The Effect of Thermal Stimuli on the Emotional Perception of Images

Moses Akazue[1], Martin Halvey[2], Lynne Baillie[3], Stephen Brewster[4]
Interactive and Trustworthy Technology Group[1, 3], Glasgow Interactive Systems Group[4]
Glasgow Caledonian University[1], University of Strathclyde[2], Heriot-Watt University[3], University of Glasgow[4]
moses.akazue@gcu.ac.uk, martin.halvey@strath.ac.uk, l.baillie@hw.ac.uk, stephen.brewster@glasgow.ac.uk

ABSTRACT
Thermal stimulation is a feedback channel that has the potential to influence the emotional response of people to media such as images. While previous work has demonstrated that thermal stimuli might have an effect on the emotional perception of images, little is understood about the exact emotional responses different thermal properties and presentation techniques can elicit towards images. This paper presents two user studies that investigate the effect thermal stimuli parameters (e.g. intensity) and timing of thermal stimuli presentation have on the emotional perception of images. We found that thermal stimulation increased valence and arousal in images with low valence and neutral to low arousal. Thermal augmentation of images also reduced valence and arousal in high valence and arousal images. We discovered that depending on when thermal augmentation is presented, it can either be used to create anticipation or enhance the inherent emotion an image is capable of evoking.

Author Keywords
Thermal stimuli; stimulation; emotion; visual; valence; arousal; dominance; thermal feedback.

ACM Classification Keywords
H.5.2. User Interfaces: Haptics IO

INTRODUCTION
Images have been shown to have the ability to elicit emotions in people when viewed on electronic devices [20]. Images consist of different properties (e.g. colours, texture etc.) and content, which contribute to the kind of emotions they are able to evoke. Just looking at the image of someone visibly experiencing cold has been shown to be enough to drop the body temperature of the viewer, this process is referred to as 'temperature contagion' [6].

Thermal stimulation is a feedback channel that has also been shown to have the ability to evoke emotions in people. Thermal stimuli is a rich and emotive feedback channel which has been demonstrated to be able to evoke emotions in humans when presented on its own, and when used to augment media [10,22,25]. Some previous work investigating the affective nature of thermal has studied this effect in isolation [25,32]. While other studies have examined the effect thermal stimuli have on media in general [1,10,21,22], these investigations have been limited to handpicked images from specific emotion categories. The findings and results reported in previous work [10,21,22] provide valuable information as to the potential of thermal stimuli for affective interaction. These papers also act as a good starting point from which more work can be conducted to fully investigate and determine how these affective properties can be harnessed for use in the design of interactive affective interfaces. In this paper we present two user studies that took a broad approach to examining the effect different thermal stimuli parameters (e.g. intensity, rate of change) and presentation techniques have on the emotional perception of images. Images investigated were chosen from different emotion categories (e.g. high arousal/high valence), and rated using affective rating scales.

Overall the objective of the two user studies was to answer the following research questions:

RQ1: Which thermal stimuli parameter(s) can be used to increase emotional ratings in various picture emotion categories? (Investigated in studies 1 and 2)
RQ2: Which thermal stimuli can be used to reduce emotional ratings in various emotion categories? (Investigated in studies 1 and 2)
RQ3: What effect does timing of thermal stimuli presentation have on the emotional perception of images? (Investigated in study 2)

In the next two sections we review related work and provide an explanation of the equipment used for the two user studies. We then present our first user study procedure and results, followed by a description of our second user

CHI'16, May 07-12, 2016, San Jose, CA, USA
© 2016 ACM. ISBN 978-1-4503-3362-7/16/05…$15.00
DOI: http://dx.doi.org/10.1145/2858036.2858307

study and results. Finally we present a discussion of our findings and some conclusions.

RELATED WORK

The use of thermal stimulation in HCI to date can be divided into two broad areas; the first is concerned with thermal stimuli perception for use as a feedback channel and the other with the affective attributes of thermal stimuli.

Thermal Stimuli Perception

Thermal stimulus is made up of properties such as intensity, direction of change and rate of change, which all contribute to how it is perceived when presented to a user. Gray *et al.* [8] found that males and females have similar thermal stimuli thresholds when presented with different combinations of these thermal properties. Other factors shown to have the ability to affect thermal stimuli perception include external factors such as ambient temperature, humidity and clothing. With the presence of clothing Halvey *et al*. [13], discovered that higher thermal stimuli intensities were needed for detection to take place. Halvey *et al*. [11] and results obtained by Wilson *et al*. [30] also showed that extreme ambient temperature and humidity conditions (humidity <30% and >90%) had a significant effect on thermal stimuli detection rate, time to detection, and subjective perceived comfort. The thermal stimuli properties used for the studies we conducted are discussed below.

Direction of Change

Thermal stimuli is bipolar; there is cooling and warming. According to Wilson *et al*. [32] both warming and cooling changes are suitable for use in thermal interface design. Salminem *et al*. [25] showed that warm stimuli on its own is able to evoke feelings of arousal and dominance in people. Kanosue *et al*. [16] and Sung *et al*. [26] also noted that stimuli polarity has the ability to affect subjective ratings of pleasantness, with warm stimuli activating portions of the brain related to emotive/affective processing. Although cold stimuli are faster to detect than warm stimuli [19], they both remain perceivable and suitable for use in thermal interface design [19,32]

Thermal Stimuli Intensity

Thermal stimuli intensity has been shown to be suitable for use in thermal feedback design within the range of 26^{o}C and 38^{o}C, and at different reasonably spaced intensities (ideally above 1°C spacing) [14,32]. Distinct stimuli intensities within this range were found to be perceptually different [32]. When using thermal stimuli for media augmentation, there is a need to carefully regulate thermal stimuli intensity. According to Halvey *et al*. [10] if intensity is not properly regulated it can distract perceivers from the media being augmented.

Thermal Stimuli Rate of Change

Rate of change (ROC) refers to the speed at which the thermal stimuli source attains defined temperature intensities. Research has shown that ROC has a significant effect on thermal stimuli perception [17]. Faster ROCs have been demonstrated to be perceptually different from slower ROCs [15]. Halvey *et al*. [10] used ROCs of 1°C/s and 3°C/s and found that these rates of change had a significant effect on valence. According to Wilson *et al*. [32] a rate of change of 1℃/s is perceivable, but a ROC of 3℃/s has a better detection rate. This was supported by Halvey *et al.* [12] who recommended using a minimum rate of change of 3^{o}C/s in order to maximise perception when using thermal stimuli for continuous interaction.

Affective Component of Thermal Stimuli

The ability of thermal stimuli to evoke various emotional responses has been demonstrated in a number of user evaluations. Gooch *et al*. [8] showed that thermal stimuli increased feelings of social presence in remote interactions when embedded in a physical artefact. Wilson *et al*. [31] investigated how participants interpret different thermal stimuli parameters when used for interaction. They found that warm stimuli were generally associated with feelings of presence, activity and quality, while cool stimuli are associated with absence and poor quality.

Similar to the way audio enhancement has the capacity to influence emotional responses to media [28], thermal stimuli has also been shown to have an influence on emotions both on its own and when used for media augmentation. Salminem *et al*. [25] when investigating the emotional effect of thermal stimulation in isolation, found that warm stimuli was rated to be significantly more arousing and dominant than cool stimuli. In contrast to previous suggestions that stimuli direction of change affects subjective ratings of comfort/pleasantness [16,26], Salminem *et al*. [25] discovered that it had little to no effect on ratings of pleasantness (valence) and approachability.

When used to augment media, thermal stimuli present interesting possibilities for enhancing interaction. Nakashige *et al*. [22] discovered that study participants perceived images of warm food to be delicious when accompanied with warm stimuli. However, the images and thermal stimuli combinations used were limited to very specific scenarios. Halvey *et al*. [10] investigated the possibility of using thermal stimuli to influence human emotional perception of images and music, they discovered that warm stimuli elevated feelings of arousal and valence. While this is a good indication of the affective possibilities of thermal stimuli, their study did not examine the effect of thermal stimuli on the full range of emotions that can be evoked by images. Akiyama *et al.* [1] found that dynamic thermal stimuli augmentation has the potential to enhance emotional experience while listening to music. Only one song was used in their study; therefore a larger study would be needed to determine the effect thermal stimulation has on music. More recently Lochtefeld *et al*. [21] found that ambient light and thermal stimuli augmentation significantly enhanced mobile media consumption experience on tablets. Although their findings help underline the affective possibilities that can be afforded by thermal stimulation, the images in the videos they augmented had no pre-identified emotional property.

The related work discussed above demonstrates that thermal stimuli are perceivable and possess the ability to influence emotions when used to augment media. However to the best of our knowledge no work has yet been carried out to identify the effect individual thermal stimuli parameters have on the emotional perception of pictures.. In this paper we combined thermal stimuli parameters, that have been demonstrated to be both perceivable and comfortable in previous studies [25,29,32], with images from various emotional categories. For the remainder of the paper we use the term 'augmented image' to refer to images augmented with thermal stimuli.

EQUIPMENT

Custom-built two-channel peltier stimulators measuring 2cm^2 were used as the thermal stimuli source in each of the two user studies we conducted. Similar peltier stimulators have been used in previous studies investigating thermal stimuli perception [10,29,32]. Each peltier stimulator allows heating and cooling, and is connected to a Bluetooth microcontroller through which they are controlled. Both peltier stimulators allowed temperatures to be set anywhere within the range of -20°C to 45°C accurate to 0.1°C. For the two studies, images (1024 x 768 pixels) were presented on a laptop screen with 14" display, and ratings were collected electronically via rating scales displayed on the laptop screen. All participants used an external mouse attached to this laptop computer to provide ratings for each augmented image perceived (see Figure 1 for example setup). All studies were conducted in a quiet, private room.

Figure 1: Example setup for participant taking part in studies 1 and 2.

STUDY 1: THE EFFECT OF THERMAL STIMULI PARAMETERS ON THE EMOTIONAL PERCEPTION OF IMAGES

The aim of the first study was to investigate the effect different thermal stimuli combinations have on images with known emotional properties. The thermal stimuli parameters that were examined are: stimuli intensity, stimuli direction of change and stimuli rate of change.

All thermal stimuli combinations were presented to the thenar eminence (the bulbous part of the palm directly below the thumb) which has been demonstrated to be the optimal hand location for thermal perception [32]. Other factors that influenced the selection of a hand location for stimuli delivery are - the convenience of placing the hand on the stimuli source, and also the ease and safety of quickly removing the hand from the thermal stimuli source if participants feel the need to. Other papers have considered various body locations [12, 31], however it is beyond the scope of this work. We already investigate a large number of variables and reserve the effect of body location for future work.

Each image augmented with thermal stimuli was rated on an emotion wheel [3], and in three emotional dimensions; namely valence, arousal and dominance, using the self-assessment manikin (SAM) [4] rating scale (see Data Gathering Methods Section). Valence in the context of this study referred to the amount of pleasure/displeasure felt by a participant upon perceiving an image; arousal referred to the level of excitement/calmness, while dominance referred to how dominated or dominant participants felt upon perceiving an image. The IAPS library [20] was the source of images used in this study. This library contains emotionally stimulating images that have been used in several studies of emotion and attention [7,24]. Each of the images contained in the library has ratings of valence, arousal, and dominance, which can be used to categorise the images into different emotion categories as illustrated in Figure 2. For ethical reasons, erotic images contained in the original image library were omitted from this study. This followed the approach of Halvey *et al.* [10]. As part of our license agreement to use the IAPS collections we are prohibited from reproducing any image from the collection in this paper. As a result, replica images are used in this paper for illustration purposes (see Figure 2).

Thermal Stimuli Combinations

Thermal stimuli combination refers to the combination of thermal stimuli parameters used in this study. They are discussed below:

A neutral stimulus of 32°C: The skin of participants was adapted to this temperature prior to each thermal stimuli delivery following the approach of [10,29,32]. A value of 32°C was chosen because it lies well within the defined neutral zone for the skin, at which there is no discernible thermal sensation [12,32], and ensured thermal neutrality before the presentation of each thermal stimuli combination which in turn optimises perception [18]. Using a fixed neutral stimuli set point also provides us with a fixed point for measurement.

Two directions of change (warming and cooling): Stimuli changed in two different directions from the neutral stimulus. There was negative change, which resulted in cooling, and positive change, which resulted in warming.

Two stimuli intensities in multiples of 3°C from the neutral stimuli: Stimuli intensities used were 26°C, 29°C, 35°C, and 38°C. Each of these intensities has been demonstrated to be both perceivable and comfortable [32].

Two rates of change (ROC) of 1°C/s and 3°C/s: This follows the approach of [10,32]. They have both been shown to have significant effect on ratings of valence.

The combination of parameters resulted in 9 thermal stimuli combinations, namely: A neutral stimuli of 32°C (no change). Warming stimuli of 35°C and 38°C, with ROCs of 1°C/s and 3°C/s each. Cooling stimuli of 29°C and 26°C, with ROCs of 1°C/s and 3°C/s each.

Image Categories

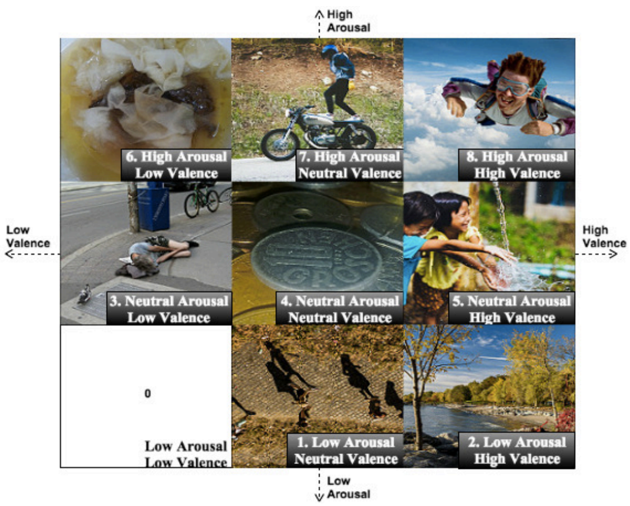

Figure 2: IAPS image emotion categories with representative images obtained from the Internet.

In order to ensure the images selected for augmentation spanned the entire affect space, images in the library used for this study were divided into 9 different emotional categories based on their valence and arousal ratings (see Figure 2). According to Russell circumplex model, emotional states can be represented by combinations of valence and arousal [23]. The emotional dimensions of affective valence, arousal and dominance were chosen to carry out the emotional assessment of the augmented images. They were selected because they have been demonstrated to be able to directly measure a person's reaction to a wide range of emotive stimuli [4]. Also this was the same data collected by IAPS for images in their library. Analysis of the image emotion categories revealed an uneven distribution of images across the different sections of the valence, arousal affect space, with most images clustering around the mid to high arousal axis, and the low arousal, low valence section containing no image. As noted by Tellegen [27] this is because high positive affect and high negative affect both involve high levels of arousal. The low arousal/low valence image category was omitted because it contained no images. The category with the second lowest number of images (low arousal, high valence) had 11 images. In order for image selection to cover as many emotional categories as possible, 9 pictures from the 8 image categories were randomly selected for each participant and each image was combined with one of the 9 thermal stimuli combinations. Augmented images were randomly presented to participants in 4 sets of 18 images to allow for breaks in between sets. Participants were first presented with a demonstration to familiarise them with the study before starting the main evaluation. Study had a total duration of approximately 1 hour 30 minutes with each set lasting for approximately 12 minutes.

Image Presentation

Presentation and duration of display of each augmented image followed the same pattern used by IAPS [20]. Images combined with thermal stimuli were presented for 6 seconds, While SAM and emotion wheel rating scales (see Data Gathering Methods section below) were displayed for 15 seconds each. Thermal stimuli returned back to neutral during these 30 seconds for adaptation to occur, this 30 seconds adaptation time follows the best practise approach of [32]. Using the same evaluation timing as the IAPS enabled a direct comparison of results obtained from this study with findings published by IAPS.

Data Gathering Methods

Quantitative and qualitative methods were used to gather data for this study. Affective reporting tools used were the self-assessment manikin (SAM) [4] and the emotion wheel [3] SAM is a non-verbal method for quickly assessing the pleasure, arousal and dominance associated with a person's emotional reaction to a stimuli [4]. It is a 9-point Likert scale with human-like figures at each point, which helps minimise the confusion a participant may face while trying to figure out the meaning of each of the emotional dimensions being rated. This was the same tool used to collect subjective ratings for the IAPS library. The valence scale ranged from positive valence to negative valence; arousal from excited to calm; dominance from dominated to dominant. A "9" on the valence and arousal scales corresponded to 'negative valence' and 'calm' respectively, while on the dominance scale it corresponded to 'dominant'. The emotion wheel is a 0° – 360° circular scale made up of 4 quadrants corresponding to pleasure/high arousal, displeasure/high arousal, displeasure/low arousal and pleasure/low arousal. Each quadrant contains 6 emotive words arranged 15° apart [3]. Baillie *et al.* [3] found that the wheel was easy to use and very efficient in capturing users' emotions. The wheel was used as an additional tool to collect self-reported subjective data, in order for us to be able to assess how participants report their perception of augmented images. Participants were asked to click on the emotion that best described how they felt when they viewed an augmented image. An interview was conducted at the end of the experiment, to obtain subjective feedback. Interview questions were:

1. *Overall, what are your thoughts about augmenting images with thermal stimuli?*

2. *How enjoyable do you rate combining images with thermal stimuli? Do you think thermal stimuli augmentation contributed to how enjoyable the experience felt?*
3. *Which thermal stimuli do you rate as pleasant or unpleasant?*
4. *For images that felt pleasant / unpleasant do you think the thermal stimuli augmentation contributed to the feeling of pleasantness/unpleasantness?*
5. *If images you have on your personal devices could be augmented with thermal stimuli, is this something you would want?*

Participants
A total of 27 (19 males and 8 females) participants, were recruited for this study. Their ages ranged from 19 to 43, with a mean age of 30.

Variables
This study had a total of 4 independent variables; direction of change, amount of change, image category and rate of change. 4 dependent variables (valence rating, arousal rating, dominance rating and emotion wheel rating) were analysed. Since the images used for the study already had valence, arousal and dominance ratings, the existing ratings of the images from the IAPS were compared with the ratings obtained from `our 2 user studies. This comparison generated *valence difference*, *arousal difference* and *dominance difference* dependent variables.

STUDY 1 RESULTS
As data was not normally distributed Friedman Tests and Wilcoxon Sign Rank Tests were used for analysis. Modal values were calculated for the emotion wheel variable. This follows the approach adopted by Beattie *et al*. [2].

Direction of Change

Groups	Valence	Arousal	Dominance	Emotion Wheel
Cooling	5.09(5.0) σ = 2.60	5.16(5.0) σ = 2.58	5.27(5.0) σ = 2.73	60=Excited
Warming	4.97(5.0) σ = 2.69	4.88(5.0) σ = 2.62	5.36(5.0) σ = 2.79	60=Excited

Table 1: Mean, median in parenthesis & standard deviations of responses relative to thermal stimuli direction of change.

Table 1 shows comparisons between the two directions of change. There was a statistically significant difference between the two groups (warming and cooling) for arousal ($Z = -2.72$, $p = 0.007$). Warming temperatures made images feel more arousing than cooling temperatures. There was no significant effect on valence and dominance. This is in line with the results reported by Halvey *et al*. [10] that warm changes increase feelings of arousal compared to cold changes. Salminem *et al.* [25] also reported similar results, where warm stimuli were rated to be significantly more arousing and dominant.

Amount of Change (Stimuli Intensity)
Table 2 shows the impact of stimuli intensity. Friedman tests revealed a significant difference for arousal (X^2 (2) = 9.98, p=0.007), dominance (X^2 (2) = 16.90, $p < 0.001$) and the emotion wheel (X^2 (2) = 8.84, $p = 0.012$). This led to a pairwise comparison of the groups contained in each of these independent variables (p=0.0167 with a Bonferroni correction). For arousal, 3 degree changes made the images feel more arousing than when there was no change in temperature (z = -2.88, p=0.004). For dominance, 6°C changes in temperature made the images feel more dominant than when there was no change in temperature (z = -3.45, p = 0.001). For the emotion wheel, 3 degree changes made participants feel relaxed while no change had a calming effect on the perceivers (z=-3.32; p=0.001).

Groups	Valence	Arousal	Dominance	Emotion Wheel
No Change	5.02(5.0) σ = 2.63	5.22(5.0) σ = 2.62	5.16(5.0) σ = 2.84	285=Calm
3°C Change	5.05(5.0) σ = 2.65	5.07(5.0) σ = 2.64	5.34(5.00) σ = 2.77	285=Calm
6°C Change	5.02(5.0) σ = 2.65	4.97(5.0) σ = 2.57	5.29(5.0) σ = 2.76	60=Excited

Table 2: Mean, median in parenthesis & standard deviations of responses relative to amount of thermal stimuli change.

Rate of Change (ROC)
Pairwise comparisons revealed rate of change did not have a significant effect on valence, arousal, dominance and the emotion wheel. This is consistent with results reported by Halvey *et al*. [10] who used the same ROCs of 1°C/s & 3°C/s and mentioned that ROC had no significant effect on the emotional perception of images. Thus indicating the suitability of both ROC's for use in the design of interactive thermal interfaces.

Image Category
The image category variable is made up of 8 groups thus a Bonferroni correction was made for pairwise comparisons with p=*0.0018*. As expected, analysis of the valence, arousal and dominance dependent variables revealed that images in the different image emotion categories still maintained their distinct emotive properties after thermal stimuli augmentation, thus for reasons of space this analysis is not included.

We obtained the valence difference, arousal difference and dominance difference variables by subtracting the original ratings of each of the IAPS images from the ratings we obtained in this study after augmenting them with thermal stimuli. A Friedman test revealed a significant difference for valence difference (X^2 (7) = 1337, $p < 0.001$). All the image categories significantly differed from each other except categories 5&2, 8&2 and 8&5 (see Figure 3). Analysis revealed that thermal stimuli increased feelings of pleasantness in image categories with low valence while reducing feelings of pleasantness in image categories with high valence. The only exception to this was images from the neutral valence, low arousal category, which had reduced valence as a result of thermal stimuli augmentation. A Friedman test of arousal difference revealed a significant difference (X^2 (7) = 788.6, $p < 0.001$) for all image categories except categories 2&1, 5&3, 4&3, 5&4 and 7&6. Thermal stimuli augmentation increased feelings of arousal in image categories with low and neutral arousal, while reducing arousal in images from the high arousal category. For dominance difference, Friedman test also revealed a significant difference (X^2 (7) = 59.19, $p < 0.001$). Categories 6&1, 7&1, 4&2, 5&2, 6&3, 6&4, 7&4, 6&5, 7&5 and 8&1 significantly differed from each other. Analysis revealed that thermal stimuli increased feelings of dominance across all the image categories.

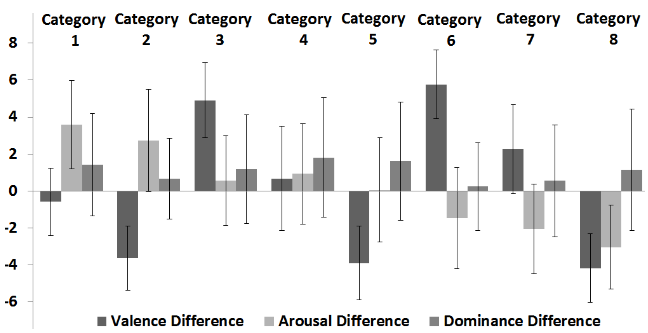

Figure 3: Mean ratings of responses relative to image emotion categories. Val diff, Aro diff and Dom diff ratings are based on a 9-point likert scale

Analysis of the emotion wheel revealed a significant difference between all the groups (X^2 (7) = 197.3, $p < 0.001$). All the image categories significantly differed from each other except categories 3&2, 4&2, 5&2, 4&3, 5&3, 5&4, 6&5, 7&5, 8&5 and 8&7. Images from the low arousal, high valence category as well as neutral arousal, neutral valence categories were perceived as calm after thermal stimuli augmentation. Images in the high arousal/low valence category were perceived as sad, while neutral arousal/high valence images evoked excitement, as well as with high arousal/high valence images. Images with high arousal and low to neutral valence evoked fear. Comparisons between emotion wheel ratings for un-augmented and augmented images only showed a difference for category 3 images. Participants felt alarmed when viewing un-augmented category 3 images (low arousal, low valence) and sad after augmentation

Qualitative Results

Interviews were transcribed and analysed using thematic analysis [5]. Emergent themes were collapsed into the following main themes:

Effect of thermal stimuli on valence: Images augmented with thermal stimuli were considered by 24 participants to be more enjoyable (have higher valence) than images without any augmentation. Two participants stated, "*I really enjoyed viewing the images with thermal stimulation"* (P21).*"I enjoyed viewing the pictures with temperature more than when there was no temperature" (P25).*

Preferred Stimuli and Effect of thermal Stimuli on Arousal: A majority (22 out of 27) of the participants noted that the preferred stimuli depended on the emotional property of the image being augmented. A participant stated that: "*Preferred stimuli depended on context. Warm stimuli will be preferred for images communicating danger*" (P14). When participants were able to establish a connection between an image and the thermal stimuli presented together with it, thermal stimuli either increased or decreased arousal. According to two participants "*Images felt more interesting when augmented with thermal stimuli*" (P05). "*I prefer warm stimuli with exciting images and cool stimuli with calm images"* (P04).

Stimuli Intensity and Attention: High intensity stimuli made 18 out of 27 participants pay more attention to the image being augmented, and attach more meaning to it. According to a participant "*Thermal stimuli acted as a means of drawing my attention to the image, especially when I was starting to get bored*" (P10). Another participant mentioned "*Extreme temperatures when presented with images created the impression that I may be missing something in the image*" (P06). This highlights the possibility of using the stimuli intensity variable to draw the attention of users.

STUDY 2: THE EFFECT OF THERMAL STIMULI PRESENTATION TECHNIQUE ON THE EMOTIONAL PERCEPTION OF IMAGES

The aim of this second study was to determine the effect thermal stimuli presentation techniques has on its emotional perception. Thermal stimuli combinations found to be effective in influencing emotions in study 1 were used for study 2. Previous work investigating the effect of presentation technique on media has demonstrated their ability to influence affect in limited instances with music [1,10]. Akiyama *et al.* [1] showed that music augmented with dynamic thermal stimuli had the potential to enhance emotional experiences. While Halvey *et al.* [10] found that pulsing thermal stimuli increased feelings of arousal in music. However, this study to the best of our knowledge is the very first to investigate the effect of the timing of thermal stimuli presentation on the emotional perception of images.

Thermal Stimuli Presentation Techniques

The same thermal stimuli combinations used in study 1 were also used in this study. Since 1°C/s and 3°C/s rates of change were revealed to be perceptually similar in study 1, we decided to use a single ROC of 3°C/s in this second study. Four different thermal stimuli presentation techniques were used in this study (see Figure 4). All the presentation techniques followed a similar pattern. Presentation began with a pre-image phase, followed by an image display phase, and ended with a post-image display phase. After this rating scales (SAM & emotion wheel) were presented on screen for participants to provide ratings of how the combinations made them feel.

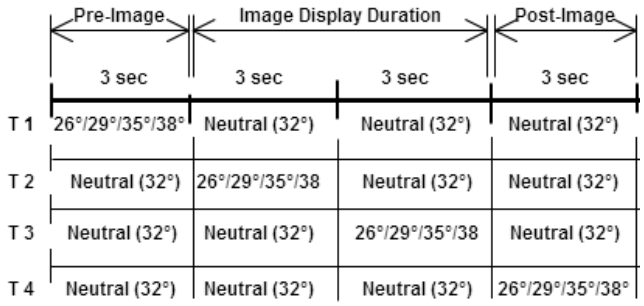

Figure 4: Presentation techniques and timings

Pre-image Phase: In this phase thermal stimuli was presented on its own for 3 seconds immediately before an image appeared on screen.

Image Display Phase: Here an image was presented on screen for 6 sec. Thermal stimuli presentation for this phase was divided into two halves; the first 3 seconds of image display and the last 3 seconds of image display.

Post-image Phase: In this phase a thermal stimuli combination was presented for 3 seconds immediately after an image disappears from screen.

A 3 seconds time division was chosen because it takes at least 2 seconds for the highest intensity stimuli (26°C & 38°C with an ROC of 3°C/s) to reach its target temperature from neutral.

Technique 1 (T1): Here a thermal stimuli combination (26°C/29°C/35°C/38°C) was presented during the pre-image phase, while the neutral stimuli (32°C) was presented during the entire 6 seconds image display phase and post-image display phase.

Technique 2 (T2): This involved presenting the neutral stimuli during pre-image, a thermal stimuli combination (26°C/29°C/35°C/38°C) during the first 3 seconds of image display, and neutral stimuli during the last 3 seconds of image display and 3 seconds of post-image display.

Technique 3 (T3): In this presentation style, the neutral stimulus was presented during pre-image phase, the first 3 seconds of image display and post-image display, while a thermal stimuli combination (26°C/29°C/35°C/38°C) was presented in the last 3 seconds of image display.

Technique 4 (T4): In this presentation style, a neutral stimulus was presented during pre-image and entire 6 seconds of image display phase, while 4 different thermal combinations (26°C/29°C/35°C/38°C) were presented one at a time during the 3 seconds of post-image phase.

There was a control condition in which neutral stimuli was presented during pre-image, image display and post-image phases. Each presentation technique (1, 2, 3, and 4) produced a total of 4 presentation combinations, while the control condition had 1 presentation combination. Each presentation combination was randomly selected and combined with an image from each image emotion category. This gave a total of 136 augmented images (32 from each presentation technique and 8 from the control condition).

Image Presentation

Selection of augmented images in the 4 presentation techniques and control group was randomised. Augmented images were presented to participants in 4 sets of 34 images each, giving a total of 136 augmented images presented to participants. Perception and evaluation of images in each set lasted for approximately 24 minutes. Dividing images into sets was to allow time for participants to take short breaks between sets. Breaks in between sets lasted for 2 minutes, and the entire study lasted approximately 2 hours.

Data Gathering

Data collection followed the same pattern used in study 1. Participants were allotted 15 seconds to provide valence, arousal and dominance ratings on SAM and another 15 seconds to provide ratings on the emotion wheel. At the beginning of the rating phase, thermal stimuli returned back to neutral for adaptation to occur. Participants were interviewed at the end of the study. The interview questions were as follows:

1. *Overall, what are your thoughts about presenting different thermal stimuli intensities while an image is being displayed?*
2. *Was this something you enjoyed? Compared to presenting the images on their own?*
3. *Was there any presentation technique that felt pleasant or unpleasant?*
4. *For images that felt pleasant / unpleasant do you think the timing of the thermal stimuli augmentation contributed to the feeling of pleasantness/unpleasantness?*

Participants

21 participants (13 males, 8 females) between the ages of 18 and 44 volunteered for this study. Participants had a mean age of 28.

Variables

This study had a total of 4 independent variables; direction of change, amount of change, image category and presentation technique. Dependent variables were valence, arousal, dominance and emotion wheel ratings. As in study 1, valence difference, arousal difference and dominance difference were also analysed for the image category independent variable.

STUDY 2 RESULTS

As data was not normally distributed Friedman Tests and Wilcoxon Sign Rank Tests were used for analysis.

Image Category

This independent variable is made up of eight (8) groups, thus a Bonferroni correction was made for pairwise comparisons with p=*0.0018.* As expected, there was a significant difference between the different groups, because the images were grouped based on their inherent emotional properties. A Friedman test revealed a significant difference for valence difference (X^2 (7) = 1994.97, $p <$ 0.001). All the emotion categories significantly differed from each other except category 8 and 5 (see Figure 5). This is consistent with what was found in study 1. Thermal stimuli augmentation increased feelings of valence in low and neutral valence images, while reducing valence in high valence images.

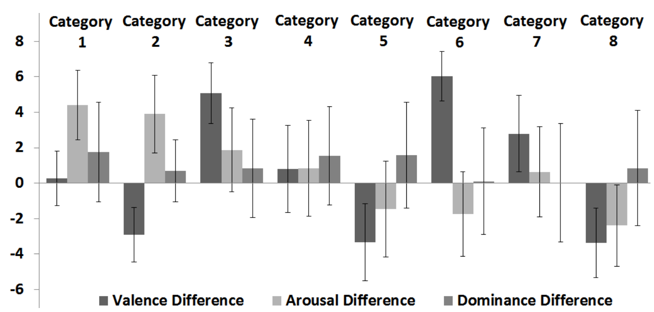

Figure 5: Mean ratings of responses relative to image emotion categories. Val diff, Aro diff and Dom diff ratings are based on a 9-point likert scale

A Friedman test for arousal difference showed a significant difference (X^2 (7) = 1401.87, $p <$ 0.001) for all image categories except categories 7&6 and 5&3. As in study 1, thermal stimuli augmentation was shown to increase feelings of arousal in low and neutral arousal images, while reducing arousal in high arousal images. The only exception to this was images from the neutral arousal/high valence category, which had reduced arousal ratings and images from high arousal/neutral valence, which had increased arousal ratings. A Friedman test also showed a significant difference for dominance difference (X^2 (7) = 116.21, $p <$ 0.001). All image categories significantly differed from each other except categories 4&1, 5&1, 3&2, 8&2, 4&3, 5&3, 8&3, 5&4, 8&4, 8&5 and 7&6 (see Figure 5). As found in study 1, thermal stimuli also increased dominance ratings across all image categories in study 2.

For the emotion wheel (X^2 (7) = 495.36, $p <$ 0.001), all image emotion categories significantly differed from each other except for categories 2&1, 5&3, 5&6 and 5&7. As with study 1, images with low arousal and neutral to high valence were perceived as calm after thermal stimuli augmentation. Images with neutral arousal/low valence were perceived as sad, while neutral to high arousal and high valence images evoked excitement. Images with high arousal and low to neutral valence were perceived as alarming. Comparisons between emotion wheel ratings for un-augmented and augmented images only showed a difference for images in categories 1, 2 and 3. Participants felt tired when viewing un-augmented category 1 images (low arousal, low valence) and calm after augmentation; relaxed when viewing un-augmented category 2 (low arousal, high valence) images and calm after augmentation; alarmed when viewing un-augmented category 3 images (neutral arousal high valence), and sad after augmentation.

Analysis of Presentation Techniques

A Friedman test revealed no statistically significant difference between the 4 presentation techniques used in this study, and the effect thermal stimuli parameters had on the 4 presentation techniques combined. Results showed that all the presentation techniques were perceived to have similar effect on the emotional perception of images. Analysis of individual presentation techniques however showed slight differences in the effect thermal stimuli parameters had on the emotional perception of the images we presented.

Effect of Direction of Change on individual Presentation Techniques

In presentation technique 1, a Wilcoxon test showed a significant difference for direction of change for the emotion wheel (z=-2.1, p = 0.034). Warming temperatures were perceived to be alarming, while cooling temperatures were perceived to be calming. Direction of change had no statistically significant effect for techniques 2, 3 and 4.

Effect of Amount of change on Presentation Technique

Analysis of temperature amount of change showed no significant difference for ratings of valence, arousal, dominance and the emotion wheel. This result is different to what was found in study 1, where amount of change was found to have a significant effect. This could have been as a result of the short 3 seconds multiple thermal stimuli presentation phases used in study 2, compared to the 6 seconds single presentation phase used in study 1. Therefore, determining the effects duration of thermal stimuli presentation has on the emotional perception of images is an important factor to be investigated in future work.

Effect of Individual Presentation Techniques on Gender

Some differences based on gender were noted in the results, so we investigated this in more detail. A Wilcoxon test of data for T1 showed a significant gender difference for valence (z=-2.067, p=0.039), arousal (z=-3.709, p<0.001) and the emotion wheel (z=-2.160, p=0.031). Images augmented with T1 were rated to be more pleasant by females than males, while males perceived the images to be more arousing than females. Females perceived images augmented with T4 as calm, while males perceived them as alarming. Wilcoxon test showed a significant difference for arousal in T2 (z=-3.352, p<0.001). Males perceived images in all emotion categories to be more arousing than females. For images augmented with T3, Wilcoxon test showed a significant difference for valence (z=-2.342, p=0.019), arousal (z=-3.723, p<0.001) and the emotion wheel (z=-

2.084, p=0.037). Females rated images augmented with T3 to be more pleasant than males, while males rated these images to be more arousing than females. T3 had a calming effect on females and had an alarming effect on males. Analysis of T4 showed a significant difference for arousal (z=-3.208, p<0.001) and the emotion wheel (z=-2.298, p<0.022). Males perceived images in all categories to be more arousing than females. Females perceived images augmented with T4 as calm, while males perceived them as alarming.

Qualitative Results

Thematic analysis [5] was again used for analysis in the second evaluation. Emergent themes were collapsed into the following main themes:

Pre-image stimuli presentation (T1): 17 out of the 21 participants stated that pre-image stimuli did have an effect on how they perceived the images. According to interview data, it created anticipation for the image to be displayed. A participant had the following comment: "*Pre-image stimuli had the highest effect. It kind of gave an expectation for the image to be displayed, like you know when you're watching a movie and the soundtrack gives anticipation*" (P23). Warm stimuli were interpreted as preparing the participants for a low valence image, while cool stimuli were interpreted as preparing the participant for a high valence image. Two participants described it as follows: "*I generally associated very warm stimuli before an image to mean the image to be displayed will be bad*" (P3). "*Cool stimuli created anticipation for nice images and increased how pleasant they felt when they were presented*" (P21).

Stimuli presentation during image display (T2 & T3): According to 10 out of 21 participants, T2 and T3 enhanced the original emotion being conveyed by the image when they were able to establish a connection between thermal stimuli augmentation and the images displayed (i.e. warm stimuli with warm themed images and cool stimuli with cool themed images). A participant described it as follows: "*I saw a snake together with normal temperature and felt it was a normal tropical snake, then the temperature suddenly went down and it gave the impression that the snake was about to strike*" (P13). 5 out of 21 participants found extreme warming and cooling temperatures (26°C and 38°C) presented during T2 and T3 reduced how pleasant and arousing they perceived the image. "Sometimes I saw an image *and felt a certain way about the image, but then the temperature would get really warm and it would annoy me, because it was too warm*" (P12)

Post-image stimuli presentation (T4): According to interview results, post image stimuli had little to no effect on the emotional perception of the images. Only 4 of the participants reported T4 as having an effect on how they felt. A participant reported this effect was a negative effect, while the others mentioned that it changed their opinion about the image they had already had a chance to see. "*It changed my perception about the image negatively and made me unsure of what to feel*" (P15). "*A war picture followed by warm temperature just before providing ratings made me want to get involved*" (P16).

Gender Difference

Previous research has shown that males and females have similar thermal stimuli thresholds when presented with different thermal stimuli combinations [9]. In addition Sabatinelli *et al*. [24] found that males and females have similar emotional reactions to the affective images we used in studies 1 and 2. However as a result of some small differences noted between genders for the presentation techniques in study 2, we reanalysed data from studies 1 and 2 based on gender. A Wilcoxon test revealed a significant difference between males and females for dominance (see Table 3) in study 1. Augmented images made female participants feel more dominant than males (z= =-4.08, p < 0.001). Gender had no statistical significant on valence, arousal and the emotion wheel.

Groups	Valence	Arousal	Dominance	Emotion Wheel
Female	5.04(5.0) σ = 2.64	5.06(5.0) σ = 2.30	5.51(6.0) σ = 2.76	105=Alarmed
Male	5.01(5.0) σ = 2.66	5.06(5.0) σ = 2.73	5.19(5.0) σ = 2.77	105=Afraid

Table 3: Mean, median in parenthesis & standard deviations of responses relative to gender in study 1.

For study 2 a Wilcoxon pairwise comparison of the male and female groups revealed a significant difference for arousal (z=-7.156, p < 0.001). Males rated images in all image categories to be more arousing than females (see Table 4). No significant difference was found for valence, dominance and the emotion wheel.

Overall this difference in gender is an interesting but inconclusive observation. Since previous work [9,24] indicated that there are no gender differences for thermal stimulation our studies were not designed to investigate gender differences. Thus we are unable to make any definitive conclusions. Gender differences regarding the emotional perception of augmented images may need to be investigated further in future work.

Groups	Valence	Arousal	Dominance	Emotion Wheel
Female	5.36 (5.0) σ = 2.44	6.18 (7.0) σ = 2.48	5.21 (5.0) σ = 2.62	105=Alarmed
Male	5.51 (5.0) σ = 2.31	5.35 (5.0) σ = 2.39	5.18 (5.0) σ = 2.39	285=Calm

Table 4: Mean, median in parenthesis & standard deviations of responses relative to gender in study

DISCUSSION

Thermal stimuli can be used to increase valence in low valence images and arousal in all image emotion categories (Addressing RQ1): Thermal stimuli augmentation led to an increase in ratings of valence and arousal for images in the low valence and neutral to low arousal emotion categories. This was in a large part due to the effect of direction of change and thermal stimuli intensity. Results revealed that images presented with warm stimuli intensities (3°C changes) were perceived to be significantly more arousing than when there was no augmentation. Participants rated 3°C changes as relaxing on the emotion wheel, while no change in temperature had a calming effect. Qualitative results also revealed that cool stimuli helped reduce how negative images with low valence felt. As a result, in the design of affective thermal interfaces, our results suggest cooling temperatures will be best suited for increasing how pleasant images classified to have low valence are perceived, while warm 3°C changes will be effective in making images feel more arousing.

Thermal Stimuli can be used to reduce valence in images and how arousing images in all emotion categories are perceived (Addressing RQ2): Augmenting high valence, high arousal images with thermal stimuli was found to reduce how pleasant and arousing they felt. This was supported by the qualitative results, where extreme warm stimuli (38°C) in T2 and T3 reduced valence and arousal in the image augmented. This finding could be useful in helping interface designers control the amount of affect an image can evoke in a perceiver. The qualitative results showed that fast changing warm stimuli acted as a means of alerting participants to what was being augmented. Rate of change had no significant effect of how images are perceived; both 1°C/s and 3°C/s changes are suitable for use in the design of affective interfaces.

Thermal stimuli augmentation increases the feeling of dominance in images. (RQ 1, 2): Salminem *et al*. [25] found that warm stimuli presented in isolation significantly increased feelings of dominance. Results from studies 1 and 2 showed that thermal stimuli when used to augment images still maintained its ability to increase dominance. The dominance ratings recorded for augmented images were significantly higher than the dominance ratings recorded for the images without any thermal stimuli augmentation. Thus when designing thermal interfaces, 6°C intensity changes from a neutral point of 32°C can be used to increase feelings of dominance in images across all emotion categories. These stimuli intensities can be warming or cooling with ROC's of 1°C/s or 3°C/s.

Pre-image stimuli (T1) generate anticipation for the image to be presented (Addressing RQ3): Based on the qualitative results, pre-image stimuli generated anticipation for the image that shows up afterwards, with most people interpreting the presence of cool stimuli to mean a high valence image will be displayed, while warm stimuli was attached to low valence images. These findings were supported by results obtained from the emotion wheel, which showed that during the pre-image phase, warming temperatures were perceived to be alarming, while cooling temperatures were perceived to be calming.

Simultaneous presentation of thermal stimuli with an image (T2 & T3) enhances the emotion the image is capable of evoking (Addressing RQ3): Qualitative results showed that participants perceived that presentation techniques 1 and 2 enhanced the emotions the images are able to evoke. This finding was however not supported by the quantitative data. This shows the advantage of using mixed data gathering techniques to obtain subjective emotive feedback. According to these qualitative results, presentation techniques 2 and 3 can be used by designers to enhance the inherent emotional property of the image been presented. For this to be effective, content of images may need to be matched with the specific thermal stimuli properties, i.e. warm stimuli intensities with warm themed images and cool stimuli intensities with cool themed images.

The results we obtained have extensive potential applications in media. Augmenting motion pictures with thermal stimuli has the potential to allow movie producers enhance or reduce affect in movies as well as create a more immersive movie experience. Allowing people to choose different temperatures that should be presented with photos posted on social media or sent to personal contacts, can allow individuals to communicate more affect through images. With the increasing popularity of media consumption on mobile devices, augmenting images viewed on smaller-screened devices has the potential to create a more affective media viewing experience. This is consistent with findings reported by Lochtefeld et al. [20] that showed thermal augmentation of media on a tablet contributed to enriching the user experience of mobile media consumption. Thermal augmentation could also provide an avenue for designers to communicate more affect information or enhance specific emotions in artefacts displayed in museums or art galleries.

CONCLUSION

This paper has presented a detailed investigation of the emotional responses different thermal properties can elicit in images. We also presented the first known investigation of the effect different presentation techniques have on the emotional perception of images. We found that low valence (unpleasant) images can be made more negative by augmenting them with warming thermal intensities or less negative by augmenting them with cooling intensities. Depending on the timing of thermal stimuli presentation, thermal stimuli presentation technique tends to either create anticipation in a perceiver or enhance/reduce affect in the images being augmented. These findings have the potential to enable designers to have more control over the emotions that can be evoked by images viewed on devices currently not optimised for high levels of user engagement.

ACKNOWLEDGEMENTS

Thank you to Graham Wilson for all of his assistance with the equipment and our user evaluations.

REFERENCES

1. Shimon Akiyama, Katsunari Sato, Yasutoshi Makino,

and Takashi Maeno. 2013. ThermOn -Thermo-musical Interface for an Enhanced Emotional Experience. Proceedings of the 17th annual international symposium on International symposium on wearable computers - ISWC '13, ACM Press, 45–52.

2. David Beattie, Lynne Baillie, and Martin Halvey. 2015. A Comparison of Artificial Driving Sounds for Automated Vehicles. Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing, 451–462.
3. Lynne Baillie, Lee Morton, David C. Moffat, and Stephen Uzor. 2010. Capturing the response of players to a location-based game. Personal and Ubiquitous Computing 15, 1, 13–24.
4. Margaret M. Bradley. and Peter J. Lang. 1994. Measuring Emotion: The Self-Assessment Manikin and the Semantic Differential. Journal of Behavior Therapy and Experimental Psychiatry 25, 1, 49–59.
5. Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology Using thematic analysis in psychology. Qualitative research in psychology 3, 2, 77 – 101.
6. Ella A. Cooper, John Garlick, Eric Featherstone, Valerie Voon, Tania Singer, Hugo D. Critchley, and Neil A. Harrison. 2014. You Turn Me Cold: Evidence for Temperature Contagion. PloS one 9, 12, e116126.
7. Sylvain Delplanque, Karim N'diaye, Klaus Scherer, and Didier Grandjean. 2007. Spatial frequencies or emotional effects?. A systematic measure of spatial frequencies for IAPS pictures by a discrete wavelet analysis. Journal of Neuroscience Methods 165, 1, 144–150.
8. Daniel Gooch and Leon Watts. 2010. Communicating Social Presence Through Thermal Hugs. Proceedings of the first Workshop on Social Interaction in Spatially Separated Environments SISSI2010, 11–19.
9. Lincoln Gray, Joseph C. Stevens and Lawrence E. Marks. 1982. Thermal stimulus thresholds: Sources of variability. Physiology & Behavior 29, 2, 355–360.
10. Martin Halvey, Michael Henderson, Stephen A. Brewster, Graham Wilson and Stephen A. Hughes. 2012. Augmenting media with thermal stimulation. Haptic and Audio Interaction Design 7468, 91–100.
11. Martin Halvey, Graham Wilson, Stephen Brewster and Stephen Hughes. 2012. "Baby it's cold outside": The Influence of Ambient Temperature and Humidity on Thermal Feedback. Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12, ACM Press, 715–724.
12. Martin Halvey, Graham Wilson, Stephen A. Brewster and Stephen A. Hughes. 2013. Perception of thermal stimuli for continuous interaction. CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13, ACM Press, 1587.
13. Martin Halvey, Graham Wilson, Yolanda Vazquez-Alvarez, Stephen A. Brewster and Stephen A. Hughes. 2011. The Effect of Clothing on Thermal Feedback Perception. Proceedings of the 13th international conference on multimodal interfaces - ICMI '11, ACM Press, 217–220.
14. Kenneth O. Johnson, Ian Darian-Smith, and Carole LaMotte. 1973. Peripheral neural determinants of temperature discrimination in man: a correlative study of responses to cooling skin. Journal of Neurophysiology 36, 2, 347–370.
15. Lynette A. Jones, and Michal Berris. 2002. The psychophysics of temperature perception and thermal-interface design. Proceedings 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. HAPTICS 2002, IEEE Comput. Soc, 137–142.
16. Kazuyuki Kanosue, Norihiro Sadato, Tomohisa Okada, et al. 2002. Brain activation during whole body cooling in humans studied with functional magnetic resonance imaging. Neuroscience Letters 329, 2, 157–160.
17. Dan R. Kenshalo, Charles E. Holmes, and Paul B. Wood. 1968. Warm and cool thresholds as a function of rate of stimulus temperature change. Perception & Psychophysics 3, 2, 81–84.
18. Dan R. Kenshalo, and Harley A. Scott Jr. 1966. Temporal course of thermal adaptation. Science 151, 3714, 1095–1096.
19. Dan R. Kenshalo. 1986. Somesthetic Sensitivity in Young and Elderly Humans. Journal of Gerontology 41, 6, 732–742.
20. Peter J. Lang, Margaret M. Bradley, and Bruce N. Cuthbert. 2008. International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8. University of Florida, Gainesville, FL.
21. Markus Löchtefeld, Nadine Lautemann, Sven Gehring, and Antonio Krüger. 2014. AmbiPad: Enriching Mobile Digital Media with Ambient Feedback. Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services - MobileHCI '14, ACM Press, 295–298.
22. Mutsuhiro Nakashige, Minoru Kobayashi, Yuriko Suzuki, Hidekazu Tamaki, and Suguru Higashino. 2009. "Hiya-Atsu" Media: Augmenting Digital Media with Temperature. Proceedings of the 27th international conference extended abstracts on Human factors in computing systems - CHI EA '09, ACM Press, 3181–3186.
23. James A. Russell. 1980 A circumplex model of affect. *Journal of Personality and Social Psychology 39*, 6, 1161–1178.

24. Dean Sabatinelli, Tobias Flaisch, Margaret M. Bradley, Jeffrey R. Fitzsimmons, and Peter J. Lang. 2004. Affective picture perception: gender differences in visual cortex ? Neuroreport 15, 7, 1109 –1112.
25. Katri Salminen, Veikko Surakka, Jukka Raisamo, Jani Lylykangas, et al. 2011. Emotional responses to thermal stimuli. Proceedings of the 13th international conference on multimodal interfaces - ICMI '11, ACM Press, 193–196.
26. Eun_Jung Sung, Seung-Schik Yoo, Hyo W. Yoon, Sung-Suk Oh, and Hyun W. Park. 2007. Brain activation related to affective dimension during thermal stimulation in humans: a functional magnetic resonance imaging study. The International journal of neuroscience 117, 7, 1011–27.
27. Auke Tellegen. 1985. Structures of mood and personality and their relevance to assessing anxiety, with an emphasis on self-report.
28. Anaya B. Weddle, and Hua Yu. 2013. How does audio-haptic enhancement influence emotional response to mobile media? 5th International Workshop on Quality of Multimedia Experience, QoMEX Proceedings, 158–163.
29. Graham Wilson, Stephen Brewster, Martin Halvey and Stephen Hughes. 2012. Thermal Icons: Evaluating Structured Thermal Feedback for Mobile Interaction. Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services - MobileHCI '12, ACM Press, 309-309.
30. Graham Wilson, Stephen Brewster, Martin Halvey, and Stephen Hughes. 2013. Thermal Feedback Identification in a Mobile Environment. Haptic and Audio Interaction Design, 10–19.
31. Graham Wilson, Gavin Davidson, and Stephen Brewster. 2015. In the Heat of the Moment : Subjective Interpretations of Thermal Feedback During Interaction. CHI'15 Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, 2063–2072.
32. Graham Wilson, Martin Halvey, Stephen Brewster, and Stephen Hughes. 2011. Some Like it Hot: Thermal Feedback for Mobile Devices. Proceedings of the SIGCHI conference on Human Factors in Computing Systems. CHI '11.