Does Heat Matter in Phone Usage? Antecedents and Consequences of Mobile Thermal Satisfaction

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Abstract. Overheated phones lead to uncomfortable user experience and degrade the reputation of the phone brand. This paper focused on the antecedents and consequences of mobile thermal satisfaction. The paper proposed the top influencing factors that affect the thermal satisfaction of mobile phones and emphasized the importance of mobile thermal performance in user experience and purchasing decision. A two-phase study was conducted. In phase I, 10 experts in human–computer interaction and phone engineering participated in a focus group study to obtain influencing factors of mobile thermal satisfaction. The experts highlighted the importance of thermal performance by ranking it with other key performance indexes of mobile phones. In phase II, 82 experienced phone users with gaming experience were interviewed on their thermal experience during daily phone usage. The user interviews provided key insights into how thermal satisfaction influenced user experience and indicated that thermal performance played an important role in purchasing decision of mobile phones.

Keywords: Thermal satisfaction · Mobile phones · User experience

1 Introduction

With the development of smartphones and phone applications such as phone games, people are using phones more frequently compared to traditional phone call usage. In addition, the power consumption of mobile phones has increased dramatically leading to their higher surface temperature. Overheated phones can result in uncomfortable user experience and degrade the reputation of the phone brand [1]. Therefore, users' thermal satisfaction is a pressing concern for mobile phone manufacturers. This study is aimed at measuring thermal satisfaction from a comprehensive perspective, including both physiological and psychological factors and emphasizing the importance of thermal performance in phone usage.

According to international safety standards [2], the surface temperature of handheld devices should be below 48 °C to avoid safety hazards, such as skin burns and battery damage. Studies on human temperature perception suggested that the comfortable thermal threshold of users is from 28 °C to 40 °C in general [3, 4]. Experiments using

simulators were carried out to examine the underlying characteristics of human thermal perception, such as the changing speed of temperature and gesture [3–5]. However, experimental studies have limitations because the controlled environment cannot simulate usage scenarios completely. Therefore, unstudied questions still remain on how people perceive and evaluate mobile thermal performance when they are engaged in daily phone tasks.

This study proposed to generate the influential factors from different perspectives and obtain a deeper understanding of users' thermal experience of mobile phones. A two-phase study was conducted to achieve these objectives. In the first phase, we organized a focus group including experts in user experience and phone engineers to build the framework of thermal satisfaction and obtain the key influencing factors. In the second phase, an in-depth interview was carried out based on the results of phase I to further explore the user experience related to the thermal performance of mobile phones.

2   Focus Group Study

2.1   Methodology

In order to obtain representative opinions from different perspectives, 10 experts from different fields, i.e., five experts in human–computer interaction and five experts in mobile engineering were invited to a focus group study.

The focus group discussion concentrated on the influencing factors of mobile thermal satisfaction and the importance of mobile thermal performance during phone usage.

The experts used a brain storming method to generate as many influencing factors of thermal satisfaction as possible. These influencing factors were then summarized, classified, and ranked by their importance to finally compile a list of 10 influencing factors. A similar methodology was used during the discussion regarding the importance of thermal performance. The experts summarized key performance indexes of mobile phones including thermal performance and ranked these indexes by their influence on overall user experience.

2.2   Influencing Factors of Mobile Thermal Satisfaction

Satisfaction is a mental state, which refers to a subjective evaluation of quality of a product. In this study, mobile thermal satisfaction is defined as users' subjective evaluation of mobile thermal performance. Further discussion was based on the unified definition. Experts explored the influencing factors from three perspectives, phone, user and environment. Ten influencing factors were summarized according to experts' discussion.

Temperature. Temperature of phone surface is indicated to influence users' thermal perception and thermal satisfaction directly. Previous studies also pointed out that the thermal perception should be influenced not only by the current surface temperature but also by the changing speed of temperature [6].

Phone Usage. Phone usage refers to both the using time of mobile phones and the task content. Being exposed to over-heated for long time is supposed to increase users' dissatisfaction. In addition, task content is considered as an indirect factor of thermal satisfactory during phone usage because high-engagement task, like phone games might decrease users' awareness of environment and thermal sensation.

Physical Design. Physical design refers to the hardware design of mobile phones, including the material of phone shell, the location and size of CPU (heated part of mobile phones). According to experts, material will influence the tactile feeling as well as the heat dissipation of mobile phones.

Environment (Physical). Thermal satisfaction is regarded as a kind of local thermal sensation and might be influenced by the overall thermal sensation, which is decided by the environmental factors [7]. According to previous studies on thermal comfort, temperature, humidity and illumination were indicated to influence environmental thermal comfort simultaneously which would indirectly influence users' thermal satisfaction of mobile phones [8].

System Performance. As phone heating is the result of over-loaded CPU and power-consumption, it is sometimes accompanied by system slowdown and other reliability problems. Although system performance has nothing to do with the thermal perception, it will influence user experience and satisfaction. Considering users may ascribe decreased system performance on phone heating, system performance is summarized as one of influencing factors of thermal satisfaction.

Mood. Mood is also suggested to be included as an indirect influencing factor. Given an example, Sam just finished a game on phone and got a little annoyed with the failure. Then he felt the over-heated phone shell, it is understandable that Sam would be more dissatisfied with the thermal performance of his mobile phone than usual as he was already in a poor mood.

Gesture. Gestures refers to the way users hold their mobile phones and gesture decide the contact region on hands during phone usage. It has been proved that thermal sensation of different region on human bodies are different [9, 10]. Therefore, the way people holding their phones will influence the thermal sensation and thermal satisfaction. Moreover, when people are playing mobile games, they are not holding the phones still. Green studied dynamic tactile simulation in 2009 and suggested dynamic contact could inhibit nociceptive and thermal sensation on the hands [11].

Individual Difference. Individual differences including gender, age and other individual characteristics were found in previous studies on thermal comfort [12]. It can be deduced that individuals also have differences in thermal sensation and thermal endurance of mobile devices.

Brand Effect. As mobile phones are products, they are unavoidably influenced by brand reputation. Good brand reputation may influence users' attitude towards phone heating phenomenon, and decrease their dissatisfaction when the heating is in an acceptable range.

Culture. Culture is a core concept of anthropology and contains a series of phenomena that are transmitted through the sociology department in human society. In Hanley's iceberg theory [13], culture will influence people's internal drive, social motivation, values etc., including users' behavior and decision-making. Therefore, cultural factors should be included as one of indirect influencing factors (Table 1).

Table 1. Ranking results of influencing factors

Influencing factors	Experts scores										Average score	Rank
	1	2	3	4	5	6	7	8	9	10		
Temperature	10	10	10	10	10	10	10	10	10	9	9.9	1
Phone usage	6	7	6	5	7	8	8	9	8	8	7.2	4
Physical design	7	8	5	8	8	7	9	8	9	7	7.6	2
Environment	8	9	7	7	9	9	7	3	4	10	7.3	3
System performance	5	3	4	9	3	6	5	7	7	6	5.5	6
Mood	9	6	8	8	2	4	6	6	5	3	5.7	5
Gesture	1	4	9	3	5	5	4	5	3	5	4.4	7
Individual difference	4	5	2	4	6	3	3	4	6	4	4.1	8
Brand effect	3	1	3	1	4	2	1	2	2	1	2	9
Culture	2	2	1	2	1	1	2	1	1	2	1.5	10

Experts were asked to rank the ten influencing factors by importance individually. For the convenience of calculation, the importance of each factor would be scored continuously according to the ranking order of each expert, the most important item scored 10 and the least important one scored 1. The importance scores were shown in the following table. By calculating the mean of importance scores given by ten experts, we can obtain the top influencing factors: temperature, physical design, environment and phone usage. According to the definition and description of influencing factors, ten influencing factors were categorized from three perspectives, phone, user and environment, as shown in Fig. 1.

2.3   Performance Indexes of Overall User Experience

Six key performance indexes were summarized to evaluate the overall user experience of mobile phones: interactive experience, battery, screen, display quality, sound quality, and thermal performance. Interactive experience constitutes both the hardware features and software features related to the interaction.

Experts were asked to rank the six performance indexes by importance individually. For the convenience of calculation, the importance of each index would be scored continuously according to the ranking order of each expert. The most important item was scored 6 and the least important one was scored 1. Experts unanimously agreed that interactive experience should be the top influencing factor in the overall user experience. However, thermal performance did not rank high in the overall performance indexes and experts' attitude toward thermal performance varied differently. The
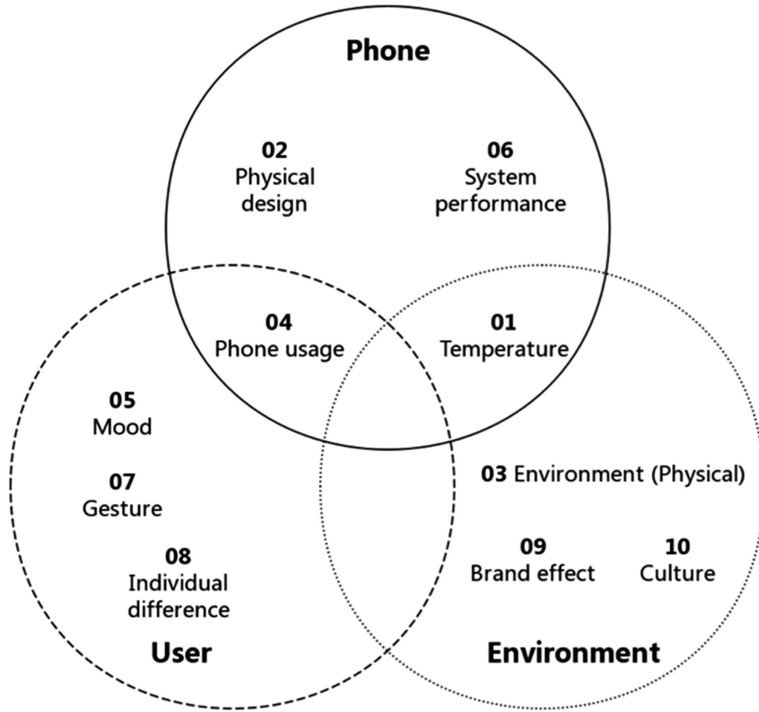
Fig. 1. Influencing factors of mobile thermal satisfaction

differences can be explained by their different mobile experience. Although experts are also mobile phone users at the same time, we still need to investigate more ordinary mobile users in order to understand the impact of thermal performance on overall user experience (Table 2).

Table 2. Ranking results of performance indexes

Performance indexes	Experts scores										Average scores	Rank
	1	2	3	4	5	6	7	8	9	10		
Interactive experience	6	5	6	6	6	6	6	6	6	6	5.9	1
Battery	4	2	5	4	2	5	5	5	5	1	3.8	3
Screen	2	1	2	3	3	3	2	4	2	5	2.7	4
Display quality	5	6	3	5	5	4	4	2	4	4	4.2	2
Sound quality	1	3	1	1	4	2	1	1	1	3	1.8	6
Thermal performance	3	4	4	2	1	1	3	3	3	2	2.6	5

3   Interviews of experienced Mobile Users

3.1   Methodology

According to experts in phone engineering, the heating phenomenon usually occurs during high-load tasks, for example, mobile games. When users play mobile games, they tend to hold their phones for a long time and hence deeply experience mobile thermal performance. Therefore, we interviewed 82 experienced mobile users (40 males and 42 females) with mobile game experience, aged between 18 and 25. The participants were recruited via questionnaires on social media.

To explore user experience with phone heating, open and explorative questions were formulated. The questions were primarily about participants' experience with mobile thermal performance, and their attitude and feedback toward the mobile heating phenomenon. Six basic questions used for the interview are listed in Table 3. More detailed questions were asked based on the participants' responses.

Table 3.   Interview questions

Six basic questions	Further detailed questions
1. Under what circumstances would the phone be hot?	What kind of mobile tasks? When? Where?
2. What would happen when phones become overheated?	Will phone performance decrease with heat?
3. Did mobile thermal performance influence your user experience?	Mood? Comfort?
4. Did you complain about mobile thermal performance?	Did you complain to your friends, on the SNS, or to the mobile manufacturer?
5. Did you worry about the phone safety when it was overheated?	What kind of worries? Why? What would you do?
6. Would phone thermal performance influence your consuming behavior?	What else would influence your consuming behavior?

3.2   Interview Findings

Mobile Thermal Experience. Most (89%) participants reported phone heat during their usage. Consistent with the views of experts in the focus group study, experienced users related phone heating to the phone tasks closely. Playing games, charging, and watching videos were the most mentioned phone tasks among these participants. Two participants mentioned their phones sometimes simply got overheated without any reason. In addition to phone tasks, 24% (20 of 82) participants reported that the phone would get overheated more easily and frequently in summer. Five participants also mentioned other environmental factors such as direct sunshine and temperature (Table 4).

Table 4. Reported phone task when phone is hot

Reported mobile task when phone is hot	N	%
Playing games	62	76
Watching videos	18	22
Charging	41	50
Multi-task switching	4	5
Phone calling	3	4

Perceived Impacts of Thermal Performance. More than half of the participants (52%) mentioned that phone heating would cause negative mood, including irritability, anxiety, worry and distraction. Thirty-one participants of the total 82 (38%) pointed out that phone heating would decrease their thermal comfort on hands. Sweating and thermal pain were two main reasons for their lower comfort. In addition to the direct influence of phone heating, 29% (24 of 82) participants mentioned that phone reliability would decrease when phone got overheated. They ascribed the decreased reliability, such as system slowdown, quick power consumption, auto power-down, and other failures to bad thermal performance. Some participants claimed they did not worry about mobile thermal performance unless it was accompanied with decreased phone reliability.

User Complaints on Overheated Phones. The majority of participants (78%) would complain about the unsatisfied mobile thermal performance. However, most of them choose to keep the complaints only to friends; only seven of them would complain on social media. Only two participants claimed they had experience of reporting the thermal-related mobile problem to an official. Eighteen mobile users did not show intention of complaining because they thought it was common for mobile phones to get hot and the thermal performance of their phones was in an acceptable range. The interview results showed that only a few people would show their dissatisfaction on mobile thermal performance to the public, which may lead to a gap between the users' attitude toward mobile thermal performance and what phone manufacturers believed (Table 5).

Table 5. Reported thermal-related complaining behaviors

Reported thermal-related complaining behaviors	N	%
Complain to friends	46	56
Complain on SNS	7	9
Complain to mobile manufactures	2	2
Do not complain	18	22

Quality Worries. Fifty-three participants of the total 82 (65%) mentioned they were worried about the quality of mobile phones when faced with overheated phones. Decreased performance, shortened phone life, and safety concerns were users' major worries. Twenty-seven participants of the total 82 (33%) mentioned phone explosion

when charging and expressed their worries about overheated phones. One of the participants mentioned his intensity of quality worries depended on the phone brand. Sixty-two participants of the total 82 (76%) would stop using phones when phone got overheated. Some participants would adopt certain measures to reduce the phone temperature, such as shutting down the phone, removing the phone case, and changing the environment temperature. Although most participants agreed that an explosion is an accidental event, they still could not stop worrying about the phone quality when their phone got overheated and adopted measures to cool down the phone. Some users mentioned that they would be more worried and more sensitive to mobile thermal performance if mobile phone brand had a history of explosion.

Impacts on Purchasing. Twenty-two participants of the total 82 (27%) would consider thermal performance in the first place and search for related information during purchase survey. Thirty-two participants of the total 82 (39%) mentioned they would consider thermal performance when other key performance indexes were similar. The rest of the participants (34%) mentioned they did not pay much attention to thermal performance in their experience. From another perspective, for 54 participants who reported unsatisfied thermal experience with their current mobile phones, 70% (38 of 54) of them mentioned the thermal performance would influence their repurchasing decision. In addition to thermal performance, users mentioned other influencing factors on phone purchasing, such as system performance, physical design, battery, image quality, sound quality, brand image, prize, and after-sale service. The influencing factors and the word frequencies are summarized in Table 6.

Table 6. Influencing factors of purchase

Category	Influencing factors of purchase	N	%
System performance	System configuration	38	46
	Smooth	17	21
	Memory	13	16
	Photography	8	10
	Reliability	1	1
	Phone life	1	1
Physical design	Appearance	9	11
	Screen	2	2
	Size	2	2
	Weight	1	1
Battery	Battery life	12	15
	Charging speed	1	1
Image quality	Image quality	6	7
Sound quality	Sound quality	1	1
Brand image	Brand	10	12
	Reputation	4	5
Prize	Prize-quality ratio	7	9
	Prize	7	9
After-sale service	After-sale service	1	1

4   Discussion

Based on the result of focus group study, 10 influencing factors of mobile thermal satisfaction are summarized below. In addition, the temperature of phone surface, physical design, environment, and phone usage are supposed to play important roles in mobile thermal satisfaction. From the in-depth interview, users discussed regarding their thermal experience, including the phone task, using time, and the environmental factors when they faced overheated phones. From the users' perspective, they focus more on direct feeling on body and brain, like sweating, thermal pain, decreased mood, and distraction from the task. In addition, many users regarded the phenomenon of system slowdown as a result of phone heating when they occurred together. Therefore, their satisfaction is closely related to system performance when the phone is hot. The brand effect was mentioned by some users when they discussed phone safety and users' worries. Gesture, individual differences, and culture were not mentioned by participants as they were indirect factors and sometimes difficult for ordinary users to determine.

In addition to discomfort and negative mood reported by users, thermal performance may cause users' concerns about phone quality and safety when the phone is overheated. Although some users understand that explosion is an accidental event, most still expressed worries about the overheated phone and phone charging, especially the brands with a bad history. As a result, most users would avoid continuing using overheated mobile phones and some of them would try some measures to help phones cool down. However, the interruption will decrease mobile user experience as well. To summarize, poor thermal performance will cause

- Discomfort (sweating and thermal pain)
- Negative mood (annoyed, anxious, distraction)
- Safety worries
- Interrupted user experience.

Most of the participants experienced unsatisfied mobile thermal performance, but not many of them would deliver the complaints to phone manufacturers. They just voted on foot and reduced trust on this brand. This may explain why phone engineering considers thermal comfort as important as other key performance indexes in the focus group study (fifth of six indexes). There exists a gap between users' and phone manufacturers' opinions toward thermal performance because phone companies only receive a small percentage of complaints. When users make a purchasing decision, they may not consider thermal performance as the primary factor. However, when they use the phone, they will experience thermal performance more directly. Bad thermal performance will have negative effects on the brand image and influence users' repurchasing decisions. Therefore, phone manufacturers should pay more attention to mobile thermal performance to improve overall mobile user experience and mobile sales. In summary, a graphical representation of antecedents and consequences of mobile thermal satisfaction is presented below showing the influencing factors of thermal satisfaction and its impact on user behaviors (Fig. 2).
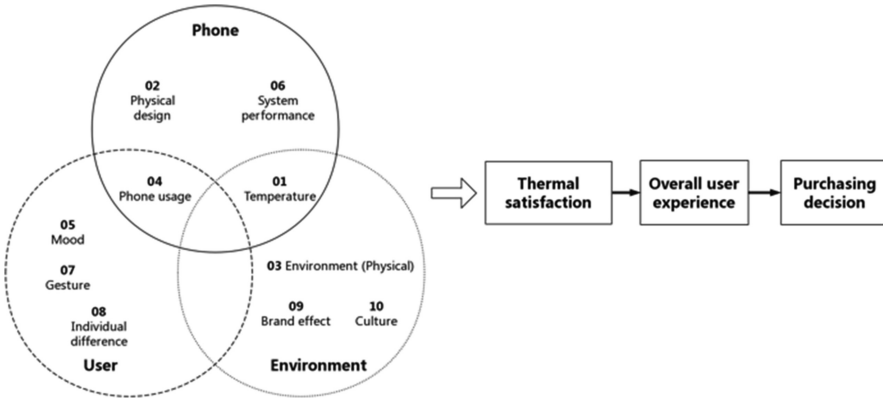
Fig. 2. Antecedents and consequences of mobile thermal satisfaction

5   Conclusion

This study proposed to explore the antecedents and consequences of thermal satisfaction during mobile phone usage. First, 10 influencing factors were summarized and ranked by importance according to experts' discussion. Temperature, physical design, phone usage, and environment were the top four factors in mobile thermal satisfaction. The evidence from in-depth interviews also suggested many users regarded decreased system performance as a result of phone heating. Therefore, phone engineers should pay more attention to system performance as well as temperature and physical design to improve mobile thermal satisfaction. In addition, the study discussed the importance of mobile thermal satisfaction from the perspectives of both experts and experienced phone users. The results of focus group study and in-depth interviews indicated that phone users cared more about mobile thermal performance than phone manufacturers believed. According to users, bad thermal performance will result in discomfort, negative mood, safety worries, and influence user experience. Furthermore, thermal satisfaction is suggested to influence users' purchasing and repurchasing decisions. In conclusion, this research emphasized the importance of thermal satisfaction in overall mobile user experience and users' purchasing decision.

One of the limitations of this interview study was that only subjective results were collected and the bias caused by self-reported measures could not be eliminated. However, as thermal satisfaction is a subjective feeling, it is acceptable that only interviews were included in this study. Another limitation is the sampling of interviewees, which were not representative enough, as most of the participants were young, college students.

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