The PERFORM Mask: A Psychophysiological sEnsoRs Mask FOr Real-Life Cognitive Monitoring

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Abstract. Everyday life is driven by a wide range of mental processes organized in cognitive, emotional and executive functions. The assessment of these abilities could be improved thanks to the rising of Virtual Reality (VR) technologies, that show a more ecological validity in respect to the artificial laboratory settings. Moreover, mental processes can be investigated via electrophysiological measures, due to the modulation of deep structures controlling the autonomic system, and in turn peripheral organs activity. According to scientific literature, measurements could derive from sensors over periocular area, that is the same area covered by a typical VR headset.

The aim of this paper is to introduce the PERFORM prototype, a wearable mask with embedded sensors able to collect biomedical signals in a non-obtrusive way for the assessment of online cognitive abilities in VR scenarios. We show that PERFORM can collect data related to cardiac pulse, galvanic skin response, movements and face temperature during cognitive tasks in VR. Thanks to the specific electrode placement and the employment of VR scenario, PERFORM will be an ecological tool to assess psychophysiological correlates of online cognitive performances.

Keywords: Cognitive functions · Virtual reality · Psychophysiological signals

1 Introduction

Herein we present the PERFORM prototype, a wearable mask with embedded sensors intended to collect biomedical data in a non-obtrusive way. This mask could be used for assessing real-time cognitive functioning during tasks, putatively performed in virtual reality (VR) environments. The PERFORM prototype would allow studying cognitive functions in naturalistic-like scenarios of VR. The concept of PERFORM prototype is based on previous psychophysiological studies that we summarize in the following. On these bases, we identified the most effective sensor placements to collect signals in a non-obtrusive way for detecting the physiological correlates of cognitive functioning.

G. M. P. O'Hare et al. (Eds.): MobiHealth 2019, LNICST 320, pp. 86–93, 2020.
https://doi.org/10.1007/978-3-030-49289-2_7

1.1 Cognitive Functions: A Brief Overview

Cognition is involved in everything a human being might possibly do; that every psychological phenomenon is a cognitive phenomenon. Cognition refers to all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used [1]. Cognitive functions comprise a variety of mental processes including attention, memory, decision making, perception and language comprehension: however, cognitive abilities are strongly sustained by executive functioning, driving people to achieve everyday goals [2–4]. Classically, cognitive functioning is assessed in the laboratory with a neurocognitive approach that measure scores and time during the execution of specific tasks; however, investigating parsed and isolated components of cognitive functioning has also limitations [5, 6] since they might not reflect the integrated abilities during real-life in which the focus of attention has to cope with the complexity of real scenarios [7].

1.2 Virtual Reality: An Ecologic Alternative to Laboratory Setting

Virtual reality (VR) is an evolving technology that allows the immersion in and the interaction with near-realistic 3D scenarios [8, 9]; it leads to the development of the "sense of presence" by means of a constant interaction and manipulation of the virtual scenario [10, 11].

Thanks to its characteristics, VR can be used to study cognitive functions in ecologic, naturalistic-like scenarios, allowing overcoming classical limitations of neurocognitive assessment and thus scientific advances in the direction of assessing cognitive abilities such as attention [6], spatial abilities [5, 12], memory [13] and executive functions [14, 15] in real-life [16, 17].

1.3 Central and Peripheral Electrophysiological Markers of Cognitive Functions

Most of the cognitive and executive functions involve brain structures located in the frontal lobe, from which volleys of activity modulate deep structures controlling the autonomic system, the heart rate, the skin blood flow and sweating activity [18].

Compared to cognitive correlates directly from brain activity (via electroencephalography), more robust against movement artifacts [19] and thus more robust for ecologic studies (freely behaving, etc.). Actually, from these signals, the following cognitive correlates can be derived:

- Galvanic Skin Responses (GSR): the changes of the electrical conductance of the skin in response to pulsatile sweat secretion. GSR is a correlate of sympathetic nervous system activity [20];
- Heart Rate (HR): the inverse of the frequency of heartbeats. Changes in HR has been related to cognitive/emotional activations;
- Heart Rate Variability (HRV): indices of HR variability as a function of time of frequency. The indices correlate with the activity of different components of the autonomic nervous system;

– Skin Temperature (T): the face skin temperature is an indirect indicator of a subjective cognitive state. The physiological replication of increasing blood flow to the facial skin is triggered by the autonomic nervous system [21];

On this basis, we conceived a device able to collect in a non-obtrusive way peripheral physiologic signals with correlating the cognitive functioning in VR environment. A suitable solution that we explored was the integration of all the sensors into a single wearable headset, in order to record real-time biomedical signals during cognitive tasks in VR without constraints related to multiple body sites of recording (electrode wiring issue, etc.).

2 Methods

In order to assess real-time cognitive functioning, we chose to record specific psychophysiological parameters (i.e. GSR, HR, T, movement) that are susceptible to cognitive abilities. The choice of the wearable mask in which the sensors are embedded in is intimately linked to the need of recording signals in non-obtrusive way, in order to avoid confound or side effects related to an invasive signals collection. Moreover, the placement of the sensors above the periocular area is highly motivated by the need of projecting a headset to wear during VR task.

2.1 Where to Place Sensors?

The idea is to place the sensors within a wearable headset. We verified the feasibility of the idea on scientific literature that confirmed that sensors placed over periocular area could be valid tool for collecting physiologic peripheral signals:

– Forehead is one of the most reactive body sites to collect GSR, due to its high sweat gland density [22];
– Glabella (the small area between the eyebrows and above the nose) is a valid site to collect pulse signal thanks to the thinning of cranial bone. For this reason, in respect to the gold standard measures (i.e. clinical setting monitoring), it is less invasive [23];
– Forehead, as well as peri-orbital region, represent two face sites for the collection of skin face temperature [24, 25];

2.2 How to Collect Signals?

Despite the great flexibility among the systems currently marketed for the acquisition of biomedical signals, some limitations such as GSR sensor placement, no-dry ECG electrodes, not available sensors to collect the surface temperature in order to perform differential measurements have to be highlighted.

For this reason, we chose a personal computer as signal processing device, while for the hardware platform we decided to use Arduino Nano for the collection of biomedical parameters.

We also developed a tailored software (compatible with Windows 10 O.S.) for data acquisition from PERFORM system. The software is able to real-time visualizing and recording the signals from PERFORM.

In order to design a sensorized headset, signals will be collected by a set of seven dry electrodes placed as describe in the follow:

- four sensors for temperature: two over the forehead and two over the zygomaticus muscle;
- two sensors over the forehead for recording GSR signal;
- one central sensor over the glabella for recording HR signal;
- 3-axial accelerometer placed on the left side of the mask for recording movements;

Locating all the sensors in the periocular space allows integrating them into a wearable mask suitable for the detection of selected parameters during cognitive performance (Fig. 1).

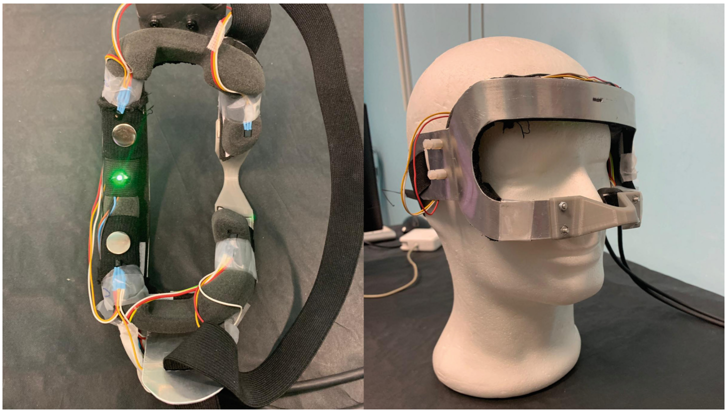

Fig. 1. PERFORM mask prototype: on the left sensor placement in the foam, on the right a front view of the wearable mask.

In the PERFORM prototype, the multiple signals recording has been based on two Arduino Nano 3.x electronic boards, and as biosignals we adopted the following:

- GSR: sensore Grove – GSR (Seeed Technology Co., Ltd.);
- HR: PulseSensor (World Famous Electronics llc);
- Temperature: digital sensors DS18B20 (Maxim Integrated);
- Accelerometer: 3-Axis Analog Accelerometer; Axis Analog Accelerometer (Seeed Technology Co., Ltd);

For bio-signal collection, two Arduino Nano are used:

- Arduino 1 for GSR, Pulse sensors and Accelerometer.
- Arduino 2 for T sensors.

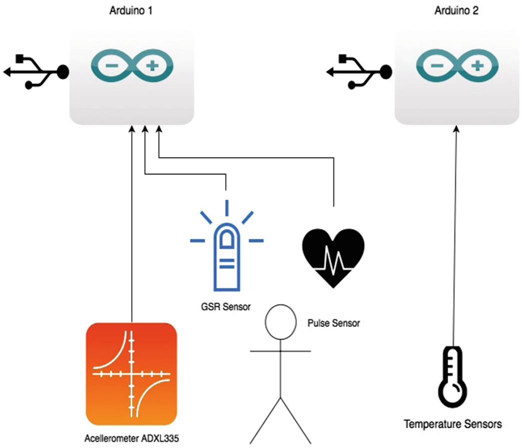

Fig. 2. Schematic description of the PERFORM prototype.

Both Arduino 1 and 2 are wired to a software station via serial communication interface (Fig. 2). This software is conceived for the real-time monitoring of biomedical signals, as well as their processing and storing.

3 Results

The actual prototype of PERFORM can acquire and store the data from sensors ranging from GSR, to heart pulse, movements and skin temperature during the performance of cognitive task. All the sensors are embedded in a foam of a common VR headset. In Fig. 3 the signals (10 s) from different sensors are shown. We are validating PERFORM recording signals while undergoing different cognitive tasks implemented on PEBL

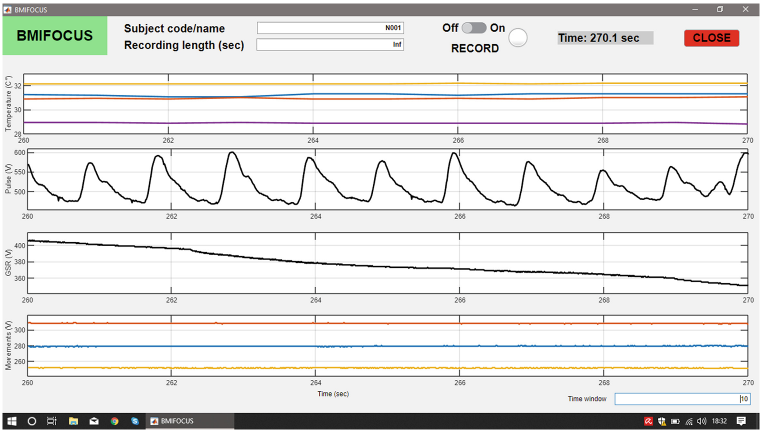

Fig. 3. Ten seconds window of real-time signals from temperature, Pulse, GSR sensors and accelerometers.

software [26]. The cognitive assessment comprises tasks for multicomponent evaluation of: attention (divided, focused, sustained attention); executive functions such as risk taking, decision making, problem solving; visuo-spatial abilities. The sensors will collect signal variations during the task performance associated to the psychophysiological correlates of cognitive functioning. In Fig. 4 an example of one task with the recorded temperature time course is shown.

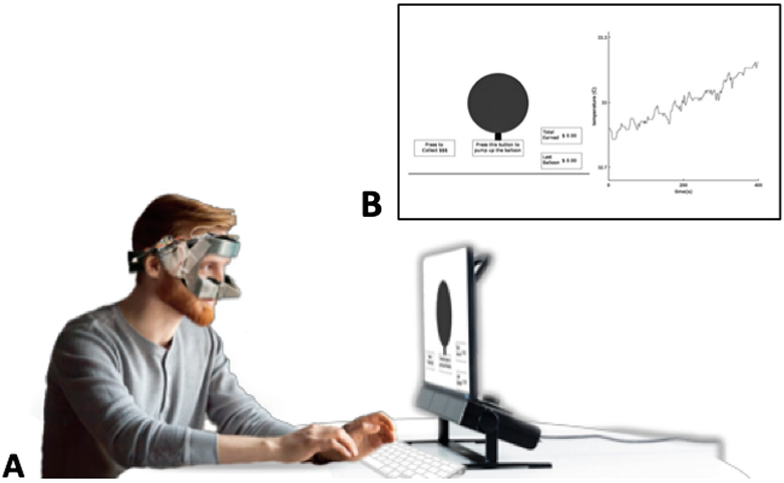

Fig. 4. Panel A. The Balloon Analogue Risk Task (BART) is a cognitive test for measuring risky decision making, i.e. how the potential for reward versus loss is balanced. In the task, the participant is presented with a balloon and earns money by incrementally inflating the balloon, however, at some threshold, the balloon is over inflated and explodes; at this point the participant loses all previously earned money. The participant must decide when to stop inflating and save the earned money. Panel B. Monitoring skin face temperature during the task showed an increasing trend.

4 Conclusion

VR offers an ecological and integrated assessment of cognitive functions. For the electrophysiological assessment of cognitive abilities, the investigation of peripheral activity - GSR, HR, T- is more suitable and ecological than electroencephalography and, herein we demonstrate that all these parameters can be feasibly collected from periocular area. Based on the current lack of ecologic settings for signal collection during cognitive functioning, we present the PERFORM prototype, a wearable mask embedding multiple sensors aimed at collecting biomedical data for assessing real-time cognitive abilities during task in VR. This wearable headset, with GSR, T, Pulse and Movement sensors integrated into the foam of common VR headsets, can be a solution for the "ecologic validity issue" related to classical neuroscientific investigation of cognitive abilities.

Acknowledgments. The research leading to these results was funded by the Project “Brain Machine Interface in space manned missions: amplifying Focused attention for error Counter-balancing” (BMI-FOCUS, Tuscany Region POR CREO 2014/2020). We also thank Davide Cini and Andrea Berton (both at the Institute of Clinical Physiology – CNR Pisa) for the technical assistance.

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