A Method to Monitor Operator Overloading

Dvijesh Shastri, Ioannis Pavlidis, and Avinash Wesley

Computational Physiology Lab, Department of Computer Science,
University of Houston, Houston, TX, 77204
{dshastri,ipavlidis,awesley}@uh.edu

Abstract. This paper describes research that aims to quantify stress levels of operators who perform multiple tasks. The proposed method is based on the thermal signature of the face. It measures physiological function from a stand-off distance and therefore, it can unobtrusively monitor a machine operator. The method was tested on 11 participants. The results show that multi-tasking elevates metabolism in the supraorbital area, which is an indirect indication of increased mental load. This local metabolic change alters heat dissipation and thus, it can be measured through thermal imaging. The methodology could serve as a benchmarking tool in scenarios where an operator's divided attention may cause harmful outcomes. A classic example is the case of a vehicle driver who talks on the cell phone. This stress measurement method when combined with user performance metrics can delineate optimal operational envelopes.

Keywords: Human-Machine Interaction, divided attention, stress, thermal imaging.

1 Introduction

In many occasions, machine operators simultaneously perform more than one task. When a combination of overlapping events demands critical decisions and rapid actions, they raise the operator's alertness. If this persists, it develops to stress that overloads the operator. Stress due to operator's divided attention may lead to degradation of his/her performance.

This work aimed to analyze stress-induced change in facial physiology during divided attention situations. The supraorbital thermal signature emerged as the physiological variable of interest, which can be measured through thermal imaging. In fact, thermal imaging based stress monitoring is an increasingly popular approach [1] [2] [3]. In contrast to probe based stress monitoring methods, it is totally unobtrusive [7] [8].

Although concurrent performance of multiple tasks is part of human life, insufficient research has been done to understand its effect on human emotional states and performance. The purpose of this study is to develop an effective tool to gauge stress load of operators engaging in multi-tasking. The experimental design focused on cellphone communication during driving simulation [9][10][11] and was tested on 11 participants. However, other task pairs could have been chosen, such as reading in the presence of background distractions.

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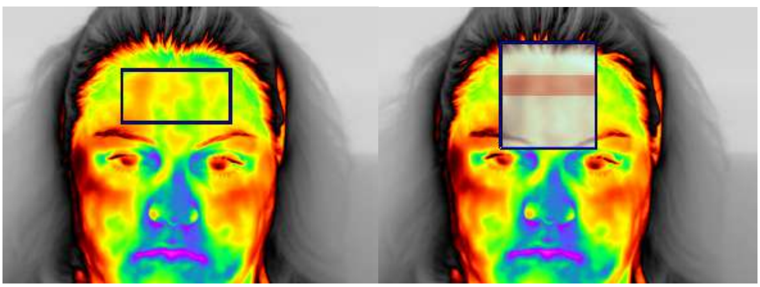
2 Methodology

During dual tasking there is considerable temperature increase in the supraorbital region of a participant. This locally elevated temperature is the result of increased metabolic activity due to activation of the forehead muscle group. The phenomenon is consistent with findings in prior experiments involving Stroop color conflict testing [1]. In that previous work, the stress signal was extracted from the evolution of the mean thermal footprint of the entire supraorbital region (see Fig. 1. a). This approach, however, introduced noise in the extracted signal, partly due to the wide probing area and partly due to sub-optimal tracking performance [4]. In the present work, the tracking region was differentiated from the measurement region. An even bigger area that included sharp contrasts (e.g., skin versus hair) was selected for tracking. This improved tracking performance. However, only a small subset within the tracking region was selected for the thermal measurement. This subset was confined in the area were metabolic changes are more dramatic, to reduce the effect of probing noise (Fig. 1. b).



(a) (b)

Fig. 1. (a) Tracking and measurements regions coincide in legacy method. (b) Measurement region (in pink) is a subset of tracking region in the current method.

For every participant in the experiment, tracking and measurement regions of interest were selected as described above. The mean temperature of the measurement region of interest was computed for every frame in the thermal clip. Thus, a 1D supraorbital signal was produced from the 2D thermal data. Any residual noise in the supraorbital signal was suppressed by a noise cleaning algorithm based on Fast Fourier Transform (FFT) [5]. The supraorbital signal was split into segments corresponding to the phases of the experiment (resting, initial single task, dual task, latter single task, and cool-off). Each segment was approximated with a linear fit (Fig. 2), which described the local metabolic rate at the time.

3 Experimental Design

A high quality Thermal Imaging (TI) system was used for data collection. The centerpiece of the TI system was a ThermoVision SC6000 Mid-Wave Infrared (MWIR) camera (FLIR Systems) (sensitivity = 0.025°C) [12]. The experimental protocol included thermal imaging of the participant's face while he was resting, engaging in a driving simulation game (single task), engaging in a driving simulation game and talking on the cell phone (dual task), and relaxing.

The dataset featured participants of both genders, different races, and with varying physical characteristics. The participants were placed 6 feet away from the thermal camera (Fig. 3). We used a XBOX-360 game console and the *Test Drive: Unlimited* game to simulate driving. The participants were asked to follow all traffic signs, drive normally, and not race during the experiment. They were given an opportunity to test-drive before the experiment began to acquaint themselves with the driving simulation. In the first formal phase of the experiment, the participants were asked to rest for 5 min while being imaged. This helped to isolate effects of other stress factors that participants may have carried inside them. This was the *baseline* phase.

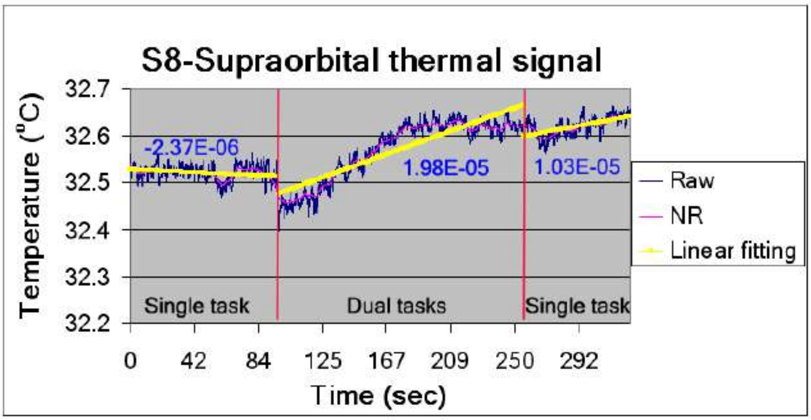


Fig. 2. Supraorbital raw thermal signal (marked in blue color), noise cleaned thermal signal (marked in pink color) and linear fitting (marked in yellow color). Slope values for the linear segments are shown in blue colored text.

Next, the participants were asked to play the driving simulation game. This phase of the experiment also lasted about 5 min. After around 1 min of driving simulation (initial *single task* phase), the participant received a cell phone call that played a set of prerecorded questions in the following order:

Instruction: Please do not hang up until you are told so.

Q1: Are the lights ON in the room, yes or no?
Q2: Are you a male or female?
Q3: Who won the American civil war, the north or the south?
Q4: What is 11 + 21?
Q5: How many letters ‘e’ are in the word *experiment*?
Q6: I am the son of a mom whose mother in law's son hit. How am I related to the other son?
Q7: My grandma's son hit his son. How are the sons related?
Q8: A man is injured in 1958 and died in 1956. How is that possible?
Q9: What is 27 + 14?

Instruction: You may now hang up the phone and pay attention to the game.

The question set was a combination of basic, logical, simple math, and ambiguous questions. The order of the questions was designed to build-up pressure on the participants. Additional pressure was achieved by repeating one more time every question that was incorrectly answered. The participants were supposed to drive while talking on the cell phone (*dual task* phase). At the end of the phone conversation, participants put the phone down and continued driving till the end of the experiment (the *latter single task* phase).

Finally, the participants relaxed for 5 minutes. The purpose of this so-called *cool-off* segment was to monitor physiological changes after the simulated driving experiment.

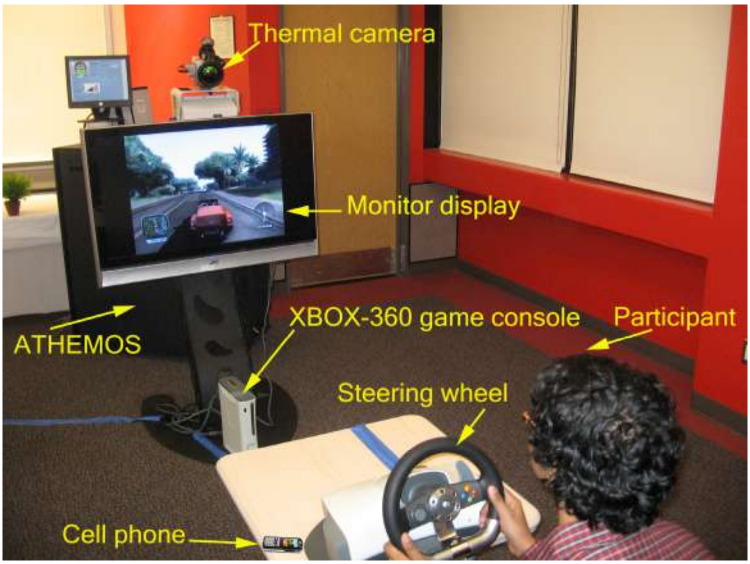


Fig. 3. Experimental setup: Participant, imaging equipment, xBOX-360

4 Experimental Results

The slopes of the linearly fitted segments, computed according to the method described in Section 2, were used as stress indicators. Fig.4 shows the mean slope values of the various segments for the entire data set (statistically constructed mean participant). The graph clearly indicates that the temperature increase during dual tasking is the highest among all segments (sole exception was participant S-6). Since the temperature increase is correlated to metabolic rate, the results indicate elevated metabolism in the supraorbital region during dual tasking. This is presumably due to strong muscle activation, associated with frowning, a facial expression autonomically associated with mental engagement.

Stress during the latter single task phase was stronger than the initial single task phase (Fig. 4). Apparently, this was due to residual effect from the dual task that preceded the latter single task phase. Most of the participants admitted during debriefing that they were thinking about their dual task performance while performing the latter single task.

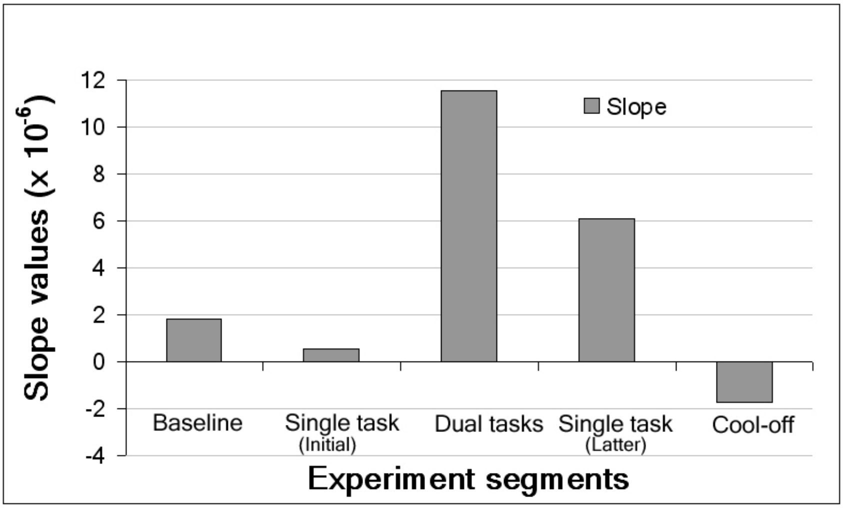


Fig. 4. Mean slope value of the experimental segments. This stress indicator is the highest during dual tasking.

Interestingly, baseline stress was a bit higher than the initial single task stress. This indicates that either the baseline was poorly designed (just sitting idle can be stressful) or participants carried some residual stress from the informal test-driving phase that preceded it.

Participant S-6 is an interesting case. It appears that his stress started decreasing in the middle of dual tasking (Fig. 5). On careful examination of the data, the investigators found that this is the only participant who started perspiring in the middle of the experiment, apparently due to overwhelming stress. Perspiration reduces the thermal signature and the current method wrongly interprets this as lower metabolic rate and thus, lower stress. It is exactly the opposite. A method that identifies the emergence of perspiration and switches measurement metrics is needed to overcome this issue.

In all cases, the rate of thermal change of the cool-off segment had an opposite global trend than that of the dual task segment. In most cases, the rate of thermal change of the cool-off segment had also an opposite global trend than that of the initial and latter single task segments. This illustrates that the participants indeed felt relaxed after 5 minutes of intense mental activity but at various degrees. Those participants who were thinking about their performance during the cool-off period exhibited slow recovery. This is an interesting finding, as it illustrates that not only an action but also thoughts about the action (past action in this case) could affect stress levels.

Performance of the drivers degraded during the dual task segment, as measured by the point system of the simulator. This was inversely proportional to the mean stress level measured through the supraorbital channel.

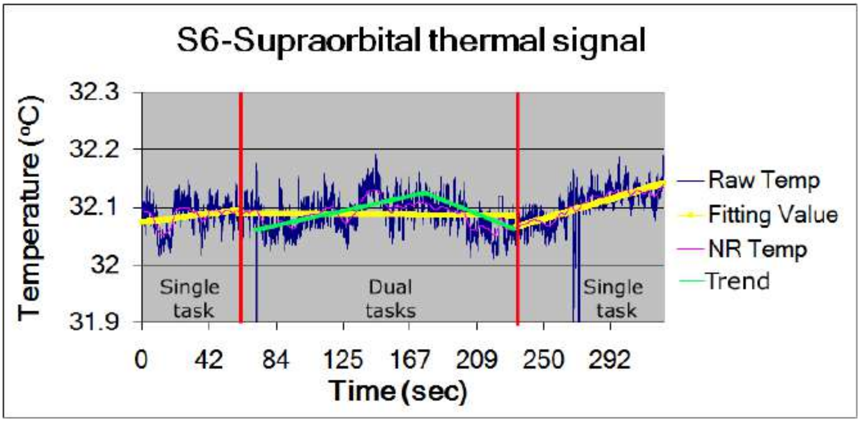


Fig. 5. During the dual task period, the supraorbital signal (marked in blue color) of S6 showed ascending global trend in the first half and then descending global trend in the second half (marked in green color). The culprit is the onset of perspiration.

5 Conclusion

This research brings to the fore a stress quantification method ideally suited to situations where the attention of the machine operator is divided. Unobtrusive quantification of stress and its correlation to operator performance and emotions are of singular importance in man-machine interaction. A feedback system can be developed that alerts the operator about his/her stress status based on the facial thermal signature. Results from a pilot experiment on the effect of cell phone communication during driving are more than encouraging. They open the way for a plethora of other multitasking experiments drawn from daily life. At the technical level, the issue of perspiration, which corresponds to the onset of extreme stress, cannot be handled with the current method. A method that identifies perspiratory patterns and handles thermal computation in a different manner from that point onward is needed in the future.

Acknowledgments

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