USING FUNCTIONAL INFRARED THERMAL IMAGING TO MEASURE STRESS RESPONSES

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A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Master of the Arts in Psychology: Academic Research

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July 2018

Abstract

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The stress response reflects a coordinated pattern of physiological changes that serves the adaptive function of increasing an organism's ability to cope with situations that require action or defense. The changes in blood flow associated with the stress response may be detectable using the relatively new research technique of functional infrared thermal imaging (fITI). The present study was designed to determine the time-course and topography of temperature changes in human faces during the experience of a stressor. Infrared images were taken from 29 female participants while they completed the mental arithmetic component of the Trier Social Stress Test (TSST). Continuously self-reported stress levels confirmed that this task caused a significant increase in stress levels. Skin temperature was measured from 5 facial regions of interest (ROIs: forehead, periorbital, nasal, cheeks, and perioral). Stress caused a significant increase in the forehead and cheek regions, and a significant decrease in the perioral region. These results demonstrated that stress is detectable from facial skin using thermography. However, the ability of this technique to distinguish between different affective states (e.g., stress vs embarrassment) remains to be determined. As such, more research is needed before fITI is deemed a reliable tool for measuring affective states in real-world settings such as airports.

Acknowledgements

I would like to thank my thesis advisor, Dr Amanda Hahn, for all of her help and support throughout this process. I feel incredibly lucky to have been able to work with her and be her first “science muffin” at Humboldt State. I would also like to thank my parents, because without their love and support, I would not be where I am today. Lastly, thank you to all my friends who have turned into family along this journey.

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Introduction

Non-verbal, emotional interaction has long been recognized as an important form of communication in humans (Oatley, Keltner, & Jenkins, 2006). Emotions are the instinctive mental states that arise from one's autonomic arousal, subcortical brain activity, and possible interpretation or appraisal of an event (Cannon, 1927; Reisenzein, 1983). Emotions serve an intrapersonal function, allowing us to communicate our internal states, feelings, and beliefs with others in a non-verbal way. Emotions can alter attention, influence others' behaviors based on how they react to the elicited emotion, and bring about memories associated to the elicited emotion. They can also serve as a personal tool to establish our place in our environment, allowing us to connect more with certain people while repelling us from others (Levenson, 1999).

Studying emotional responses is a strong focus of contemporary research, including research to further our understanding of why we show emotions (Oatley, et al., 2006), whether they are universal (Elfenbein & Ambady, 2003), and how to measure them (Bradley & Lang, 2000). As previously discussed, emotions allow us to communicate our internal thoughts and feelings in a non-verbal manner, which can help us decide to either bond or distance ourselves from others. Barrett, Mesquita, and Gendron (2011) argue that although emotions may be widely recognizable by different cultures, it is largely based off the context and perception of the elicited emotion. If someone was to zoom in on a photo to show just the face a human celebrating, it may look like they're in pain or angrily shouting, but if you zoom out and see their hands raised in celebration it becomes more apparent that they are excited.

Researchers implement many different techniques to observe and measure emotions. However, it has been argued by some that there is no "gold standard" for measuring emotions; physiological, behavioral, and experiential measures can all be beneficial for measuring different emotional states and shouldn't always be considered interchangeable (Larsen & Prizmic-Larsen, 2006). In a systematic review of the literature, Mauss and Robinson (2009) found that researchers measure emotions using a variety of techniques, including: self-report measures, autonomic measures, startle response magnitude, brain states, and various behavioral measures. Each of these techniques has both benefits and limitations. For example, it has been shown that participants often feel the need to respond with socially desirable answers on self-report scales, which leads to a decrease in reporting of negative emotional states than being realistically experienced (Paulhus & Reid, 1991).

One emotion that is ubiquitous in modern society is stress (Ellis, Jackson, & Boyce, 2006). The term 'stress' refers to a hypothetical construct that is characterized by both a physiological response and subjective response (generally considered a change in subjective well-being). Although these two aspects differ, they are integrally related in that a physiological change can be followed by a change in subjective wellbeing and vice versa. Thus stress can be considered from a purely physiological perspective as well as from an emotional or affective perspective. Indeed, stress is often characterized as an emotional or affective state in thermal research literature (Engert, et al., 2014; Ioannou, Gallese, & Merla. 2014a; Merla & Romani, 2007). The stress response, present in humans and non-humans alike, evolved to prepare us for action, increase our chances of survival, and decrease chance of injury (Nesse, Bhatnagar, & Young, 2000). Hans Selye (1936; 1950) is widely considered to be the father of modern stress research; he coined the term stress after a series of experiments in which he made rats undergo different adverse stimuli and observed their behavioral and physiological reactions. He observed three distinct response stages to the changes in environment, involving both the autonomic nervous system and the neuroendocrine system. The first stage is the alarm stage (6-48 hours after adverse stimuli), in which the rats showed increased autonomic nervous system activity, which was characterized by a decrease in body temperature due to vasoconstriction (i.e., constriction of the blood vessels which causes an increase in blood pressure), swelling of the adrenal cortex, and a decrease in the size of the thymus, spleen, lymph glands, and liver. The second stage is the resistance phase (48 hours after adverse stimuli), in which the rats became more adapted to their environment, their autonomic activity decreased, but their cortisol levels increased due to continual hypothalamic-pituitary-adrenal (HPA) axis activation (see below for a more detailed description of the HPA axis). The third and final stage is the exhaustion phase (1-3 months after adverse stimuli), in which the rats lost their resistance and succumbed to the adverse stimuli, showing similar reactions to the first stage but eventually resulted in disease or even death. This observation of the physiological changes to adverse stimuli that caused possible detrimental changes to the animals led Selye to coin the term "stress". He defined stress as the "non-specific response of the body to any demand to change”. He posited that stress has two components: the General Adaptation Syndrome (GAS) which is the set of physiological responses brought on by a stressor, and the development of a pathological state resulting from chronic stress (Selye, 1956).

The term stress is now engrained in our vocabulary, and has been defined in many different ways since Selye’s original definition. The overall consensus is that stress is a physiological state in response to perceived external challenges to survival. However, stress can be positive/beneficial or negative/detrimental depending on the amount and perception of the stressor (Folkman, 1984; Selye, 1985). Positive stress, or eustress, is a motivating factor that can increase our functioning and chances of success (Li, Cao, & Li, 2016; Selye, 1974). Negative stress, or distress, can cause many detrimental physiological and behavioral changes, such as low birth weight when the mother experiences high levels of distress (Rondó, et al., 2003), higher rates of dropout in college students (Sher, Wood, & Gotham, 1996), decreased long-term memory formation (Kuhlmann, Piel, & Wolf, 2005), and weakened immune functioning (Khansari, Murgo, & Faith, 1990; Segerstrom & Miller, 2004).

Biologically, the human stress response involves two major pathways: the autonomic nervous system and the hypothalamic-pituitary-adrenal axis (HPAA). Together, these two systems orchestrate psychological and physiological processes that help the body deal with an environmental change or challenge. Acute stressors, such as braking when traffic suddenly stops or jumping when a pan accidentally falls, activate the sympathetic branch of the autonomic nervous system (Kemeny, 2003). The autonomic nervous system (ANS) is a branch of the peripheral nervous system that generally readies us for action (e.g., controls heart rate) and helps our body maintain homeostasis (Jänig, 2006). The sympathetic portion of the ANS primes our body for action, whether that is to confront the stressor or avoid it. Canon (1915) termed this the “fight-or flight” response, also known as the sympathetic adrenomedullary system. When the amygdala receives sensory information from the thalamus and perceives that external stimulus as a possible threat, it sends out a signal that activates the postero-lateral hypothalamus. The hypothalamus then sends nerve impulses through the spinal cord and out the preganglionic neurons, which originate from the thoracolumbar region of the spinal cord, specifically T1-L3. These preganglionic neurons travel to a sympathetic chain ganglion, where they synapse with a postganglionic neuron. These postganglionic neurons then travel throughout the body, activating the different aspects of the sympathetic response (see Figure 1). This activation occurs due to preganglionic neurons releasing acetylcholine into the synapses, triggering the postganglionic neurons to release norepinephrine, which activates adrenergic receptors that are present in the tissue of the peripheral target organs. The activation of these adrenergic receptors in the target tissue is what causes the sympathetic response. For example, after the adrenal medulla is activated, it secretes epinephrine and norepinephrine, which readies the body for action by increasing heart rate, metabolic rate, and blood pressure (Kreibig, 2010; Moore, Agur, & Dally, 2002).

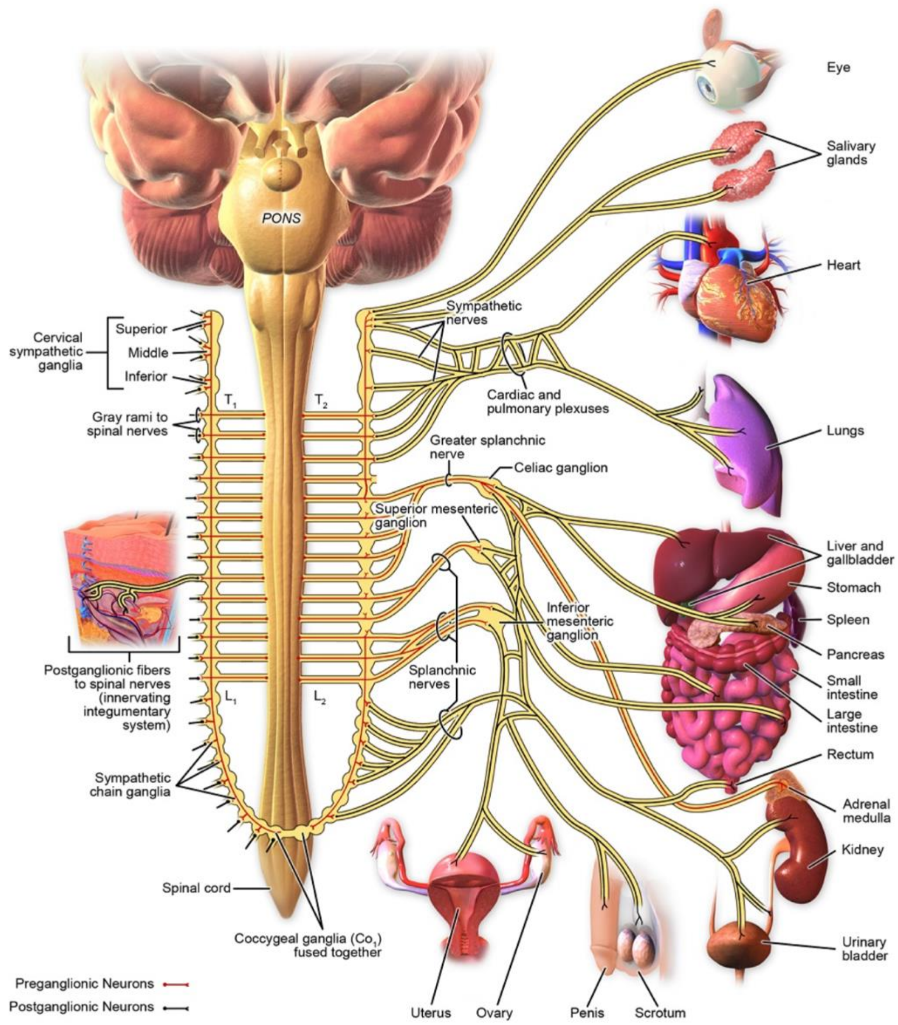

Figure 1. Biological effects of sympathetic nervous system. Image credit: biologydictionary.net/sympathetic-nervous-system/

Another physiological effect that is caused by sympathetic nervous system activation is vasoconstriction (Convertino, Rickards, & Ryan, 2012). Blood vessels constrict and bring blood to internal parts of the body, generally causing cooling of the extremities. Vasoconstriction is beneficial during the experience of stress because it brings oxygen to areas of the body that require increased oxygen during action, as well as acting to prevent major external bleeding if injured. Because vasoconstriction leads to a change in blood flow, it is likely that the experience of stress causes changes in body temperature, potentially including areas such as the face. These physiological responses that occur when the sympathetic nervous system is activated can be observed when humans encounter an acute stressor. Therefore, measuring these responses can help to measure the perception of that stressor.

In order to measure these physiological responses to stress, researchers induce stress in a laboratory setting using a variety of techniques. There are physiological stress induction techniques, such as the Cold Pressor Test, which requires participants to submerge their hand in ice water for about one minute, creating changes in blood pressure and heart rate (Hines & Brown, 1936). A psychosocial stress induction technique that is perhaps the most prevalent method for inducing stress in the laboratory is the Trier Social Stress Test (TSST), created in 1993 at the University of Trier (Kirschbaum, Pirke, & Hellhammer, 1993). The TSST has two components for inducing stress: a math component (discussed in ‘Procedure’ section below), and a public speaking component. Many studies over the years have used this psychosocial stress induction technique, and have found that it is a valid and reliable way to induce acute stress in participants (Allen, Kennedy, Cryan, Dinan, & Clarke, 2014; Dickerson & Kemeny, 2004). Past studies that have used the TSST found that it significantly increased stress levels by showing an increase in the concentration of adrenocorticotropic hormone (ACTH), cortisol, growth hormone (GH), prolactin, as well as an increase in heart rate (Kirschbaum, et al., 1993; Kudielka, et al., 2007). Goodman, Janson, and Wolf (2017) found that the TSST induced strong cortisol responses (d=.93), and was most effective when given in the afternoon. Schommer, Hellhammer, and Kirschbaum (2003) administered the TSST to participants three different times with a 4-week interval between sessions, and measured their ACTH, plasma cortisol, salivary cortisol, epinephrine, norepinephrine, and heart rate. They found that although ACTH and cortisol significantly decreased across the three sessions, epinephrine and norepinephrine did not significantly decrease. Epinephrine and norepinephrine are secreted during acute stressors that activate the sympathetic nervous system, while ACTH and cortisol are signs of more prolonged chronic stressors that activate the HPAA. These results show that the TSST continually activates the sympathetic nervous system, but participants may show a weakened HPAA response over time and repeated exposure. This further validates the TSST as a psychosocial acute stress induction technique.

The final challenge in stress research is how best to measure the stress response. There are many ways to measure stress, from self-report scales to physiological measurements, such as testing hormone levels or heart rate – each method has its benefits and pitfalls. The main self-report report method used to measure perceived stress is the Perceived Stress Scale (PSS). Cohen, Kamarck, and Mermelstein (1983) created this 10-

item scale, which inquires about feelings and thoughts in the past month. A couple examples of the questions on the PSS are: “In the past month, how often have you felt nervous or ‘stressed’?” and “In the past month, how often have you felt things were going your way?” These questions are meant to assess how stressful the participant perceives their life has been in the past month. The researchers provided evidence toward the validity of this scale; for example, they found that higher PSS scores correlated to increased vulnerability to stressful life-event related depressive symptoms. As discussed earlier, self-report scales can pose some issues when participants respond with what they believe are the socially desirable answers; participants sometimes feel the need to emit reporting their negative emotions, while others may over-report feelings of either distress or happiness (Paulhus & Reid, 1991).

Another common method for measuring the stress response is a physiological measure of stress obtained by measuring salivary or serum cortisol levels (Hellhammer, Wüst, & Kudielka, 2009; Kirschbaum & Hellhammer, 1989). Cortisol is a biomarker commonly referred to as the “stress hormone”. When humans experience chronic stress, their HPA axis is activated. The paraventricular nucleus (PVN) of the hypothalamus secretes corticotropin-releasing hormone (CRH), which stimulates the anterior pituitary gland to secrete adrenocorticotropic hormone (ACTH). ACTH travels to the adrenal gland, specifically the adrenal cortex, which then secretes the glucocorticoid cortisol (Tsigos & Chrousos, 2002; see Figure 2).

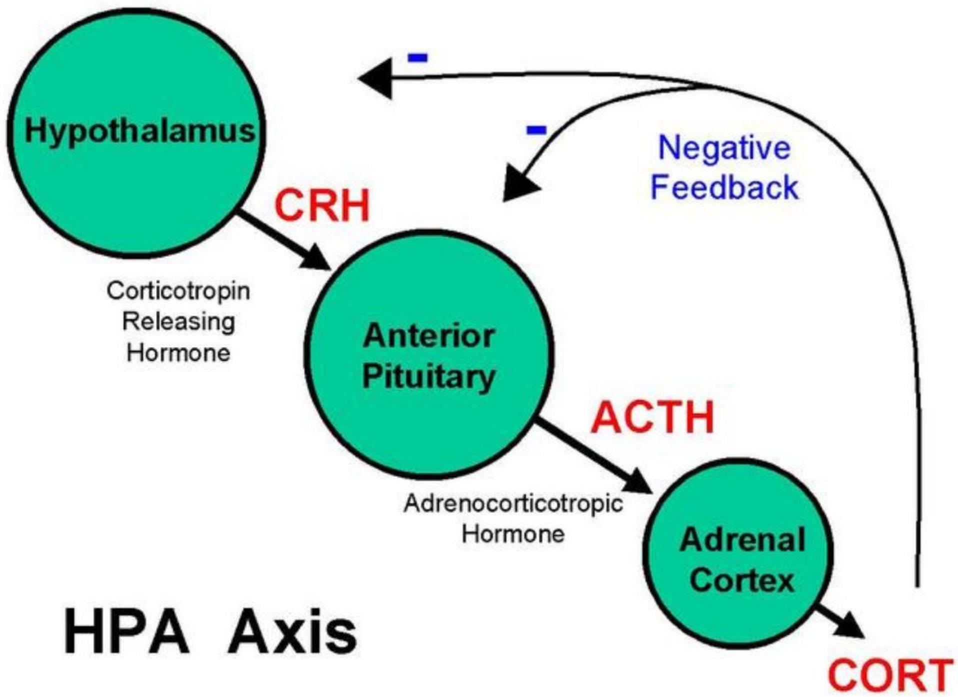

Figure 2. Hypothalamic-Pituitary-Adrenal Axis Image credit:

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Chronic stress continually activates this HPAA, leading to higher amounts of cortisol in the body. This is why cortisol is referred to as a biomarker of stress (Charmandari, Tsigos, & Chrousos, 2005). However, recent research has suggested that cortisol might not be as reliable of a biological measure for stress as once thought, due to the indirect influence from other modulators, receptors, and binding proteins that may influence and effect salivary cortisol levels. Hellhammer and colleagues (2009) discuss the differential effects of CRF, ACTH, and arginine vasopressin (AVP) on serum and salivary cortisol levels. They state that slightly different measurements can be found when measuring ACTH levels, total cortisol in blood, and salivary cortisol, so all three of these should be obtained for the most accurate cortisol level. However, they admit that this can be a limitation because it can be difficult to collect all three, even in a laboratory setting, since collecting blood is not usually desired by participants. This led researchers to search for a technique that is less invasive than finding the total cortisol level.

When studying emotions, it is ideal to collect data without interrupting or altering interactions, which proves to be difficult or even impossible with other measurement tools currently being implemented in emotion research (Clay-Warner & Robinson, 2015). Measuring stress using salivary or serum cortisol requires the collection of saliva or blood, which necessitates contact with participants during the physiological measurement meant to track stress levels. This direct experimenter contact could potentially impact the measured stress response in a way that is unrelated to the experimental task. This issue is leading researchers to look into other possible non-intrusive, non-contact ways to measure emotions such as stress, in hopes of implementing other reliable measurement techniques to further the validity of research on emotions. One such alternative physiological measurement technique, the use of functional infrared thermal imaging (fITI), has gained increasing popularity in recent affective research (Cardone & Merla, 2017; Ioannou, et al., 2014a; Robinson et al., 2012).

Thermal infrared imaging is a non-invasive technique that uses specialized cameras that detect thermal infrared signals to illustrate skin temperature (Hahn, Whitehead, Albrecht, Lefevre, & Perrett, 2012; Nhan & Chau, 2009; Ring & Ammer, 2012; Shastri, Merla, Tsiamyrtzis, & Pavlidis, 2009). Skin temperature is dependent on cutaneous blood perfusion, vasoconstriction and vasodilation, local tissue metabolism, and sudomotor responses – all of which are, in turn, controlled by the sympathetic system (Merla, Di Donato, Romani, & Rossini, 2003). Given the link between sympathetic nervous system activity and the stress response, as well as the link between sympathetic nervous system activity and skin temperature, thermography provides a new non-invasive avenue for studying stress. Since this technique implements the use of cameras, it allows researchers to collect data without interacting with and possibly influencing the participants during the physiological measurement of stress, as the camera can be controlled remotely. fITI, or thermography, thus shows major potential toward the ideal non-contact collection of data in emotion research.

A variety of affective states, such as aggression (Hahn, et al., 2012) and emotional arousal (Nhan & Chau, 2010; Nozawa & Tacano, 2009; Zajonc, Murphy, & Inglehart, 1989) have been shown to elicit thermal responses detectable in the facial skin, suggesting that changes in facial skin temperature may be indicative of affective states.

For example, embarrassment and sexual arousal show a rush of blood to the cheeks (Hahn et al., under review; Shearn, Bergman, Hill, & Abel, 1990), while fear or anxiety responses show a decrease in blood flow to this region (Levine, Pavlidis, & Cooper, 2001; Pavlidis, Levine, & Baukol, 2000). This rush of blood to the cheek region when feeling embarrassed is caused from the activation the sympathetic nervous system due to the embarrassing occurrence. The release of adrenaline during this response acts as a stimulant, causing dilation of pupils, acceleration of heartbeat, and vasodilation in certain areas. Vasodilation is the dilating of blood vessels, causing more blood to flow to certain regions, improving blood flow and oxygen to these regions, and also increasing temperature due to the increase in blood (Drummond & Su, 2012; Holling, 1965). This rush of blood from vasodilation thus explains the commonly observed cheek reddening when encountering an embarrassing situation. Social or interpersonal contact has also elicited measureable changes in facial skin temperature, particularly when gaze is directed at the individual (Ioannou et al., 2014b) or when the individual interacts with a member of the opposite sex (Hahn, et al., 2012).

This method has also been used in research with non-human animals. Ioannou, Chotard, and Davila-Ross (2015) used fITI to study emotional responses of rhesus monkeys; they found significantly different thermal reactions in the monkey’s facial regions during play, food teasing, and feeding, providing more evidence that this is a reliable non-contact measurement technique for emotions in animals as well. Current research is investigating whether the differences in observed thermal reactions based on various emotional responses are unique enough to classify and categorize emotions using thermal infrared cameras (Nhan & Chau, 2010).

While there is strong evidence to support the claim that thermography is a reliable measure of affective arousal (Cardone & Merla, 2017; Ioannou et al., 2014a; Kukkonen, et al., 2010), the ability of this methodology to distinguish between different types of arousal remains to be determined. Recent research has begun exploring the similarities and differences between the thermal reactions of various emotions in order to determine if it is possible to identify and classify emotions based on these thermal responses. Some research has indicated that different emotions show detectably different patterns of blood flow, suggesting that the experience of different emotions could be accurately categorized based on observed thermal reactions (Ioannou et al. 2014a; Merla & Romani, 2007; Nhan & Chau, 2010). For example, as previously discussed, embarrassment has shown a rush of blood to the cheeks, which results in a higher temperature measured from skin in the cheek region (Shearn, et al., 1990). Conversely, a startle stimulus or fear response may show a decrease in the perioral and forehead regions, with little to no change in the periorbital region (Gane, Power, Kushki, & Chau, 2011; Merla & Romani, 2007).

The current study aims to explore the topography of thermal changes in the face during the experience of psychosocial stress, and further validate fITI as a measurement technique for emotional responses. When observing the thermal response of stress, Pavlidis and Levine (2002) found an increase in temperature around the periorbital area when participants were stressed by being asked to lie, so they argue that increased blood flow circulation around the eyes is associated with anxious states. Similarly, Puri, Olson, Pavlidis, Levine, and Starren (2005) observed a significant temperature increase in the forehead when using the Stroop task to induce stress. However, Merla and Romani (2007) also used the Stroop task to induce stress, but did not report increases in the forehead region. Rather, they observed an increase in temperature around the perioral region, accompanied by a decrease in temperature in the nasal region. This finding regarding decreased nasal temperature was also observed by Nozawa and Tocano (2009) as well as Engert and colleagues (2014), and is observed as a relatively reliable thermal response to stressors.

Ioannou, Gallese, and Merla (2014a) created a review of 23 experimental procedures that studied different emotions using fITI, and found these significant thermal responses in the articles relating to stress: an overall significant temperature decrease in the nasal region, both an increase and decrease in forehead temperature (ROI with most stable temperature), and a decrease of temperature in the perioral region. These findings suggest that there may be consistent effects regarding nasal temperature, but highlight that other areas of the face have shown inconsistent changes during the experience of a stressor and warrant further research.

A direct comparison between thermal infrared cameras and other physiological measurement techniques to establish validity have proven to be somewhat difficult due to differences in response latencies, and these different physiological mechanisms are aroused by different control systems (Ioannou, Gallese, & Merla, 2014a). The most current infrared (IR) imaging cameras being used, which is the fourth generation of thermal cameras, are shown to have the most reliability and sensitive to infrared systems because of the large focal plane array (FPA) detectors, increased number of pixels, higher thermal sensitivity, and increased acquisition frequency (Cardone & Merla, 2017). However, use of these cameras in practical settings, such as use in airports for mass-security screening purposes, is not currently recommended because the validity is still being established. Consequently, this technique is not suitable for large-scale application yet (Pavlidis, Eberhardt, & Levine, 2002). More research is required to determine the specific time course and topography of thermal changes during the experience of various emotions before this technology can be used in more mainstream settings.

This current study will address some limitations of these past studies. This study used female participants, leading to a more balanced amount of research on this topic and the dichotomous variable of gender. We also used the arithmetic component of the TSST as a psychosocial stress induction technique, which better parallels the type of stressors students encounter today, and fits more closely with previous stress research as this is the predominant method for inducing stress in the laboratory. Lastly, analysis of this data will further the current information regarding the validity of this technique to measure emotions, as well as the extent to which it can differentiate between different emotions by adding to the stress aspect of the literature.

Secondary Data Statement

This thesis project is an analysis of previously collected data. Data were collected in 2011 as part of a larger project Dr Hahn was running on thermal responses to various affective states (data available at osf.io/2exzm). Dr Hahn's research focused on sexual arousal and data on stress were collected but never analyzed. The study included a stress condition, a sexual arousal condition, and an embarrassment condition, and each participant completed these three conditions in a randomized order. Notably, a rest period was incorporated between each condition to ensure that the participants' body temperature returned to baseline, allowing for independent analyses of the various affective conditions. I, Julia Kandus, will conduct all data processing and data analysis. This research was approved by the University of St Andrews Teaching and Research Ethics Committee (Appendix A), and all participants provided written informed consent (Appendix B) prior to completing the study. IRB approval was also obtained from Humboldt State University (IRB 17-192) for the analysis of secondary data (Appendix C), as required by the graduate school.

Method

Participants

Twenty-nine females between the ages of 18 and 26 residing in St Andrews, Scotland participated in this study. They signed up through the University of St Andrews' SONA system, which is a voluntary online research participation pool. They were paid £5.00/hour for their participation in this study.

Imaging Equipment

Thermal responses were measured using a Testo (881-1) thermal imager (FPA 160 x 120 pixel a.Si, spectral range: 8–14 μm, thermal sensitivity (NETD) less than 80 mK, standard lens with 32° x 23°/0.1 m field of view) set to capture images at a rate of approximately 1 frame per 2.5 s). Object emissivity was set at 0.98, the standard value for skin (Steketee, 1973). The camera captured a frontal view of the participant's head and chest from a distance of 0.5 m.

Materials

During the stressor task (see Procedure section), a sliding scale was used as a continuous self-report measure for the participant's perceived stress during the task (this data is henceforth referred to as "slider data"). This sliding scale was constructed using a string with different colored stickers placed in equal distances along it to signify different levels of perceived stress, and a sliding bead that was used by the participants to indicate their current stress level continuously throughout the task (see Figure 3) and was visible in each image captured during the experiment. Participants held one end of the slider string in each hand and were able to pulled this string to move the pink ball back and forth between the blue tab (lowest stress level, coded as 1) and the red tab (highest stress level, coded as 5) based on their perceived stress at each moment in time during the task.

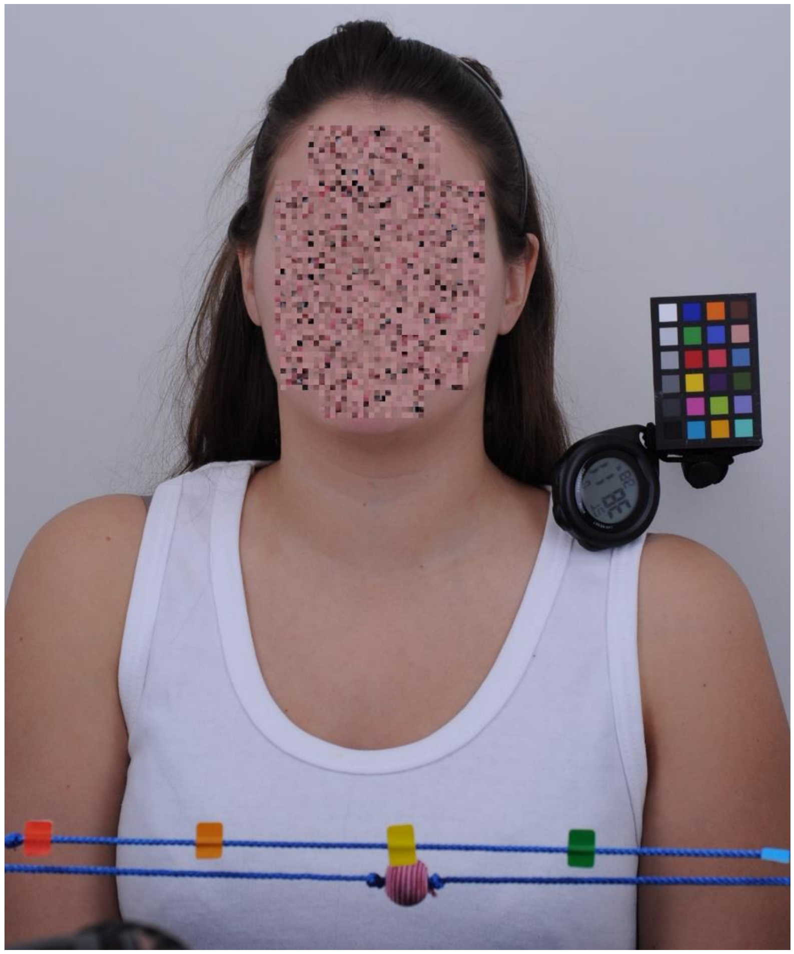

Figure 3. Stress slider bar. Participants were required to provide a continuous report of their stress level throughout the experiment. The 5-point stress scale ranged from a blue tab (on the participant's left) indicating the lowest level of stress (1) to a red tab (on the participant's right) indicating the highest level of stress (5). Participants pulled a string to move the pink bead from one side to the other in order to record their level of perceived stress as it changed throughout the condition. Here, a participant (face blurred to protect identity) is shown reporting a moderate level of stress (slider = 3) during the task. Participants were required to practice using this slider bar before the experiment began.

Thus, participants were able to use this scale to provide real-time data regarding their current stress level. The five tabs provided a 5-point perceived stress scale, and the information was converted into numerical form based on which tab the ball was positioned in front of during each image captured during the experiment. For example, the ball positioned in front of the green would indicate a 2 (low stress level), in front of the red that would indicate a 5 (extreme stress level), etc.

A post-condition questionnaire (Appendix D) was used after the stressor task, in which participants were asked to rate different emotions felt during the test condition such as stress, embarrassment, and sexual arousal using a Likert-style scale ranging from 1 through 5. This questionnaire was included to ensure that stress was the main cause for increased arousal during the stressor task. The post-condition questionnaire also asked how well the participant remembered to use the sliding scale. If a participant forgot to use the sliding scale, their data was removed from analysis. Only one participant forgot to use the sliding scale, and their data was removed for that portion of the analysis.

Procedure

Upon arriving at the laboratory participants signed the informed consent form, then were asked to change into a standard white top and wear a headband to ensure that the regions of interest on the face and chest were clearly visible. Following previous studies using facial thermography (Di Giacinto, Brunetti, Sepede, Ferretti, & Merla, 2014; Hahn et al., 2012; Merla & Romani, 2007; Pavlidis, et al., 2000), all participants were given a 20-minute acclimation period to allow for temperature normalization prior to the experimental task. During this time, they completed a demographics questionnaire wherein age and health factors that might affect blood flow (e.g., blood/circulatory disorders, recent exercise) were reported and completed a face rating filler task. Any participants who reported a circulatory disorder will be excluded from the analyses. After completing the questionnaire and filler task, participants were seated in a temperature-controlled room (range 19.5-22 °C; Ring & Ammer, 2006; Ammer & Ring, 2007) and asked to relax while listening to a 10-minute clip of calming music.

The math component of the Trier Social Stress Test (TSST) was then implemented as the stressor task in this study. The math component of the TSST consists of an anticipation period, in which the participants were told they were going to be performing a complex mental math task, followed by the test period during which they were required to count backwards in units of 13 from a random, large starting value (e.g., 1027). While participants attempted this difficult mental math, the experimenter provided negative feedback – insisting they go faster and indicating when a mistake had been made. Throughout the task, participants were required to continuously report their stress level using a slider bar (see Figure 3). When the 10-minute test period was over, the participants completed a short post-condition questionnaire (Appendix D). They were then debriefed, thanked for their time, and asked to change back into their clothes in the private area.

Image Analysis

Using Testo software and following previous research (Hahn et al., 2012), all thermal images were adjusted to set the emissivity at 0.98 (Steketee, 1973) and the temperature scale to a fixed range of 20℃- 40℃. After that the images were put into greyscale format, outputted into bitmap format, and mapped using 0-255 RGB color space. In this new representation, 0 represents the lowest temperature value (20℃) and 255 represents the highest temperature value (40℃). This allows for an automated analysis of facial temperature in several regions of interest (ROIs, more detail below) using the PsychoMorph software program (Tiddeman, Perrett, & Burt, 2001).

To account for any head movement throughout the stress task and to perform the automated thermal analysis, PsychoMorph was used to delineate (i.e. map) the images. Each image was then 3-point aligned (based on interpupillary distance) so that mouth center and eye centers matched up in every image. Using these aligned images, I specified set “patches” to analyze the representing ROIs. Based on areas analyzed in previous research (Hahn et al., 2012; Hahn et al., under review; Nhan & Chau, 2010; Shastri, et al., 2009) five different ROIs have been chosen for analysis: the forehead, the periorbital (eyes) region, the left and right cheeks (average temperature of both cheeks), the nasal region, and the perioral (mouth) region (see Figure 4). PsychoMorph was then used to provide an average color value within each ROI patch, and this value (ranging from 0-255) can be converted back into an average temperature value using the formula:

$$20 + 20 * \frac{patch\ color\ value}{255}$$

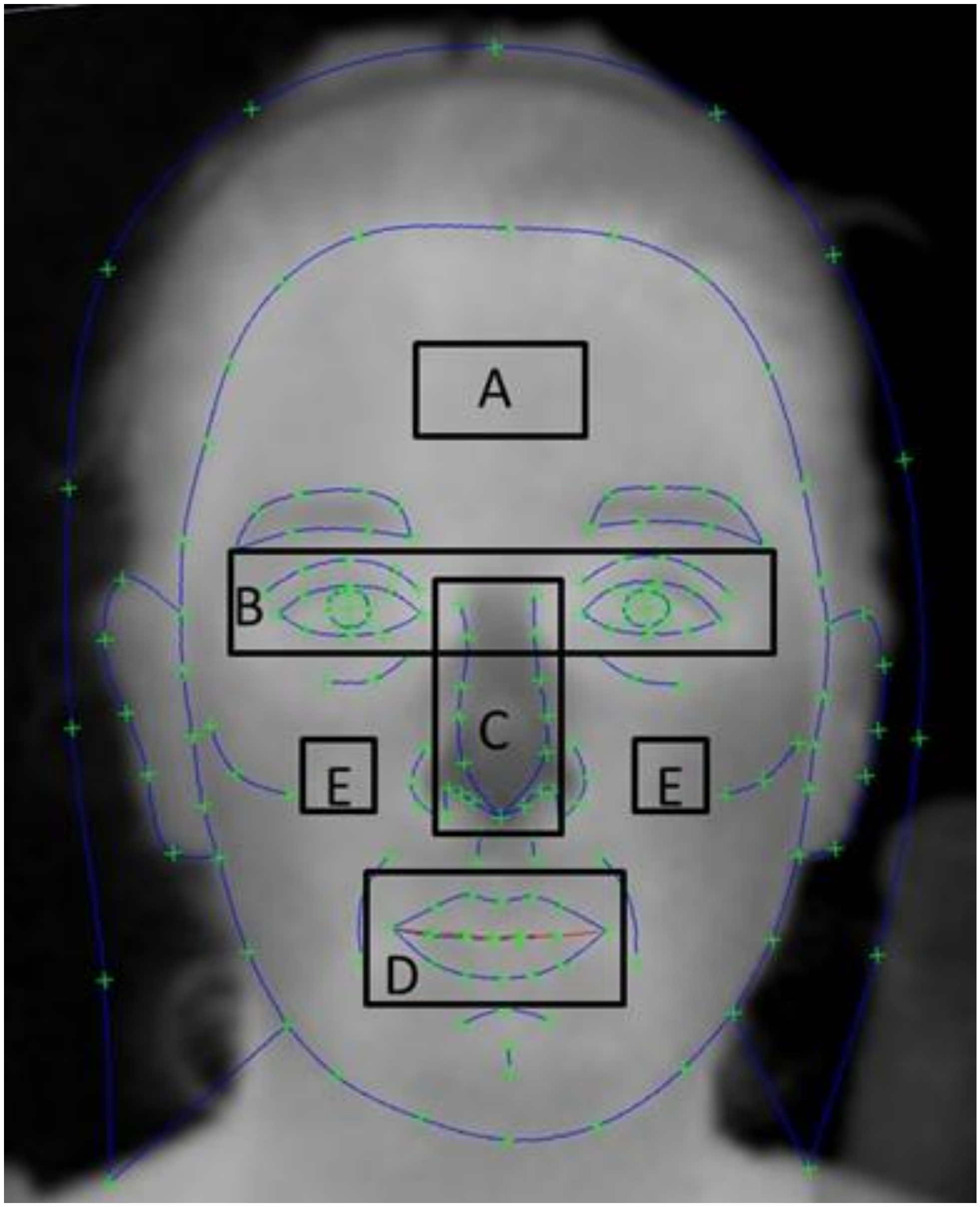

Figure 4. Regions of Interest: Area A – forehead, Area B – periorbital region, Area C – nasal region, Area D – perioral region, Area E – average of the left and right cheeks

Design and Analyses

This study used a within-participant design. Thermal images were collected from each participant throughout the stressor (i.e., the TSST). For each participant a pre-stress and post-stress image were selected for analysis; these images reflect an image captured before the TSST began and an image captured after the TSST concluded, respectively. Visual inspection of each image was performed to ensure consistency with respect to the mouth and eyes being open or closed – images were replaced with the next available image if the eyes were not open and/or the mouth was not closed as these changes could artificially influence the thermal data. Data analysis was done using the program R.

Analysis 1 (Reported stress). To confirm that participants actually experienced increases in stress during the TSST, a repeated measures ANOVA was run on the continuously reported slider data using time as a within-subject factor (2-levels: pre-stress task, post-stress task).

Analysis 2 (Skin temperature during stressor). As my primary analysis, a 2x5 repeated measures ANOVA was conducted, with time (2-levels: pre-stress task, post-stress task) and ROI (5 levels: forehead, periorbital, nasal, perioral, cheek) serving as within-subject factors. The pre-stress image provided the baseline temperature for each participant, while the post-stress image depicted the temperature changes during a stress response. This analysis determined where temperature changes occurred in the face during the experience of psychosocial stress. Since a significant time x ROI interaction exists, I ran post-hoc t-tests (correcting for multiple comparisons) to determine which ROIs showed significant changes in skin temperature.

Analysis 3 (Correlation of perceived stress and ROI temperature). Lastly, correlations were run between the average temperature change of each ROI (post-stressor temperature minus pre-stressor temperature) and each participant's overall experience of stress (calculated from their self-reported stress levels, post-stress slider value minus pre-stress slider value) to illustrate the connection between perceived stress and temperature change in the different ROIs.

Hypotheses

Hypothesis 1. I expect to find a main effect of time in the continuous slider data (analysis 1 above), such that reported stress levels are higher post-test compared to pre-test. This result would confirm that the TSST caused the expected increase in participants' stress levels.

Hypothesis 2. This study is largely exploratory in nature given the relatively novel application of thermography to detect and possibly differentiate emotional responses. Based on past research however, we predict the following pattern of results for our ROIs (reflected in a significant interaction between time and ROI in Analysis 2)**.**

Forehead. While some studies have suggested that the forehead generally holds a stable temperature during the experience of emotional arousal (Calvin & Duffy, 2007; Stoll, 1964), Puri et al. (2005) have previously reported a significant increase in this ROI during the experience of stress or frustration in a sample of men. As such, we predict a similar increase in our female sample.

Periorbital. Previous studies have reported an increase in temperature in the periorbital regions (Pavlidis, 2002; Shastri, et al., 2009), so we expect to also observe an increase in the periorbital region.

Nasal. Previous research has demonstrated a decrease in nasal temperature following stress in infants and children (Ioannou et al., 2013; Nozawa et al., 2009) and adults (Engert et al., 2014; Hong et al., 2016). Therefore, we predict a decrease in nasal temperature following this psychosocial stressor.

Perioral. Merla & Romani (2007) previously reported a decrease in perioral temperature in men after performance of a mentally taxing activity (the Stroop task), suggesting that we may also observe a decrease in perioral temperature in our female sample.

Cheek. Previous studies using stressful experimental tasks have not reported changes in cheek temperatures. Therefore, we do not expect to observe a significant thermal change in this ROI.

This study will add to the current body of growing publications that address the use of thermal infrared cameras to measure emotional responses as a non-contact and non-invasive measurement technique.

Hypothesis 3. Although no previous studies have investigated individual differences in thermal responses during emotional arousal, I would predict that the thermal changes would be largest in those participants who report greater levels of self-perceived stress (based on their slider reporting). Given that the subjective experience of stress triggers activation of the stress response (including ANS activation and HPA activation), I predict a positive correlation between change in temperature and change in stress such that participants who reported feeling greater levels of stress during the task will show the largest thermal changes.

Results

Reported Stress

In order to confirm that the participants did perceive heightened feelings of stress during the stressor task, a repeated measures ANOVA was run on the reported slider data with time as a within-subject factor with 2 levels (pre and post stressor). This analysis revealed a significant effect of time ($F(1, 26) = 114.8$, $p < .001$, $\eta_p^2 = .687$). The reported perceived stress rose significantly from pre-stressor ($M = 1.18$, $SD = 0.257$) to post-stressor ($M = 3.7$, $SD = 1.2$) (see Figure 5).

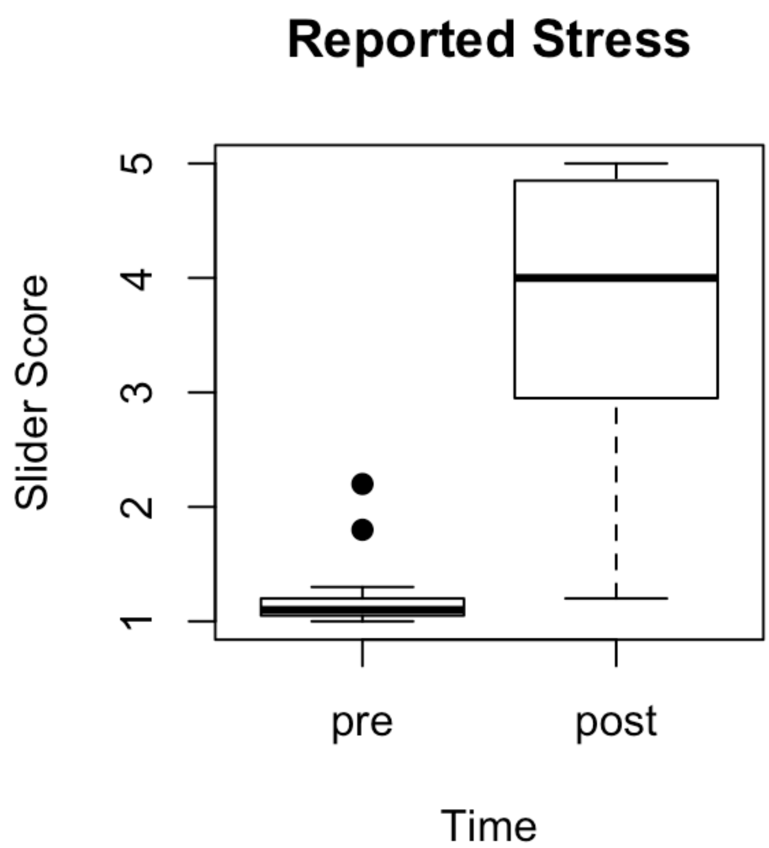

Figure 5. Box plots for self-reported perceived stress pre and post TSST

Skin Temperature During Stressor

To analyze the temperature change in the different ROIs over time, a 2x5 repeated measures ANOVA was used with time (2 levels: pre-stressor, post-stressor) and ROI (5 levels: forehead, periorbital, nasal, cheek, perioral) as within-subject factors. Greenhouse-Geiser Epsilon adjustments were used in all instances of violation of the assumptions of sphericity. This analysis did not find a significant main effect of time ($F(1, 27) = 0.665$, $p = .422$, $\eta_p^2 = .00$), demonstrating that there is not necessarily a general, widespread detectable thermal response to stress. However, the analysis did show a significant main effect for ROI ($F(4, 108) = 46.21$, $p < .001$, $\eta_p^2 = .43$) and this main effect was qualified by a significant interaction for ROI and time ($F(4, 108) = 21.29$, $p < .001$, $\eta_p^2 = .02$). This interaction demonstrates that a significant thermal response to the experience of a stressor is apparent in some facial ROIs. To investigate this interaction between ROI and time, post-hoc t-tests were run on each of the five different ROIs.

Bonferroni-corrected pairwise comparisons showed a significant temperature increase over time for the forehead ($t(27) = -3.14$, $p = .004$, $d = 0.59$) and the cheeks ($t(27) = -2.93$, $p < .05$, $d = 0.55$), and a decrease in the perioral region ($t(27) = 8.8$, $p < .001$, $d = 1.66$). As shown in Figure 6, the mouth (i.e, perioral) showed the greatest decrease in temperature ($M_{difference} = -1.87$, $SD_{difference} = 1.22$), while the cheeks showed the greatest increase in temperature ($M_{difference} = 0.58$, $SD_{difference} = 1.00$), followed by the forehead ($M_{difference} = 0.31$, $SD_{difference} = 0.48$). No significant changes were observed in the periorbital region ($t(27) = -1.53$, $p = .14$, $d = 0.29$, $M_{difference} =$

0.16, $SD_{difference}$ = 0.47) or nasal regions ($t(27) = -0.65$, $p = .52$, $d = 0.12$, $M_{difference}$ = 0.34, $SD_{difference}$ = 2.07).

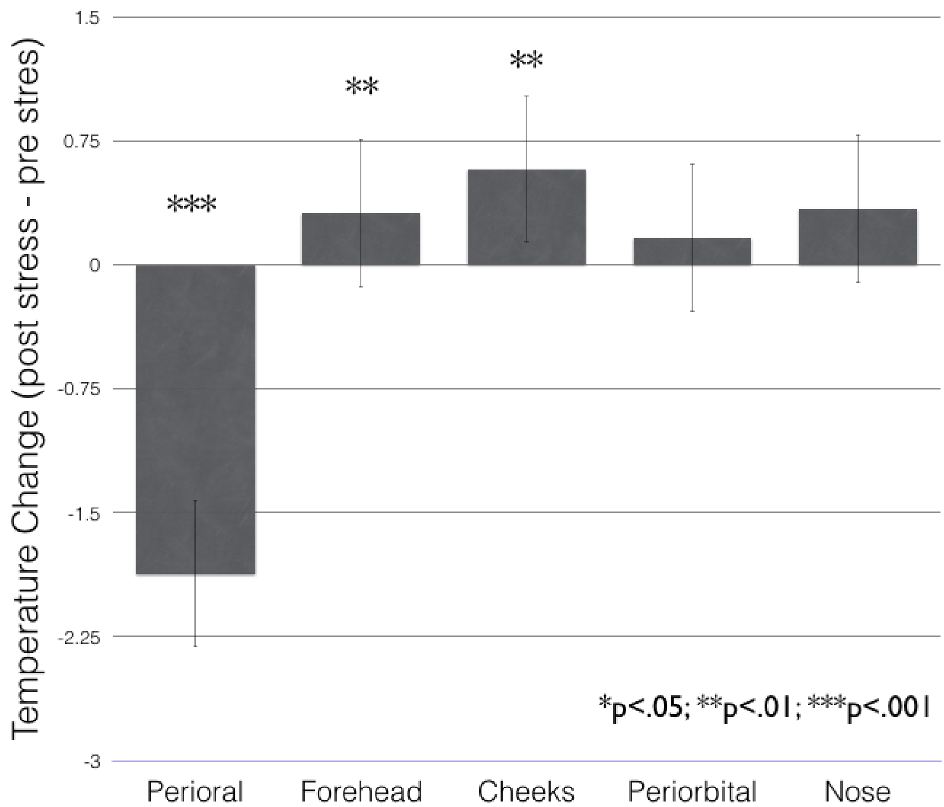

Figure 6. Bar graph illustrating the mean temperature change in each ROI following the experience of a stressor. Error bars represent standard deviation.

Correlation of Perceived Stress and ROI Temperature

For the final analysis, correlations were run between the change in stress from pre to post stressor and the mean temperature change of each ROI in order to assess whether participants who found the TSST most stress inducing also showed the biggest thermal response.

The only significant correlation was found in the perioral region (r = -.49, p < .001). A significant decrease in temperature in the perioral region was observed in Analysis 2. This analysis further supports that by showing the largest temperature change in the mouth by those who reported feeling the most stressed by the task. Although both show a positive relationship, as would be predicted, no significant correlation was found between the magnitude of the temperature change and the level of stress reported for the forehead (r = .21, p = .13) or the cheeks (r = .12, p = .45). Additionally, there was no significant correlation between temperature change and reported stress level for the periorbital (r = .16, p = .26) or nasal regions (r = .11, p = .44), however there was little reason to expect a relationship for either of these ROIs given that no significant change in temperature over time was observed for these ROIs in analysis 2. Together these results provide equivocal support for the hypothesis that those women who reported the greatest experience of stress would show the greatest thermal response.

Discussion

This study looked at skin temperature during a stressful task using functional infrared thermal imaging (fITI) to assess whether changes in skin temperature occurred, where in the 5 regions of interest on the face they occurred (forehead, periorbital, nasal, perioral, and average of the left and right cheeks), and whether the intensity of the stress experience related to the observed temperature changes. Data from the perceived stress sliding scale, which was assessed as a continual self-report measure, demonstrated that the participants did report increased levels of stress during the stressor task. As they performed the arithmetic portion of the Trier Social Stress Test, participants reported a significant increase in stress. This supports our first hypothesis, in which we expected to find a main effect of time in the continuous slider data, showing that the participants reported feeling increased levels of stress from the task. This finding is in line with previous studies (Allen, et al., 2014; Dickerson & Kemeny, 2004) using the TSST to induce stress in the laboratory.

Temperature changes in the different regions of the face were then evaluated, and significant changes in response to stress were found in the forehead, perioral, and cheek regions were found. The participants showed a significant temperature increase in the forehead and cheek regions, and a significant decrease in the perioral region. There was no significant change of temperature in the nasal or periorbital regions. These findings provide some support for our main hypothesis (H2), but are not completely in line with our predicted results, highlighting the need for further research identifying thermal signatures for various affective states before this technology can be utilized in a practical setting.

In line with our predictions, we found a significant increase in forehead temperature and a significant decrease in the perioral region. These findings are consistent with previous research on adult samples using the Stroop task to induce stress. Using the Stroop task, Merla and Romani (2007) found that stress increased facial sweating, which could have contributed to their observed temperature decrease in the mouth in male participants. When physiological or emotionally strained, our body responds with a galvanic skin response, increasing sweating in regions including the face. One of the functions of sweating is to cool the body, so increased sweating while stressed may explain some of the observed temperature decreases. While our results for the perioral region are in line with our prediction based on Merla and Romani's (2007) finding, it is worth noting that other studies have observed a significant increase in the perioral region (Shastri et al., 2009) using a different mental stressor task. Discrepancies in findings for the perioral region across studies could be particularly susceptible to image selection as breathing could impact observed temperature, depending on the size and location of the ROI specified for extraction. Although the images were chosen meticulously to avoid error, if a participant's mouth was slightly open or pursed more than the others, this could have decreased the recorded temperature. Also, the participants were required to speak during the stressor task, which could have also affected the data.

Puri and colleagues (2005) also found a significant increase in the forehead ROI when observing thermal reactions of stressed participants, again using the Stroop task. However, Mizukami et al. (1987; 1990) found a significant temperature decrease in infant's forehead regions when stressed. Notably, our results are consistent with previous studies on adults (Puri et al., 2005) but not previous studies on infants (Mizukami et al., 1987; 1990), suggesting there could be age-related differences in thermoregulatory responses to stress. Future research is needed to explore this potential explanation. It is also possible that methodological differences could explain this pattern of results, given that adult samples are traditionally stressed via a mental or physiological task whereas infant samples are stressed by maternal separation, which could induce a variety of emotional responses. Because it is not possible to have explicit confirmation of emotions experienced with an infant sample in the way that it is for adults, these findings for infants should perhaps be interpreted more cautiously than the findings for adult samples. Notably, our findings extend this previous work on adults to include female participants, suggesting that the forehead region's thermal responses to stress may be consistent across the general adult population.

While our predictions for the forehead and perioral region were supported, our predictions for the cheeks, periorbital, and nasal regions were not. We had not predicted a change in temperature in the cheeks due to the fact that previous research has not reported a change in this region in response to stress. Previous research investigating other affective states, however, has reported thermal changes in the cheeks. Shearn (1990) reported significant increases in cheek temperature during the experience of embarrassment whereas Levine et al (2001) and Pavlidis et al. (2000) reported significant temperature decreases in this region during the experience of fear. Given that our participants experience a psychosocial stressor, that involved performing mental arithmetic in front of the experimenters, it is possible that the observed increase in cheek temperature reflects feelings of embarrassment at poor performance on the task. This highlights the importance of further developing our understanding of the differential (or potentially not) thermal signatures for various affective states – can this technology accurately differentiate between various emotional states?

The hypothesized significant increase in temperature in the periorbital region was not observed. Previous research has demonstrated significant temperature increases in this region (Pavlidis, 2002), and the researchers have argued that increased blood flow to periorbital region relates to fight or flight type responses. While it is still possible that increased blood flow to the periorbital region does help the body engage in fight or flight responses, our data suggest that the psychosocial stress experienced as a result of the TSST may not be significant enough to trigger such an intense fight or flight response. One additional possibility for this difference could be the all-female sample in this study, compared to the mixed sex sample used by Pavlidis et al (2002). Estrogen levels have been linked to vasodilation (Mendelsohn & Karas, 1994), suggesting that underlying endocrinological factors may interact with changes in blood flow and sudomotor responses. Future studies should implement additional between-group comparisons to further clarify this discrepancy in findings across studies.

The hypothesized decrease in temperature in the nasal region was also not observed in this study. This finding is surprising since nasal temperature decreases have been observed relatively consistently across previous thermal studies (Engert, et al., 2014; Merla & Romani, 2007; Nozawa, 2007; Pavlidis, et al., 2012). When comparing all the images, there was a large amount of variation in temperature in this region (SD = 2.07, almost double the SD for any other ROI). The nasal region is another ROI that is particularly susceptible to breathing effects on temperature. Although some of the participants showed the hypothesized decrease in nasal temperature, the widely distributed range of temperature changes observed prevented this change from reaching statistical significance. Future studies could acquire a larger sample size in order to correct for these individual variations in facial temperature.

The final analysis (Analysis 3) found some evidence that these temperature changes were greatest in those who reported the most stress from the task. Women who reported a greater experience of stress during the task also showed the largest temperature decreases in the perioral region. However, the magnitude of their stress experience did not correlate with temperature changes in the forehead or cheek areas. Although not all of the correlations were strong, our third hypothesis was still supported to some degree. This is the first study to explore individual differences in thermal responses to an induced affective state. Previous work investigating the cortisol response to stress has also demonstrated that the magnitude of the cortisol response to the TSST was unrelated to participants' self-reported stress levels (Kirschbaum et al., 1995). Further research is needed to better develop our understanding of the subjective experience of an emotional state interacts with these physiological responses.

Although the temperature changes observed in this study do not completely map onto those observed in past research, they still may reflect what we would expect from activation of the sympathetic nervous system due to the stressful activity. Vasoconstriction during stress brings blood away from some regions, like the nose, which explains some of the temperature decrease observed in the perioral region. However, the vasodilation that also occurs during the sympathetic response brings blood toward other regions, such as the cheeks or forehead. This helps to explain the differences in temperature observed in the separate regions during various expressions of emotions.

Variation in the findings across studies could also be due to the different tasks being implemented to induce stress. Previous research has used a variety of stressor techniques, including the Stroop test (Merla & Romani, 2007; Puri, 2005), social and physical isolation (Mizukami, et al., 1987; 1990), lying (Pavlidis et al., 2002) and other mental tasks (Shastri et al., 2009).

Although this study attempted to induce and measure stress, there is also a possibility that the participants felt other emotions, such as embarrassment or fear. This would alter their thermal response, and may have led to the differences in thermal signatures in this study. The increased arousal from the stressor task could also be the case for the temperature increase observed in the cheeks. In addition, embarrassment could have occurred for some participants, especially if they answered incorrectly during the stressor task. This would have increased the blood flow to the cheeks, further increasing the temperature in this region. Variations in temperature changes due to a combination of emotions can be controlled for by inquiring which emotions the participants were feeling using a post-condition questionnaire. Randomizing the order in which the participants performed the stress condition, sexual arousal condition, and embarrassment condition was implemented to avoid order effects. Also, the rest period incorporated between each condition to ensure that the participants' body temperature returned to baseline allowed for independent analyses of the various affective conditions. After examining the effect of the self-report scores assessed from the post-condition questionnaire (using linear regression), embarrassment was not a significant predictor of temperature change in any of the 3 ROIs that demonstrated a significant temperature change during the task. However, the self-report stress scores from the post-condition questionnaire were not significant either, so these post-test assessments may not provide accurate depictions of emotions after the task is completed since the participants reported a significant increase in stress during the task using the self-report sliding scale.

When comparing this study to others, the most salient difference is the lack of observed decrease in nasal temperature in this study. This decrease in nasal temperature during stress has been reported in several previous studies (Merla & Romani, 2007; Pavlidis, et al., 2012; Shastri, et al., 2009). This oddity could have been due to outliers; some participants may have exhibited hotter thermal signatures overall, despite the acclimation period, thus pulling this average up past the significant point. Also, as mentioned previously, these other studies used mixed gender or male-only samples. This study used strictly female participants, which could explain some of the variation in results. Future studies should further investigate the similarities and differences in facial temperatures between genders while stressed.

A possible limitation of this research could be the selection of the images for analysis. While selecting the pre- and post-stressor images for analysis, we attempted to choose images that were the most similar. Even though the face mapping controls for movement and lip opening, some minor differences in pre and post images could have influenced the analysis of the thermal signatures. For example, if a participant's lips were more pursed in one photo than the other, this could have influenced the thermal data. This can perhaps be controlled for in the future by developing more stringent data collection protocols that prohibit participant movement. However, if thermal imaging is to be used in any sort of practical setting, it must be robust to these types of normal movements. In regards to the decrease in perioral temperature specifically, breathing rate is a potential confound. When inhaling, a decrease in temperature may be observed due to the intake of oxygen, whereas an increase in temperature may be observed during exhalation. Using a stressor task that does not involve speaking may help reduce this potential source of error, however participants will always need to breathe and the measurements taken from the perioral and nasal region will, therefore, always have this inherent source of noise in the data. Future work may consider taking the average of several images collected at each time period to help create a more accurate composite measure of skin temperature in these regions.

Future directions for this research should involve continuing observation of different emotions using fITI in order to establish whether different emotions elicit significantly differentiated thermal signatures. Importantly, however, these various affective states should be measured and analysed in the same individuals under the same experimental parameters to allow for more accurate assessment of this technology as a tool for differentiating between various affective states. As mentioned, some emotions may display similar thermal signatures, making it difficult to differentiate between certain emotions. More research is needed to establish whether there are significant changes at each region of interest when observing different emotions with a thermal camera, and whether these changes are different enough when comparing different emotions to be able to accurately document what the participant is feeling. Furthermore, this study showed that significant changes might show up in unexpected areas when observing different populations. These female participants showed a very significant decrease in temperature in the perioral region during the stressor, while an increase in temperature in this region has been frequently reported in past research (Engert, et al., 2014; Merla & Romani, 2007). Other emotions, such as anxiety, fear, and embarrassment should be controlled for in future fITI stress research as well, which was attempted for using the post-condition questionnaire in this study. Lastly, future studies could analyze the pre-stressor and during-stressor images to determine whether analysis of post-stress or during-stress images provide the most accurate depiction of the stress response. Although we expected post-stress images to still be elevated in temperature, during-stressor images may provide a more accurate thermal reading for analysis.

Regarding real-world applications of thermal infrared cameras, we agree with other thermal authors that more research needs to be done in order to establish a reliable level of validity for this technique to be applicable. Because there is still some debate as to whether or not all emotions can be differentiated between using these cameras, it is not suggested that they be used in places such as airports. The proposed idea of using thermal infrared cameras in airports to measure traveller's levels of stress and anxiety can pose many issues. Many times, people are running late for their flights and will be showing the telltale signs of being extremely stressed or anxious. However, thermal cameras cannot tell why someone is stressed, so this information could be misconceived in an incorrect manner. When running late to a flight, the last thing someone needs is to be stopped by TSA to be questioned because of his or her thermal signature. For these reasons, use of this technology in airports and other real-world scenarios has been cautioned against.

This study highlights the importance of the continuation of research regarding the use of thermal infrared cameras to study emotions. This measurement technique has the potential to be a non-invasive, non-contact, and relatively inexpensive way to measure emotions. However, more research needs to be done on differentiating between the significant temperature changes at the separate regions during different elicited emotions. Since this is still being established, it can make it difficult to assess which specific emotion a participant is showing. Greater validity needs to be established before fITI should be used as a sole measurement technique when observing and measuring emotions. Also, more research is needed before real-world applications such as use in airports can be approved. As Shastri and colleagues (2009) stated, "the presence of multiple contributing thermal factors (e.g., blood flow, sweat gland activation, and breathing), as well as significant noise from tracking and segmentation imperfections renders modeling of the raw facial signals hard". The necessity for continued research in this field allows future researchers to expand on these past studies, develop better protocols for the use of fITI in emotion research, and may further the opportunities for this technique in and possibly even out of the laboratory.

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Appendix A

University of St Andrews Teaching and Research Ethics Committee Approval

University of St Andrews

University Teaching and Research Ethics Committee

11 October 2011

Ethics Reference No: *Please quote this ref on all correspondence*	PS8001
Project Title:	Detectability of Thermal Signatures to Various States of Arousal
Researchers Names:	Amanda Hahn, Marion Albrecht, Carmen Lefèvre, Ross Whitehead
Supervisor:	Professor David Perrett

Thank you for submitting your application which was considered at the Psychology School Ethics Committee meeting on the 5th October 2011. The following documents were reviewed:

1. Ethical Application Form 10/10/2011
2. Advertisement 10/10/2011
3. Participant Information Sheet 10/10/2011
4. Consent Form 10/10/2011
5. Debriefing Form 10/10/2011
6. Questionnaires 10/10/2011

The University Teaching and Research Ethics Committee (UTREC) approves this study from an ethical point of view. Please note that where approval is given by a School Ethics Committee that committee is part of UTREC and is delegated to act for UTREC.

Approval is given for three years. Projects, which have not commenced within two years of original approval, must be re-submitted to your School Ethics Committee.

You must inform your School Ethics Committee when the research has been completed. If you are unable to complete your research within the 3 three year validation period, you will be required to write to your School Ethics Committee and to UTREC (where approval was given by UTREC) to request an extension or you will need to re-apply.

Any serious adverse events or significant change which occurs in connection with this study and/or which may alter its ethical consideration, must be reported immediately to the School Ethics Committee, and an Ethical Amendment Form submitted where appropriate.

Approval is given on the understanding that the 'Guidelines for Ethical Research Practice' (http://www.st-andrews.ac.uk/media/UTRECguidelines%20Feb%2008.pdf) are adhered to.

Yours sincerely

pp Convenor of the School Ethics Committee

Ccs Prof. D. Perrett (Supervisor)
School Ethics Committee

UTREC Convenor, Mansefield, 3 St Mary's Place, St Andrews, KY16 9UY
Email: utrec@st-andrews.ac.uk Tel: 01334 462866

Appendix B

Participant Informed Consent Form

Participant Information Sheet

Project Title
Detectability of Thermal Signatures to Various States of Arousal

What is the study about?

We invite you to participate in part 1 of a research project that will (1) measure changes in skin colour and temperature during various types of arousal, and (2) determine if these changes are visible. During part 1, we will be collecting thermal images and regular photographs of individuals during various states of arousal in order to empirically track skin colour and temperature changes in the face and neck. During part 2, the data we collect here will be used to determine if these changes are visible to observers.

This study is being conducted as part of Amanda Hahn, Carmen Lefevre and Ross Whitehead's PhD Theses, and Marion Albrecht's Honours Degree in the Department of Psychology of the University of St Andrews.

Do I have to take Part?

This information sheet has been written to help you decide if you would like to take part. It is up to you, and you alone, whether or not to take part. If you do decide to take part you will be free to withdraw from the study or any specific part of the study at any time without providing a reason.

What would I be required to do?

The experiment will take place over 5 individual blocks. Each block will involve either skin colour measurements or an arousal state as follows:

(1) Skin Colour Measurements – This is done using a simple, non-invasive technique. We simply place a light-capture device on your skin at various locations which provides us an accurate reading of the specific colour of your skin.
(2) Baseline – We will have you relax for 10 minutes while listening to music to ensure that you are in a calm, baseline state. We will then take a series of test photos of you to ensure that all camera equipment is properly aligned. These baseline images will be used for comparison against images taken in the experimental blocks to determine if temperature or colour changes have occurred.
(3) Pressure/Stress – During this block, you will be asked to perform a verbal maths task while being observed. If you are uncomfortable with this condition, you are free to withdraw from the study or decline participation in this block.
(4) Arousal – During this block, you will view a love scene video clip. This clip is sexual in nature, and will show two individuals engaging in a romantic encounter. The clip has been taken from a movie rated 18 (Rated-R on the US rating scale) and will show female breasts, but no other explicit body parts. Note, this is ***not*** a pornographic video clip; it is a simulated sex scene between actors. The experimenters will not be present in the room while you are viewing the video clip. If, for any reason, you feel uncomfortable about watching this clip or would rather not participate in this block, you are free to ask the experimenter to skip this condition ***without penalty***. You are also free to withdraw from the entire experiment at any point in time.
(5) Social Scenario – During this block, you will be asked to sing while being recorded on a video camera. You will then watch the playback of your video. The recording will be deleted after you finish the block and will not be used for any future part of the study, or shown to others. If you are uncomfortable with this task, you are free to decline participation.

After each block, you will complete a brief questionnaire detailing how you felt during the experiment. Overall, the study should last approximately 90 minutes.

Part of our research involves taking photographic images and videos. These images and recordings will be kept secure and stored anonymously with no identifying factors i.e. consent forms and questionnaires.

Photographs and recorded data can be valuable resources for future studies therefore we ask for your additional consent to maintain data and images for this purpose.

I agree to have my photo taken and to being videoed	☐ Yes	☐ No
I agree for my photo material to be published as part of this research	☐ Yes	☐ No
I agree for my photos to be used in future studies	☐ Yes	☐ No
I agree for my skin colour to be measured	☐ Yes	☐ No
I agree to have thermal images taken	☐ Yes	☐ No

Participation in this research is completely voluntary and your consent is required before you can participate in this research. If you decide at a later date that data should be destroyed we will honour your request in writing.

Name in Block Capitals ____

Signature ____

Date ____

Appendix C

Humboldt State University IRB Approval

HUMBOLDT STATE UNIVERSITY
Institutional Review Board for the Protection of Human Subjects

707-826-5165 | irb@humboldt.edu | www.humboldt.edu/human_subjects

MEMORANDUM

Date: **4/5/2018**

To: **Amanda C Hahn**
Julia Kandus

From:
Institutional Review Board for the Protection of Human Subjects

IRB #: **IRB 17-192**

Subject: **Measuring Stress Using Thermography**

Thank you for submitting your application to the Committee for the Protection of Human Subjects in Research. After reviewing your proposal I have determined that your research can be categorized as Exempt by Federal Regulation 45 CFR 46.101 (b) because of the following:

Your research will involve the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, and the sources are publicly available or the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

The Exempt designation of this proposal will expire on **4/4/2019**. By Federal Regulations, all research related to this protocol must stop on the expiration date and the IRB cannot extend a protocol that is past the expiration date. In order to prevent any interruption in your research, please submit a renewal application in time for the IRB to process, review, and extend the Exempt designation (at least one month).

Important Notes:

- Any alterations to your research plan must be reviewed and designated as Exempt by the IRB prior to implementation.
  - Change to survey questions
  - Number of subjects
  - Location of data collection,
  - Any other pertinent information
- If Exempt designation is not extended prior to the expiration date, investigators must stop all research related to this proposal.
- Any adverse events or unanticipated problems involving risks to subjects or others must be reported immediately to the IRB (irb@humboldt.edu).

cc: Faculty Adviser (if applicable)
Institutional Review Board for the Protection of Human Subjects

The California State University

Bakersfield • Channel Islands • Chico • Dominguez Hills • East Bay • Fresno • Fullerton • Humboldt • Long Beach • Los Angeles • Maritime Academy • Monterey Bay • Northridge • Pomona •Sacramento • San Bernardino • San Diego • San Francisco • San Jose • San Luis Obispo • San Marcos • Sonoma • Stanislaus

Appendix D

Post-Condition Questionnaire

Post-Condition Questionnaire

Please circle the appropriate response to the following statements below in terms of how you felt during the last block of the experiment:

(1) How **EXCITED** did you feel?

Not At All				Extremely
1	2	3	4	5

(2) How **EMBARRASSED** were you during the task?

Not At All				Extremely
1	2	3	4	5

(3) How **UNCOMFORTABLE** did you feel?

Not At All				Extremely
1	2	3	4	5

(4) How **STRESSED** were you?

Not At All				Extremely
1	2	3	4	5

(5) How **SEXUALLY AROUSED** did you feel?

Not At All				Extremely
1	2	3	4	5

(6) Overall, how **STIMULATED** did you feel during this part of the experiment?

Not At All				Extremely
1	2	3	4	5

(7) Did you remember to use the slider to report arousal during the task?

YES NO ONLY PART OF THE TIME

(8) Please place an **X** on the line below corresponding to how accurate you think your self-reported arousal was when using the slider:

0% -- 50% -- 100%

Do you have any other comments about the task?

____

____