Physiological Signals in Driving Scenario

How Heart Rate and Skin Conductance Reveal Different Aspects of Driver's Cognitive Load

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Abstract: Driver's cognitive load has always been associated with the driver's heart rate activity and his/her skin conductance activity. However, what aspects of cognitive load that these signals relate to have never been clearly studied. This paper presents our preliminary results about the relationship between the different physiological signals (heart rate and skin conductance) and the driver's cognitive load. Via one experiment with simulated car driving environment and one experiment in real flying environment, our data suggests that subjects' heart rate relates to the number of events to be processed by the human driver while the skin conductance relates to the novelty of the driving task. Given the small population involved in these experiments, tests on more subjects are planned and reported in the future.

1 INTRODUCTION

Advances in technology nowadays have created increasingly intelligent devices, including smartphones, high performance computers, and assistive robotic systems. The ultimate objectives of all these new technologies are always to ease human's works, provide a better living environment, and help the human in his/her daily activities. We argue that the user's internal state is a very important information for these systems during an interaction/cooperation task, and by applying psychology knowledge about emotional intelligence, we can customize the system to fit the user's preferences and thus maximize the benefit of the Human-Machine Cooperation.

In fact, psychologists had recognized the undeniable role of human's emotional process in the adaptability of human race, as described in (Scherer, 1986), (Lazarus, 1991). It is also well known that emotional intelligence greatly relates the human's ability to cope adaptively with changing situation and thus stressful situations (Matthews and Zeidner, 2000) (Zeidner et al., 2006). However, while emotion modelling draws increasing interest of researchers in virtual agents and social robotics to simulate human's emotional process in artificial creatures (Dang et al., 2011), emotion-based interaction seems to occupy a marginal place in research domains such as Human-Machine Cooperation. Most of the research in the field, study individual phenomena of human's emotional process (such as attentional tunnelling) (Tessier and Dehais, 2012), anxiety (Liu et al., 2006), or negative and positive affective states in children (Leite et al., 2013).

In the domain of intelligent vehicles, the internal state the most studied is the driver's "Cognitive Load". The cognitive load represents how much information is processed in the working memory of the driver. If the driver's cognitive is overload, his/her performance may decrease. When someone is cognitively overload, his/her stress level may increase as a result of intensive use of working memory. It is thus possible to calculate the cognitive level of human driver from his/her physiological signals (such as heart rate, skin conductance). For example, in the works of (Engstrom et al., 2005), (Davies and Robinson, 2011), the effect of visual and cognitive load of the drivers in simulated and real driving situation was studied. Their results show that these measures can be good candidates to assess drivers' cognitive load, especially in the real life situations. Tessier and colleagues in (Tessier and Dehais, 2012) studied the cognitive load of people remotely controlling a robot for search missions. They also tested and found that skin conductance and heart rate variability are good indicators of one's cognitive load level.

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However, while these researches are supporting the theory that various physiological signals help to predict the cognitive load, we've found very few works that look into the role played by each of these physiological signals in predicting human's cognitive load. This is the aspect addressed in our paper. We present some preliminary results that show the link between the various physiological signals (skin conductance and hear rate) and the human's behaviors and we reveal interesting information about the human's cognitive load.

2 DRIVING IN SIMULATED ENVIRONMENT

The objective of the experiment with the simulated environment is to study the change of cognitive load of the human drivers in different driving situations, such as changes in traffic flow, dangerous pedestrians, changes of driving conditions (e.g., city driving, countryside driving). To assess the driver's cognitive load, we use the physiological signals such as heart rate activity and skin conductance activity.

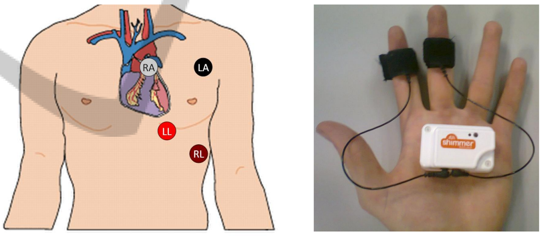
2.1 Experimental Setup

To simulate the driving environment, we use the software named TRS (Traffic Simulation) provided by the company *nisys GmbH* [1]. TRS gives us a wide range of possibilities to organize the traffic simulation for our case. The virtual vehicle is controlled by the human subject via a Logitech's G27 Racing Wheel and Pedals.

The equipment used in this experiment consists of a computer that runs the TRS simulation, a projector to project the simulated driving scene on the white wall, the Logitech G27 wheel and a gas pedal and brake, and a chair where the driver sits during the whole experiment (as shown in Fig. 1).

The driving course prepared for the experiment consists of 47 km of road, including countryside lanes and city streets. The parameterizable events of the system are the pedestrians passing the road in a dangerous manner, the number of simultaneous cars on the road, the side-ward scene (busy city or peaceful countryside). We designed two difficulty levels of the drive: easy drive and difficult drive. The difficulty level of the drive is measured by the interval between two consecutive events of the same type. For example, in the easy drive, a pedestrian passes in a dangerous manner the road every two minutes, and in the difficult drive, this interval is shortened to one minute.

Figure 1: Scene setting of the experiment in simulated driving environment.



a)

b)

Figure 2: Positioning of a) Shimmer ECG electrodes and b) Shimmer GSR electrodes.

For the retrieval of heart rate data (and skin conductance) of the driver, we used Shimmer ECG (respectively, GSR) sensor to acquire the driver data in real-time and transfer this data via Bluetooth communication to the computer for further processing. ECG (GSR) sensor is strapped on the driver's body (left hand) and connected to the four (two) electrodes as recommended in the Shimmer ECG (GSR) User Guide [2] (Fig. 2). The sample rate is 51.2Hz for the ECG sensor and 10.2Hz for the GSR sensor.

2.2 Subjects

The participants were recruited through local community. Twelve subjects participated (2 females and 10

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[1] http://www.nisys.de/

[2] http://www.shimmer-research.com

males), their age varies between 23 to 47, with a mean age of 27. They all have technical background.

2.3 Procedure

Before starting the experiments, the participants filled a pre-study questionnaire about their demographic information. At the beginning of the experiments a short introduction about the context and the setting was presented to the users. The physiological sensors were attached to the body of the participants for the measurement of the heart rate and the skin conductance in real-time. The participants are given 10 minutes to try the simulator and to get used to the driving setting.

The main experiment consisted of 10 minutes of music relaxation and 20 minutes of driving. The 10-minute of music relaxation helped us to measure the baseline threshold of the physiological signals of the participant for further use. The step of music listening serves to put the participant in a relaxation state (minimize the cognitive load), which can be used as a reference to distinguish between the driving state and non-driving state. In the 20-minutes driving setup, the first half of the time-period is the easy driving part and the second half corresponds to the difficult driving part. As explained earlier, the difference between the difficulty levels consisted in the occurrence interval of the traffic-related events. These traffic-related events include passing pedestrians, traffic lights, other cars on the road. In our design, the event's occurrence interval of difficult driving part is set-up as half as the one used for the easy driving part. Moreover, the easy drive setup corresponds to a peaceful countryside environment, while the difficult drive has busy city sight environment.

During the 20-minutes driving, we also asked participants to do a secondary task, which is the blink their signal light when they see a particular lightbulb on the side of the street. This task is intended to help us assess the participant's cognitive attention during the drive. Unlike the traffic-related events, the occurrence interval of this particular lightbulb is not changed between easy and difficult drive.

Moreover, our driving system is equipped with a vocal feature that warns the driver about some traffic-related events, such as passing pedestrians and traffic lights. The vocal warning messages are played about 3 seconds before the occurrence of the events, so as to help the driver to better cope with the situation.

At the end of the drive, the participants are asked to answer a questionnaire about their emotional impression about the drive and the design system.

2.4 Hypothesis

With the experiment of driving in simulated environment, we want to test the following hypotheses:

- **Hypothesis 1.** Participants' heart rate should correlate with the difficulty level of the driving task. The more difficult the task is, the higher the heart rate level is.
- **Hypothesis 2.** The participants' skin conductivity should correlate with the difficulty level of the driving task. The more difficult the task is, the higher the skin conductance level is.

2.5 Data Analysis and Discussion

In the scope of this paper, we will present the results of the physiological signals collected from the experiment. The average skin conductance level and the average heart rate of each participant in the simulated driving condition are depicted in Figure 3 and Figure 4. The overall average of these physiological signal data are presented in the Table 1.

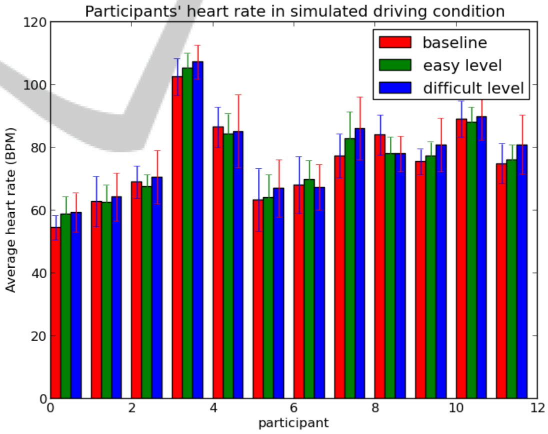

Figure 3: Average heart rate of the participants in simulated driving condition.

Table 1: Overall average (and standard deviation) of the physiological signals (heart rate in Beat Per Minute and skin conductance in MicroSiemens) from the experiment of driving in simulated environment.

Physio. Signal	Heart rate	Skin Conductance
Baseline	75 (12)	3.25 (1.9)
Easy level	76 (12)	3.95 (2.3)
Difficult level	77 (12)	3.24 (1.9)

As observed in Figure 3 and from Table 1 about the data related to the heart rate activity of the participants, their heart rates have the lowest level in the relaxation situation (i.e., only listening to the music) and the highest level in the difficult driving level sit-

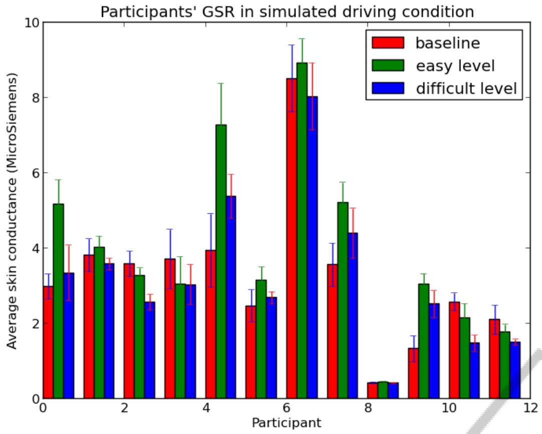

Figure 4: Average skin conductance level of the participants in simulated driving condition.

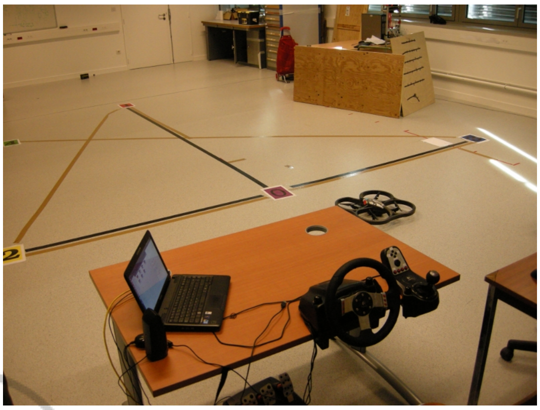

Figure 5: Scene setting of the driving experiment in real environment.

uation. Inversely, the skin conductance data reveals a different view. From Figure 4 and from Table 1, participants' skin conductance measure in the easy driving level situation is higher than in the difficult driving level situation. This finding supports our Hypothesis 1. but the skin conductivity does not support our Hypothesis 1. For the Hypothesis 2, our finding shows that skin conductivity does vary in terms of the task difficulty, but not in the supposed manner, thus it rejects our Hypothesis 2 about the correlation between the skin conductivity and task's difficulty level.

To discuss further about our results of heart rate activity and skin conductivity, we suggest that the difference between the two signals is completely normal. That is, while heart rate correlates with the intensity of events' occurrence during the drive, skin conductance variability correlates with the complexity of the driving task. In our design, the intensity of events' occurrence changed between difficulty levels but the types of events did not change across the levels. This may suggest that heart rate signal might represent how intense human subjects processed the driving situation at cognitive level and skin conductance signal may be representative of how complicated the execution task is.

Moreover, the difference between the heart rate activity and the skin conductivity can also be explained by the fact that the participants are exposed to a simulated driving environment. This has already been discussed in the work of (Davies and Robinson, 2011) that points out that when exposed to a simulated environment, people do not necessarily get as stressed as in real situations. In order to further investigate our findings, we conducted a follow-up experiment where people are invited to drive a real quadrotor drone following predefined trajectories. We present in details the experiment setting and results in the next section.

3 DRONE DRIVING IN A REAL ENVIRONMENT

We conducted a follow-up experiment where we invited people to drive a PARROT quadrotor drone using the Logitech's G27 Racing Wheel. In this section, we present the experimental setting, procedures and preliminary results that we obtained recently.

3.1 Experimental Design

The real-world drone driving system consisted of the Logitech's G27 Racing Wheel, a computer running Linux and ROS, and a PARROT quadrotor from PARROT company [3]. The computer served to map the wheel signals to the quadrotor's flying commands and to do additional data collection and processing.

The driving environment is a closed room of 4x4 m2. On the ground there are coloured markers serving to define different flying trajectories. Markers are connected by straight lines (serving as flying tracks) (as shown in Figure 5). We designed two difficult levels. Easy flying trajectory consisted of moving from one marker to another while staying on the tracks until all marker are visited. Difficult flying trajectory consisted of moving from an initial marker to one marker then going back to the initial marker before moving to another marker. During the flight, the target marker is shown on the screen so that the driver knows which target he/she has to fly to. Images from the below camera of the quadrotor are sent to an image processing program that helps to detect if the quadrotor is on track or not and to detect if the quadrotor is arrived at the target marker or not.

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[3] http://www.parrot.com/

A vocal system has also been implemented and can be activated to additionally assist the driver during the flight. It uses the result from the image processing system to determine the appropriate message. The vocal assistance system is used to warn the driver about the quadromotor position (on/off track) and to announce the next marker when a new targeted marker became available. It also helps the driver to keep track of the timing.

For the retrieval of heart rate data and skin conductance data of the driver we used the same system as described in Section 2.1.

3.2 Subjects

The participants are recruited through local community. Seven subjects participated (1 female and 6 males), their age varies between 24 to 33, with a mean age of 27. They all have technical background. One of them did not participate in the previous experiment with the simulated driving system.

3.3 Procedure

Before starting the experiment, the participants were asked to fill-up a pre-study questionnaire about their demographic information. After that, a short introduction about the experiment context and the setting was made. The physiological sensors are then attached to the body of the participant for the real-time measurements of the heart rate and the skin conductance signals. The participants are given about 20 minutes to learn to fly the quadromotor with the Logitech's G27 Racing Wheel and to get used to the driving setting.

The main experiment consisted of 5 minutes of music relaxation and four times of 5-minutes flight. We designed four different conditions: in terms of difficulty level (easy trajectory vs. difficult trajectory) and vocal assistance (vocal assistance activated vs. vocal assistance not-activated). Trajectories are predefined and announced to the participant before the beginning of each flight. The participant is asked to finish each trajectory in 5 minutes or less. If he/she finishes the trajectory before 5 minutes he/she can pass to the next condition. The order of the four conditions are changed from one participant to another. After each condition, the participant is asked to answer a questionnaire about his/her emotional impression about the flight before beginning the next flight.

At the end of the experiment, the participants are asked to fill-up a last questionnaire about his/her overall impression about the system.

3.4 Hypothesis

With the experiment of driving in a real environment, we want to test the following hypotheses:

- **Hypothesis 1.** Participants' heart rate should correlate with the difficulty level of the driving task. The more difficult the task is, the higher the heart rate level is.
- **Hypothesis 2.** The participants' skin conductivity should correlate with the repetitiveness of the driving task. The more repetitive the driving trajectory is, the lower the level of the skin conductance is.
- **Hypothesis 3.** The variability of the participants' physiological signals between task conditions in the real world environment experiment should be greater than the variability of these signals in the simulated environment experiment.

3.5 Data Analysis and Discussion

As stated in the previous section, for the purpose of this paper, we will present only the results of the physiological signals collected from the experiment. The average skin conductance level and the average heart rate of each participant in the drone driving condition are depicted in Fig. 6 and Fig. 7. The overall average of these physiological signal data is presented in Table 2.

Table 2: Overall average (and standard deviation) of the physiological signals (heart rate in Beat Per Minute and skin conductance in MicroSiemens) from the experiment of driving the quadromotor drone in a real environment.

Physio. Signal	Heart rate	Skin Conductance
Baseline	79 (5)	3.66 (3.1)
Easy level	82 (8)	5.08 (3.2)
Difficult level	84 (9)	4.69 (3.3)

Interestingly, the heart rate and the skin conductance level of the participants collected during this experiment show the same phenomenon as in the previous experiment with the simulated driving environment. This also supports our two hypotheses (i.e. Hypothesis 1 and Hypothesis 2) about the activity of these physiological signals for this experiment. It is observable from Figure 6, Figure 7, and from Table 2) that heart rate correlates positively with the difficulty level of the flight and the skin conductance signal correlates negatively with the difficulty level of the flight. Moreover, the variation of physiological signals in this experiment is larger than in the previous experiment. This can show that human subjects have higher internal reactions in real situations rather than

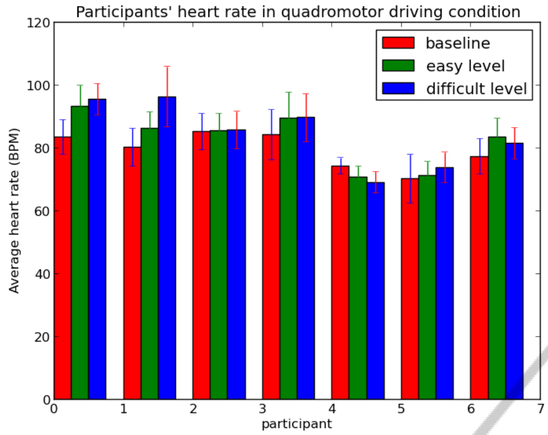

Figure 6: Average heart rate of the participants in quadromotor drone driving condition.

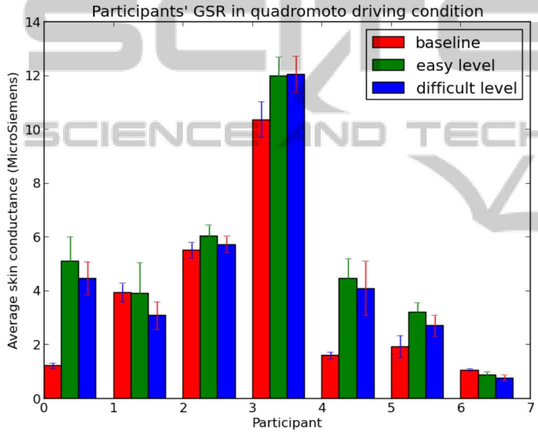

Figure 7: Average skin conductance level of the participants in quadromotor drone driving condition.

in the simulated situations. This supports our Hypothesis 3 about the variability of the subjects' physiological signals in real situations comparing to simulated situations.

From these results, we suggest that heart rate is a better indicator of the human subject's cognitive load while the skin conductance is best to describe how human subjects' feel about the task's novelty. The number of events to be processed while executing a task can affect the human's heart rate, the repetitiveness of a task can influence the human's skin conductance level. However, our current findings are from a very small population, thus need more experimental data to be conclusive.

4 CONCLUSIONS

Throughout the paper, we have been presenting our early findings about how to use heart rate activity and skin conductance to predict different aspect of human's cognitive load in driving situations (car simulation and drone real-world). Via one experiment in simulated car driving environment and one experiment in real drone driving situation, we found that heart rate can reveal information about how cognitively charged people are when confronting with occurring events while driving, whereas skin conductance would help us to know if the driver is confronting with a novel situation or not. However, statistical analysis on larger test population is needed in order to validate the suggested hypotheses. More experiments are schedule and we will report our further findings in future publications.

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REFERENCES

Dang, T., Hutzler, G., and Hoppenot, P. (2011). Emotion modelling for intelligent agents - towards a unifying framework. In *WI-IAT '11, 2011 IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology*. IEEE Computer Society.

Davies, I. and Robinson, P. (2011). Emotional investment in naturalistic data collection. In *International Conference on Affective Computing and Intelligent Interaction*.

Engstrom, J., Johansson, E., and Ostlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. In *Transportation Research*.

Lazarus, R. S. (1991). *Emotion and Adaptation*. Oxford University Press, London, 2nd edition.

Leite, I., Henriques, R., Martinho, C., and Paiva, A. (2013). Sensors in the wild: exploring electrodermal activity in child-robot interaction. In *Proceedings of the 8th ACM/IEEE international conference on Human-robot interaction*, HRI '13, pages 41–48. ACM/IEEE Press.

Liu, C., Rani, P., and Sarkar, N. (2006). Human-robot interaction using affective cues. In *RO-MAN '06*.

Matthews, G. and Zeidner, M. (2000). Emotional intelligence, adaptation to stressful encounters and health outcomes. In *Handbook of emotional intelligence*.

Scherer, K. R. (1986). On the nature and function of emotion: A component process approach. In *Approaches to emotion*.

Tessier, C. and Dehais, F. (2012). Authority management and conflict solving in human-machine systems. In *The Onera Journal*.

Zeidner, M., Matthews, G., and Roberts, R. D. (2006). Emotional intelligence, adaptation, and coping. In *Emotional intelligence in everyday life: A scientific inquiry*. Psychology Press.