Assessment of cognitive load through biometric monitoring

Klemen Novak*, Kristina Stojmenova**, Grega Jakus** & Jaka Sodnik**
* NERVteh, Ljubljana, Slovenia
** University of Ljubljana, Faculty of electrical engineering, Ljubljana, Slovenia
klemen.novak@nerv-teh.com, {kristina.stojmenova, grega.jakus, jaka.sodnik}@fe.uni-lj.si

***Abstract*— This study explored the relationship between human biometric signals, such as heart rate, galvanic skin response (GSR) and skin temperature, and cognitive load induced by a secondary cognitive task in a simulated driving environment. NERVteh motion-based driving simulator [1] was used to simulate an immersive driving environment. Microsoft wrist band was used for collection of driver biometric data. Cognitive load was induced with the Delayed Digit Recall Task (*n* – back task) [2] and the Detection Response task (DRT) [3] was used as a reference measurement. The results show that it is possible to reliably detect changes in cognitive load with a low cost device, such as the Microsoft wristband 2 [4]; however, specific cognitive difficulty levels cannot be differentiated. Galvanic skin response and skin temperature showed to be better indicators for increased cognitive load compared to mean heart rate data, when performing measurements with a low cost wristband.**

Keywords: biometric, cognitive load, heart rate, galvanic skin response (GSR), skin temperature, fitness band, Detection response task (DRT), *n* – back task.

I. INTRODUCTION

In everyday situations such as learning new information, driving a car or even talking – human cognitive load is constantly changing. The limitation of the capacity of the working memory sometimes leads into cognitive overload, which can cause the course of processing new information to be changed or even stopped [5]. People however, rarely detect when they experience cognitive overload in everyday tasks. In such situations humans cannot consciously prioritize which information should be processed and which should be left out. In most daily situations this can go unnoticed, as people simply try to perceive the unprocessed information once again later; however, this can be quite dangerous when put into a dynamic or challenging situation, for example while driving a car or working on a rooftop of a building. It is therefore useful to try to find ways how to detect increase in cognitive load in various situations, in order to be able to avoid possible defective outcomes due to it. Furthermore, it is especially interesting to find unobtrusive and relatively robust measurements, which can be performed also in dynamic situations, without interfering with the primary task and that can obtain good signal-to-noise ratio results. In this study, we present an evaluation of three different parameters: heart rate, galvanic skin response and skin temperature that could be used to indicate changes in cognitive load.

II. RELATED WORK

Cognitive load has been observed in many different fields, and special attention has been given to dynamic situations such as aviation and driving [6]. Assessing cognitive load and finding ways to reduce it in these environments can be crucial; however due the environments nature is not always as simple. Researchers have therefore searched ways to replace direct measurements such as neurological brain activities-electroencephalogram (EEG), and instead have looked for alternative indirect measures. Observing biometrical data such as: heart activity [7], skin responses [8, 9] or even pupillary activity [10], have shown to be good indicators of changes in cognitive load. The technology used for obtaining this kind of data is also important. Due to the active performance of pilots and drivers, easy wearable and unobtrusive measurement equipment has also been explored such as wristbands and similar wearable technology, and the obtained results showed to be quite encouraging [11]. This allows collection of data in dynamic environments also out of the laboratory, in many different experimental set-ups.

The aim of this study is to explore the correlation between different biometric data and increase in cognitive load, using non-invasive and low cost equipment – a fitness wristband. In this paper, we try to answer the following research question:

Can changes in cognitive load of drivers be detected based on changes in skin temperature, galvanic skin response and heart beat rate (beats per minute), using a low cost device?

III. METHODS

We performed a short between-subject design experiment with 8 participants. Biometric data was collected with a Microsoft Band 2 wrist band [12], equipped with various biometric sensors, such as heart rate sensor, galvanic skin response sensor, and temperature skin sensor. Data from the wristband was collected with a custom developed Android application, displaying data real time on a mobile phone screen (in our case OnePlus2 [13]). Additionally, the application was connected to a PC, and could receive simple "START" and "STOP" messages to control the wrist band.

A. *Reference measurement*

As a reference measurement for detecting changes in cognitive load, we used the tactile Detection response task (TDRT) [3]. With this method, a small vibromotor is placed on the driver's collar bone, and is presented tactile (vibration) stimuli every 2-5 seconds. The driver than responds to the stimuli by pressing a button, placed on the right hand index finger, against the steering wheel. Response times are than processed as the indicators of cognitive load.

B. *Cognitive task*

For inducing cognitive load, we used the Delayed Digital Recall task (modified *n* – back task) as a cognitive task [2]. This task requires the driver to vocally repeat auditory presented single digit numbers with a certain time delay, as presented in Table 1. We used three levels of difficulty: 1-back, 2-back, and 3-back task.

Table 1: Consecutive order of presented numbers and required answers for the 2-back task

	Consecutive order of n – back task numbers							
Presented number	1	3	8	5	3	9	4	5
Driver's answer	--	--	1	3	8	5	3	9

C. *Experiment design*

The experiment was performed in a NERVteh driving simulator [1], using countryside scenery, where the driver drove on a single lane two-way road.

Figure 1. Experimental set-up

Participants were asked to drive within the lane, and to follow a car in front of them at a self-estimated safety distance. Participants were explicitly asked not to overtake the leading car. As their second priority, they were asked to promptly answer to DRT stimuli and to perform the secondary cognitive task as accurate as possible. The dependent observed variables were: heart rate, galvanic skin response (GSR), skin temperature, and DRT response times. The independent variable was the cognitive load, presented in three difficulty levels.

The experiment consisted of 5 trials, each lasting approximately 90 seconds. In the first trial, participants did not perform any task. This trial was used a reference measurement. In the second trial, participants had to drive in the simulator and answer to DRT stimuli. In the remaining three trials, they had to drive, answer to DRT stimuli and perform a cognitive task that differed in difficulty in each of the trials.

IV. RESULTS

The results from a linear model analysis (Between-subjects effects test) for the *n* - back task showed significant results between response times ($p<0.05$) to DRT stimuli when exposed to different levels of cognitive load. Pos hoc tests showed statistically significant differences between trials without the cognitive task and trials with the 1-back and 3-back task ($p<0.01$)(Figure 2).

Between-subjects effects test showed that there were statistically significant differences in heart rate ($p<0.01$). Post hoc Bonferroni test showed significant differences in heart rate between the rest mode trial compared to all active trials and trials without the cognitive task compared to all trials with a cognitive task ($p<0.01$). Significant differences were also found for the trial with highest cognitive load (3-back task) compared to trials with lower level of cognitive load ($p<0.05$)(Figure 3).

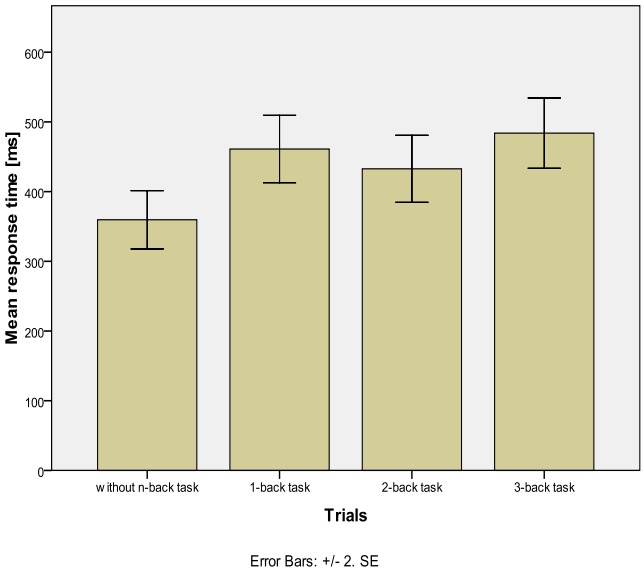

Figure 2. Mean response times for trials without and with different levels of imposed cognitive load

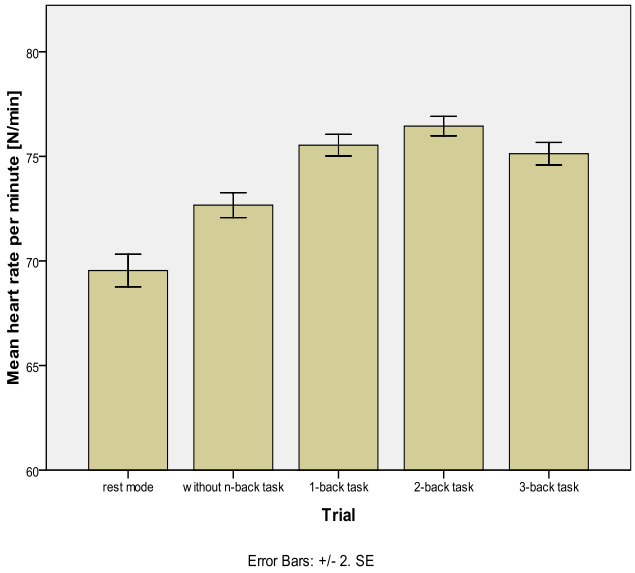

Figure 3. Mean heart rate for each trial.

Based on Between-subjects effects test, there are significant differences between GSR ($p<0.01$). Post hoc Bonferroni test showed significant differences in GSR between the rest mode trial compared to all active trials and trials without the cognitive task compared to all trials with a cognitive task ($p<0.01$)(Figure 4).

Between-subjects effects test showed significant differences also for changes in skin temperature ($p<0.01$). Post hoc Bonferroni test showed significant differences in skin temperature between the rest mode trial compared to all active trials and trials without the cognitive task compared to all trials with a cognitive task ($p<0.01$)(Figure 5).

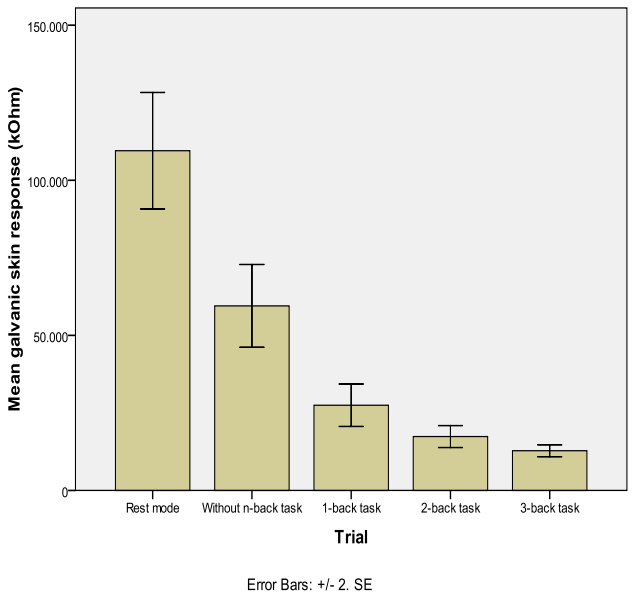

Figure 4. Mean galvanic skin response for each trial

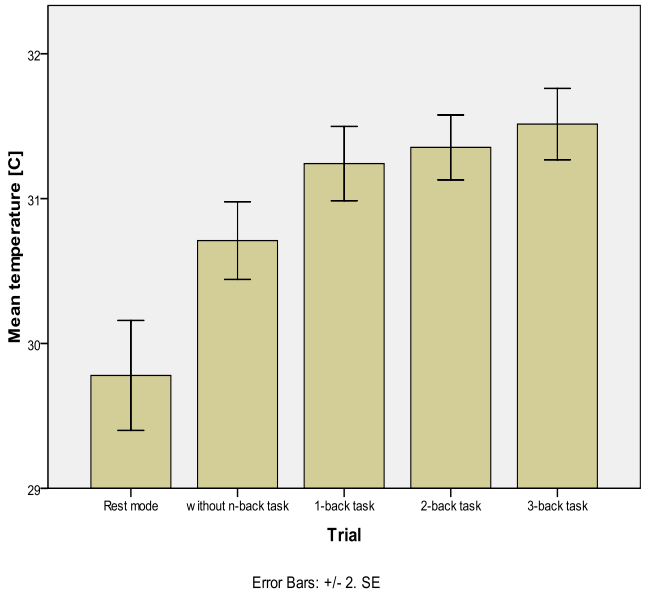

Figure 5. Mean skin temperature for each trial

V. DISCUSSION

Results on the DRT response times, showed changes in cognitive load for different levels of cognitive difficulty, however, the increase in response times was not proportional to the increase in level of cognitive difficulty. One of the possible reasons for this kind of results could be learning effect which may have occurred due to the fact that participants always started with lowest level of cognitive load, and finished with the most demanding one.

For the biometric data, we report also on the first trial – rest mode, a 90 second long period of time at the beginning of the experiment during which participants were asked to sit and try to relax in order to obtain their usual heart rate, GSR and skin temperature. The results of the heart rate measurements show increase in beats per second for every level of increased cognitive load except for the highest. We can speculate that the participants were at the beginning of the experiment more altered and after few trials started to relax, which could be the reason for reduced heart rate for the highest level of cognitive load.

The results for GSR and skin temperature on the other hand show significantly higher difference - in kOhm and C° respectively - between trials without and with a cognitive task. However, the results did not show significant differences between different levels of cognitive load. This could mean that the observed biometrics can be used to detect change of cognitive load, however cannot be used for differentiation of different levels of cognitive difficulty. Here it is important to take into consideration that the measurements were performed with a low cost device, and that a professional tool for assessing these biometric parameters may show significant differences also between different levels of cognitive load. The results could also have been affected by the duration of the experiment – the longer a person wears the wristband, sweatier and warmer their hands become. This effect can be reduced if the participants wear the wristband few hours prior to the experiment. Furthermore, the used wristband does not provide continuous data on GSR and skin temperature values; it

sends data only when a change occurs. This means that the data samples were different for each trial, which may have also influenced the results.

I. CONCLUSSION

The results showed significant differences in the observed parameters, indicating that biometric data such as GSR, heart rate and skin temperature obtained with a low cost device can be observed as indicators of increased cognitive load.

However, the post hoc test revealed that these indicators couldn't differentiate between different levels of cognitive load, as there were not found any significant differences among the trials with different levels of cognitive load. This was also present in the results for the DRT, rising question whether cognitive load was properly induced. Another significant influencing factor that must be considered is also the relatively small number of participants in the study, and the limited capability of the device for appropriate collection and representation of the observed biometric data. In our future work, we are going to repeat the study with a professional wrist band for capturing biometric data (ex. Empatica [14]) and compare the results with this study.

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