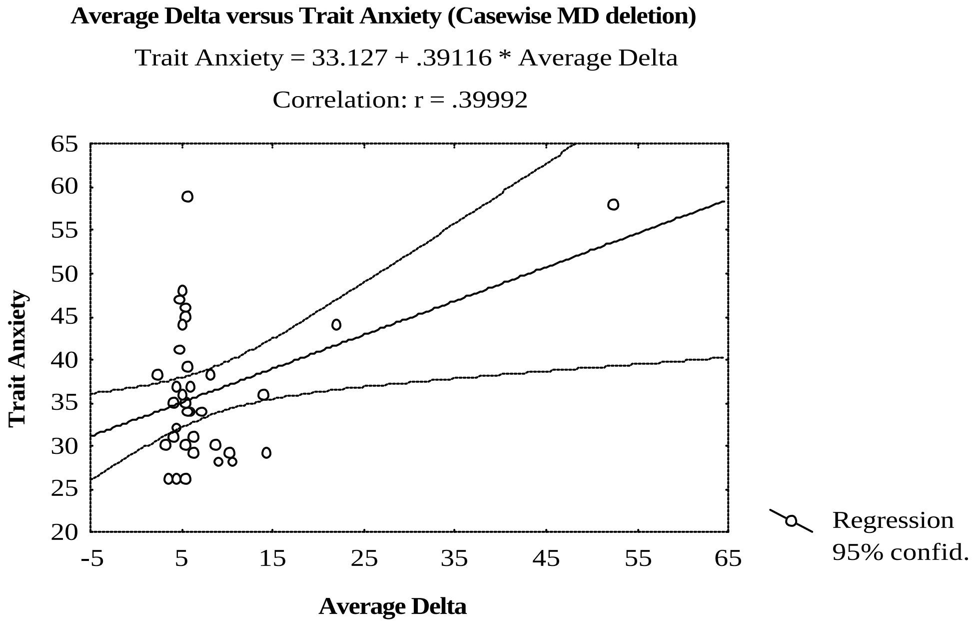

Figure 2 A negative linear regression line of delta magnitude changes with Vigor-Activity

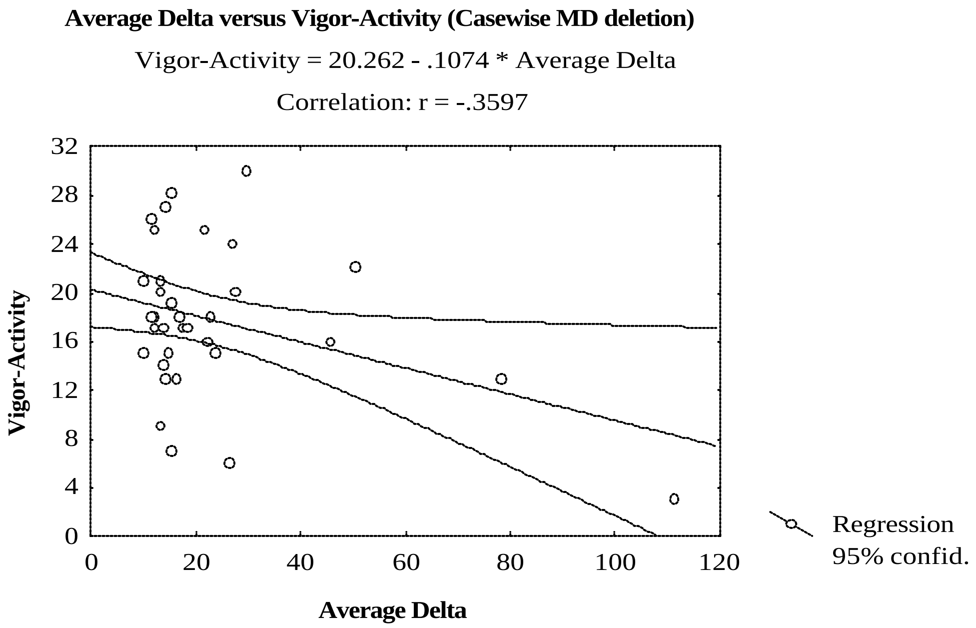

Table 1 Showing all correlation between average EEG changes across the entire brain and psychological variables at $p<0.05$

Psychological Measure **Amplitude associations**	**Delta**	**Theta**	**Alpha**	**Beta**
Trait Anxiety	0.40/0.02	0.35/0.04	-	-
Post State-Anxiety	0.42/0.01	-	-	-
Control Efficacy	-	0.35/0.04	-	-
Tension Anxiety	0.40/0.02	-	-	-
Vigor-Activity	**-0.44/0.009**	-	-	-
Fatigue-Inertia	0.39/0.02	-	0.36/0.03	**0.43/0.009**
Pre-study Fatigue State	0.37/0.03	-	-	**0.49/0.003**
Post-study Fatigue State	-	**0.44/0.009**	-	-
Magnitude associations				
Trait Anxiety	0.36/0.03	-	-	-
Pre State Anxiety	0.40/0.02	-	-	-
Post State Anxiety	0.40/0.02	-	-	-
Tension Anxiety	0.40/0.02	-	-	-
Vigor-Activity	-0.36/0.03	-	-	-
Post study Fatigue State	0.40/0.02	-	-	-

Note: Results are reported as correlation (*r*)/*p value*.
Significant correlation with $p<0.01$ are shown in bold.

Only psychological variables that correlated with EEG changes at $p<0.05$ were entered into a standard multiple regression analysis to determine those variables that uniquely contributed to changes in EEG signals associated with fatigue in different sites on the cortex. The regression for the frontal region was significant ($F=2.49$, $df=6, 28$, $p<0.05$, $R=0.60$, $R^2=0.35$, adjusted $R^2=0.21$) for six psychological variables (Trait anxiety, Tension-Anxiety, Vigor-Activity, Fatigue-Inertia and pre- and post-study state anxiety) together explaining 35% of the variance in delta activity during fatigue. However, the only individual factor that was significant in the regression equation was Fatigue-Inertia ($p<0.04$). Twenty four percent of theta variability ($F=5.0$, $df=2, 32$, $p<0.01$, $R=0.49$, $R^2=0.24$, adjusted $R^2=0.19$) in the temporal region of the brain was significantly explained by Trait anxiety ($p=0.04$) and post study fatigue status ($p=0.03$). Together Trait anxiety, locus of control and post study fatigue state explained 26% of theta variability in the central area of the brain ($F=3.72$, $df=3, 31$, $p<0.02$, $R=0.51$, $R^2=0.26$, adjusted $R^2=19\%$). When all three variables were entered into the regression, only post study fatigue status was significant ($p<0.05$). Fatigue-Inertia ($p=0.04$) and pre study fatigue status ($p=0.006$) accounted for 33% of beta variability in the occipital region during fatigue ($F=7.78$, $df=2,32$, $p<0.01$, $R=0.57$, $R^2=0.33$, adjusted $R^2=0.29$). For the magnitude changes, the regression was significant ($F=3.2$, $df=2,32$, $p<0.05$, $R=0.41$, $R^2=0.17$, adjusted $R^2=0.11$) for the frontal region with two variables (pre-and post-study state anxiety) explaining 17% of delta variability during fatigue. The subjects also completed a self-rated Fatigue State questionnaire before the simulated driving task. On the day of the study, majority of the subjects (60-80%) reported similar physical and mental fatigue levels as usual. Nearly 30% reported worse or much worse than usual fatigue states. Based on the assessment of the physical fatigue levels, 12 subjects needed to rest more and felt more drowsy than usual. Eleven subjects reported lack of energy and 8 found less strength in their muscles than usual. Nine subjects found that they could start things without difficulty but they got weaker much more than usual as they continued. From the mental fatigue assessment 8 to 11 subjects stated that their concentration, slips of the tongue and eyestrain were worse or much worse than usual. In their present lifestyle, six reported more problems than usual in thinking clearly and five reported more problems with remembering.

4.4 Discussion

The nature of driving requires cognitive effort, such as sustained vigilance, selective attention, complex decision-making and the exercise of largely automated perceptual motor-control skills (Brown, (15)). In early research, fatigue was conceptualised as a generalised response to stress experienced over time (Cameron (16)). In other words fatigue was viewed as not only the experience of symptoms associated with continuous work but also as the individual's ability to cope with the stressful demands that are responsible for those symptoms. Fatigue could therefore be viewed as a condition determined by both physiological and psychological factors. Since psychological and physiological changes are thought to be associated with fatigue, the current research aimed to isolate any psychological factors that may be associated with physiological changes in the EEG that occur during fatigue.

It was found that EEG changes occurring during the transition to fatigue in a simulated driving task were associated with psychological factors such as anxiety and mood. This suggests that psychological factors can influence fatigue status and hence driving performance. In a recent study, Lal et al. (5) showed that environmental stimuli and psychological factors such as mood and anxiety affect cognitive task performance. In the current study, it was found that increased trait and state anxiety, and negative mood states such as Tension-Anxiety and Fatigue-Inertia were associated with EEG indicators of fatigue such as increased delta and theta levels. The results suggest that having higher levels of anxiety are associated with higher levels of theta activity. Therefore, it is possible that increased anxiety status raises the potential to become fatigued. In this study 17% of the variation in delta activity during transition to fatigue was accounted for by state anxiety. For a single psychological factor to explain at least a fifth of the variance in EEG delta during fatigue is quite impressive. The results also indicate that having a higher Tension-Anxiety level (heightened musculoskeletal tension) also increases risks of experiencing fatigue. The Tension-Anxiety mood sub-scale incorporates somatic tension as well as observable psychomotor manifestations such as 'shaky' and 'restless'. It also refers to vague and diffuse anxiety states. Increased Fatigue-Inertia was also positively correlated to the EEG of fatigue. Fatigue-Inertia represents a mood of weariness, inertia and low energy levels. Not surprisingly, Vigor-Activity was negatively associated with increased delta activity occurring during fatigue. As the name suggests, this factor indicates a lack of vigorousness and high energy. Increased trait anxiety levels predicted theta increase and Fatigue-Inertia predicted beta changes during fatigue. Personality traits can be conceptualised as relatively enduring differences among people in specifiable tendencies to perceive the world in a certain way and in dispositions to react or behave in a specified manner with predictable regularity (Spielberger et al. (12)). Trait-anxiety refers to relatively stable individual differences in anxiety-proneness, that is, to differences between people in the tendency to perceive stressful situations as dangerous or threatening and to respond to such situations with elevations in the intensity of their state anxiety reactions (Spielberger et al. (12)). It is important to distinguish the effects of the two types of anxiety (state-trait anxiety and Tension-Anxiety, a mood sub-scale). Distinguishing types of anxiety may clarify the different associations found between brain activity and anxiety. For example, anxious apprehension and anxious arousal have been hypothesised to be psychologically distinct phenomena. Studies on regional brain activity have shown these two to be distinguished neurophysiologically (Heller et al. (6)). Therefore, in studies of brain activity for anxiety and mood states, it is important to specify the type of anxiety under examination. For practical purposes, fatigue may be conceptualised as the subjective experience of individuals who continue working beyond the point at which they are confident of performing their task efficiently. The experience of fatigue may therefore be regarded as behavioural and physiological feedback that provides a protective function, in that it predisposes the individual's response toward recovery and the avoidance of further stress. The results of this research suggests that being more anxious, having higher levels of psychomotor tension, cognitive inefficiency and low energy levels may hinder performance by raising the chances of becoming fatigued. This is the first study that has identified the possibility that mood states such as vigour, fatigue and anxiety may affect a driver's fatigue state and performance.

From the self-rated Fatigue State questionnaire, it was evident that similar numbers of subjects were suffering from physical (66%-89%) and mental fatigue (69%-86%) on the day of the study, similar to what they normally experience. However, the remainder of subjects reported that their fatigue levels were worse or much worse than usual. Given that the subjective component of fatigue is very important, questionnaire investigations may be beneficial in the study of driver fatigue.

Based on the assessment of the physical fatigue levels, 12 subjects felt more drowsy than usual. Eleven subjects reported lack of energy and eight found less strength and nine subjects found that they got weaker at tasks much more than usual as they continued. The assessment of physical fatigue denotes the amount of reduced performance of a muscle after stress and is characterised by reduced power and movement. Physical fatigue impairs co-ordination and increases chances of errors and accidents (Grandjean (17)). Physical fatigue is a complex phenomenon influenced by numerous psychophysiological factors and is associated with: (1) A decline in alertness, mental concentration and motivation. (2) Reduced work output. (3) Weaker and slower muscular contractions. (4) Muscular tremor and localised pain. (5) Loading of respiratory, circulatory and neuromuscular functions. (6) A decrease in the frequency of the electromyogram (EMG) signal. (8) A decrease in duration of sustained isometric exertions and endurance time. (9) Increased lactate accumulation. (10) Increased core temperature (Åstrand et al. (18)). From the mental fatigue assessment 8 to 11 subjects stated that their concentration and eyestrain were worse or much worse than usual. Six reported more problems than usual in thinking clearly and five reported more problems with memory. Mental fatigue is believed to be a gradual and cumulative process that is linked to disinclination for any effort, reduced efficiency and alertness and impaired mental performance (Grandjean (17), Grandjean (19)). However, it should be understood that many factors could influence fatigue such as nutrition, physical health (Wisner (20)), environment, physical activity (Sjoberg(21)) and recuperation periods (Okogbaa et al. (22)). Mental fatigue leads to a sensation of weariness, feelings of inhibition and impairs everyday activity. Generally, there is no desire for physical or mental effort and there is a heavy, drowsy feeling. A feeling of weariness is not unpleasant if allowed to rest, but can be distressing if an individual is not allowed to rest.

The above findings suggest that self-rated questionnaires can provide useful information on the fatigue experienced by a person in their lifestyle. It can also provide information about fatigue such as the time fatigue occurs and any factors contributing to fatigue. However, it should be noted that to maintain scientific validity, questionnaires alone cannot be the sole indicator/identifier of fatigue symptoms. Objective measures need to accompany these questionnaires for verification of fatigue. Questionnaire and survey research has limitations. For instance, they cannot provide moment-to-moment reports of fluctuations of sleepiness. Also self-report techniques could hardly be considered to measure sleepiness per se. Survey research is also prone to low validity and poor reliability. It would therefore be preferable to include both self-report and objective physiological measures when conducting fatigue related research. Not withstanding this, the findings from this study suggest that fatigue research would benefit from psychological assessments of mood states, anxiety as well as self-reported fatigue levels together with assessment of physiological changes.

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