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Facial Temperature as a Measure of Mental Workload

Hans J.A. Veltman

Wouter W.K. Vos

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Hans (J.A.) Veltman
Wouter (W.K.) Vos
TNO Defense, Security and Safety
Soesterberg, The Netherlands

We conducted an experiment to explore the relation between facial temperature and mental effort. Participants had to perform mentally demanding tasks while their face was captured with an infrared camera. The temperature of the nose decreased during these tasks and increased during the successive rest periods. Other parts of the face did not change due to mental effort. The advantage of this workload measure is that it can provide objective and real-time information about mental effort of operators without attaching sensors to an operator. This measure can be used to measure the workload of operators in relatively stable environmental conditions such as air traffic controllers and operators of unmanned aerial vehicles.

Introduction

The task of air traffic controllers and operators of unmanned aerial vehicles can be highly demanding from time to time. Although people can adapt efficiently to changing task demands, a high mental workload does have negative effects such as an increased likelihood of human error.

There are many different techniques to measure mental workload. These techniques can be categorized into performance measures, subjective measures and physiological measures. These types of measures do not provide the same information (Veltman & Jansen, 2003). Performance is often difficult to measure in applied situations and when it can be measured, it often does not provide adequate information. Operators have the ability to adapt to changing task demands by investing more effort and therefore, an adequate level of performance can often be maintained at the cost of high workload. If the workload becomes too high, the performance often decreases dramatically. It is important to have information about the state of an operator before the level of performance decreases. Subjective workload measures provide more information about the workload but these measures are also difficult to obtain in applied situations. Finally, physiological measures mainly reflect the amount of mental effort that an operator has to invest in order to perform the task adequately. They can provide continuous and objective information about the state of an operator. This is necessary if one wants to prevent a decrease of performance (Hockey, 2003).

An important disadvantage of physiological measures is that most often electrodes or other sensors have to be attached to the person, which restricts the use of these measures in many applied settings. The measurement of facial skin temperature by means of an infrared camera might not have this practical limitation. There are some indications that the face temperature, especially the temperature at the nose, decreases when mental workload increases (e.g. Genno et al., 1997).

In this paper we describe an experiment in which the applicability of facial temperature for the assessment of mental workload is further explored. In this experiment participants had to perform mentally demanding tasks during which the facial temperature was measured with an infrared camera. We explored if the facial temperature changes due to mental effort. Moreover, we explored the most sensitive locations on the face and the sensitivity to different levels of task load.

This experiment is part of a research program in which the possibility for adaptive automation is investigated. Adaptive automation is a concept in which the level of automation is adapted to a specific situation. The state of the operator can provide relevant information for adaptive automation such as a high workload of the operator. If the mental workload of an operator is too high, the overall performance might increase if the taskload is reduced. This can be accomplished for example by taking over some tasks from the operator, present some tasks to another operator, or wait to present less relevant information until the workload of the operator is reduced.

Facial temperature seems to be a promising element in adaptive automation concept because it might provides objective information about the workload of an operator and it can be obtained relatively easy.

Method

Participants

The experiment has been performed on eight participants, six males and two females, their ages ranging from 23 to 41.

Task

The participants had to perform three mentally demanding tasks. We used the auditive version of the Continuous Memory Task (CMT) that has been shown to be a highly cognitive demanding task in earlier experiments (e.g. Veltman & Gaillard, 1998). This task is mentally demanding because the participants have to compare each letter with the letters from the memory set and more important, they have to use their working memory continuously.

The participants had to remember two or four target letters (CMT2: A-B and CMT4: A-B-X-Y). Letters from the alphabet were presented randomly with an interval time of three seconds. About 30% of the letters were targets. The participants had to press a button when they heard a target letter and press another button when they heard the letter for the second time. Thus, they had to react to the target letters and had to count them independently.

The word “okay” was presented after a correct response and the word “nope” after an incorrect response and after an omission. The participant had to restart counting after feedback was provided.

The duration of each task was three minutes. Before and after each task there was a rest block of three minutes (see Figure 1).

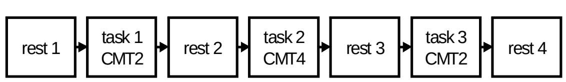

Figure 1. *Scheme of the experimental conditions. Each block lasted three minutes. CMT2 is the Continuous Memory Task with two target letters and CMT4 is the Continuous Memory Task with four target letters.*

Procedure and Apparatus

Before the experiment the participant was trained in the CMT: one minute training for the two-target letter task and one minute of training for the four-target letter task. The training was primarily meant to inform the participant about the goal of the task. The participants were told that they had to make fast responses and had to avoid errors.

The task was meant to induce a high mental effort only. The performance on the task was not relevant and therefore, this will not be presented.

We used a FLIR SC 2000 infrared camera that was able to take temperature pictures with an accuracy of 0.07 °C (14 bit). The resolution of the camera was 320 x 240 pixels. The camera took pictures with an interval time of 5 sec. So there were 36 pictures of the face in each block.

Since it was expected that the nose temperature would be the most interesting area, four points on the nose were manually selected in the first picture of each participant in Matlab 6.5.1. Another 13 points were selected on the rest of the face (see Table 1).

Table 1. *Measurement locations on the face.*

NR.	Location
1	Middle forehead
2	Left side forehead
3	Right side forehead
4	Upper inside left eye
5	Lower inside left eye
6	Outside left eye
7	Upper inside right eye
8	Lower inside right eye
9	Outside right eye
10	Nose bridge
11	Left side nose
12	Right side nose
13	Nose tip
14	Left cheekbone
15	Right cheekbone
16	Between nose and upper lip
17	Between lower lip and chin

A chin rest was used to stabilize the head. Despite this chin rest, the participants were not able to keep their head at the same position throughout the experiment. Therefore, a procedure was developed to match the selected points in each picture. The seventeen points were selected in the first picture with mouse clicks. A rectangle around the nose was also selected in this picture. This rectangle was correlated in the X and Y-axis with a larger rectangle in the consecutive pictures (20 pixels larger at each side of the original rectangle). Based on this two-dimensional correlation, the points in consecutive pictures were shifted. The adjusted positions were visually checked and it appeared that all selected points remained to their place relative to the head. The correlation procedure helped us much in the present experiment. However, it will only work for minor changes of the head position. In a situation in which operators can move their head freely, a more elaborate procedure to get fixed locations of the face has to be developed.

Data Analysis

In each block we had 36 temperature values for each location. The temperature of each location consisted of an average in a circular area with a diameter of 5 pixels (≈ 7 mm). Within each block, we fitted straight lines (least squares method) through the data points for each location. Measurements outside ± 3 times the standard deviation range were removed. This resulted in 17 (locations) x 7 (blocks) regression lines for each participant.

We used an ANOVA repeated measurement analysis to analyze whether differences in temperature were significant. The following comparisons were made:

- differences between the seven experimental blocks (one factor with seven levels);
- differences between the three task blocks (one factor with three levels);
- differences between the four rest blocks (one factor with four levels);
- differences between the three locations at the nose that appeared relevant in the previous analysis. For this analysis we calculated the average value of the three rest blocks and the average values of the three task blocks and tested whether the temperature changes were different at the three locations.

Differences were further explored with post hoc analysis (Tukey HSD).

Results

Figure 2 presents an example of the data for one participant. The temperature at the forehead and the left side of the nose is plotted for each camera frame. The regression lines are also plotted in this figure. The slopes of these regression lines were used for statistical analysis. This picture shows that the temperature at the nose decreased during tasks and increased during the following rest period. The temperature at the forehead is almost stable for this participant. The temperature of the nose changed substantially during a rest and a task block.

The change of the nose temperature started almost directly after the start of a block. This indicates that it is a fast reacting measure. The data of the other seven participants showed similar patterns, but the average range was lower than the data in Figure 2.

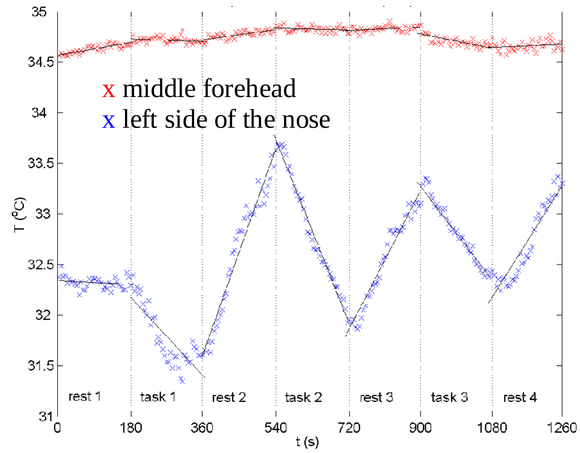

Figure 2. *Measurements of the temperature around two locations on the face (forehead and nose) of one participant. For each period straight lines were fitted through the data with the least squares method.*

Figure 3 presents the average temperature slopes for all locations. The rest blocks are presented separately from the task blocks in this figure. The strongest differences between the blocks were found at the left side of the nose [($F(6,42)=12.25$, $p<0.001$)], at the right side of the nose [($F(6,42)=10.81$, $p<0.001$)] and at the nose tip [$F(6,42)=9.57$, $p<0.001$]. During the tasks, the temperature decreased substantially for these locations and during the rests the temperature increased. Post hoc analysis revealed that the temperature slopes during all three tasks differed significantly from all four rests for the three locations at the nose (location 11, 12 and 13).

The temperature decreases during the three tasks was different for the left side of the nose [$F(4,14)=6.6$, $p<0.01$] and for the nose tip [$F(4,14)=4.86$, $p<0.05$]. Post analysis revealed that the temperature decreased more during CMT4 (second task) than during the first CMT2 task.

Figure 3 also shows a rather small decrease in temperature at the upper lip (location 16) during task2 and task3 and an increase during rest2, rest3 and rest4. Statistical analysis revealed that only the temperature during task2 was different from rest2. No other statistical effects were found for this location.

Some other significant effects were found, but these effects were very small and were not systematic. Therefore, they are not described here. The smallest temperature changes were found at the forehead. These differences were far from significant.

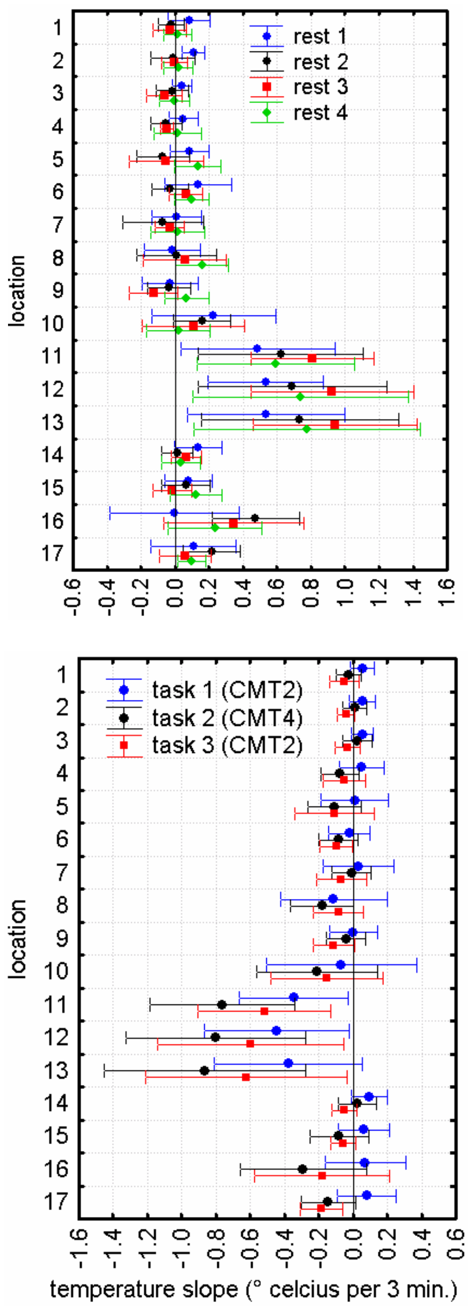

Figure 3. *Average temperature change for each measurement location. The top figure shows the temperature changes during rests and the bottom figure shows the temperature changes during tasks.*

Discussion

The results of this experiment show that mental effort can be distracted from changes in temperature of the nose. There was a clear difference between the temperature change during tasks and during rests. We found a small difference between the nose temperature during the four-target CMT (task2) and the temperature during the two-target CMTs (task1 and task3). The temperature decrease during the four-letter CMT was stronger than during the first two-letter CMT for the left side of the nose and the nose tip. A smaller and not significant difference was found between the four-letter CMT and the second two-letter CMT. This indicates that there is a relation, albeit not a strong one, between the amount of mental effort investment and the decrease in nose temperature. It should be noted that a higher task demand does not necessarily result in an increased mental effort. It is possible that some participants already did their utmost best during the two-target CMT task. The more demanding four-target CMT task would not have increased their effort investment anymore.

The decrease in nose temperature is most probably due to a dilation of the veins in the nose. This causes a reduction of blood flow and as a consequence the nose temperature will adapt faster to the environmental temperature. The diameter of the veins in the nose is mainly regulated by the sympathetic part of the autonomic nervous system (Widdicombe, 1993; Lung, 1995). Mental effort causes a reduced para-sympathetic activity and an increased sympathetic activity. This is the reason why most physiological measures, such as cardiovascular measures are sensitive to mental effort.

An increased sympathetic activity is probably not the only cause of the decrease in temperature. Mental effort often results in increased ventilation (Wientjes, 1993; Veltman et al., 1998). More relative cold air might flow through the nose during tasks compared to rests and therefore, the nose temperature drops. The data of the present experiment indicate that respiration might be involved in the present results. The heads of the participants were fixed with a chin rest, which forces them to breathe through the nose. This causes a flow of air around the nose. We found a small difference in temperature on the measurement location between the lip and the nose. Although these differences were not statistically significant, it indicates that respiration does play a role. Further experiments must clarify what the exact mechanisms of the temperature change are. However, for the application of this measure it is less relevant, because both mechanisms result in a temperature decrease during mental tasks.

There are several applications for workload measures. One of the applications is the evaluation of interfaces with regard to differences in mental effort investment. The nose temperature can be used for this, because there are several participants involved in such tests. If a few participants do not show changes in nose temperature, this does not affect the outcome very much.

Another application is adaptive automation for which it is very important to have highly reliable information about the effort investment. Operators will never accept that a system will take over tasks or delay less relevant tasks based on incorrect measurements. The reliability of nose temperature is too low to be used in adaptive automation. The reliability of the effort measured can be increased if the nose temperature is combined with other measures. Preferably this should be measures that do not require sensors to be attached to the operator or measures that are obtained with wireless sensors that do not hinder the operator in performing tasks. Examples of such measures are wireless heart rate sensors and eye point of gaze measures.

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