Brain Activity Tracking Using Smart Eyewear

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Abstract

This paper describes our approach towards the concept of a brain fitness tracker. A wearable sensing platform that is capable of tracking cognitive load and mental state of the user. We discuss some of the promising sensing modalities, implementations and approaches as well as physiological mechanisms that can give us valuable insights on the cognitive processes.

Author Keywords

Sensing; Smart Eyewear; Facial Thermography; Electrodermal Activity; Cognitive Activity Tracking; Mental State Tracking

ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous; See [http://acm.org/about/class/1998/]: for full list of ACM classifiers. This section is required.

Introduction

Our world is changing faster than ever before. It is becoming increasingly interconnected, smartphones have become an indispensable part of our life, Internet connection speeds grow exponentially. All these changes have resulted in an explosive growth of available information. In our everyday lives, we are exposed to more information than we can process. Now the biggest issue is the attention deficit.

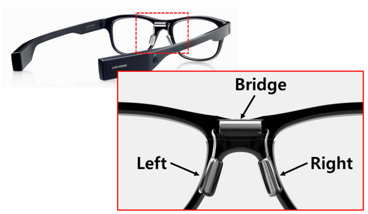

Figure 1: Jins MEME and 3 EOG electrodes

Our research aims to create a platform capable of cognitive activity tracking in everyday situations. Helping people to keep track of their cognitive load, attention distribution, stress, etc. on a long-term scale. A device that would act as a fitness tracker for the brain. If the user will be able to see how the cognitive load is distributed throughout the day, redistributing it to fulfill his personal goals is much easier. To be able to control something we have to quantify and understand it first.

The form factor of eyewear seems to be the most promising because humans receive most of their sensory information via the head, making it a particularly interesting location for sensing. Since the laboratory equipment used for cognitive activity tracking can hardly be called portable or durable and cannot be worn throughout the day, we need to develop new methods to assess the cognitive load in an unobtrusive way suitable for long-term daily usage.

There were many attempts to quantify mental states and cognitive load. Some researches even achieved some level of portability of their systems. For example Suzuki et al. used a portable Near Infrared Spectroscopy (NIRS) device to estimate cognitive load in e-learning scenario[2]. Wilson et al. used Transcranial Doppler Ultrasonography to get an estimate of cerebral blood velocity which is related to cognitive load in an online learning scenario.[1]. However, both Doppler Ultrasonography and Near Infrared Spectroscopy require massive obtrusive devices that cannot be used in everyday situations.

Approach

Electrodermal Activity
One possible approach is measuring the facial Electrodermal Activity (EDA) using the nose pads of glasses as electrodes. Jins MEME smart eyeglasses demonstrate that this electrode placing is suitable for Electrooculography (EOG), and our early prototypes show that using the same electrode placement is suitable for EDA sensing. However, more testing is required to obtain solid results. Initial results show that it seems to be possible to detect stress and relaxation using an EDA sensing device in the form-factor of eyewear. Electrodermal Activity tracking has a long history in psychological research. One of the pioneers of EDA in psychology was Carl Jung. The first mention of EDA usage for psychophysiological research was found in his book "Studies in Word Association" published in 1906. Today it is still widely used in psychology and psychotherapy as a common measure of autonomic nervous system activity. It also is used in polygraphs (lie detectors) as one of the principle components.

Facial Thermography
Another very promising approach is based on measuring the temperature differences between certain facial areas. Many studies investigating this topic have already been done [6]. However, none of them aim at a wearable device design but concentrate on stationary setups. At a first glance temperature differences of facial areas can seem to be unintuitive and insignificant parameter that hardly has any relation with the cognitive activities. However, after taking a closer look at arterial and venous systems of the head the relation becomes straightforward and clear. First, let's sum up well established facts about cognitive activity, the cerebral blood flow and heat exchange.[5, 4]

1. during higher cognitive loads (e.g. studying) cerebral neurons are more active than in resting state, i.e. they require more oxygen and glucose to function. Around 1/3 of the energy produced by oxygen and glucose reactions is released as heat, i.e. the brain produces more heat under cognitive load. 2. Fat and bones of the skull act as a heat

insulator, which significantly decreases the importance of convective cooling, making the blood circulation the main heat exchange mechanism. 3. Emissary veins, intracranial venous sinuses and multiple vascular anastomosises (connections between different branches of blood vessels) in the facial area play the main role in the brain cooling.

According to the above, we find it reasonable to assume the possibility of assessing the brain activity based on the temperature and the state of the cooling mechanisms. Basic mechanism of brain cooling relies on venous blood cooled down in the scalp or facial(especially nasal) tissues. Multiple veins bring blood to the sisnuses inside the brain where they cool down arterial blood passing through them, that is supplying the brain. However, since the venous blood goes towards the brain from the scalp and face, it cannot give a good estimation on the intracranial temperature.

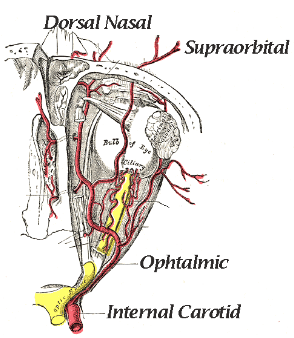

Figure 2: Arteries of the eye

However the arterial vascular system gives us an opportunity that venous cannot. Some branches of the opthalamic artery(supplies the eyes and surrounding tissues) (See2), namely the dorsal nasal artery, supraorbital artery, supratrochlear artery and others are supplying the eyebrows, lower part of the forehead an the nose. The opthalamic arteries are branches of internal carotid arteries that are the main blood supply of the brain. Internal carotid arteries branch off the common carotid arteries, and are connected to all other main brain arteries via the circle of Willis. Thus, the opthalamic artery brings blood directly from the central brain blood supply and can be used to assess the brain temperature. However the absolute temperature values are of no use without a point of reference.

To solve this issue we propose to use another branch of the common carotid artery: the external carotid artery. The branching of the common carotid artery into internal and external happens in the throat area. The external carotid is supplying the face and the scalp, and internal mainly supplies the brain, but through the opthalamic artery blood also comes to the nasal and forehead areas of the face. This vascular placement lets us compare the temperature differences between tissues supplied by blood from internal carotid artery (the eye, parts of the nose, and lower part of the forehead) with the tissues supplied by the external carotid artery (cheeks, temples, nasal area). Thus we can estimate the temperature differences between two branches of the common carotid artery: one that went through the brain and another that did not. The change of this difference can give a significant clue about the cognitive load.

Our initial studies support our hypothesis. Using a thermal imaging camera we recorded 5 participants during a series of tests. Participants were asked to view 3 movie trailers and try to remember as many details as possible. After each trailer researchers asked hard detailed questions about the trailer.

We logged the temperature changes of over 10 areas of the face (See Fig.3) and could identify three major groups that show almost identical temperature trends when compared to each other. These areas were forehead and eyes (A1), cheeks (A2), and Nose (A3). Which perfectly corresponds to the vascular anatomy of the face. A1 are supplied by opthalamic artery. A2 are supplied by the facial and infraorbital artery, and A3 are supplied by branches of both, facial and opthalamic arteries, but since the nose acts as a heatsink and because of increased respiration during the interview A3 temperature change patterns are significantly different from A1 and A2. We found out that during the Q&A session the temperature of the central forehead was decreasing significantly (-0.5C) compared to average facial temperature. The temperature of cheeks compared to the forehead was higher during the video viewing and lower

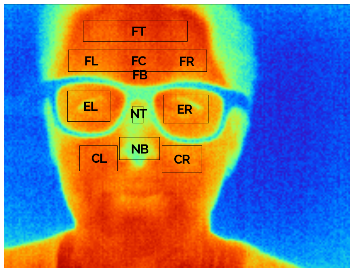

Figure 3: Regions of interest that were used in the study

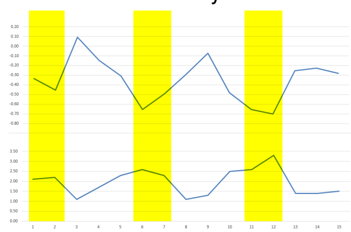

Figure 4: X is temperature; Y is the number of measurement. Upper graph is the difference between FC area and average temperature, lower graph is the difference of average of CR and CL temperatures and FB area. The data on yellow background represents video watching, and white background is the Q&A.

during the interview. However a much bigger number of participants and different testing scenarios are required to make a complete picture of the relationship of temperature differences and cognitive activities.

For our project we intend to use the TI TMP006 contactless IR thermophile sensors on smart eyewear. Tiny chip size (1.6 x 1.6mm) together with impressive resolution (0.03125 deg. C) and the contactless measurement abilities open promising perspectives for our approach.

Other Approaches

The earlier mentioned Jins MEME are capable of reading EOG data giving valuable information on eye blinks and eye movement, which promise to be important clues about cognitive processes[3]. Finding relationships between eye motion and mental load is the focus of our current study.

It is worth mentioning that there are other signs that can be used to estimate cognitive load and mental cstate of the user: pupil dilation, head movement, heart rate and heart rate variance, blood flow changes measurable using Near Infrared Spectroscopy (NIRS), etc.

Conclusion

The topic of smart eyewear and cognitive load tracking on daily basis has very high potential. Our experiments and prototypes show the feasibility of the concept using new sensory and processing hardware. We believe that related approaches and methodologies as well as new sensing modalities deserve more attention and discussion in the scientific community.

Acknowledgments

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REFERENCES

1. Jay J. Loftus, Michele Jacobsen, and Timothy D. Wilson. 2016. Learning and assessment with images: A view of cognitive load through the lens of cerebral blood flow. *British Journal of Educational Technology* (2016), n/a–n/a. DOI: http://dx.doi.org/10.1111/bjet.12474
2. Y. Murata and S. Suzuki. 2015. Artifact robust estimation of cognitive load by measuring cerebral blood flow. In *2015 8th International Conference on Human System Interaction (HSI)*. 302–308. DOI: http://dx.doi.org/10.1109/HSI.2015.7170684
3. Tamami Nakano, Yoshiharu Yamamoto, Keiichi Kitajo, Toshimitsu Takahashi, and Shigeru Kitazawa. 2009. Synchronization of spontaneous eyeblinks while viewing video stories. *Proceedings of the Royal Society of London B: Biological Sciences* (2009). DOI: http://dx.doi.org/10.1098/rspb.2009.0828
4. A. L. Sukstanskii and D. A. Yablonskiy. 2007. Theoretical limits on brain cooling by external head cooling devices. *European Journal of Applied Physiology* 101, 1 (2007), 41–49. DOI: http://dx.doi.org/10.1007/s00421-007-0452-5
5. Huan Wang, Bonnie Wang, Kieran P. Normoyle, Kevin Jackson, Kevin Spitler, Matthew F. Sharrock, Claire M. Miller, Catherine Best, Daniel Llano, and Rose Du. 2014. Brain temperature and its fundamental properties: a review for clinical neuroscientists. *Frontiers in Neuroscience* 8 (2014), 307. DOI: http://dx.doi.org/10.3389/fnins.2014.00307
6. Robert B. Zajonc, Stephanie Murphy, and Marita Inglehart. 1989. Feeling and facial efference: implications of the vascular theory of emotion. *Journal of Applied Physiology* 96, 3 (1989), 395–416.