An investigation into peripheral physiological markers that predict monotony

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Abstract

Behavioural performance gradually declines when individuals perform monotonous tasks. The road safety research community tends to agree that driver monotony alters driving performance, especially for professional drivers. Monotony is a well known but poorly understood driver state that can lead to road crashes. With sophisticated instrumentation it is possible to determine if a driver or test subject is likely to be in these or similar states.

This paper investigates the state of monotony to determine if relatively simple instrumentation can measure wether or not a driver is likely to be in or approaching this state. First the Mackworth clock test, a well known protocol for producing a monotonous state is reproduced in a laboratory based experiment. A number of physiological indicators and Electroencephalograph (EEG) are monitored during the experiment. The stimuli (event) contains 24 different targets the participant reacts to during a 1-hour testing session. The state of monotony is verified by continuous EEG recording, a baseline is determined by examining pre and post event activity. A range of possible peripheral measures are then also simultaneously recorded such as Galvanic Skin Response (GSR), Electrocardiogram (EKG), Electrooculograph (EOG), Electromyograph EMG and 3D head tilt (using a custom built accelerometer based device) together with user inputs. Preliminary results from a test pool of eight subjects indicates that some of these peripheral physiological measures may contain markers that correlate well with alpha and theta EEG activity, thus indicating the state of monotony. A sensor that shows a lot of promise for future research is the GSR. Inexpensive instrumentation and an in-car based test procedure are recommended for further investigation in order to develop a sustainable Monotony Diagnosis Module (MDM).

I Introduction

Driver fatigue is often solely regarded as sleepiness problem or condensed to a sleep deprivation problem. Fatigue is a multi-dimensional phenomenon. The context in which fatigue is evaluated must be broadened to include factors such as task monotony and not limited to sleep deprivation studies.

While most crash causes are multifactorial, monotony has never been satisfactorily associated with the other factors that contribute to crashes. Most of the studies on monotony have been conducted in laboratories. The road safety research community tends to agree that drivers' monotony alters driving performance, especially for professional drivers (Wertheim, 1978; Thiffault et al 2002; Thiffault et al; 2003; Dinges, 1998; Hartley, 1998). The lack of crash data prevents us from assessing the seriousness of monotony as a road safety problem. To our knowledge, there is neither objective nor subjective crash data that quantify the association between monotony and road crashes. This is probably due to the complexity of monotony and the absence of a clear distinction with other factors such as fatigue and hypovigilance.

Webster's dictionary defines monotony as *tedious sameness* and associates it with phenomena such as *boredom, ennui, dryness, flatness, uniformity*. Monotony is often associated with three dimensions:

- The nature of a monotonous task. Such a task is often repetitive, predictable or requires low activation of sensory organs. Straight, uneventful and long road infrastructure are well-known factors that contribute to the increase of driver monotony. Radar or lifeguard surveillance are other examples of monotonous tasks.

- The physiological or biochemical state of monotony. This dimension can be measured by physiological sensors such as EEG, skin conductance and possibly others as well e.g. head tilt.

- The psychological dimension of monotony, a subjective symptom of feeling boredom or lack of interest which can generate a range of physiological phenomena.

It has been shown in the past that performing a monotonous task causes a drop of vigilance over a period of time, providing a good starting point in researching physiological sensors to detect a monotonous state (Thiffault et al 2002). The symptoms of monotony causes an increase in EEG alpha and theta activities. Alertness affected the EEG spectrum when test subjects completed a monotonous task over time (Jung *et al*, 1997). Jung et al used both visual and auditory stimuli in a monotonous manner and had the test subjects participate in each task for 3 or more 28 minute sessions. EEG data was collected from both the central (Cz) site and midway between the parietal and occipital sites (Pz/Oz). The alertness of the subjects was measured by a local error rate that was the percentage of targets not detected. The results showed sharp increases in the EEG power at around and below 5 Hz and also near 14 Hz. These peaks in power correspond to the peaks in the error rate. The error rate rose as time progressed.

The aim of this experiment is to select a set of psychological sensors that can be reasonably used in cars and able to detect monotony symptoms with certain accuracy. Based on the clear results from (Jung *et al*, 1997), we use EEG measurements as reference point to detect the symptoms of monotony as opposed to use EEG as a monotony monitoring device that could be used in real driving conditions. In general EEG is too obtrusive and electrical activity from cars and movement artifact tend to interfere with EEG readings. Table 3 outlines the five sensors used during this experiment and brief description of why they were chosen for the task.

Sensors	Ease of use it	Factors	What it measures	Nb of Channels
EEG	Have a good understanding of where a drop in vigilance will occur in the data. Cannot use in a vehicle.	Will be the reference point for the other sensors for detecting a drop in vigilance.	Measures the brain waves from sites on the head. When a drop in vigilance occurs there is a rise in amplitude of theta and alpha waves.	2 (Cz and Pz)
EOG	Can tell the blink rate and blink duration easily. Good to monitor eye movement.	Easier to analyse blinks this way then going through video footage.	Eye movements are indicators of mental activities. EOG shows gaze pattern.	2 (vertical and horizontal movement)
GSR	Easily attached but requires some circuitry work to be able to measure on the existing system.	No reliable data. Good for car use as it is non-obtrusive	Skin conductance. This has been shown to change as the body goes into different states	2(bipolar)
EKG	Easily attached	Good for car use as it is non-obtrusive.	Measures heart rate. Heart rate decreases and variability increase during monotonous conditions	2(bipolar)
3D Accelerometer	Easily attached	Uses a different approach to measuring motion using an EMG sensor.	Attaches to the top of the head to measure any head movement.	4 (bipolar x-axis and y-axis)

Table 3 Possible Physiological sensor list for selection

II Methods

Routine psychophysiological pedagogy was used to conduct the tests in a laboratory based experiment as a precursor to trials in a car based investigation. The laboratory offers a more controlled environment and is better suited to a preliminary investigation where many sensors are required to be instrumented.

Subjects

The experiment was conducted in the psycho physiology laboratory at Griffith University, Mt Gravatt Campus after ethics approval was granted. 9 male university students were recruited. Subjects were asked to try and avoid any energy boosting drinks such as coffee before their session. To prevent any distortion from fatigue the experiment was always run before 1:30pm in a brightly lit, air conditioned isolated room.

Questionnaire

A brief questionnaire was given to each test subject to complete before commencement of the experiment to help highlight any reason for unexpected data and to get a subjective measurement of their state of mind . Following were the questions asked:

- Are you feeling tired or drowsy?
- How much sleep did you have last night?
- Have you had any caffeine or energy supplements this morning?
- On a scale of 1 to 5, rate how alert you feel.
- Do you suffer from any medical conditions?

After the completion of the experiment, the test subject was given another questionnaire to find their feelings throughout and after the experiment.

- Are you feeling tired or drowsy?
- If so…do you recall when you started to feel this way?
- Did you feel less alert as time progressed?
- Did you begin to daydream or blackout at any time?

Monotonous task

A computerised version of the Mackworth Clock Test (MCT), a well known protocol for producing a monotonous state, was implemented in Python development environment to provide the stimuli for the experiment (Lichstein et al, 2000). MCT task measure the ability to sustain attention in the face of monotonous stimulation. MCT has been used by NASA to assess monotony and fatigue of aircrews monitoring radar and control equipment involved the persons being tested to observe the second hand on a clock (Connors, 1985). The clock's second hand would occasionally jump more than 1 second at a time which is when the subject would have to react. This experiment gives the subject a repetitive task but tries to keep them alert by reacting to the targets (clock hand moving more then one second) and still keeping the task at a low intensity.

Task performance testing

The MCT works by having an arrow (representing the second on a clock) rotate in a circle 100 steps per cycle. At random times throughout the experiment the arrow will skip 4 places (a target). The technical specification of MCT is identical to (Lichstein et al , 2000) and summarized in Table 1. The simulation has been programmed in Python language and runs on 350 MHz PC. The monitor resolution was set to 1024x769 pixels on a 17" screen. Appearance of each event on the screen was monitored visually and recorded as a temporal marker with other psychophysiological measures for pre and post event synchronisation.

Requirement	Description
R1	Blank face.
R2	Triangular hand, base=0.5cm, length=3cm.
R3	100 steps per cycle.
R4	Test subject sits 0.5m away from computer screen.
R5	Target is 4 steps in 1 second
R6	12 signals per 30minutes.
R7	Signals occur at the following intervals: %min, %min, 1min, 1min,2mn,3mn
R8	First 30minute sequence is repeated for 1 hour test

Table 1: MCT technical specification

The test subject reacts each time a target appears by pressing the spacebar on the keyboard. Time of key-press is recorded and a hit, miss or false alarm is then written to a data file. A hit is when the difference in time the user clicks the target button to when the target actually appears is less than or including 8s. A miss is when the time difference between the click and target is greater then 8s or no click is recorded. A false alarm is when the time of the target button clicked is less then the time the target appeared (the user falsely presses the button before the target occurs). *Figure 2* represents the functionality and flow of the programme while *Figure 3* is a screenshot of the interface.

Physiological sensors to detect monotony

This section details different sensors that are believed to indicate monotony. These are EEG, EOG, GSR and EKG. I will now discuss each sensor in detail in the following subsections.

ElectroEncephalogram (EEG)

EEG measures the electrical activity (brain waves) at different sites of the head. An EEG cap, lined with electrodes measures these voltages and are recorded using a NeuroScan Synamp 2 instrumentation, recorded continuously by computer at a sample rate of 500Hz. The Synamp allows for up to 32 different channels to be continuously recorded. While only Pz and Oz are required for this study, all electrodes on the cap are recorded for future reference, additionally the following sensors are recoded as additional channels to ensure data synchronisation.

Galvanic Skin Response (GSR)

By applying an electrical current to the skin the changes in skin conductance and resistance can be detected. GSR measures indirectly subtle changes in the sympathetic nervous system which affect the moisture and, through that, the conductivity of skin. These changes can be explained by Edilberg's sweat model – sweat ducts in the epidermis act as variable resistors, when they fill they cause a decrease in resistance or an increase in conductance. The tonic level of skin conductance has been shown to rise when a person is performing a variety of tasks and when anticipating the performance of the tasks (Belz, 2000). From this statement it may be assumed that when a user is approaching a monotonous state while doing a continuous task then the anticipation to perform a task will decrease. This decrease will result in a decreased level of conductance and an increased level of resistance. The best point at which to measure skin resistance is the thumb and forefinger because this part of the body is most heavily represented neurological *(GSR, 2001).* A typical person's skin resistance falls in the range of 5k to 25k ohms.

Electrocardiogram (EKG)

The electrocardiogram (EKG) records the complex rhythm of the hearts electrical activiy including the heart-rate of a person. There has been very few studies involving the EKG and monotonous tasks but monotony has been shown to cause a decrease in the heart-rate and an increase in heart-rate variability (Belz, 2000).

3D Head movement accelerometer

Head movement can be recorded in number of different ways, two techniques were selected. Electromyography (EMG) measures the muscles controlling the neck, secondly a dual-axis accelerometer can measure orientation to gravity and hence changes in position. The accelerometer was chosen as it gave accurate details of direction and size of movement as well as providing a less obtrusive in-car application when compared to the EMG. An ADXL202E accelerometer from "Analogue Devices" is used (www.analog.com). It is a low-cost +/-2 g dual-axis accelerometer with analogue outputs of 1.5V +/- 0.22V for a 3V voltage source. Output voltage is lowered to within Synamp specifications (183mV to 36mV) using ą voltage divider and fits in a matchbox size case. The case Electromyograph was attached parallel to the top of the test subjects head using double-sided tape.

III Physiological data collection

The MCT produced 24 different targets over a 1 hour testing session that required a response from the test subject. Different physiological sensors, believed to be able to indicate monotony, continuously recorded electroencephalography (EEG), electro-occulography (EOG), electrocardiogram (EKG), galvanic skin response (GSR), and head movements were attached to the subject. Figure 1 shows a sample of data record using Neuroscan software.

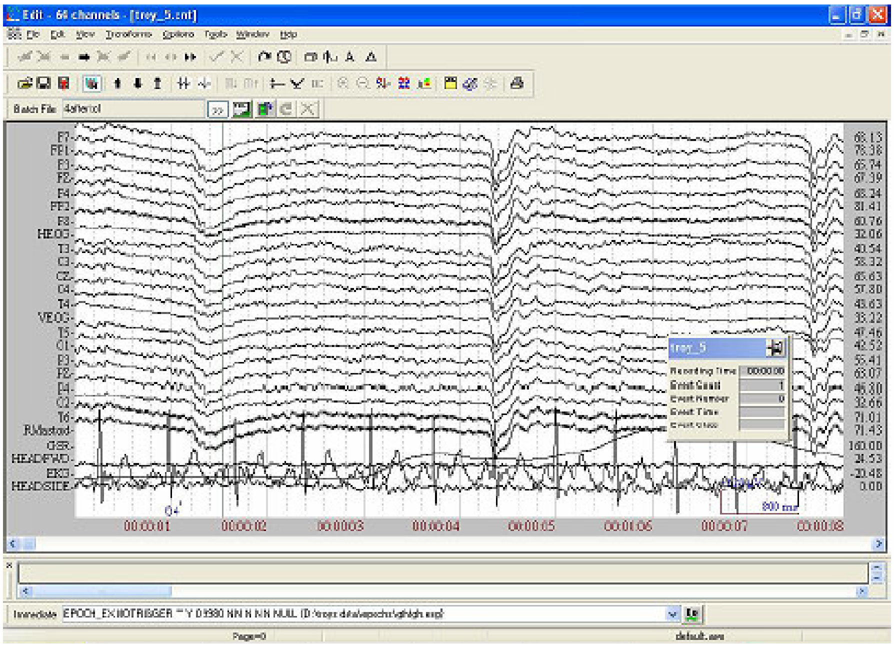

Fig 1: Screenshot of physiological data with Neuroscan

The physiological data was converted into epochs pre and post target occurrence using the MCT event marker to provide a baseline for each event. Alpha and theta brainwaves were analysed from the EEG data to identify the state of monotony. Heart rate was measured from the EKG, eye blinks from the EOG, amplitude of skin response from the GSR. Head movements were also noted.

Results of Monotony Measure

Results for each sensor were taken from different epochs created from the raw continuous NeuroScan Acquire data. To analyse the way test subjects responded to a target appearing an epoch was taken both directly before and after the target occurred. Epochs for the EEG were taken 2s either side while the remaining sensors excluding GSR epochs were taken 4s either side. GSR was only analysed from an epoch of 4s after a target, as a skin response occurs only after some stimulus is shown. GSR, EOG and EKG measurements for all test subjects were averaged against the target number and plotted together with standard deviation in Figure 1.

EEG

EEG results were processed to show how the power of theta (4Hz to 7Hz) and alpha (8Hz to 12Hz) rhythms changed over time for all test subjects. This was done by converting the EEG data to the frequency domain. Summary data across subject, pre and post event were obtained using Matlab. Final results for all test subjects and then was plotted in a 3D graph showing changes in alpha and theta over time before and after a target occurred.

EEG Alpha waves

Alpha waves are brainwaves that fall within the frequency range of 8Hz to 12Hz. The alpha waves were extracted from the spectrum analysis and the average amplitude across the frequency range was calculated. *Figures 2a* graph shows an obvious rise in the amplitude across the alpha waves for all test subjects before they have to react to a target on the screen. Of note is that as time progresses there is a drop in vigilance (seen as a rise in alpha activity), in accordance with studies conducted by (Jung *et al, 2000)*. The same trend occurs after the target (*Figure 2b)* but the average amplitude is larger contradicting what was predicted. This increased amplitude maybe caused by low frequency movement artefacts involved with pressing the button on the keyboard.

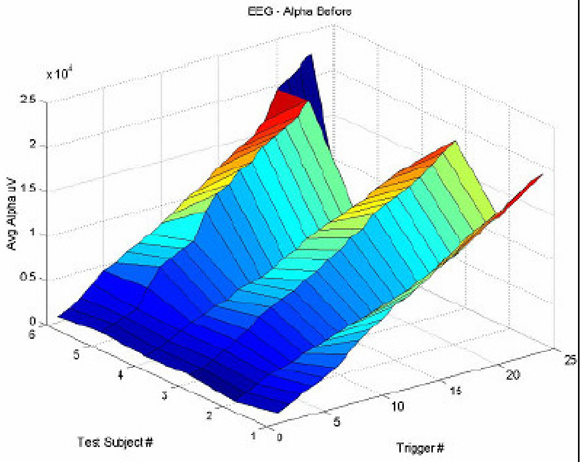

Figure 2a : EEG – Alpha before a target occurs

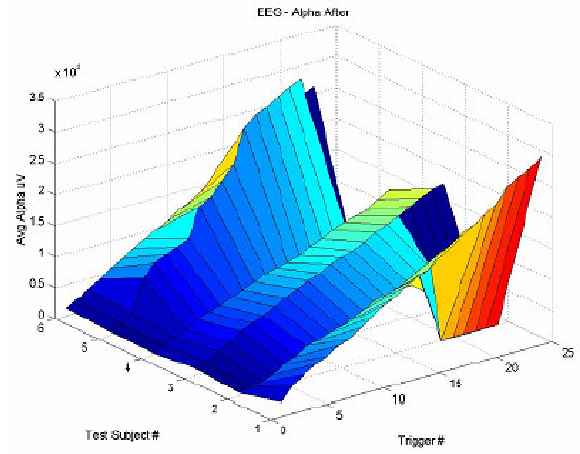

Figure 2b EEG – Alpha after a target occurs

EEG Theta waves

Theta waves are brainwaves that fall within the frequency range of 4Hz to 7Hz. *Figure 3a* and *Figure 3b* show the amplitude still increasing with time after the target has occurred. The reaction to the target causes a much larger 'jump' within the theta waves. As it has been previously shown that both the alpha and theta waves increase in amplitude when alertness has decreased from a monotonous task, the above results confirm that the programmed Mackworth Clock Test and experiment simulate a monotonous task. This is an important result as it demonstrates the validity of our experiment design and data collection, thus allowing a future scaling up of the methodology and study.

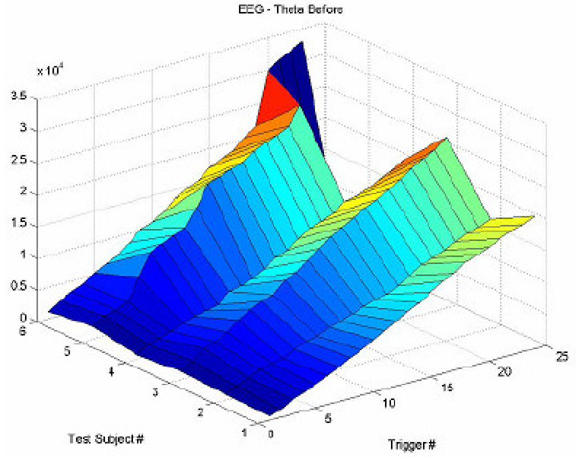

Figure 3a : EEG – Theta before a target occurs

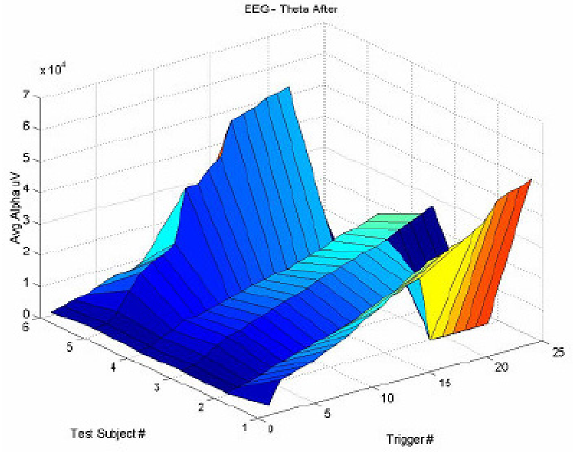

Figure 3b: EEG – Theta after a target occurs

EOG

For EOG, the blink rate was measured by manually counting the number of blinks that occurred in each epoch both before and after a target. Blink duration was also manually measured by taking the time blink began, as the sudden rise in the waveform, to the time the blink completed. If more than one blink occurred in an epoch then the average duration was used.

Figure 4a and *Figure 4b* show the average number of blinks that occurred 4s before and after a target respectively. The high standard deviation (SD) in blinks from before a target appearing shows somewhat inconsistent results between test subjects, this variability is expected as the number of blinks is comparatively low in each epoch. To lower the SD a larger subject pool would be required in the study. Over all subjects the number of blinks increased towards the end of the experiment with the major increases occurring during the 2nd half-hour. There is slight difference between the number of blinks before and after the target in the first 7 targets. As this occurred during the early stages this change would be a result of the test subject concentrating on the screen, and, once a target appeared, refreshing the eyes by blinking. These results were not expected and appear to show the test subjects becoming drowsy. Tunnel vision and constant stare arising from monotony as described by (Wertheim,1978) was tested but there were no consistent results in the horizontal eye movement to show the eyes fixating on one point towards the end of the experiment.

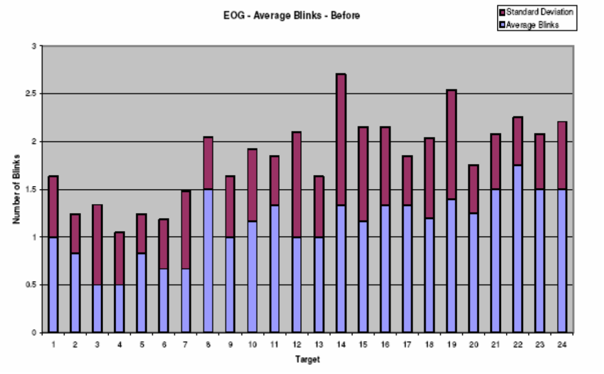

Figure 4a: EOG Average number of blinks before a target

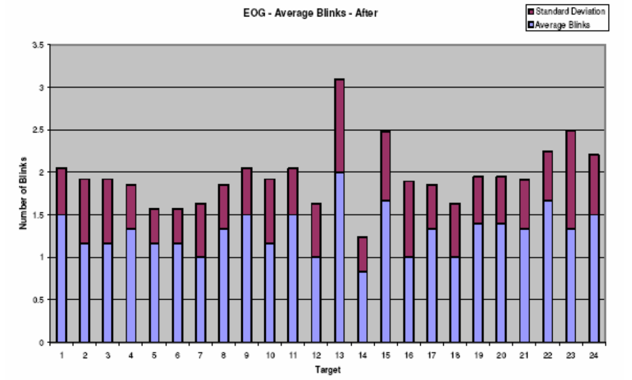

Figure 4b: EOG Average number of blinks after a target

EKG

From the raw EKG data, heart-rate was calculated by counting each beat (QRS complex), the time it took from the start of the first full beat in the epoch to the time of the last full beat and dividing it by the total number of beats. This was calculated both pre and post event.

Figure 5a and Figure 5b shows the average heart rate of all test subjects before and after a target appears respectively. Both show a higher heart rate at the beginning of the experiment which, as for the GSR, can be attributed to the settling-down of the test subject into the flow of the experiment. Perhaps a conditioning task is required to improve data quality. The average hovers just below 80 beats per second both before and after a target and with little variation between the two. From this it is unlikely that the EKG will be of any use when detecting monotony.

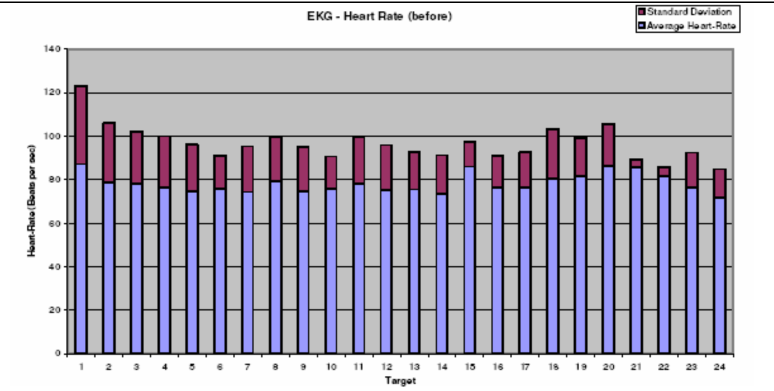

Figure 5a : EKG – Average heart rate before a target

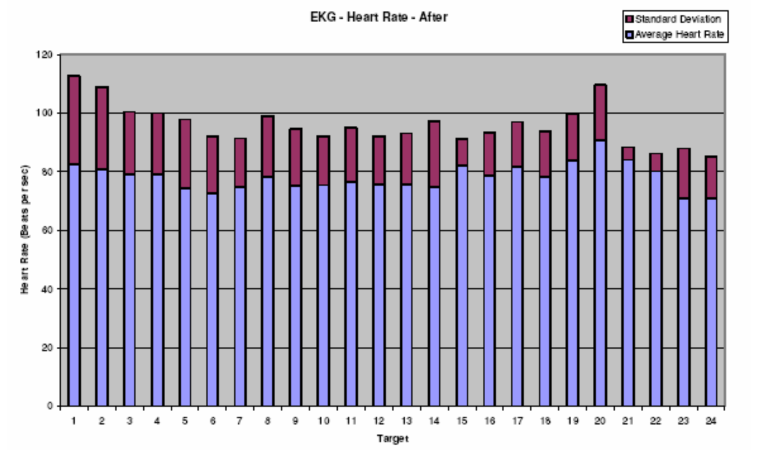

Figure 5b: EKG – Average heart rate after a target

GSR

GSR was measured by the change in amplitude of the skin response from the beginning of the rise to the maximum height before it began to drop again. Since a galvanic response can only detected after a target has appeared the pre event data is ignored. *Figure 6* shows the amplitude of the GSR after a target has occurred. At the beginning of the experiment there are several large responses from all subjects. This could be the cause of the subject not being fully aware or not habituated of what to expect by reacting strongly to target. Up to target 12 we note the GSR is decreasing as time progresses. This could be attributed to habituation. In between target 12 and 13 appearing on the screen there is a 12min gap. During this time the participant is habituated to no targets appearing so when one finally does appear they have a strong galvanic response. This triggers a larger skin response as can been seen from target 13. As time progresses, the responses begin to decrease again. A large response occurs at target 20 but the high standard deviation (SD) shows that the result is biased by an abnormal result for one of the test subjects.

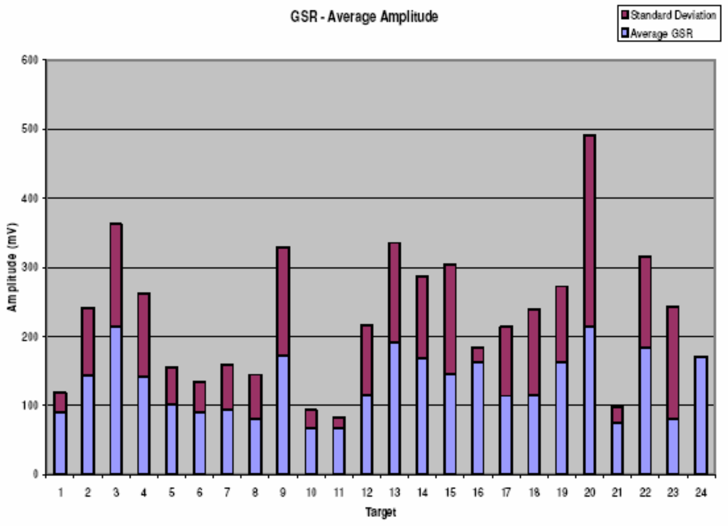

Figure 6 : GSR – Average amplitude of a skin response after target

3D Head Movement

Head movement was measured by counting the number of head movements in each epoch before and after targets by excursions above a baseline using a predetermined threshold. Visual analysis of the head accelerometer channel in both the x-axis and y-axis revealed very little movement throughout the entire experiment for all test subjects. Any movements that did occur were in no consistent pattern and after questioning the test subjects after completing the experiment were usually from them stretching their neck. Nothing representing nodding or swaying of the head was found.

IV Discussion

Results of EEG, EKG, EOG, GSR, and head movement from a computerized version of the Mackworth Clock Test on 9 test subjects, provide possible ways to further the development of a Monotony Diagnosis Module. With little existing studies on monotony some sensors produced better results then others at detecting monotony. The rise in theta and alpha frequencies within the EEG has proven that the Mackworth Clock Test successfully simulates a monotonous task. The EEG was used as a general indicator od state of mind and co-indicators were sought from simpler instrumentation.

The heart rates absence of change (over time and between the before and after epochs) eliminate the sensor from detecting monotony. Alhough more complex data maybe present within the EKG records; it is thought that this would be difficult to record and extract on a consumer based device located in a car.

In this study there was also a lack of consistent head movement giving no useful results towards the study. Due to the laboratory environment in which the experiment was conducted this sensor cannot be eliminated yet from future research. The MCT requires focus on a small section of a computer monitor removing the need of head movement that may be present when driving a car. When driving, rear and side view mirrors are regularly checked as well as general scanning of the outside road conditions. It may therefore be possible that lack of head movement is actually a symptom of monotony.

Using a combination of sensors to detect monotony allows for a device less susceptible to failures and false alarms. Each individual sensor must show significant changes over time indicating it is changing with the test subject's state of mind. The sensor must also be suitable to an in-vehicle environment. From this study the best combination of sensors to detect monotony will be the amplitude of the GSR with the number of blinks from the VEOG. A large change in the amplitude of the skin response correlating with a greater then normal blink rate is a possibility of how the sensors could be used accurately to detect a monotonous state.

For the project to proceed onto a real world in-vehicle study, the study outlined by this paper must be repeated with careful attention to the results obtained here. Specifically

a) A conditioning experiment will increase the validity of the initial phase of the MCT
b) The task needs to simulate head movement normally associated by drivers as it is postulated that the absence of head movement may be a monoty indicator
c) An increase in the subject pool will increase the statistical vbalidity of the results

Once a combination has been finalised a new experiment must be designed to study how the sensors are affected by an in-vehicle environment. Results from this new study must be thoroughly analysed so a clear distinction can be made when a person is in a monotonous state. This method must be developed into an automated process to later be implemented into a MDM.

The MDM should be made up of non obtrusive components that take measurements identical to its physiological sensor counterpart. For example: instead of attaching electrodes around the eye to measure eye blinks, a video capture device mounted on the dashboard of the car could detect eye blinks with some sort of blink identification algorithm. Skin responses could be recorded by a wrist watch type device with electrodes mounted under the face. This could double as an EKG with an electrode mounted on the wrist band to take the pulse on the wrist's underside. The head accelerometer is ideal for an in-vehicle environment (if it becomes prominent in detecting monotony) as it small and easily mounted anywhere on or around the head.

V Conclusion

This research investigated possible instrumentation that detects driver monotony. A laboratory based investigation has been undertaken measuring a wide range of physiological measures together with established procedures that generate monotony (Mackworth test) and EEG activity (a well understood techniques for determining monotony but unsuitable for mobile applications because of instrumentation complexity). Physiological sensor measures, specifically EEG, EOG and GSR, have been shown to change at different stages throughout a monotonous task. It is therefore feasible to detect a monotonous state using certain physiological sensors. These results must now be confirmed with larger (laboratory and real world in-vehicle) studies before a Monotony Detection Module is developed. By determining a way to detect monotony, the number of road accidents could potentially decrease, saving money and lives.

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