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Understanding and Designing Thermal Experiences

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ABSTRACT

This PhD explores the potential of leveraging the unique qualities of temperature experiences in the design of tactile and thermal interfaces. Thermal stimuli can evoke various emotions and sensations, from relaxation or nostalgia to feelings of vitality. The research examines the design space of temperature-related experiences, driven by the growing body of literature in multi-sensory technologies and thermal feedback. While temperature feedback has shown promise in enhancing virtual immersion or interpersonal communication, the focus has primarily been on technological aspects, leaving experiential and aesthetic dimensions largely unexplored. This paper highlights the need for a more nuanced understanding of temperature experiences to inform future design and enhance the richness of thermal interfaces in various applications.

CCS CONCEPTS

• **Human-centered computing** → *Empirical studies in interaction design.*

KEYWORDS

thermal experience, design, tacit knowledge, embodiment, heat, sauna

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1 MOTIVATION

Sitting by a cozy fireplace on a chilly evening can evoke a sense of relaxation, contentment, and nostalgia. The warmth from the fire can create a calming atmosphere that may encourage social interaction and a feeling of togetherness. Jumping into cold water after a sauna can be exhilarating and promote a sense of adventure and vitality. But how can we make use of these distinct experiential qualities of temperatures in the design of tactile and thermal interfaces?

With the proliferation of multi-sensory technologies like smell and taste interfaces, there is a growing interest in the research and design of temperature-related experiences, as demonstrated by the expanding body of literature [1]. Thermal feedback has shown promise in enhancing the immersion of virtual environments by eliciting tactile sensations through temperature variations [6, 17]. Additionally, temperature stimuli have been explored for purposes such as conveying emotional content, providing notifications, and guiding awareness [5, 10, 13, 14, 16, 21, 22].

However, the predominant focus in temperature-related studies within the domain of Human-Computer Interaction (HCI) has revolved around the technological aspects of generating thermal feedback. Only a limited number of studies have delved into the experiential or aesthetic facets of temperatures that extend beyond the basic sensations of hot and cold [10, 13, 19, 21]. The sensory experience of temperatures holds the potential for a plethora of dimensions, such as richness, emotional impact, and captivation [8]. Nonetheless, these experiential qualities of thermal feedback, as underscored by Jonsson et al. [10], remain largely unexplored due to their intricacy and subjectivity. One of the key reasons for this research gap is the challenge associated with expressing and articulating thermal sensations beyond simplistic hot-cold descriptions, which poses a hurdle for designers in terms of creating, conveying, and assessing thermal content. Similar challenges and a lack of experiential vocabulary have been observed in the haptic design of vibrotactile, ultrahaptic feedback, and electromagnetic stimulation [3, 11, 15].

2 BACKGROUND

The concept of "thermal expression," as introduced by Lee and Lim [13], represents a pivotal development in the understanding of thermal sensations in interactive systems, particularly with regard to controlling heat's impact on interpersonal communication. They emphasized the design opportunities and emotional significance of heat as a means of communication and introduced four key parameters for thermal expression control: temperature, duration, temperature change rate, and location. Their prior work also explored various characteristics, values, and potential applications of thermal expression for designers [12].

Tewell and colleagues [19] delved into the emotional aspects of thermal feedback, particularly examining factors like valence and arousal in conjunction with text messages. Their findings underscored the ability of temperature to evoke arousal, suggesting the potential of using thermal feedback to enhance text-based communication. El Ali et al. [5] echoed these findings, demonstrating that thermal feedback can modulate arousal and, in turn, influence the valence of incoming text messages. In contrast, Salminen et al. [18] reported an increase in arousal and dominance associated with warm temperatures but observed no significant changes in valence ratings. Halvey and colleagues [7] examined the role of ambient temperature and humidity on the perception of thermal feedback and found that particularly ambient temperature has a significant effect on the detection and perception of thermal stimuli.

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Furthermore, Wilson et al. [21] introduced the idea that warm feedback, experienced on the palm, can be linked to more abstract concepts such as presence, activity, and quality, while cool stimuli are associated with absence and poor quality. Jonsson and colleagues [10] contributed to the understanding of thermal qualities by formulating experiential dimensions related to internal felt experiences, subjectivity, subtlety, and material characteristics, particularly focusing on the inherent material attachment, slowness, and heat transfer between two bodies. Their comprehensive approach considered multiple regions of the body, stimulating the shoulders, hips, and calf regions on the back side, in contrast to other studies that primarily concentrated on isolated spots like the palm [18, 21], wrist [13], and arm [19].

3 RESEARCH OBJECTIVES AND METHODS

Firstly, I am approaching the research of thermal experiences from a phenomenological perspective by studying in-depth how individuals experience and express natural heat experiences across the entire body (RQ1). Since I am based in Finland and traditional Finnish sauna is a significant cultural space of temperatures, I invited ten individuals to sauna and interviewed them about their heat experiences. In this first paper, that is going to be published at TEI 2024, I explain how I used three distinct modalities of expression, namely verbalizing inspired by micro-phenomenological interviews, visualizing through body maps (see Figure 1) and tactilizing through sensorial evaluation objects in order to access individuals' tacit knowledge about thermal experiences. From these findings, I was able to identify additional qualities and parameters of heat that can serve designers for creating richer thermal experiences.

Next, I will look at different technologies that can produce thermal feedback, for example, yarn-based heaters and thermoelectric devices (peltier element) and conduct psychophysical studies to investigate human thermal perception of these artificially generated temperatures (RQ2). Looking at prior research on tactile experiences, I will ask how can we make use of certain tactile illusions to design these richer thermal experiences. For instance, how can we achieve a dynamic feeling of temperature across the skin, as mentioned by participants in the previous study, with thermal feedback. Here, I will use perceptual phenomena such as the tactile apparent motion illusion as basis to find out if the same principles apply to thermal sensation (RQ3). Tactile apparent motion refers to the perception of a continuous movement tactile sensation across the skin, even though the physical stimulus is presented at separate locations in a sequence [2]. In this phenomenon, the brain interprets a series of discrete tactile stimuli as if they are part of a continuous and smooth motion, similar to how visual apparent motion occurs when a sequence of distinct images or objects is perceived as moving fluidly.

Lastly, I will take Virtual Reality as a use case of thermal experience to increase the sense of immersion and ask what are effects of other sensory modalities such as visual, auditory or olfactory feedback on thermal perception. For instance, can certain visuals, sounds or scents influence our perception of heat and cold?

- RQ1: How do people experience natural temperatures? What are qualities of heat that can inform the design of thermal experiences?
- RQ2: What are the psychophysical properties of yarn-based and thermoelectric modules?
- RQ3: How can we design richer thermal sensations by applying the principles of tactile and thermal illusions?
- RQ4: How do visual, auditory or olfactory stimuli influence thermal perception in multi-sensory virtual environments?

Embodied design [4] and soma design [9] are growing research disciplines that give increasing significance to the sensory and experiential aspects when creating interactive technologies that come into "touch" with the human body. "Lived experience is where we start from and where all must link back to, like a guiding thread" [20]. Theoretically, I position my research in neurophenomenology, coined by Francisco J. Varela as "a quest to marry modern cognitive science and a disciplined approach to human experience" (Ibid. p. 340). With my PhD research I am inquiring knowledge about subjective experience through methods inspired by somaesthethics and phenomenology and taking into account human physiological features of thermal perception through psychophysical studies.

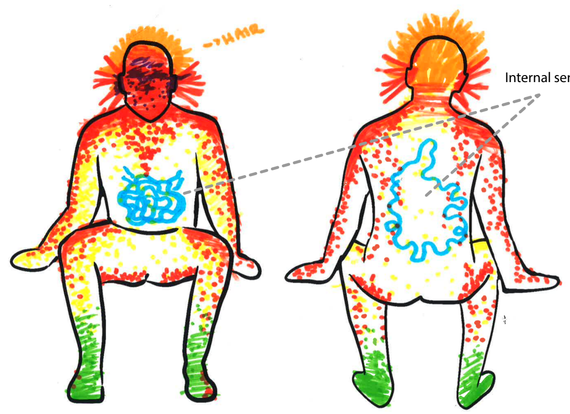

Figure 1: Visual depiction of one participants' rich thermal sensations when water is thrown onto the hot stones in Finnish sauna. Here, the participant visualized internal bodily sensations (blue) and external sensations on the skin (red, orange, yellow, and green).

4 PRELIMINARY RESULTS

My first study on natural full-body heat experience contributed to the further investigation of experiential dimensions of heat, including aspects such as the dynamic qualities of heat, the aesthetic aspects of discomfort, the nuances of texture and weight, emotional responses, and the all-encompassing nature of heat. These findings enrich our understanding of the components that constitute heat as a material for design, shedding light on its diverse potential applications. Additionally, I put forth three thermal parameters, namely motion, timbre, and distribution, which can play a pivotal role in the creation of more intricate thermal experiences (see Figure 2). These parameters not only enhance our ability to design richer thermal encounters but also lay the groundwork for further exploration in the domain of temperature interfaces.

The concept of "Motion" in temperature feedback on the skin refers to how one perceives temperature changes across time and space, generating a sense of movement across the skin's surface. This experience can manifest as a gradual transition in temperature, akin to a wave-like or flowing sensation, in contrast to a static and unchanging thermal stimulus. In the context of Virtual Reality (VR) experiences or gaming, dynamic thermal stimuli can replicate environmental conditions, such as wind or the flow of water, introducing an additional layer of realism and immersion to the virtual world.

Similar to how "timbre" in the realm of sound refers to the distinct tonal quality of different musical instruments or voices, thermal timbre can describe the unique character of temperatures. Individuals have described heat as possessing qualities like sharpness or an 'electrifying' nature, while also acknowledging its potential to exert a substantial physical force. At the same time, heat can have a soothing effect, immersing individuals in a state of bodily and mental relaxation. Thermal devices offering various timbres can be seamlessly integrated into smart home systems, enabling users to tailor their thermal experiences according to their mood or activities. For instance, a user might opt for a gentle and soothing thermal timbre at bedtime, while selecting a more invigorating one for morning wake-up routines.

"Distribution" pertains to how heat is perceived, either as a localized sensation in a specific area of the body or as a more pervasive and ambient sensation that envelops the entire body. In therapeutic settings, devices with adjustable distribution settings can be employed for targeted heat therapy. For instance, a device equipped with localized heating can be applied to specific muscle groups to alleviate pain, while a distributed heat mode can promote overall relaxation and stress reduction.

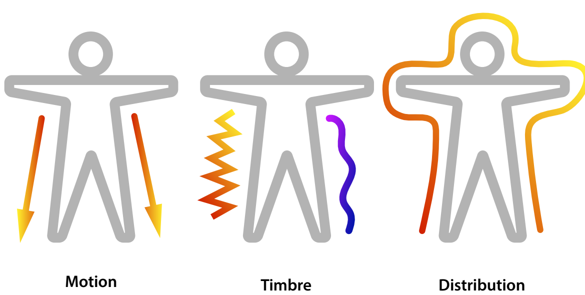

Figure 2: Additional heat parameters from first study to address RQ1

5 TIMELINE

I am currently entering the second year of my PhD program. In the first year, I conducted a study on how people experience heat in traditional Finnish saunas (RQ 1), and I am planning to present this study at the TEI 2024. Using the findings from this research, I will focus on addressing RQ 2 and RQ 3 in the second and third year by conducting psychophysical studies on how people perceive and feel heat produced by different technologies and how it relates to the perception of natural heat as explored in the first study.

In the last year, I will apply my knowledge of designing thermal experiences in the context of Virtual Reality, and will explore how different senses impact the way we feel heat (RQ 4).

Participating in the TEI 2024 graduate consortium will allow me to start building my network with other researchers in the field of tangible, embodied, and embedded interactions. It will also provide an opportunity for me to reflect on my initial study and the next ones I plan to undertake in the following years of my PhD.

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