Facial Thermography for Attention Tracking on Smart Eyewear: An Initial Study

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 CHI'17 Extended Abstracts, May 06-11, 2017, Denver, CO, USA
ACM 978-1-4503-4656-6/17/05. http://dx.doi.org/10.1145/3027063.3053243

Abstract
We are describing the first step towards the development of an unobtrusive open eyewear system for attention tracking in daily life situations. We are logging thermographic data from infrared imaging and electrooculographic readings from off-the-shelf smart glasses and measure cognitive engagement of people in different situations. We are identifying new potential areas on the face for contactless IR temperature sensing. Attached to smart glasses and in combination with the EOG potentials we can monitor the wearer's facial temperature changes, eye movement and eye blink in everyday situations, which is a major step towards becoming able to measure attention in unconstrained settings, and thus make it manageable.

Author Keywords
Thermography; Electrooculography; Attention; Psychophysiology; Eyewear; Tracking; Sensing

ACM Classification Keywords
H.5.2 [User Interfaces]: User-centered design

Introduction and Motivation
Users of smart devices, phones, tablets and a growing number of Internet of Things appliances have to deal with an increasing amount of data presented to them, such as floods of notifications. This has resulted in an explosive

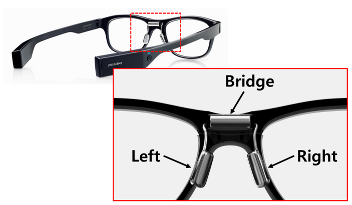

Figure 1: J!NS MEME and closeup on the EOG electrodes

growth of information available at virtually any time and any place, which leads to a situation where we are exposed to more information than we can process. But where lies the benefit in a constant exposure to available information and data, if you forget the one crucial piece of information such as a deadline? It becomes clear that we have to learn to manage and economize our use of attention every day, and allow to replenish our attention reservoir. There are several ways of subdividing attention into more defined categories, e.g. volitional attention and non-volitional attention. For our research purposes we decided to follow the The Merriam Webster dictionary which defines attention as "the act or state of applying the mind to something" and as "a condition of readiness for such attention involving especially a selective narrowing or focusing of consciousness and receptivity" [9].

In this paper we discuss the first step towards a wearable, everyday device that tracks attention. We are using physiological expressions of cognitive activity to identify perceptual processes, such as attention. This will allow us to measure attention and therefore will make the development of effective tools and applications for attention management possible. We are utilizing facial thermography measurements from infrared imaging and Electrooculography (EOG) data obtained via smart eyewear (J!NS MEME, Figure 1 [6]). So far, facial temperature has been measured in locations on the head that would render an unobtrusive, everyday wearable sensing device almost impossible to be realized. Therefore, we aim at identifying locations for temperature measurements that are adjacent to the area covered by standard off-the-shelf spectacle frames. Consequently, the development of attention tracking smart wear would enable future work in real life situations, and liberate subjects and researchers from expensive medical grade equipment.

Related Work

One approach to estimate cognitive workload, that does not directly come to mind, is based on measuring the temperature differences between certain facial areas [4, 8]. Studies investigating this topic have already been done[17, 7, 5], unexceptionally concentrating on stationary setups rather than a wearable device design though. It is proven that in times of higher cognitive load (e.g. studying) cerebral neurons are more active than in resting states. This means, they require more oxygen and glucose to function. Around 1/3 of the energy produced by oxygen and glucose based chemical reactions is released as heat, i.e. the brain produces more heat when it is in higher demand. Fat and bones of the skull act as heat insulators, which significantly decreases the importance of convective cooling, making the blood circulation the main heat exchange mechanism[15, 13].

In order to assess the changes of the brain temperature, we compare temperatures of facial tissues supplied by blood from the internal carotid artery, that is passing through the brain with temperatures of tissues supplied by the external carotid artery. The common carotid arteries are the main blood supply of the head and branch into exterior and interior carotid arteries in the throat region. The internal carotid artery is supplying the brain and is connected to all the main intracranial arteries via the Circle of Willis. Thus, blood from the Circle of Willis can be used as an indicator of the brain temperature. One of the branches of the internal carotid artery is the ophthalmic artery. It supplies the eyes and surrounding tissues, and has branches that supply nasal, eyebrow and forehead regions of the face. For reference we use the other branch of the common carotid artery, the external carotid artery, that is supplying the face and the scalp. This vascular structure lets us compare the temperature differences between tissues supplied by blood from the 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.

J!NS MEME smart glasses are equipped with sensors that allow the capturing of electrooculography (EOG) and enable the accurate measurement of eye movements, and therefore detecting eye blinks [2]. Siegle et al. use blink rates as a measure for concentration, which is directly connected to attention [12]. In times of danger, the normal human reflex is to suppress the natural eye blink in order to avoid missing vital visual information. Similarly, special ocular tasks make people time their eye blink so that the amount of missed information can be kept as small as possible [10, 14]. This means our attentional system has a direct influence on our blink reflex.

Approach

Humans receive most of their sensory information through their head, making it a particularly interesting location for sensing, tracking, and enhancing social and cognitive functions. There are first indications from controlled lab studies that specific behavior patterns and physiological signals (e.g. eye movements, eye blinks, nose temperature, and head motions) are linked to those social and cognitive functions [1]. However, most studies focus on constrained lab settings with artificial simplified tasks using expensive medical equipment. The use of unobtrusive head based sensing to estimate cognitive functions in real life situations is largely unexplored. Therefore, we believe that the form factor of wearable electronics has a very high potential for research in areas such as attention management and behavior change. Moreover, according to the National Eye Institute, 64% of the adult population of the US are wearing eyeglasses [11]. This is significantly more than the 41% of Americans wearing watches [16]. This shows the great potential of smart eyewear.

As introductorily described in the related works section, there are patterns in human physiological signals (facial temperature, eye blink, etc.) that can reveal information about cognitive activities. Our main focus is to explore how we can utilize this data in order to become able to better understand our behavior and make the allocation of attention throughout the day manageable. Moreover, we want to enable people to optimize their limited cognitive resources for their own personal and/or professional goals.

We based this study on the related research and are gathering information on relative temperature changes of different areas of the face during small tasks that require a certain cognitive activity. We will later use this data to select the most appropriate locations for the placement of contactless temperature sensors on our wearable hardware for future works.

Experiment Design

To investigate the correlation of changes in facial temperature patterns, EOG data, and cognitive load, we have to compare the measurements of subjects in situations demanding varying levels of cognitive engagement. To induce the required states we used video clips of two different categories, with the first consisting of Hollywood movie trailers. Trailers are traditionally produced and edited for the purpose of drawing the viewer's attention in a short period of time (usually about 2,5 minutes). Therefore they are ideal for an experimental setup like this. Our participants

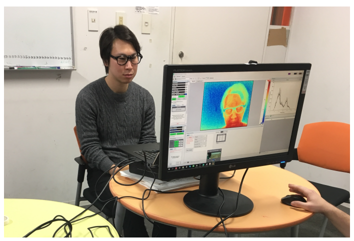

Figure 2: Candidate wearing J!NS MEME watching a video while facial temperature is logged

had to follow the storyline and pay as close attention to the contents as possible. They were informed that they will be asked questions concerning the contents of the trailer and that we will count right and wrong answer. After each trailer, we went through questions of varying difficulty regarding all kinds of facts presented in the trailers, e.g. names of production companies, publishing dates, spoken phrases, and details such as titles of books only briefly shown. We selected the official movie trailers for "Cloverfield", "Wild", and "The Theory of Everything". The second video category showed five minutes of an uncut seashore scene. The video was not edited, had no story, and only its natural soundtrack. This allowed us to keep emotional triggers or other possible attention grabbing stimuli away from the viewer. When watching this video, participants were asked to relax or even meditate, if they preferred to.

For a first experiment run, we recruited five university students between the ages of 20 and 35 of which two were female. All candidates had normal or corrected to normal vision and were of different academic backgrounds. Before starting the actual tasks, we engaged each participant for ten minutes in a light chat in order to allow their facial temperature to adjust to the room climate. The room temperature was controlled by a digital wall thermostat and set to 21°C. After this acclimatization period subjects were introduced to the coming tasks. The first three candidates were initially watching the Hollywood trailers followed by the seashore sequence. The last two students were presented with the videos in opposite order. After each of the trailers, participants were asked 15 questions from a questionnaire. Even though we registered the number of correct and incorrect answers, the sole purpose of the questionnaire was to motivate candidates to pay close attention to the trailer content and obtain demographic information.

The participants' EOG data was recorded using J!NS MEME smart glasses equipped with three EOG electrodes for logging eye movement and eye blink. Facial temperatures were recorded using a Seek Thermal XR camera at around 15 FPS during the whole study. The complete setup including a candidate wearing J!NS MEME can be seen in Figure 2. We sampled the temperature in the beginning of the experiment before the first video was played to receive a baseline value. During the trailers we logged temperatures in the middle and in the end of each trailer, and for the surveys we monitored the temperature three times, namely before starting the survey, after half of the survey, and right after the last answer was given.

Evaluation

Two participants knew the films belonging to the trailers (Group A) and showed different temperature signatures over the course of the experiment than the other three candidates (Group B), to whom all film trailers were new. We logged the temperature changes of 11 ROIs on each candidate's face (Figure 3). These ROIs were: forehead top (FT), forehead left (FL), forehead center (FC), forehead right (FR), forehead bottom (FB), eye left (EL), nose top (NT), eye right (ER), cheek left (CL), nose bottom (NB), and cheek right (CR). The analysis of the thermography and EOG data showed some interesting findings and trends. We could identify three major areas on the face that show almost identical results when compared to each other. These areas were forehead and eyes (A1), cheeks (A2), and Nose (A3). This means that the comparison of data from any ROI of the forehead to an ROI of the cheeks or nose will result in similar trends of temperature changes, which perfectly corresponds to the vascular anatomy of the face. A1 are supplied by ophthalmic artery. A2 are supplied by the facial and infraorbital artery, and A3 are supplied by branches of both, facial and ophthalmic 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. In order to explain this in more detail, we picked two significant sets of data in the following that utilize temperatures from ROIs that are in reach of contactless sensors attached to eyewear, and therefore of particular interest for us.

The most striking development was presented by the temperature gradient between the ROIs "cheeks" (average of CL and CR) and the FC area (between the eyebrows and above the bridge) of Group B. All temperatures provided are relative differences between two ROIs, and no absolutes. During the trailer presentation, the average cheek temperature rose by 1.49°C and dropped by an average of 0.43°C within 20 seconds after the trailer finished in comparison to FC. The temperature then rose gradually from the beginning until the end of each survey by an average of 0.99°C (beginning), 1.05°C (half way), and 1.14°C (end). The maximum drop in temperature we measured for Group B within the first 20 seconds after a trailer finished was -1.32°C. The survey average temperature was 1.14°C higher on the cheeks compared than on the central forehead. The average temperature of the cheeks decreased by 0.35°C when comparing video and survey periods. The forehead temperature fluctuates insignificantly around the average temperature. In comparison to Group B, Group A's readings show only minimal variations without neither any stable trends nor significant changes. This shows a first clear trend for cognitive engagement causing measurable temperature differences between the cheek region and FC.

In a second round of analysis, we compared the temperature changes of NT and FC. For Group B the average NT temperature while watching videos was 1.48°C lower than that of FC. During the surveys the NT temperature decreased even further to -1.9°C in average compared to the temperature measured on FC. As in the former set, we found significant temperature drops of approximately 0.32°C, with one candidate where the temperature dropped 0.7°C within 10-20 seconds after the videos stopped playing and between seven and 10 seconds into the survey questions. When comparing the NT temperature during the video presentation with the temperature during the surveys, we find an average decrease of 0.42°C. This is the same development as in the first example. As with the cheeks, NT suddenly got colder during the surveys whereas the FC temperature did not show any significant trends. In conclusion, we can say that the temperatures in A2 and A3 decrease during the Q&A while temperatures in A1 slightly fluctuate compared to the average facial temperature, but do not present any identifiable trends. Temperatures for Group A followed the same trends, but the differences were not as significant as for Group B.

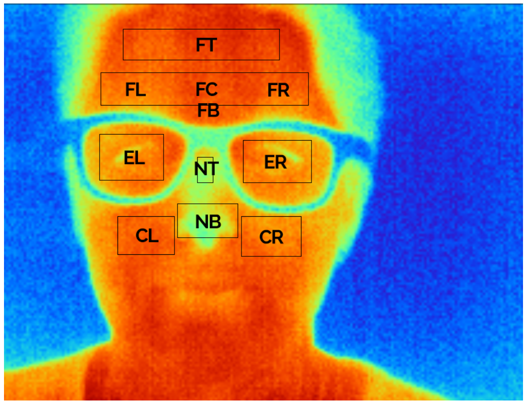

Figure 3: Candidate wearing J!NS MEME watching a video while facial temperature is logged

Figure 4: EOG data of logged eye blinks for 6 seconds during Top: Trailer, Center: Survey, Bottom: Seashore Video

The logged EOG data was used to identify eye blinks of candidates watching the trailers, answering the survey questions, and watching the unedited video. In Figure 4 we can see one example for each measurement. It shows a six second extract of the recorded eye blinks. The height of the peaks in the three graphs describes the force and the width the speed of the eye movement that can be monitored for identifying eye blinks. Therefore, we can identify fewer quick blinks during the trailer presentation, whereas blinks were slow and strong while candidates watched the seashore video. According to Nakano, delayed, quick eye blinks are a sign of higher attention [10]. In comparison a slower blink rate indicates relaxation and fatigue, in our case induced by the seashore video. As can be seen in the center image of Figure 4, our blink rate speeds up significantly while speaking [3]. The average blink rates we measured were as follows: 1/sec while watching trailers, 2/sec during the survey, and 0,5/sec in reaction to the seashore video.

Conclusion

The clear EOG results in combination with the outcomes of the thermography analysis show a definite relation between cognitive efforts of various degrees with eye blink rate and facial temperature changes. Even though the temperature changes are not a novel finding, we could discover new ROIs that are of significant meaning for the development of unobtrusive eyewear that can help us track our attention and therefore make it measurable in every day situations. Precisely, attached to the bridge of the glasses we will use sensors pointing upwards and downwards for measuring the temperature changes in FC and NT. Additional placements could be the rim of the glasses pointing at the wearer's cheeks and eyes. Our setup was designed exclusively with low cost off-the-shelf products. We believe that we could show the potential of such a design and strongly trust in its unique potential for future studies and our goal of developing an open eyewear platform for the better management of attentional resources in every day situations.

Future Work

As mentioned before, this study describes a first step towards a smart eyewear platform capable of tracking cognitive processes, such as attention. Our next step will be the creation of a physical prototype of eyewear equipped with contactless IR temperature sensors to be used in a reproduction and extension of this study. We will furthermore add areas on and around the ears and sides of the head to our ROIs for future temperature measurements.

Additionally, we are considering the implementation of facial Galvanic Skin Response (GSR) measurements in future studies. We are not aware of any attempts that utilize GSR on smart eyewear for cognitive activity tracking. The skin conductance is influenced by the amount of sweat excreted by the skin, thus GSR can be a good indicator of excitement/stress or relaxation levels. We are working on using the electrodes of J!NS MEME for measuring facial GSR.

Acknowledgments

This research is supported by JST Presto.

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