

User Experiences and Perceptions of Thermal Feedback in the Tropics

Kittawan Janjeng, Teerapong Leelanupab

Faculty of Information Technology
King Mongkut's Institute of Technology Ladkrabang (KMITL)
Bangkok, Thailand. 10520

k.janjeng@gmail.com, teerapong@it.kmitl.ac.th

Abstract: Thermal feedback provides a novel emotive, private and salient communication channel between human and computer. It could be used as an alternative to or replacement for common notification channels (e.g., visual, vibrotactile and audio feedback) for situations that are too bright, bumpy, and noisy. Until now, little investigation has been conducted on the use of thermal feedback in various situations. This paper presents the first investigation of how environmental factors affect the use of thermal feedback in a tropical area where temperature and humidity are high; relative to previous studies mostly conducted in temperate or rather cold areas. We also studied the effect of sudden change of ambient temperature that often happens in daily life situations of tropical users. Furthermore, the learning of the use of thermal feedback was examined as well as subjective comfort and intensity of each stimulus. Experimental results showed that thermal stimuli have potentials to be used for providing feedback to the users in the tropics. In addition, the transition of ambient temperatures has very little effect on thermal perception of the same stimuli. Within this context, strong stimuli with respect to intensity and rate-of change are reported to be more suitable than other weak stimuli. This is because they are relatively easier and faster, though less comfortable, to be detected by users. Moreover, the cold feedback is preferred to the warm.

Keywords: Thermal feedback, mobile interaction, non-visual feedback

1 INTRODUCTION

The tactile modality provides a potential communication channel for delivering information through the sense of touch. Thermal feedback is a new type of tactile modalities, considered in Human Computer Interaction (HCI) as an emotive, private and salient channel for computer-to-human communication [16]. At present the modalities of seeing, hearing and discriminative touching, i.e. visual, audio and vibrotactile feedbacks, are the most widely used in computing device. However, they are often not suitable in some situations. Audio feedback, for example, may be heard by other people or cannot be perceived by users in silent and noisy locations (e.g., in library, pub, cinema, etc.). Vibrotactile feedback may be felt by other people and hardly be recognized in bumpy places such as on moving vehicles, during exercise or in some working conditions. Whereas thermal feedback cannot be seen, heard and felt by others.

Previous research mostly focused on abstract uses of thermal output, on physical stimuli and their perception in virtual reality, or on peripheral expressions as thermal messages. Nevertheless, so far thermal feedback has not been fully investigated for its use in a broader scenario. For instance, the effect on user perception of clothing and different locations of human body (i.e., fingers, thenar, forearm and upper-arm) was previously studied [16]. Although the influence of ambient factors was also

investigated, the conditions of these past experiments were restricted in cold areas where, for example, the range of ambient temperature was between 6°C and 25°C [4].

Inspired by previous works, this research aims to expand the investigation of the use of thermal feedback, leading to its more practical usage in real-world situations. This is, in particular, the case of tropical areas, where users are likely or forced to frequently go from outdoor (i.e., a boiling hot environment) to indoor (i.e., a chill air-conditioned one), or vice versa. The sudden change in ambient temperature from extremely hot to cold may affect users' perception of thermal feedback. Importantly, this paper is the first to look at how the transition of environmental temperatures might affect the user perception and therefore the usability of thermal feedback. Furthermore, we present a comprehensive study on the influence of high environmental temperature and humidity, such as in a tropical country, on the use of thermal feedback. The difference in ambient temperature and humidity ranges can provide an insight into the application of thermal feedback.

2 RELATEDWORK

Thermal display was introduced by psychologists [8, 13] for studying aspects on human temperature perception. Human skin temperature is normally in a range of 28-40°C and the neutral thermal zone is rather stable, ranging between 6-8°C. It, however, usually varies in each

individual according to his condition and thermal sensitivity (e.g., 30-36°C or 28-34°C). Kenshalo [9] reported that human sensitivity towards cold temperature is faster than that towards warm temperature. In addition, while a sensation of cold is immediately perceived, a perception of warmth is gradually increased. Hagander *et al.* [3] found that thenar eminence is more sensitive to warmth sensation than the dorsal surface of hand and foot. Yet, there is no difference of the sensitivity to cold temperature for these body locations.

Temperature perception of human is detected when temperature is below or above their neutral thermal zone, in accordant with the thermal threshold and the rate of thermal change [6, 8]. Green [2] conducted the experiment on temperature sensation with three fingers using three stimulators attached on each finger. His experiment suggested that a sensation of middle finger differs from that of the two outer adjacent fingers. The magnitude of warmth or cold sensed at the middle finger is greater than that at the other two, when all three stimulators release the same thermal stimuli (i.e., warmth or cold).

An HCI community has just paid much attention to research on the use of thermal feedback recently. Nakashige *et al.* [11] conducted a small formal study on the addition of digital media, e.g., photographs, by temperature. They found that photographs with corresponding thermal feedback (pictures of food such as soup with a warm stimulus and ice cream with a cold one) are more appealing and feeling to subjects. Narumi *et al.* [12] studied the use of thermal information to identify different areas. This studied is the baseline for further mobile scenario studies.

Also, was studied the use of various thermal messages for feeling and meaning expression from one to others. Thermal stimuli were meant to be meaning of message [1, 10]. Meanwhile, there is another related research [14], studying those who experience the vibrotactile and thermal feedback. The users were requested to express the meanings or emotions for each stimulus before doing a questionnaire. The studies showed that warm temperature refers to positive feelings while cold temperature refers to negative feelings. In addition, Wilson *et al.* [15] developed intramodal that was combined between thermal feedback and vibrotactile feedback to convey information to user. Thermal identification was studied [17], aiming to examine the perception and identification of thermal stimuli while moving in outdoor environment.

Wilson *et al.* [16] showed the study of body location perception and mobility of use of thermal feedback. Body

locations that they examined are fingertips, palm, dorsal surface of forearm and dorsal surface of upper arm. Furthermore, they evaluated which thermal stimulus was the most suitable. The results showed that the palm can perceive stimulus the most and that cold feedback is more likely or comfortable than warm.

The Influence on the use of thermal feedback was more widely studied. Helvey *et al.* [5] presented the effect of clothing material on thermal feedback perception. They also evaluated [4] the effect of ambient temperature and humidity on thermal feedback perception. This evaluation was conducted in cold area where the ambient temperature between a minimum 8.45°C to maximum 27.75°C, ambient humidity between 31.4% to 93.2%.

3 EVALUATION

The aim of this evaluation is to study user experiences and perceptions of thermal feedback in the tropical area. We have to aim to answer the following research questions:

- RQ1: How does the immediate transition of environmental temperatures affect the user perception and therefore the usability of thermal feedback?

- RQ2: Does high ambient temperature in the tropics have an effect on people's ability to detect and perceive thermal stimuli?

- RQ3: Does ambient humidity in tropics have an impact on the detection of thermal feedback?

- RQ4: Do repeated uses of thermal interfaces and time interval of repetition increase the ability of users to detect and perceive thermal feedback?

3.1 Stimuli

This evaluation replicated the experiment design of Helvey *et al.* and Wilson *et al.* [4, 5, 16]. The presented thermal stimuli were a combination of two thermal direction of change (warm and cold), two thermal intensities ($\Delta 3^\circ\text{C}$, $\Delta 6^\circ\text{C}$) and two different rates of change (ROC) ($1^\circ\text{C}/\text{sec}$, $3^\circ\text{C}/\text{sec}$), giving a total of 8 stimuli.

3.2 Variables

We studied the effect of transition, temperature, humidity and training. Five independent variables were: i) two directions of change, ii) two rates of change, iii) two thermal intensities, iv) transition of environmental temperature and v) user experience. Four dependent variables were: i) detection rate (number of detection) ii) detection time (how long after stimulus was detected) iii) subjective stimulus comfort iv) subjective stimulus intensity.

Participants were asked to rate scale of subjective comfort of stimulus and subjective intensity of stimulus. The scale of comfort stimulus was 7-point Likert scale from very uncomfortable to very comfortable. The intensity scale also was a 7-point Likert scale from very cold to very warm, with zero being neutral.

3.3 Participants

Twenty-four participants were divided into three groups to study training effect: single, bi-weekly repeated and monthly repeated. Single session users took part in one session of the study only, bi-weekly users participated in a session twice a month and monthly users took part once a month for three months. Each month four participants in each group took part. Single-user group was composed of 5 males and 7 females, bi-weekly repeated group consisted of 2 males and 10 females and monthly repeated group consisted of 2 males and 2 females. Most subjects are students or employees of a university.

3.4 Environmental Conditions

Evaluation was carried out in Thailand over a period of 3 months, where the average of outdoor temperature was over 25°C and the average humidity was in the range 50-60%. In contrast, indoor temperature was controlled by air conditioners at approximately 25°C, which is a common temperature, set by Thai people.

Two very different temperature and humidity environment were conducted for the evaluation. The first was in the room where temperature was set by air conditioners. Outdoor locations were i) covered entrance way on roof-deck and ii) pathway adjacent to a university building where ambient temperature ranges from a minimum of 27°C to a maximum of 44°C and humidity from a minimum of 41% to a maximum of 68%. Both of outdoor locations were quiet and not affected by wind. Fig. 1 presents the number of experimental sessions at each (a) temperature and (b) humidity range.

Single-use session users were tested in ambient temperature from minimum of 29°C to maximum of 37°C. Temperature data were managed on three groups of range in block of 5°C, there was <30°C, 30-35°C and >35°C. Also humidity data were grouped into three groups humidity range in a block of 10%, which were <50%, 50-60% and >60%. Bi-weekly users were participated in temperature range 28-44°C and humidity range 42-68%. Monthly users were tested in temperature and humidity from 27-40°C and 38-90% respectively.

3.5 Design and Procedure

Custom micro-controller board that could drive Peltier heat pumps by an android mobile device through Bluetooth

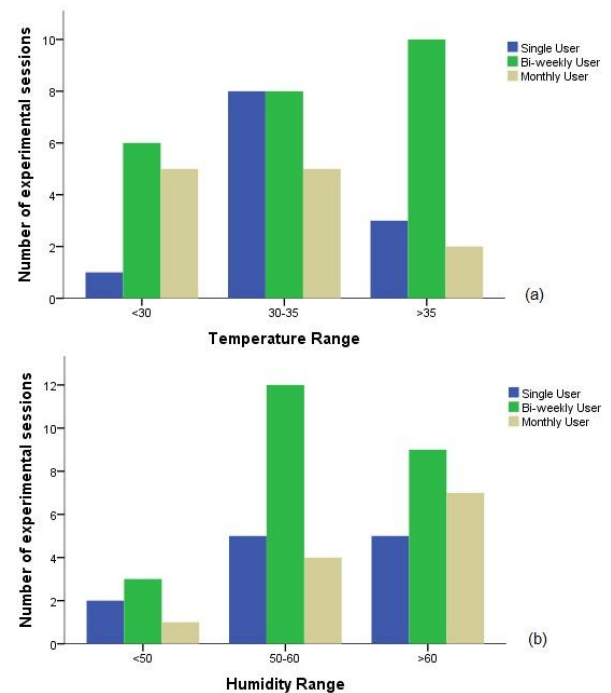


Fig. 1. The number of experimental sessions conducted at difference ranges of (a) temperature and (b) humidity.



Fig. 2. Participant sitting outdoor (left), stimulator was held against the forearm (right).

connection was developed. There are two Peltier heat pumps as warm stimulus and cool stimulus and battery for mobility use. The range of temperature that we used in the experiment was controlled in between 26°C and 38°C.

By following the research questions, participants were instructed to immediately change environmental temperature from indoor to outdoor and from outdoor to indoor (Fig. 2-(left) participant sitting outdoor). Each participant was asked to wear a Peltier stimulator on his/her forearm (Fig. 2-(right)). Forearm was chosen for this evaluation as more suitable than palm as participant might wear watch or exercise arm band; so they do not feel annoyed to.

The thermal stimulator was held against the forearm with a velcro strap. Participants also carried a mobile device for providing their response to given thermal stimuli in our developed mobile application. The tasks start with the fact that The Peltier adapted to human body temperature for 60 seconds. After that all 8 stimuli were presented in a random order. Each stimulus presentation consisted of 10 seconds and returned to human body temperature for 30 seconds for adaptation followed by stimulus presentation and 30 seconds of adaptation. If participant detect a given stimulus, they will press the button “I feel it” on mobile device screen.

4 RESULTS

4.1 Single Session

Number of Detection

Table 1 presents the average performance relative to temperature and Table 2 shows the average performance of different ambient humidity. Friedman’s analysis showed ambient temperature had a significant effect on detection rate ($\chi^2(2)=8.4$, $p=0.015$). Furthermore there were significant effect between $<30^\circ\text{C}$ vs. $30-35^\circ\text{C}$ ($Z=-1.826$, $p=0.034$) and $30-35^\circ\text{C}$ vs. $>35^\circ\text{C}$ ($Z=-2.032$, $p=0.021$). Ambient humidity was found to have a significant effect on number of detection ($\chi^2(2)=8$, $p=0.018$). Post-hoc Wilcoxon T comparisons showed significant differences between $<50\%$ vs. $>60\%$ ($Z=-1.841$, $p=0.033$) and $50-60\%$ vs. $>60\%$ ($Z=-1.841$, $p=0.033$). However, there were no significant effects of immediately change of environment, intensity, ROC and direction.

Time to Detection

Friedman’s analysis of variance by ranks revealed that ambient temperature had a significant effect on detection time ($\chi^2(2)=8.222$, $p=0.016$). Pairwise Wilcoxon T tests revealed a significant effect between $<30^\circ\text{C}$ vs. $30-35^\circ\text{C}$ ($Z=-2.521$, $p=0.006$) and $30-35^\circ\text{C}$ vs. $>35^\circ\text{C}$ ($Z=-1.68$, $p=0.046$). There was no significant effect of ambient humidity. Statistical tests also showed that transition did not have an effect on time to detection. Intensity of change was found to have a significant effect on Time to detection ($Z=-2.267$, $p=0.0115$) with the higher intensity (6°C) having better detection time (mean=4.63s.) than the lower intensity (3°C) (mean=5.01s.). Rate of change significantly affected ($Z=-2.579$, $p=0.005$) the higher ROC ($3^\circ\text{C}/\text{sec.}$) being detected more quickly (mean=4.36s.) than the lower ROC ($1^\circ\text{C}/\text{sec.}$) (mean=5.27s.). Direction of change did not have an effect on detection time.

Table 1. Average performance relative to temperature.

	<30	30-35	>35
Detection Rate (Accuracy %)	62.5	79.69	100
Detection Time (sec.)	5.38	5.47	3.31
Comfort (Scale 0-6)	2.38	2.96	3.46
Intensity (Scale 0-3)	2.13	1.88	2.13

Table 2. Average performance relative to humidity.

	<50	50-60	>60
Detection Rate (Accuracy %)	87.5	90.63	75
Detection Time (sec.)	4.69	3.99	5.81
Comfort (Scale 0-6)	3.35	2.94	2.93
Intensity (Scale 0-3)	2.08	1.97	1.89

Subjective Stimulus Comfort

Ambient temperature was found to have a significant effect on perceived comfort ($\chi^2(2)=10.889$, $p=0.004$). Wilcoxon T comparisons showed a significant difference in subjective stimulus comfort between $<30^\circ\text{C}$ vs. $30-35^\circ\text{C}$ ($Z=-2.383$, $p=0.0085$) and $30-35^\circ\text{C}$ vs. $>35^\circ\text{C}$ ($Z=-2.521$, $p=0.006$). Ambient humidity did not have significant differences in perceived comfort. Statistical test also showed that intensity of change and ROC did not have significant differences. Wilcoxon T comparisons showed significant differences of direction of change in subjective comfort ($Z=-3.262$, $p<0.001$). Cold stimulus had a significantly higher average subjective comfort rating (mean= 3.67) than warm stimulus (mean=2.35).

Subjective Stimulus Intensity

Ambient Temperature had a significant effect on perceived intensity ($\chi^2(2)=10.692$, $p=0.005$) between $<30^\circ\text{C}$ vs. $30-35^\circ\text{C}$ ($Z=-2.384$, $p=0.085$) and $30-35^\circ\text{C}$ vs. $>35^\circ\text{C}$ ($Z=-2.243$, $p=0.013$). Humidity did not have a significant differences in perceived intensity. Intensity of change significantly affected perceived intensity ($Z=-4.81$, $p<0.001$). Perceived intensity increased as 1°C (mean=1.48) and 3°C (mean=2.44) intensity respectively. Statistical test showed that ROC had a significant differences in intensity ($Z=-3.104$, $p=0.001$). With higher ROC ($3^\circ\text{C}/\text{sec.}$) (mean=2.17) being more intense than lower ROC ($1^\circ\text{C}/\text{sec.}$) (mean=1.77). Direction of change was found to have a significant effect on subjective intensity ($Z=-1.8$, $p=0.036$) with cold stimulus (mean=1.89) being less intense than warm stimulus (mean=2.04).

4.2 Repeated Session

Bi-weekly Session

Wilcoxon T comparisons were used to analyze an effect of repeated use of the thermal stimuli or training. There was no effect of bi-weekly repeated session on detection time ($Z=-0.941$, $p=0.173$). The different sessions did not have effect on detection rate ($Z=-0.264$, $p=0.396$). Subjective stimulus comfort and intensity also did not have a significant effect on bi-weekly repeated session ($Z=-0.118$, $p=0.453$) and ($Z=-0.157$, $p=0.438$) respectively.

Monthly Session

Friedman's analysis of variance by ranks was used to analyze effect of training between monthly sessions. There was no effect of monthly repeated session on detection time ($\chi^2(2)=0.5$, $p=0.779$). The different monthly repeated sessions did not have an effect on detection rate ($\chi^2(2)=0.545$, $p=0.761$). Subjective stimulus comfort and intensity also did not have a significant effect on monthly repeated session ($\chi^2(2)=1.2$, $p=0.549$) and ($\chi^2(2)=2.364$, $p=0.307$) respectively.

Comparison between Single and Repeated Session

Single and repeated user performances were analyzed by Mann-Whitely U test for comparison. Table 3 presents the data of means of single users and bi-weekly users of detection rate, time to detection, comfort and intensity between bi-weekly users and single users. Data on top rows (highlighted in grey) are performance from bi-weekly repeated users and below are single users performance. Statistical tests provided that biweekly user performance had a significant difference on detection rate and detection time in session 1 in the range >35 ($U=0$, $Z=-2.121$, $p=0.017$), ($U=0$, $Z=-1.964$, $p=0.025$) respectively. The results also showed a significant effect on detection rate in session 2 in the range >35 ($U=3$, $Z=-1.732$, $p=0.0451$). In session 2 in the range 30-35, the results showed a significant effect on subjective comfort of stimulus ($U=3$, $Z=-1.858$, $p=0.0315$). However, training effect did not have a significant effect on intensity.

Table 4 also presents comparison between class of users at the same temperature range (no monthly users in session 1, 2 and 3 participated in the range >35 , 30-35 and <30 respectively). Mann-Whitely U test showed that the learning effect had significant effect on detection time in session 1 in the range 30-35 ($U=2$, $Z=-1.779$, $p=0.0375$) and detection rate in session 2 in the range >35 ($U=0$, $Z=-1.732$, $p=0.0425$). Nevertheless, there was no significant effect on comfort and intensity.

Table 3. Single and bi-weekly users average performance. (Statistical significance between single and repeated user performances is indicated by *.)

	session 1			session 2		
	<30	30-35	>35	<30	30-35	>35
Temp.						
Detection Rate (Accuracy %)	84.38	92.5	83.34*	87.5	83.34	87.5*
Detection Time (sec.)	4.86	4.32	4.45*	4.86	4.39	3.95
Comfort (Scale 0-6)	3.44	3.4	3.79	3.5	4*	3.06
Intensity (Scale 0-3)	2.04	1.9	2.04	2.19	1.92	1.97
	2.13	1.88	2.13	2.13	1.88	2.13

Table 4. Single and monthly users average performance.

	session 1		session 2		session 3	
	<30	30-35	<30	>35	30-35	>35
Temp.						
Detection Rate (Accuracy %)	100	75	83.34	37.5*	83.34	100
Detection Time (sec.)	4.15	4.43*	3.66	5.7	4.65	5.75
Comfort (Scale 0-6)	2.89	4.13	3.49	3.4	3.5	2.88
Intensity (Scale 0-3)	2.51	1.88	2.29	2.2	1.89	1.88
	2.13	1.88	2.13	2.13	1.88	2.13

5 DISCUSSION AND CONCLUSION

RQ1: Transition of Ambient Temperature

However, users in tropics area are likely or forced to frequently change environment from too hot (real ambient temperature) to too chill (air-conditioned one), or vice versa. The results of the number of detection and time to detection showed that transition of ambient temperatures did not have significant effect on thermal perception of the same stimuli. Whereas Hirosawa *et al.* [7] examined the relationships between warm threshold or cool threshold of the middle fingertips and room temperature. They reported that room temperature change affects the warm and cool threshold.

RQ2: Effect of Tropical Temperature

Halvey *et al.* [4] studied the effect of temperature in cold environment, the range of temperature was between 6°C and 25°C. They found that ambient temperature had significant effect to user perception. Green [2] also reported ambient feeling perception affected actually feeling perception. The results of this evaluation showed ambient temperature had a significant effect on detection rate, detection time, comfort and intensity. Our results also indicated that the optimal perception performance is in greater than 35°C in term of detection rate and detection time.

RQ3: Effect of Ambient Humidity

Ambient humidity had a significant effect on number of detection. Our results showed the optimal performance in

term of number of detection and detection time was in the humidity range 50-60%. However humidity did not have a significant effect on detection time, comfort and intensity. Humidity range that examined was 41-68%. Halvey *et al.* [4] found extreme humidity had a negligible effect of sense.

RQ4: Training Effect

Comparison between monthly session results indicated that training effect did not have an impact on the use of thermal feedback. The results from comparison between bi-weekly sessions also presented that there was no significant effect. Furthermore to offer more deep investigation, previous research [4] reported that the repeated user sessions (monthly repeated session) had an effect on thermal feedback perception. Our results from comparison between single user and monthly user performance implied that training had an effect on detection time and detection rate in session 1 and 2 in 30-35°C and >35°C respectively. In addition, comparison between single user and bi-weekly user performance indicated that there was effect on number of detection and time to detection in session 1 and also have significant effect on detection rate and comfort in session 2.

In conclusion, this paper studied how environmental factors affect the use of thermal feedback in a tropical ambient. Ambient temperature influence on perception and ambient humidity was a negligible effect on its use. In addition, we presented the results of the sudden transition of environment. It was shown that there was no significant effect to perceive the thermal stimuli. Training effects had some difference but did not follow any patterns.

In consequence, thermal feedback is practical for use with people living in tropical area. Stimuli that are more preferable to be perceived in tropical climate are both intensities and both rates of change because strong intensity and large rate of change are much faster to detect but not much comfortable. Moreover, cold is more likely to be detected than warm. Future work will investigate the use of tactile modality in some situations to assure that thermal feedback can be used as an alternative to or a replacement for common feedback.

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