USING THERMAL IMAGING OF THE FACE TO MONITOR CONSTRUCTION FOREMAN'S PERFORMANCE

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ABSTRACT

This study investigated the feasibility of using an objective method that measures nose tip temperature variations to evaluate mental workload. Each of the 10 participants performed five trials of directing construction tasks, during which their nose tips were monitored by an infrared camera. The analysis was focused on the scaffold assembly. In addition, interviews and the NASA Task Load Index (NASA-TLX) questionnaire surveys were administered to understand each participant's subjective cognition of the mental workload caused by undergoing the five trials. An analysis of variance of the average relative temperature of each participant measured during the five trials showed significant differences. A paired comparison demonstrated that the average relative temperatures do correspond to the subjective cognition of their mental workload, though the results may differ among participants. In summary, an elevated mental workload significantly reduced nose tip temperature. This indicates that the measurement of nose tip temperature can effectively evaluate the mental workload of the scaffold assembly foremen.

Keywords: nose tip temperature, mental workload, infrared thermal imaging, NASA-TLX.

1. INTRODUCTION

Many methods have been used to measure workers' productivity (e.g., time-studies techniques, foreman interview or questionnaires, and activity sampling). Among these techniques, activity sampling is considered reliable if the statistical aspects of data gathering are carefully treated (Oglesby et al., 1989). Activity sampling includes 5-min ratings, productivity ratings, and field ratings. A common feature of these techniques is that productivity analysts are present onsite to observe the operation status of the workers (Thomas and Daily, 1983). Both field ratings and 5-min ratings categorize the work of the employees as either working or nonworking, whereas productivity ratings divide work into effective work, contributory work, and ineffective work.

Effective work is work that directly increases the number of project completions or facilitates project completion, such as assembling wooden forms. Contributory work is work that does not directly increase the number of project completions or facilitate project completion, but is required

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to complete effective work. For example, the communication between workers and foremen in deciding the sequence of formwork completion that should be done in a day does not contribute directly to project completion but is required. Work that cannot be categorized as either effective work or contributory work is ineffective work, for example, loitering on the work site empty-handed.

Field ratings and 5-min ratings can easily underestimate labor productivity by categorizing contributory work as ineffective work, making evaluations of workers' performance using these two methods less justifiable than those made using productivity ratings. In addition, all three methods of activity sampling require observers to determine whether the observed employee is working within a short period; thus, different observers may have different interpretations of whether a worker is working, leading to very different results. Therefore, a more objective technique should be adopted to avoid this subjectivity. A possible solution to this is to measure the physiological responses of people during work. Oxygen consumption at work can be used to effectively distinguish between effective work tasks, but is ineffective at distinguishing some contributory work and ineffective work items (Hsiao et al. 2012). When performing cognitive tasks (e.g., engaging in effective or contributory work) mental workload is generated (DiDomenico and Nussbaum, 2011). This can be monitored by measuring physiological responses such as heart rate, eye blinks, and nose temperature (Veltman and Gaillard, 1996; Itoh and Ibaraki, 2009). Among these, the measurement of nose temperature is the least invasive, as it can be performed by taking thermal images (Itoh and Ibaraki, 2009), therefore making it the preferred method.

This study adopted an infrared thermal imaging camera to capture the facial thermal images of scaffold assembly foremen during five trials and to analyze their nose tip temperature. The results were subsequently used to verify the feasibility of evaluating the mental workload of the participants by objectively measuring nose tip temperature variations. After the trials, interviews and NASA Task Load Index (NASA-TLX) questionnaire surveys were conducted to understand each participant's subjective cognition of mental workload caused by undergoing the five trials.

2. METHODS

2.1. Participants

Thirty male student volunteers from Chaoyang University of Technology participated in the experiment. None of them had prior experience of this task. These students were aged between 22 and 26 years with a mean age of 23.0 ± 1.31 years, average height of 172.5 ±3.89 cm, and average body weight of 68.8 ± 11.79 kg.

Each participant was in good health and reported no history of cardiovascular system disease and musculoskeletal diseases. Informed consent was obtained and the procedure was approved by the University's Institutional Review Board.

2.2. Experimental design and independent variable

This study analyzed the variations in nose tip temperature of construction workers who were placed under various degrees of mental workload. Therefore, the participants' mental workload was chosen as the independent variable. Scaffold assembly was performed to simulate construction tasks. All 30 participants were divided into 10 groups. Each group comprised three participants: two were assembly workers and one, the foreman, was the primary participants. All participants had no previous experience in scaffold assembly. To generate various degrees of mental workload for the participants during the experiments, the foreman was asked to read the assembly manual for 30 seconds before assembling the scaffolds. He was then asked to lead his partners to assemble the scaffolds before fully comprehending the assembly procedures. In addition, the assembly workers could only follow the commands of the foreman and could not work on their own. Each experiment took 15 min, during which a thermal facial image of the foreman was recorded every 20s using an infrared camera. Furthermore, to understand the difference between pre-experiment nose tip temperature and post-experiment temperature measured in the recovery stage, a facial thermal image of the resting foreman was taken every 20s for 2 min. Each group participated in five trials. However, to minimize the influence of each trial on another, the participants were allowed to take a 20-min break between two consecutive trials. The experimental procedures are shown in the flowchart in Figure 1. A photograph of a participant directing two assembly workers is shown in Figure 2. Additionally, in the last (fifth) trial, all groups were asked to compete with each other. NT$1000 was awarded to the group that correctly assembled the scaffolds in the shortest time. To examine the participants' subjective cognition of the mental workload caused by each trial, they were asked to attend interviews and respond to the NASA-TLX questionnaires after each trial.

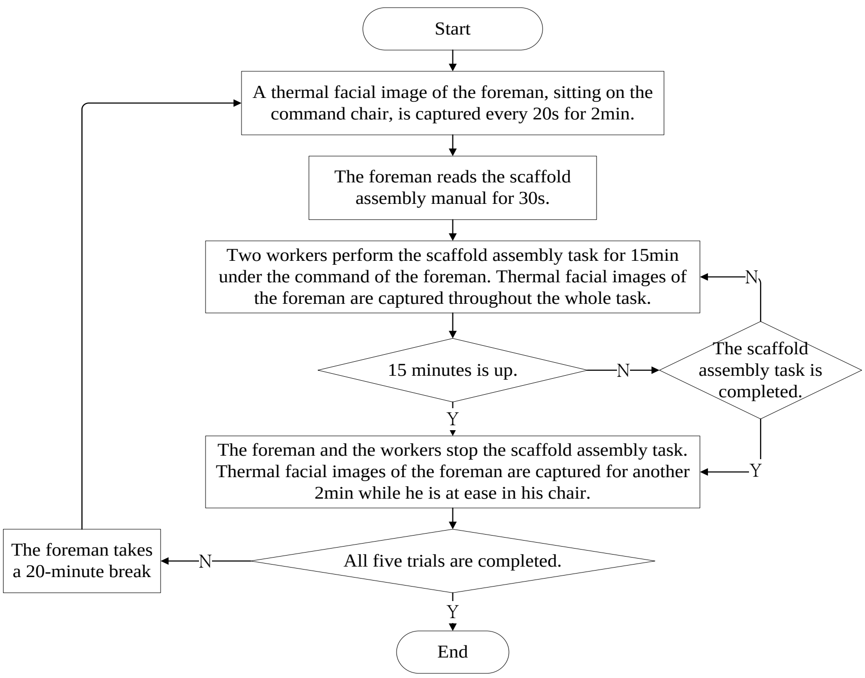

Figure 1: Experimental procedures flowchart.

Figure 2: Photograph of a participant directing two assembly workers.

2.3. Apparatus

Temperatures at the tips of subjects' noses were recorded with an infrared thermal imaging camera (NEC TH7120) every 20s. Calibration of the thermal camera was performed regularly according to the standard procedure specified by the camera manufacturer. NEC InfReC Analyzer NS9500 software was used to analyze the data offline (Figure 3).

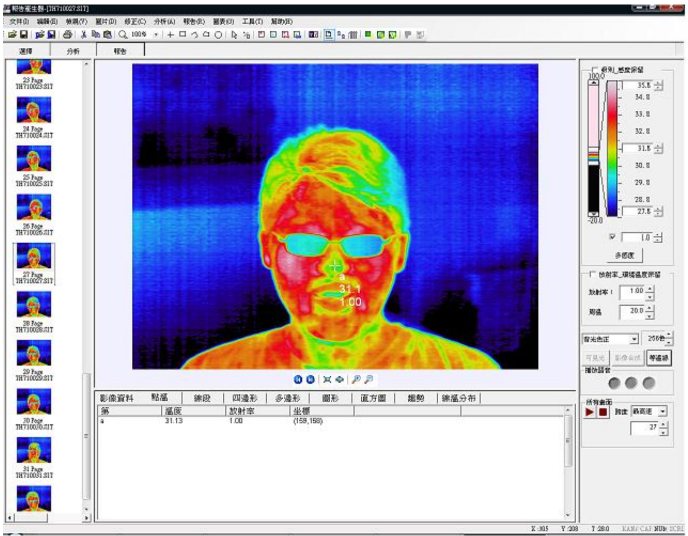

Figure 3: Capturing the temperature at the tip of the nose.

2.4. Data analysis

A one-way repeated-measures analysis of variance (ANOVA) was conducted to compare and verify the variability of nose temperatures while participants were performing different trials of scaffold assembly tasks. Once a significant variation in the average value of the entire group is found, post-hoc analysis is used to further identify the different trials with significantly different average values. The alpha level was set at 0.05.

3. RESULTS

3.1. Objective measuring

The relative temperature was used to judge the mental workload status of the subject. Let T_{ijtr} be subject i's (1 to 10) nose temperature in time t (1 to 6, time was counted every 20 s) at rest before trial j. The average temperature ($\overline{T}_{ijtr}$) at rest before trial j can be derived using equation (1). The relative temperature RT_{ijt} of subject i in time t of trial j is calculated using equation (2).

$$\overline{T}_{ijtr} = \sum_{t=1}^{6} T_{ijtr} \Big/ 6 \qquad (1)$$

$$RT_{ijt} = T_{ijt} - \overline{T}_{ijtr} \qquad (2)$$

(T_{ijt}, subject i's nose temperature in time t of trial j)

The experimental results show that the relative temperature differed between participants; however, it corresponded to the variation trends of the participants' subjective cognition of their mental workload. When the experiment started, the relative temperature significantly plunged, and gradually increased to almost zero during the break between two trials, as shown in Figure 4. The greatest decline of relative temperature occurred in the first trial and the decline of relative temperature gradually reduced in the subsequent trials. The third and fourth trials, however, displayed relative temperatures that were almost identical. The decline of relative temperature during the fifth trial increased compared to the previous two trials. An ANOVA of the fifth trial reached the level of significance ($F = 143.96$, $p < .05$), and a paired comparison (Table 1) showed no significant difference in relative temperature between the third and the fourth trials. Significant differences can be found between all other trials.

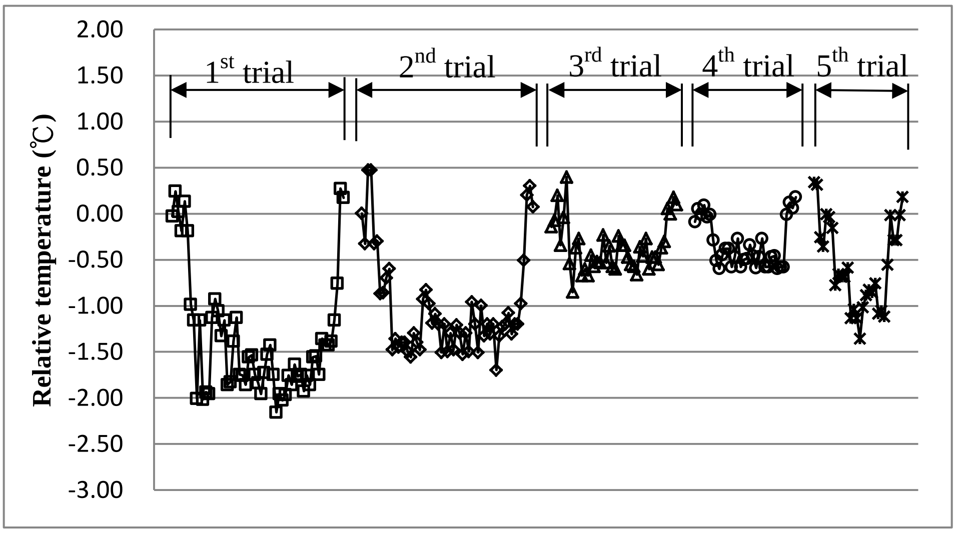

Figure 4: Typical participants' variations of relative temperatures in the five trials.

Table 1: Multiple comparisons of the average relative temperatures of the five trials

Trial no.(I)	Trial no. (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Upper limit	Lower limit
1	2	-0.38778*	0.05164	0.000	-0.5348	-0.2407
	3	-1.14700*	0.05773	0.000	-1.3114	-0.9826
	4	-1.16691*	0.06372	0.000	-1.3484	-0.9854
	5	-0.75378*	0.06831	0.000	-0.9483	-0.5592
2	1	0.38778*	0.05164	0.000	0.2407	0.5348
	3	-0.75922*	0.05773	0.000	-0.9236	-0.5948
	4	-0.77913*	0.06372	0.000	-0.9606	-0.5977
	5	-0.36600*	0.06831	0.000	-0.5605	-0.1715
3	1	1.14700*	0.05773	0.000	0.9826	1.3114
	2	0.75922*	0.05773	0.000	0.5948	0.9236
	4	-0.01991	0.06875	1.000	-0.2157	0.1759
	5	0.39322*	0.07303	0.000	0.1853	0.6012
4	1	1.16691*	0.06372	0.000	0.9854	1.3484
	2	0.77913*	0.06372	0.000	0.5977	0.9606
	3	0.01991	0.06875	1.000	-0.1759	0.2157
	5	0.41313*	0.07785	0.000	0.1914	0.6348
5	1	0.75378*	0.06831	0.000	0.5592	0.9483
	2	0.36600*	0.06831	0.000	0.1715	0.5605
	3	-0.39322*	0.07303	0.000	-0.6012	-0.1853
	4	-0.41313*	0.07785	0.000	-0.6348	-0.1914

*: The average differences at a significance level of .05 were significant.

3.2. Subjective measuring

The participants were asked to attend the interviews after each trial and to complete the NASA-TLX questionnaires after the first and fourth trials to measure the subjective mental workload. The NASA-TLX questionnaire measures a participant's mental load according to six indices: mental demand (MD), physical demand (PD), time demand (TD), performance (P), effort (E), and frustration level (FL). The questionnaire respondents in this study had to complete an evaluation form containing six indices and a paired comparison of the importance of each index (15 sets in total) to calculate weighted values. The score of the mental workload was calculated using (3), the higher scores indicating an elevated mental workload.

$$W = \sum_{i=1}^{6} \times W_i \times R_i \qquad (3)$$

where

R_i is the score of each index; and W_i is the weighted value of each index

The post-experiment interviews reveal that most participants responded that their mental workload was extremely high during the first trial because they had no prior experience in scaffold assembly. Although the participants gained some experience of scaffold assembly in the first trial, they still did not possess the comprehensive concept of completing the assembly task. Considerable mental workload, though lower than that of the first trial, existed in the second trial. However, most groups in the second trial completely assembled the scaffolds and comprehended the concept of scaffold assembly. In the third trial, mental workload was solely caused by unfamiliarity, which was slightly higher than that in the fourth trial. In the fifth trial, the participants completely comprehended the concept of scaffold assembly and had an elevated familiarity with the process. However, because their performance determined whether they received the award, the tension and mental workload caused by the assembly slightly increased. Table 2 shows the scores of the NASA-TLX questionnaires responses after the first and fourth trials. All respondents scored lower in the fourth trial (64.2 ± 10.9) than in the first trial (46.3 ± 5.9), implying a significant decrease in mental workload. In addition, an analysis of the questionnaire results displayed that P and FL had the most significant score decrease among the six indices (98.0 ± 3.7% and 58.0 ± 15.8%, respectively). This matched the results of post-experiment interviews.

Table 2: NASA-TLX scores measured after the first and fourth trials

Group	1	2	3	4	5	6	7	8	9	10	mean	Std. dev.
1st trial	77.8	58.4	69.4	67.9	75.2	59.2	69.9	51.3	43.2	69.7	64.2	10.9
4th trial	47.7	38.5	48.8	54.1	52.7	50.0	49.1	41.2	37.2	43.3	46.3	5.9

4. CONCLUSIONS

This study investigated the feasibility of proposing an objective method that measures nose tip temperature variations to evaluate mental workload. Each of the 10 participants performed five trials of scaffold assembly as the foreman in his group, during which their facial images were captured by an infrared thermal imaging camera to record temperature variations at the nose tip. After the experiments, interviews were conducted and NASA-TLX questionnaire surveys were administered to understand each participant's subjective cognition of mental workload caused by the five trials. The ANOVA of the average relative temperature of each participant measured during the five trials showed significant differences. A paired comparison demonstrated that the average relative temperatures do correspond to the subjective cognition of their mental workload, though the results may differ among participants. In summary, high mental workload is associated with significantly lower nose tip temperature. This indicates that the measurement of the nose tip temperature can effectively evaluate the mental workload of scaffold assembly foremen.

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