Association between physiological signal from wearable device and alertness of office workers

Yoonhee Lee and Chungyoon Chun*

Department of Interior Architecture & Built Environment, Yonsei University, Seoul, South Korea

** Corresponding author: chun@yonsei.ac.kr*

ABSTRACT

Through physiological signals, detecting the changes of occupants' physical and psychological aspects is possible, and wearable devices have enabled measurement in dailylife. In this study, to see whether the wearable device could be used for interpreting the state of the office workers, a field experiment was conducted.A wearable device was applied for monitoring the occupant, and productivity responses were collected inside a real office. As a result, when the productivity and alertness decreased, the room temperature was high, and the skin temperature and electrodermal activity were increased. A comparison between the group of alert and drowsy states was also made. The average and the gradient of skin temperature had a significant difference between the states. The result of skin temperature could be interpreted as suppressing the sympathetic nervous systems in the drowsy state, increasing blood flow, and increasing temperature at the terminal skin. Significant relation with the electrodermal activity can be explained through sweat secretion. The results showed the insight of understanding the occupants' alert state through wearable device measured data.

INTRODUCTION

The recent development of wearable technologyenabled wireless real-time measurement of various parameters, and the technology is being used in numerous fields. Wearable devices can measure vital signs such as heart rate, blood pressure, skin temperature, sweat,posture, and physical activities.By using wearable devices, continuous field data could be achieved, and researchers could monitor certain features' patterns. Furthermore, attempts to detect or predict certain events or status was made. (Sim et al., 2018; Can et al., 2019; Liu et al., 2019)

Also, in the field of the indoor environment study, the wearable device could be made useful in various aspects. When it comes to the office environment, productivity and alertness are some of the main concerns, and supporting the workers to be more effective is crucial. Studies to make a productive environment by controlling the HVAC system were conducted (Tanabe et al., 2015; Geng et al., 2017). To fully support this control system, understanding the occupant's state should be preceded. This is the part where the wearable device can play a role. The wearable device can provide continuous feedback from the occupants, including physiological signals. Physiological signals can reflect the physical and psychological changes, and the data can be used for understanding the state of the person.

Therefore, based on previous research, this study focused on detecting workers' alertness based on the data from the wearable device. Through the field experiment, the office environment, which occupants were exposed, was measured, and the wearable device was used to collect the occupants' physiological signals. The goal was to find the association between the physiological signals from the wearable device and theoffice workers' state and to discuss the direction of environmental control depending on the state of workers.

METHODS

Field experiments were held place in an office at Yonsei University from June to November 2019. The survey response of occupants in the office was obtained,and physiological signals of the occupants were measured using the wearable device.

Twelve females and 24 males, a total of 38 healthy office occupants in their 20s, participated.The working hour of the office was from 10 a.m. to 6 p.m. During office hours, occupants responded to the alertness survey regularly (1-hour intervals in June and 20-minute intervals in September, 10-min intervals in October and November) through their phone or computer. The participants used their computers to perform their usual tasks and usually were in a sedentary position. The occupants were given control of the indoor environment, such as air conditioning and window opening, and participated in their usual clothes.The thermal condition inside of the office was measured with the survey responses and physiological signals.

To analyse the alert state of the office occupants, perceived productivity and alertness were collected.Perceived productivity was measured using a five-point scale used in the SCATs project (McCartney and Humphreys, 2002), 1 'Much higher than normal' - 5 'Much lower than normal'. The nine-point scale (KSS scale) was used to respond to the alertness (Kaaida et al., 2006), 1' Extremely alert' to 9 'Very sleepy, great effort to keep awake'.(Table 1)

Table 1 Survey scale

Perceived productivity		Alertness	
Scale	No.	Scale	No.
Much higher than normal	1	Extremely alert	1
Slightly higher than normal	2	Very alert	2
Normal	3	Alert	3
Slightly lower than normal	4	Rather alert	4
Much lower than normal	5	Neither alert nor sleepy	5
		Some signs of sleepiness	6
		Sleepy, no effort to stay awake	7
		Sleepy, some effort to stay awake	8
		Very sleepy, great effort to keep awake	9

To see the thermal environment to which occupants were exposed, ComVote (Kwon, 2018), a small environmental measuring device, was placed on the desk of each occupant, and anemometer TA 465 (TSI, USA), was placed one per four occupants. Indoor air temperature, globe temperature, indoor relative humidity, and indoor air velocity were measured as indoor environmental factors.The sensors measured the environmental factors automatically at one-minute intervals. (Table 2)

Table 2 Data collection device information

Variables	Collection frequency	Equipment specification	Accuracy
Air temperature	1min	Sensirion SHT21	±0.3 °C
Globe temperature	1min	S+S Regeltechnik RPTF-2	±0.2 °C
Relative humidity	1min	Sensirion SHT21	±2 % RH
Air velocity	1min	TSI TA465	±0.2 m/s

The physiological signals were measured through the wearable device Empatica E4 wristband (Empatica Inc., USA), enabling real-time, continuous physiological measurements.E4 wristband consists of four sensors, a photopolymer(PPG) sensor, an electrodermal activity (EDA) sensor, a 3-axis accelerometer, and an infrared thermophile sensor. The PPG sensor detects the blood volume pulse (BVP) signal,and the signal can be used to obtain inter-beat-interval (IBI) and heart rate data. The EDA sensor detects the electrodermal activity on the skin surface, and the infrared thermophile sensor measures peripheral skin temperature.

Figure 1. Empatica E4 wristband

Physiological signals, the skin temperature, heart rate, and electrodermal activity, were analyzed after excluding the outliers, including when the temperature dropped rapidly due to poor contact or heart rate measurement lower than 40. The artifact of the electrodermal activity was removedusing the algorithm based on skin temperature and accelerometer values. (Taylor et al., 2015)

For the analysis, Pearson correlation coefficients were used to see the correlation between response and physiological signals in the office. The average and standard deviation 10 minutes before the response of the physiological signals were calculated. In the case of the skin temperature, the gradient over 10 min before the response was calculated. The value of the skin temperature at the time of the response was subtracted by the value of 10 minutes prior to the response and then was divided into 10, which was the timeframe of the features. This was not only to understand the state when the response happened but also to reflect the changes.An independent two-sample t-test was also performed to compare the thermal environment and physiological signals of the alert and the drowsy state.

RESULTS

From the field measurement, a total of 3,555 responses were collected from June to November.During the cooling season, the air temperature ranged from 22.4 to 28.8 °C, and the average air temperature was 26.3 °C with a standard deviation of 1.5 °C. Conversely, in the heating season, the air temperature ranged from approximately 18.7 to 26 °C with an average of 22.9 °C and a standard deviation of 1.1 °C. The overall office environment appeared comfortable and neutral in all the measurement periods when the thermal environment was calculated based on the Predicted Mean Vote(PMV). (Fanger, 1970) 93% of the environment was within the range of PMV -1 and PMV 1.

The overview of the responses could be summarized as follows. The perceived productivity responses showed that about half (49.7%) of the time occupants felt 'normal', not higher or lower productivity from the normal state. 31.5% of the response was the occupants were feeling lower productivity than the normal state - 27.3% 'slightly lower than normal', 4.2% 'much lower than normal'- and 18.8% felt higher productivity than usual– 17.7% 'slightly higher than normal', 1.1%'much higher than normal'. Alertness response showed that about 41.3% was in an alert state-0.9% 'extremely alert', 4.9% 'very alert', 12.5% 'alert', 23% 'rather alert' - 17.6% neither alert nor sleepy, 41.1% feeling sleepiness – 20.9% 'some signs of sleepiness', 12.5 % 'sleepy, no effort to stay awake', 6% 'sleepy, some effort to stay awake', 1.7% 'very sleepy, great effort to keep awake'. As shown from the responses, various alert states of the occupants were collected.

Before the analysis of the physiological signals, the seasonal difference was considered. The skin temperature can be affected by the surrounding thermal environment and certain skin temperature can mean different states in cold or hot conditions. Therefore, to minimize the misinterpretation of the physiological signals, the analysis was divided into cooling season and heating season, based on air conditioner use inside the office.

In the cooling season, the result of the Pearson correlation coefficients showed that perceived productivity was significantly correlated with average skin temperature and electrodermal activity, higher skin temperature, and electrodermal activity in more drowsy states. However, the correlation was weak. The alertness responses were significantly related to average skin temperature, electrodermal activity, and skin temperature gradient. The correlation showed that the alertness seems lowerwhen the skin temperature was high or increased and when the electrodermal activity was high. However, the overall correlation was weak.

In the heating season, similar to the cooling season, perceived productivity was significantly correlated with the average skin temperature and electrodermal activity, and the alertness had a significant correlation with the average skin temperature. The result demonstrates that when the skin temperature was higher, the occupants felt lower productivity and drowsiness. However, the correlation was weak in the heating season as well.

To gain more detailed physiological feature of the different state of the occupants, a comparison analysis was made. The analysis was conducted to compare the physiological signals in an alert state and drowsy state. T-test analysis was used to compare the alert group and the drowsy group.

The group's criteria were based on the alertness response, the 'alert' and 'drowsy' group. In the alertness responses, 1 'Extremely alert', 2 'Very alert', 3 'alert', 4 'Rather alert' was classified into 'alert' group and 6 'Some signs of sleepiness', 7' Sleepy, no effort to stay awake', 8' Sleepy, some effort to stay awake', 9 'Very sleepy, great effort to keep awake' were classified into 'drowsy' group.

In the cooling season,average skin temperature, skin temperature gradient, and electrodermal activity significantly differed between the two groups. Figure 2 demonstrates the physiological signals according to the alertness. The skin temperature result showed that the skin temperature was lower in the 'alert' group than in the 'drowsy' group. Also, the skin temperature gradient, which shows the amount and direction of change in skin temperature, was higher in the 'drowsy' group, meaning that when occupants felt drowsier than alert, the skin temperature was high and the skin temperature was rising, electrodermal activity was significantly higher in the 'drowsy' group than in the 'alert' group.

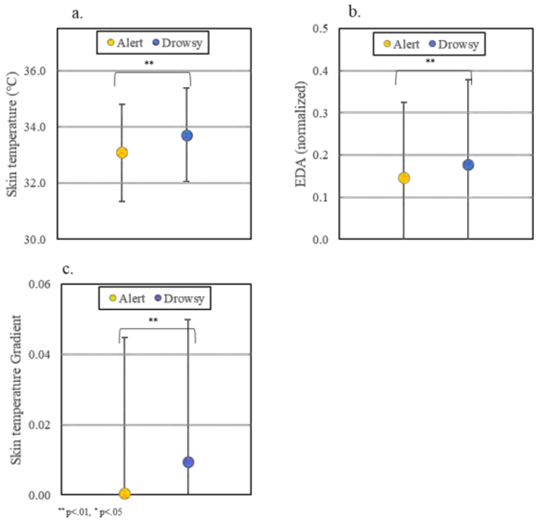

Figure 2. Physiological difference between alert and drowsy group in cooling season (a) average skin temperature, (b) average electrodermal activity, (c) gradient of skin temperature

Also, in the heating season, the average skin temperature showed a significant difference between the states, and the standard deviation of skin temperature and electrodermal activity showed significant differences in 'alert' and 'drowsy' group.

As demonstrated in Figure 3 skin temperature was significantly lower in the 'alert' group than in the 'drowsy' group, similar to the cooling season. Also, the standard deviation of skin temperature was significantly bigger in the 'alert' group than in the 'drowsy' group. The standard deviation of electrodermal activity was significantly bigger in the 'alert' group than in the 'drowsy' group. This means that when occupants feel drowsy than awake, skin temperature was high, and the deviation of skin temperature and electrodermal activity was small.

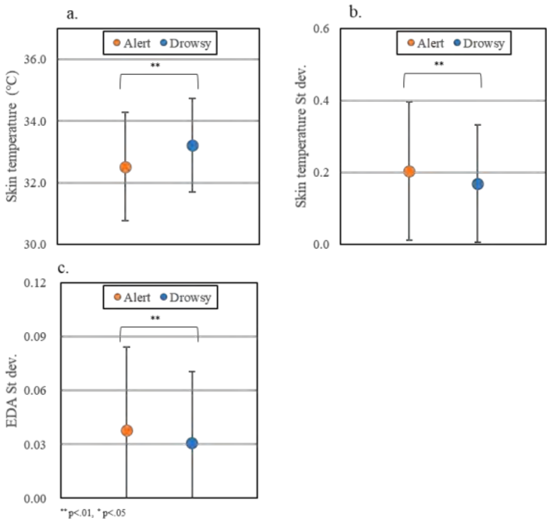

Figure 3. Physiological difference between alert and drowsy group in heating season (a) average skin temperature, (b) standard deviation of skin temperature, (c) standard deviation of electrodermal activity

The results above showed that the varying alertness of occupants havesignificant difference in terms of physiological signals from wearable device. The skin temperature was especially shown to have a significant relationship with the occupants' alert state. This suggests the possibility of distinguishing the alert state of occupants by using physiological signals from the wearable device.

DISCUSSION

Physiological signals are used as indicators of the perceptual, psychological, or physical response of the occupants to the environment. This study attempted to analyse the alert states of office occupants based on the physiological signals of the wearable device through long-term measurement inside the office. As aresult alert state ofthe occupants showed a significant correlation with the physiological signals from the wearable device, especially the skin temperature and electrodermal activity.

The correlation found could be explained through previous studies. According to a study by Bando et al. (2017), suppression of the sympathetic nervous system in a drowsy state increases blood flow at the terminal skin temperature and increases skin temperature. Similarly, this study also showed that perceived productivity and alertness were negatively correlated with skin temperature. The higher and rising skin temperature in lower perceived productivity and alertness may be caused due to the physiological responses of the drowsy state.

In the case of electrodermal activity, according to a study by Hagbarth (1972), the electrodermal activity can be used as a measure of psychological and physical arousal. The stronger the stimulus, the greater the electrodermal activities and the greater the number of peaks. Therefore, Haag et al. (2004) used the electrodermal activity as an indicator of the alert state and drowsy state. The reason for increased electrodermal activity canbe divided into two cases: increased sweat secretion due to activation of the sympathetic nervous system or due to the thermoregulation system. In this study, the electrodermal activity was expected to be the indicator of the arousal state of the occupants; however, the electrodermal activity seemed higher in the drowsy state than the alert state. This can be interpreted as a result of sweat secretion influenced by thermoregulation and rising skin temperature rather than sympathetic nervous system activation andalertness.

The heart rate is also commonly used as an indicator for interpreting the state of the individual, as the heart rate is affected by the mental state. When the human is in a stable condition, the parasympathetic nervous system prevails over the sympathetic nervous system so that the heart rate is relatively low.Rahim et al. (2015) demonstrated a decrease in heart rate when changing from the alert state to the drowsy state. However, in this study, a certain tendency or significant correlation was not observed.

Moreover, there was a slight difference between the seasons regarding significant features. In the cooling season, the major condition for the change of the indicator was due to sweat and thermoregulation through high or rising skin temperature. However, in the heating season, the skin temperature and the deviation of the skin temperature and electrodermal activity showed a significant relationship. This showed that the main features for interpreting the state of the alert state differ from season to season, and high skin temperature played a role as a consistent indicator for the low alert state.

In this study, when observed through the wearable device, the occupants were feeling drowsy, the skin temperature and electrodermal activity were high, and the skin temperature was rising. This result implies that the state of the occupant, especially the drowsy state, could be detected through the simple wearable wristband. By monitoring the physiological signals, including the skin temperature, when the skin temperature or the electrodermal activity rises to a certain level, the office could detect the drowsiness and provide the appropriate setting for the occupants. For example, the support could be provided by changing the thermal conditions, such as using fans, room temperature, or a personal comfort system.(Lipczynska et al., 2018; Tanabe et al., 2015; Kim et al., 2019)

However, there are limitations to this study. First, the criteria or the algorithm to determine whether the occupant feels alert or drowsy need further investigation.Also, other factors such as environmental factors could be used to determine for interpreting the more accurate state of the occupant, for example, explaining whether the skin temperature rose due to sleepiness or the office became hot. The popular machine learning algorithms method could be a good plan to apply when processing the abundant data with various features like in this study.

Second, the wearable device had problems in terms of poor contact issues. Poor contact prevented this study from acquiring quality data, especially the IBI signals, which can provide heart rate and heart rate variability. The quality of the physiological datacould be one of the main issues for wearable technology in the future. For the last, there could be an ethical issue when implementing to the real office, such as using the alert and drowsy state information for surveillance purposes. The importance of personal data should be set as a high priority and should be kept confidential.

CONCLUSIONS

This study aimed to see the possibility of applying the wearable device in the indoor environmentalscience by analyzing the association with the alertness responses and the physiological signals from the wearable device.

A significant relationship was found between the alertness responses and the physiological signals, especially the skin temperature and the electrodermal activity, through statistical analysis. The average skin temperature, the gradient of the skin temperature, and average electrodermal activity significantly differed between two groups. The resultsshowed that when office occupants felt somewhat drowsy than alert, their skin temperature was higher or increasing, and the electrodermal activity was higher.

The above results imply that the data acquired from the wearable device could be used as indicators for alert state detection. Especially in this study, the skin temperature from the wrist seemed to be an important variable for the detection and can be considered as data with appropriatequality from the wearable device.

Further steps should be made to fully support the office occupants and contribute to the office systems. However, the data collected from this study was straight from the field, and the relationship discovered is closely linked with the real environment. Therefore, based on the features found from this study, future studies which can more carefully reflect the responsesof the occupant state would be possible, along with understanding the various features and aspects of applying the wearable device to the field.

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