Constructing the Thermal Affective Design Space for Emotion Regulation

An Autoethnographic Research Through Design Inquiry

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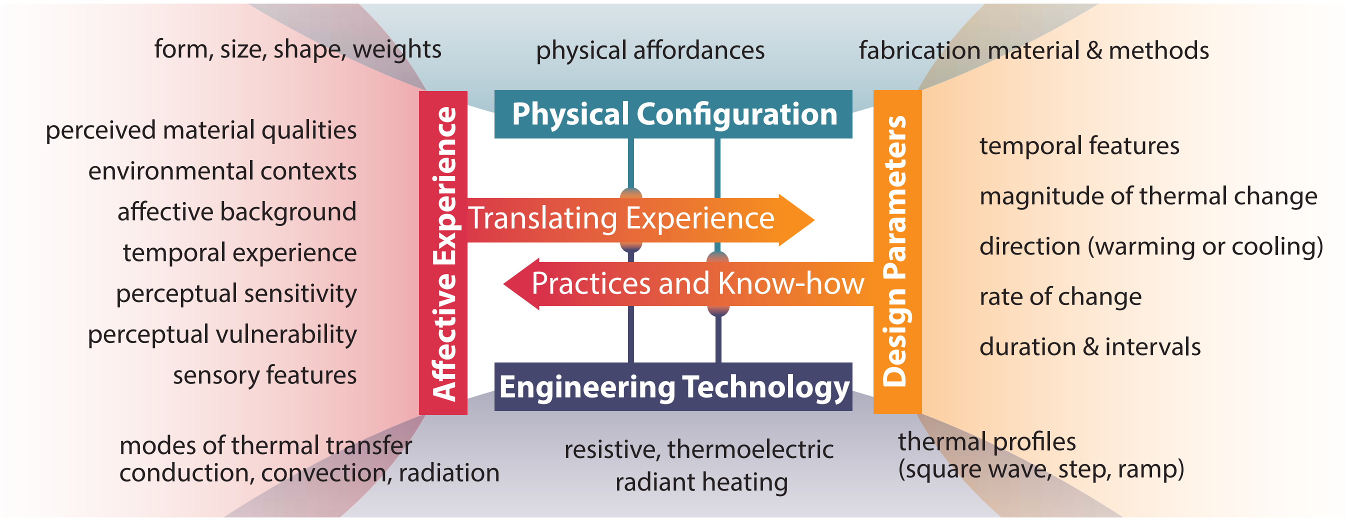

Figure 1: Our design space for thermal-affective design has four overlapping aspects: Affective Experience, Design Parameters, Engineering Technology and Physical Configuration. Full details see Figure 9.

Abstract

Temperature has strong potential to mediate emotion in a range of contexts; augmenting sensory experience and/or supporting emotion regulation. Hence, there is growing interest in leveraging thermal cues for affective technologies. At present, however, the design space for thermal technologies for emotion regulation remains underexplored and largely undefined. We construct a design space for thermal affective emotion regulation technologies, clarifying the rich, expressive nature of thermal cues as a design material. We develop this through a Research through Design (RtD) approach, grounded in an 18-month autoethnographic inquiry based on the first author's emotion regulation practice. We contribute a structured design space for thermal affective interaction, linking experience and design implementation with designerly know-how. By discussing the creation of this design space we provide insights into the generative process of developing intermediate-level knowledge from autoethnographic study and design practice.

CCS Concepts

• **Human-centered computing → HCI theory, concepts and models**; **Haptic devices**; **Interaction design theory, concepts and paradigms**; *Interaction design process and methods.*

Keywords

Thermal, Temperature, Emotion regulation, Sensory modality, Design space, Research through design, Autoethnography

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1 Introduction

Emotion regulation is a key factor in maintaining mental well-being in everyday life [60, 101, 102]. As computing systems have increasingly come to mediate personal and intimate aspects of experience, the HCI community has explored how emotion regulation can be supported by interactive technologies. One important direction has been the use of sensory modalities for affective communication and regulation. HCI researchers have explored the affective qualities of haptic [73], olfactory [9], and other sensory stimuli. Psychologists, meanwhile, have emphasised opportunities to leverage sensation in emotion regulation [92, 93], and called for empirical exploration of sensory-based emotion regulation strategies under more ecological conditions. Such work is necessary to understand how interventions integrate with other emotion regulation strategies and therapies [93], and are influenced by individual and cultural differences.

Within the design space of sensory technologies for emotion regulation, thermal stimuli occupy a compelling yet underexplored niche. Our emotional language is commonly grounded in thermal metaphor (e.g., "cold-hearted," "warm welcome") [e.g., 64], while empirical studies show associations between thermal stimuli and affective states [e.g., 3]. Existing work in this area has clarified how users interpret [81, 116] and respond to [67, 117] thermal cues, and articulated basic principles for integrating thermal cues into affective technologies [31]. However, despite promising results, thermal design for emotion regulation still faces conceptual and technical limitations. Design research often addresses temperature in a relatively simplistic way, as a binary or linear dimension (e.g., warm vs. cold), divorced from individual differences and contextual factors [31, 32, 81]. Interaction patterns are commonly limited to discrete, on/off patterns, at odds with the continuous, time-extended, and multisensory nature of everyday thermal experience [32].

Efforts to develop understandings of thermal design for emotion regulation currently face both empirical and theoretical barriers. Collecting subjective experiences of emotion regulation and sensation is difficult via conventional second- and third-person methods, since untrained participants struggle to articulate emotional and sensory experiences in adequate precision and detail [8, 90, 114]. Further, realistic experiences of emotion regulation arise from contextual and personal factors that are difficult, and often unethical, to recreate experimentally. Finally, while recent work has articulated high-level principles for conceptualising and communicating thermal experience [31, 59], we still lack a systematic design space to guide investigations of thermal cues for emotion regulation.

To address these challenges, we conduct a first-person inquiry into thermal affective design, grounded in emotion regulation experiences and practices. From this, we construct a design space for thermal affective technologies, addressing both conceptual and practical considerations, and articulating thermal cues not merely as passive signals, but as rich, affectively expressive design materials. This inquiry, combining a Research through Design (RtD) approach [124] with autoethnography, unfolded over eighteen months of affective regulation practice [1]. Over this time, the first author designed, deployed, and refined a set of thermal artefacts based on their experience and practice of affect regulation. This dual positioning — as both designer and participant — afforded a uniquely situated perspective on the lived, moment-to-moment negotiation of emotional and sensory experience, while simultaneously enabling iterative design exploration in real-world contexts.

Our work makes three contributions. First, we present a systematically constructed design space articulating the expressive and interactive potentials of thermal cues in emotion regulation. This outlines key design aspects and options for the design of sensory-based emotion regulation technologies, and shows how designers can use parameter definitions to translate experiences into technical implementations. Second, we offer insights into the process of creating intermediate-level knowledge from our design process — generating our design space through iterative design, reflection, and documentation of design and personal practice. These insights support future work seeking to develop practicable, functional, intermediate-level knowledge [56] through design. Third, our findings show how autoethnographic RtD can surface rich, first-person insight, otherwise difficult to capture. We discuss how these insights are essential for designing in affective contexts where experiential nuance, bodily awareness, and contextual sensitivity are central.

2 Background

2.1 Thermal-Affective Interaction

In daily life, thermal perception and affective experience are deeply intertwined [31, 33, 89] — from the comfort and relaxation offered by a hot bath, to the way a cold grey day can make the whole world seem sad [5]. This connection has long attracted attention in HCI. To support the integration of thermal cues in interactive experiences, researchers have, for example, investigated conceptual metaphors and sensory correspondences — e.g., "warm is soft" or "cool is hard" [70] — and examined how heat could support long-distance interpersonal connection through wearables [67].

Much work in this area has focused on controlled experiments, often adopting sensory psychology "forced-choice" paradigms to test how thermal cues convey emotions [3, 74, 117]. Such studies provide valuable evidence linking temperature and affective states. However, evidence indicates that such associations, and even basic experiences of thermal qualities, are subject to significant individual and context-based variation [e.g., 16, 18, 39, 79]. As such, there is a need to move beyond controlled laboratory settings and account for the dynamic, situated qualities of interaction.

Recent work has begun to respond to this need, increasingly studying thermal cues in applied contexts — from immersive and aesthetic experiences [10, 48, 120] to affective augmentation [29] and support for meditation [20]. Yet, despite these advances, most work in HCI continues to conceptualise thermal interaction through

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[1] In HCI research, the terms emotion regulation and affect regulation are often used interchangeably. This contrasts with discussions in psychology and affective science where distinctions are often drawn [e.g., 17, 40]. In this paper, we follow the conventional use in HCI, referring to emotion regulation in a broader sense that encompasses both affect regulation and emotion regulation.

limited dichotomies — "hot/warm" versus "cold/cool" — implementing thermal experiences as discrete on/off patterns [31, 81]. This is at odds with the temporal, spatial, and contextual subtleties of real-world thermal and affective experience [16, 31, 39]. There is a need to expand the design space of thermal interaction and treat temperature as a continuous, expressive, and relational design material, sensitive to individual experiences and the circumstances of the user [31, 32, 81].

2.2 Sensory-based Emotion Regulation

There is growing interest in how interactive systems can scaffold self-regulation practices [77, 105], both within and beyond therapeutic contexts [6, 41]. This joins broader strands of research addressing affective health and HCI [96], the use of everyday digital technologies for emotion regulation [102], mental well-being [97] and mental health [106]. Reviews of this field have identified several gaps in current research on design for emotion regulation. Slovák et al. note the need to focus more on aspects of intervention, and to conduct long-term evaluation of interventions and experiences [101, p. 7]. Meanwhile, Sanches et al. emphasise the need to help "sufferers cope in the real world" [96, p. 9] by investigating "new types of technology-assisted coping mechanisms outside of virtual or online environments". They further highlight the need to look beyond approaches that depend on data captured from large populations of users, and to support a more diverse range of therapeutic approaches that can respond to a wider range of needs [96, p. 9].

In clinical practice, sensation plays a prominent role in various treatments for emotional disorders: for example, to "anchor" [46, chapter 3] or direct attention to bodily sensations and cultivate present-moment awareness [53], or promote sensory awareness and increase parasympathetic activity [34]. Yet work in cognitive psychology has emphasised that, despite the strong potential of sensory-based emotion regulation strategies, such approaches are still under-explored and their mechanisms poorly understood [93]. Noting this gap between understanding and practice, Rodriguez and Kross [93] call for more empirical work to explore how sensory experience can either serve as the basis of emotional regulation or support other emotional regulation strategies. They point to the need to understand the particularities of individual responses and the sensitivity of such approaches to context.

Such issues have begun to be explored in HCI. Umair et al. investigated haptic patterns for affect regulation with off-the-shelf, wrist-worn devices, showing that vibrotactile and thermal cues helped immediate stress coping in a stressor task [108, p. 894]. Roquet and Sas explored how warm cues could support introspection, attention regulation and meditation [20], and Ezer et al. designed and evaluated a targeted warmth somaesthetic wearable for meditation [30]. However, such work has explored only limited aspects of the potential design space for thermal experience (e.g., fixed durations and binary stimuli [30, 108]). To date, there has been little work on longer-term engagement with thermal affective technologies for emotion regulation, nor their integration alongside other forms of therapy.

3 Methodology

3.1 Autoethnographical Research-Through-Design (RtD)

Autoethnography is an interpretive, inductive method in which the first-person experience of the researcher is both the site and the source of knowledge. This approach, centring the subjectivity and expertise of the researcher, aligns with long-standing arguments for the epistemic value of subjective data and practices in research — from Polanyi's recognition of tacit knowledge in scientific inquiry [80] to Varela's development of first-person methods in cognitive science [111], and Eisner's emphasis on the essential nature of a researcher's perceptions and past experiences [28].

In HCI, autoethnography has gained traction for its ability to capture the intricacies of lifeworlds [38] and to reveal long-term interactional phenomena unlikely to surface in short-term studies [72, 109]. The approach has been particularly prominent in research on embodiment, well-being, and assistive technologies, where it is valued for providing first-hand access to phenomena and generating nuanced, personal insights. In particular, it has been valued for studying topics and contexts that may otherwise be hard to access [63, pp. 8-10]. It can be hard, for example, to elicit accounts of emotion, bodily sensations and the temporal evolution of experiences via third-person methods [23], particularly for highly personal and context-sensitive phenomena such as emotion regulation or chronic illness [54]. Participants tend to struggle with detailed introspection and precise articulation of experience — skills that require training and commitment to develop [111], particularly for experiences that are intimate or sporadic.

A growing body of work now integrates first-person research methods with design approaches such as RtD, [14, 107], particularly "where a deep understanding of one's experience is critical to the development or evaluation of a new technology" [85, p. 754]. By combining autoethnography with RtD, researchers can explore their own lived affective contexts and engage in a deep exploration of relevant design dimensions [63]. In such cases, autoethnography not only affords close attention to experiential, bodily and contextual nuance, but also serves as a generative design method, producing rich, situated knowledge to inform the design of adaptive, personally resonant technologies.

There is a broad spectrum of approaches to autoethnography, from intuitive, literary approaches that aim to evoke and transmit experiences, to theory-constructing "analytical-interpretive" approaches [1, p. 60] more closely aligned with conventional ethnography [1]. In this work, we lean towards the latter: our primary goal is not to record and then evoke *experiences* of practising and designing for emotion regulation. Instead, we aim to carefully observe and then analyse design practice as it emerges from and is informed by emotion regulation practice, to generate a design space.

3.2 Background of the Autoethnographer

In this paper, the first author conducts and participates in the autoethnographical RtD design. They are a human-computer interaction (HCI) researcher, primarily located in the Nordic region. Their educational background is in cognitive science, design and art, while their research focuses on multisensory technology, affective experience, and phenomenology. Their theoretical approach is grounded in the enactivist tradition [112], where affect and behaviours are understood as emerging dynamically through interaction in situated contexts. Pertinent to our focus on emotion regulation, the autoethnographer is neurodivergent and often experiences exhaustive stress and anxiety. As such, they have undertaken therapy focused on emotion regulation, including five months documented in this paper. Pertinent to our focus on design, the autoethnographer trained as a painter and later an industrial designer, and has maintained practices in painting, calligraphy, and design. Through this practice, the autoethnographer has increasingly become aware of the role of tacit know-how, experience, and practice in the design process, but is conscious that this is rarely brought to the surface. This motivates the present inquiry: not only to explore thermal cues as a design material for emotion regulation, but also to make explicit the role of experience and practice in working with that design material.

3.3 Design Spaces and the Design Space Schema

The notion of 'design space' is commonly used to organise a class of technologies, for instance, tangible interaction [57] or graspable interfaces [35], in a systematic way. Design spaces have often been used to organise and generate knowledge from a body of practice, for example, addressing collections of design artefacts, design ideas, sketches and annotated portfolios created by multiple independent designers [42] or a team [36]. In its broadest sense, a design space can be seen as a snapshot of the design knowledge accumulated at a particular point in time [49]. As such, it is possible to study the processes which lead to such design spaces, through a series of such snapshots [43], or a sequence of prototypes that both instantiate and filter aspects of the design space [68].

Design spaces have been represented in various ways, e.g., as a network graph [121] or a Cartesian space [98]. In previous RtD work, design spaces have been represented using the *design space schema* [7, 24] approach: a conceptual space consisting of the aspects and associated options considered by the designer/researcher at particular points in time. A design space schema is essentially a table (see Table 1), where the columns names list the **Design aspects** the designer is addressing, and the different **Options**, or alternatives the designer considers for this aspect are presented below. Here, we visualise selected aspects of the design space in case 1 in section 4.1. The **aspects** are "Actuator" (with associate **options**: Precision micro drives, model 304-116, Peltier module and Lily pad motor) and "Material" (with associated **options**: Fabric, Silicon, and Wool). As Basballe and Halskov describe [4], RtD evolves in a complex structure where design and research interests continuously interweave, couple, and decouple through processes of design, self-use and analytical reflection. By capturing analytical snapshots, the *design space schema* approach both documents and structures this process, surfacing the decisions, judgements, and actions that refine designs towards their "final" presented forms. In this work, we present three such design space schemas for particular design cases in our process. These serve as interim analytical steps on the way to developing our design space.

Table 1: An example of the Design Space Schema

Actuator	Material
Precision Micro drives, model 304-116	Fabric
Peltier module	Silicon
Lilypad vibe motor	Wool

3.4 Practice

The RtD project presented in this paper began after the first author had participated in two months of therapy, focusing on cultivating attentiveness to bodily experience under affective changes. During this period, they had already begun taking field notes, including therapy insights, reflections, and journals of their daily practice. Reviewing these notes, they saw that they offered a lens on first-person affective experience relevant to design and revealed opportunities to create interactive systems that could support emotion regulation practice. This led them to formally investigate the design space of thermal-affective sensory regulation. From then on, data collection followed a systematic structure guided by established autoethnographic methods [13, Part II]; [26, p. 31].

3.4.1 Data collection. Consistent with Yin's criteria for validity in case study research [123], we used multiple sources of evidence. The first author maintained a journal to record therapy notes, personal reflections, and daily practices related to emotion regulation strategies. This journaling began after the initial therapy session in March 2024, continuing consistently, beyond the final therapy session in August 2024 to the end of the design process in August 2025. The design process was documented through a separate design journal, conceptual sketches, photos, memos and reflective writing (e.g., Figure 2). The design journal captured the rationales for design decisions, how designs were connected to emotion regulation practice, and intended interactions for the designs. It also documented meetings with co-authors. The conceptual sketches record the ideation and iteration processes. Photos captured prototyping and rapid tinkering, supporting ongoing reflection and analysis. In addition, memos were used to record spontaneous thoughts, reflections, and challenges encountered throughout the RtD process. Finally, the reflective writings synthesised and recorded the first author's periodic reflections and examinations of their design inquiries and activities.

3.4.2 Data analysis. In autoethnography, it is recommended to begin analysis early, and continue throughout the research process in an iterative and non-linear approach [13, p. 130]. We followed this approach, interweaving data capture, design documentation, reflective writing, and engagement with prior literature. First, the first author developed a retrospective account of their emotion regulation practice and related design activities. This was then synthesised into an affinity diagram combined with reflective writings. This synthesis captured the recommended regulation strategies, the methods and frequency of practice, the associated sensory experiences, and design thinking informed by these experiences (for an

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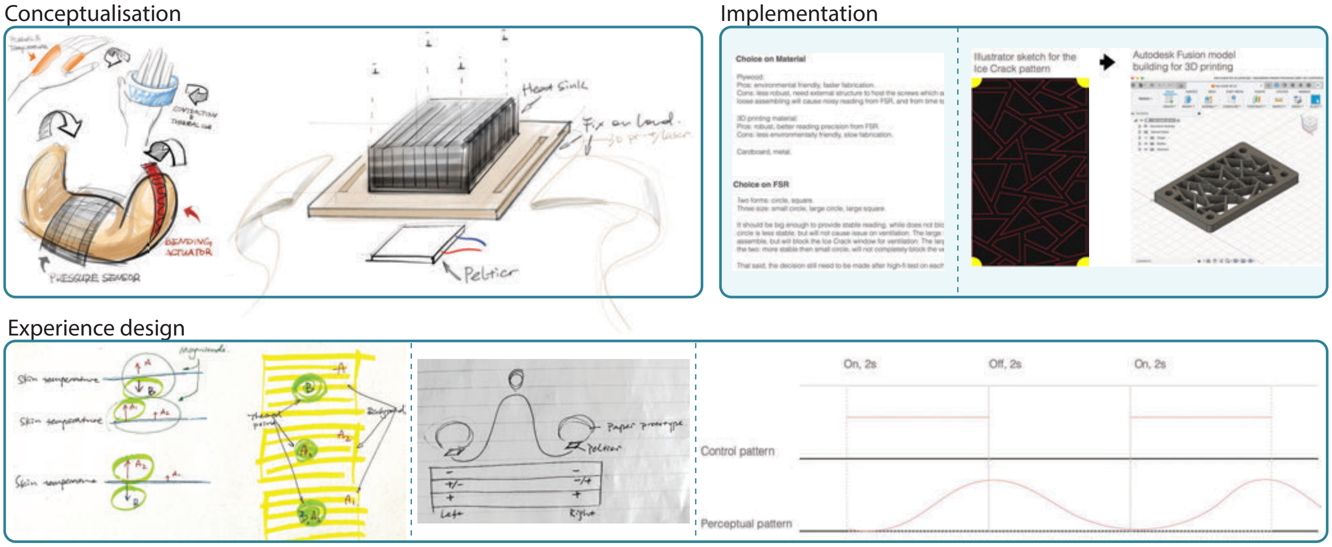
[2] Contrast and brightness on the illustrator sketch in the "implementation" pane has been increased for visibility.



Choice on Material

Plywood:
Pros: environmental friendly, faster fabrication.
Cons: less robust, need external structure to host the screws which a
loose assembling will cause noisy reading from FSR, and from time to

3D printing material:
Pros: robust, better reading precision from FSR.
Cons: less environmentally friendly, slow fabrication.

Cardboard, metal.

Choice on FSR

Two forms: circle, square.
Three size: small circle, large circle, large square.

It should be big enough to provide stable reading, while does not blo
circle is less stable, but will not cause issue on ventilation. The large
assemble, but will block the Ice Crack window for ventilation. The lar
the two: more stable than small circle, will not completely block the ve

That said, the decision still need to be made after high-fi test on each

Figure 2: Excerpt of design journals for design case 3, *Window*, showing notes from conceptualisation, experience design and iteration, and implementation and fabrication. Shown here as illustration only^2. Full-size versions are provided in auxiliary materials.

example, see auxiliary material). This, in turn, laid the foundation for three key synthesis phases:

First synthesis (July 2024): Four months into the project, the first author identified early themes related to designing thermal interaction and affective engagement. These insights informed the ongoing design focus and literature review.

Second synthesis (March 2025): After 12 months, a summative analysis was carried out, categorising entries into, e.g., design development, technical affordance, reflection-in-action and broader themes. These categories supported the initial development of a design space for emotion regulation technologies.

Third synthesis (June 2025): At 15 months, the design space was formalised using the Design-Space Schema approach [43] (see below).

In parallel, reflective writing and analysis of prior findings yielded deeper insights into recurrent design breakdowns, shifts in language, and moments of conceptual reframing. From these, we analysed a set of overarching themes that underpin the autoethnographic narrative presented in section 5.

Following Yin’s quality criteria [123], these phases involved iteration and review with other members of the research team to provide an external view on the first author’s account and interpretations. The first and second syntheses and the reflective writings were conducted by the first author, based on sustained engagement with emotion regulation practice and design activities. The design-space construction and narrative development were conducted collaboratively by the first and co-authors, enabling broader critical reflection and analytic triangulation [26].

The construction of our design space followed a systematic, two-step process of *synthesis* and *organisation*. We began by combining the schema tables from all design cases (see section 4), collating the design aspects and their corresponding options. Similar aspects were merged to avoid redundancy (see auxiliary material for details). The first two authors then organised this consolidated schema, guided by two aims: to align its structure with the overarching themes we identified in the analysis presented below, and to provide a conceptual map to guide future work on sensory-based emotion regulation technologies. Through parallel coding of design aspects, joint discussion, and iterative refinement, we distilled the schema into four components (see Figure 1), each bringing together design aspects and thematic insights developed through the analysis. Our visualisation of the design space was guided by an analysis of prior design spaces to identify visual elements useful for structuring complex conceptual relationships and design activities. The first author drafted a 2D representation. This was iteratively refined by discussion among co-authors to ensure clarity of communication and potential as a reference for both analytical and generative tasks.

3.5 Ethical Considerations

While our institutions judged the project not to require formal ethical review, we took care to consider and manage impacts on those touched by the project, guided by prior discussion of ethics in autoethnography [27, 51, 66, 103].

First, we do not report on the behaviours and experiences of people other than the first author, except to report advice from the first author’s therapist. The first author discussed the potential autoethnographical RtD project with this therapist ahead of the project. The therapist agreed with the project and encouraged it, suggesting it had potential therapeutic value. They preferred to maintain their privacy, however, and not be acknowledged or named as a contributor.

Second, we considered issues related to the consent [52], wellbeing [82], and comfort of the autoethnographer [22]. The first

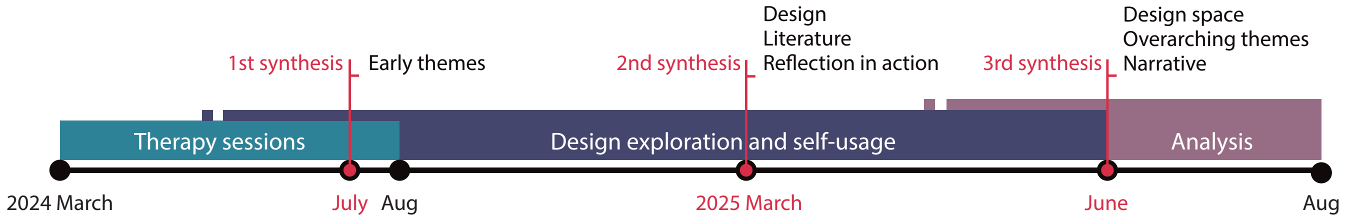


Figure 3: Timeline of the autoethnographical RtD.

author proposed and led this work independently as a senior research fellow, inviting others to join as collaborators as the project took shape. We were careful throughout to ensure the first author kept control of the process and defined a personally comfortable level of self-disclosure. The external imperative to reveal oneself has been identified as a risk factor in more evocative approaches to autoethnography [1, 66]. In our case, this was mitigated by our primary focus on developing design knowledge rather than recounting and evoking experience. Regular meetings with the other authors were maintained throughout the process [58, 82]. This provided both a space for debriefing after self-interrogation, and an outside perspective on data gathering, interpretation and analysis.

Finally, it is important to emphasise that the project neither involved nor encouraged confrontation with traumatic events or grief. The need for emotional regulation can come from many sources. In our work, the primary source was stress and anxiety provoked by normatively coded environments. This is a common, everyday experience for many neurodiverse people, and often for neurotypical people also. Emotion regulation practices mark an important, and not exceptional, response to this.

4 Design Cases

In this section, we introduce three design cases developed through the iterative, practice-led process described above. Introduction of these design cases in this section aims to provide anchor points and context for more substantive discussion of experiential qualities, patterns of use, and design space development. Here, we focus on the concrete design artefacts and high-level design rationales. Experiences of using each of the design cases are then discussed in section 5.

All three artefacts are exemplars extracted from a design process rather than complete products. They are intentionally open-ended and adaptable, focusing on the investigation of thermal cues as a design material for emotion regulation practice. Each illustrates one of the three kinds of emotion regulation activity observed in the autoethnographer's personal practice: *intentional regulation*, *retrospective reflection*, and *mindful attunement* (each described below, and in subsection 5.3). These are not abstract principles or categories, nor a general typology of emotion regulation. They describe situated patterns observed in daily life.

A design space schema is provided for each design case — the various aspects and options (material, conceptual, experiential, etc.) that emerged as relevant during the design process (see Figure 4, Figure 5, Figure 6 and subsection 3.3)[3]. Technical details, schematics, and control logic are provided in the auxiliary materials. For the following sections, to present the design cases and findings, we move to first-person language.

4.1 Case 1 — Tomato: Designing Thermal Anchors for Intentional Regulation

Tomato (shown in Figure 4) was developed based on reflections in therapy, during a period when I was working to cultivate better awareness of affective overload and exercise strategies for stress coping. This design case illustrates the use of technology in *intentional emotion regulation*: cases where I wanted to pro-actively regulate my affective response as the experience unfolded. My therapist had introduced the notion of "anchoring"- an intentional practice of up- or down-regulating affective responses by redirecting attention to a bodily sensation via **sensory cues** [115]. This aims to interrupt spiralling emotional thoughts. Anchoring often focuses on finding existing sources of sensation in the environment, yet as I applied this strategy in my daily practice, I found it helpful to create intentional, controllable sensations. I experimented with various sensory cues to serve this anchoring function, turning to thermal interaction due to my awareness of the close relationship between thermal and affective experience (see subsection 2.1).

Design Concept and Implementation: To create an attention-grabbing sensation, the artefact was designed to be held against the *thenar eminence* — the fleshiest portion of the palm, located by the second joint of the thumb and a site of high thermosensory sensitivity [12]. I designed it to respond to grasping force by producing thermal or vibrotactile cues. I chose both warming and cooling cues to allow the device to adapt to different seasons and contexts (cooling is either not noticeable or unpleasant during cold weather, for example). This interaction was designed to align with fidgeting behaviours I already used to cope with stress — squeezing a pliable, textured object, such as a half-sun-dried tomato.

My design explorations led to three functional prototypes, each investigating the effectiveness of a different kind of sensory cue for anchoring. The first (**V1**) produces either warming or cooling cues based on the intensity of grasping (Figure 4). It is composed of a Peltier module (217-2408) with heat sink, a force-sensitive resistor, and a control unit. The ceramic surface of the Peltier module is the **material** (see Figure 4) that contacts the skin. For regulatory purposes, I sometimes found it helpful to apply this surface to other **body locations**, such as my chest or neck (see subsection 5.2),

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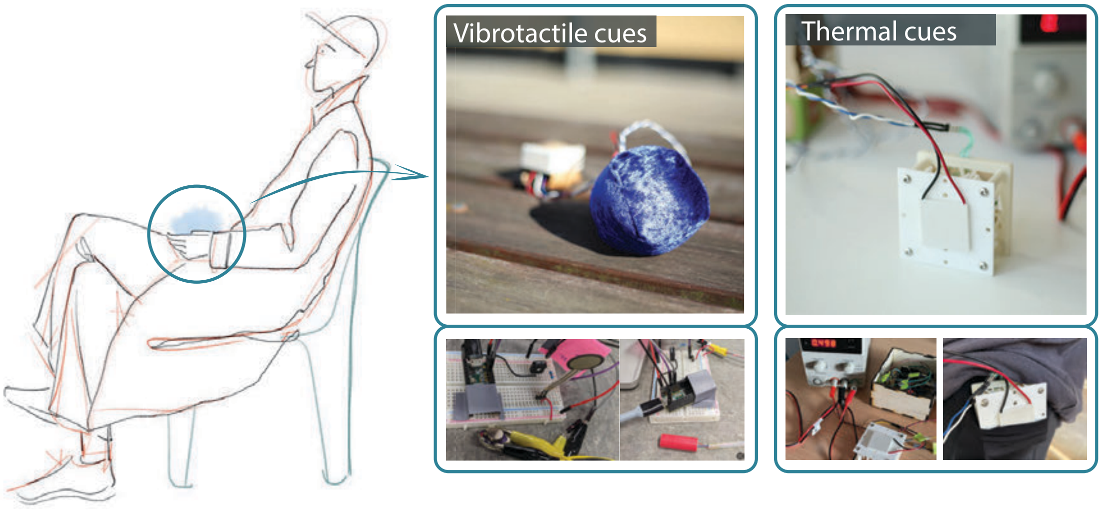
[3] For clarity, the schema tables demonstrate only the most pertinent aspects for each design case. Full details are provided in the auxiliary material.



Sensory modality	Body location	Material	Direction	Temporal Pattern	Actuator	Magnitude	Duration	Physical form	Vibrotactile patterns
Tactile thermal	Palm	Elastic filling with crushed velvet fabric	Increase	RoC: 1°C/sec 2°C/sec	Precision micro drives, model 304-116	±4°C, 8°C, 16°C steps from ambient temperature	Momentary	Portable, pocket-size (public)	Positive correlation: input force - output intensity without cut-off
Vibrotactile	Thenar eminence	Ceramic	Decrease	Interval: self-determined	Peltier module	Fixed steps: ±4, 8, and 16°C	From a sec up to however long it needs	Domestic installation (private)	Positive correlation with a cut-off
	Fingers	Dense wool pouch	Warming	Frequency: self-determined	Lilypad vibe motor	Tuned based on seasonal conditions			Negative correlation
	Close to the hip and thigh Neck Chest	Silicon cube	Cooling						
	Heel								

Note: This schema demonstrates only the most relevant aspects. Full schema provided in auxiliary material. Presence of items on the same row does not indicate that they are related to each other. Grey items were considered but could not be implemented due to technical or practical constraints.

Figure 4: Above: Prototype for Case 1: *Tomato*. Left: Concept drawing. Mid: vibrotactile cue design for outdoor use. Right: thermal cue design, limited to indoor use due to bulky components (external power supply, control unit, and heat dissipation structure). Below: Design space schema for Case 1.

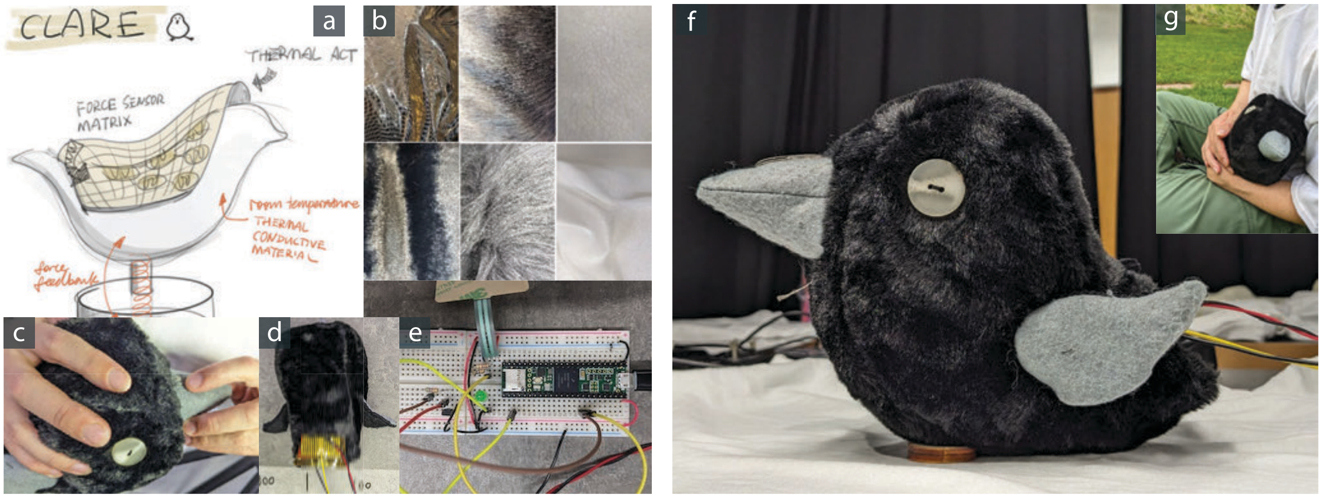
as I squeezed the grasping element. Two other variations served to investigate vibrotactile cues. **V2** explored multisensory cues — overlaying the thermal cue with feedback from a vibrotactile motor. Finally, finding that the vibrotactile sensation overrode the thermal sensation, I also created a variation with vibrotactile sensation only (**V3**).

I created two **temporal patterns**, aiming to produce thermal cues that captured attention to support anchoring: 1) discrete bursts with clear intervals and 2) continuous transitions with smoother gradients. These patterns could be applied to either **direction** of thermal change: heating or cooling. I tuned the rate of change (RoC) and **magnitude** of these thermal patterns manually. This allowed me to explore the effect of the cues (e.g., whether they felt grounding, overwhelming, or emotionally disruptive) under different conditions (see section 5). Table 4 provides an overview of the Design Space Schema.

4.2 Case 2 — Clare the Crow: Gentle Thermal Companionship for Retrospective Reflection

Clare the Crow was developed to serve a more *retrospective, reflective* role. Some of my therapy had focused on coming to understand bodily sensations as potential affective signals. I sometimes experienced moments of puzzlement when I noticed unexpected bodily changes (goosebumps, leg shaking, or throat tension) without being conscious of a corresponding emotional state. To help myself make sense of such experiences, I engaged in a reflective practice, retrospectively interpreting bodily changes within their affective contexts. *Clare* was conceived as a companion to encourage myself to engage in these reflective activities, and bring myself into the right mindset.

Design Concept and Implementation: Clare offers slow, comforting thermal cues in response to touch, and her soft, crow-shaped



Sensory modality	Body location	Material	Direction	Temporal pattern	Actuator	Magnitude	Physical form	Rate of change	Actuator spatial arrangement
Haptic thermal perception	Hand	The material assembling the crow's feather quality: Faux fur (long hair, premier plush), Polar fleece, Sugar puff.	Warming up	Slow, incremental heat. Used from 1 to 5 minutes.	Flexible heat pad	Depends on starting temperature. The max is 50°C.	An abstract form of a crow - a real crow size	0.1°C/sec.	One side, right below the area of receiving strokes
Vibrotactile cues	Chest		Cooling down	Immediate heat pulses. 5 sec up to 10 sec	Vib motor			0.3°C/sec.	Four-sided, over the surface of the artifact
Texture of the material	Cheek								In the middle of the artifact.

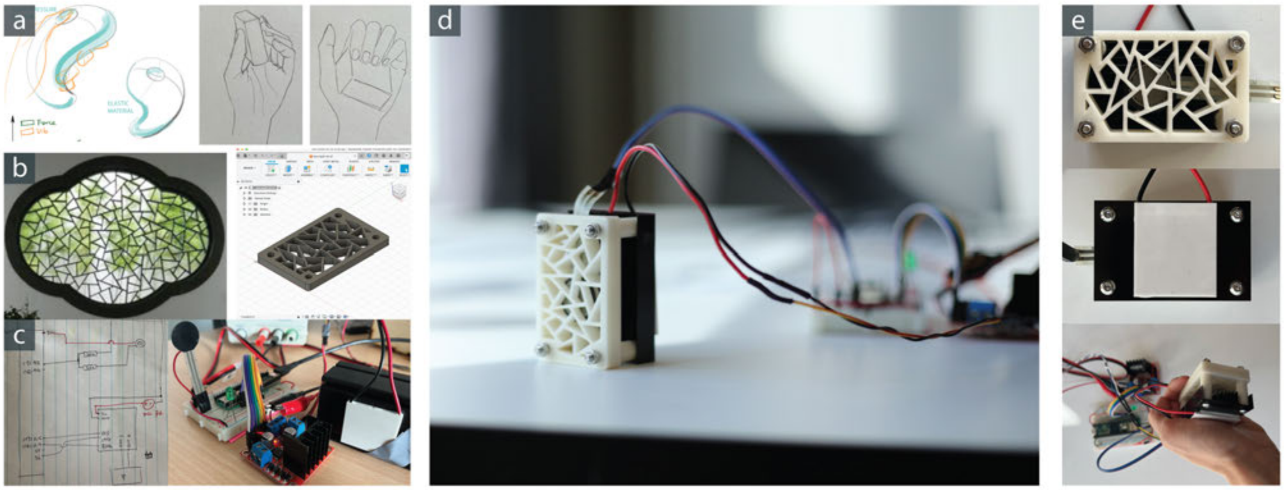
Figure 5: Above: Prototype for Case 2: Clare. (a) Design sketches. (b) Tested materials. (c) Conductive thread on the beak: stroking induces "wiggle" motion. (d) Embedded thermal pad. (e) testing the circuit. (f) Prototype in use. (g) My partner hugging and stroking Clare., Below: Design Space Schema for Case 2. (for notes see Figure 4)

form is designed to invite cradling (Figure 5). To deliver heat, I used a flexible heat pad, chosen for its large contact area and ability to conform to the hand. This was powered by a 9V battery and controlled via an Arduino Uno. I tuned the thermal cues to create the qualities desired for my reflective practice, focusing on factors such as perceived valence, continuity, and emotional tone (see section 5). Through iterative cycles of design and use, I arrived at a thermal pattern that was well adapted to my practice routine. This provided a comforting focus for my attempts to remap bodily sensations to potential emotional undercurrents, helping improve my ability to interpret my own affective states. Unlike the abrupt, attention-shifting bursts used in *Tomato*, Clare's thermal cues change continuously, through smaller increments in **magnitude**, to provide a gentle and comforting presence. The **rate of change** responds to the duration and firmness of touch or stroke, warming more quickly in response to a firmer touch or stroke. This creates a reflective feedback loop between bodily awareness and external sensation. As shown in the design space schema for this case (Figure 5), the design of this artefact explored **sensory** and **material** aspects of thermal affective experience, and the relationship between thermal parameters, i.e., **direction**, **magnitude** and **temporal patterns of thermal cues**.

4.3 Case 3 — Window: Rhythmic Thermal Cues for Mindful Attunement

Finally, window was designed for activities of *mindful attunement*. During therapy, I learned that emotion regulation is not a one-off intervention, but a long-term practice of cultivating awareness and skill. As such, I began to incorporate regulation-focused meditation into my daily routine. *Window* was designed as a meditative probe to explore how thermal cues can support attentional stability and bodily attunement during introspection.

Design Concept and Implementation: The artefact was created to facilitate the initial phase of meditation, anchoring attention to the breath — an important step in cultivating interoceptive awareness [21, chapter 7]. In early prototypes, I explored different media for thermal cue delivery, including wearable, handheld, and ambient forms. I ultimately settled on a form that rested on my upturned palms, which in turn rested on my knees — a posture typical in



Sensory modality	**Body location**	**Thermal transfer**	**Direction**	**Temporal pattern**	**Actuator**	**Duration**	**Perceptual quality**	**Material**	**Technical accomodation**
Haptic thermal	Palmer region	Fabric conduction (brushed cotton, linen, silk)	Warming up	Self-determined thermal rhythmic pulses	Peltier	Momentary: within a few secs	The candlelight pulses warm against my palms.	PETG	Heat sink for dissipating unwanted temperature
External soundtrack	Thenar eminence	Ceramic conduction	Cooling down	Preset rhythm of breathing that I'm trying to achieve.		Adaptable to the practice progress	Meld, as in the company of the person	Wood	Ventilation structure
	Finger tips	Convection with air flow				More-than-momentary: up to a minute	A gentle cadence, the sway of wheat fields	Metal	
	Hand back	Radiation with IR lamp						Cardboard	

Figure 6: Above: Prototype for Case 3: Window. (a) Design sketches. (b) Chinese "Ice-crack" pattern window and 3D model inspired by the style. (c) Circuit design and prototyping. (d) Prototype in use. (e) From top to bottom: top view, bottom view, and handheld fit. Below: Design Space Schema for Case 3. (for notes see Figure 4)

seated meditation. This configuration allowed the device to gently engage with my fingers and thermosensitive *thenar eminence* (Figure 6).

Window was sensitive to tap input. When I found it difficult to regulate my attention, I could tap its surface to the rhythm of my breathing patterns. *Window* records these rhythms and reproduces thermal pulses via Peltier modules (one on each hand) to help focus my attention on the breathing rhythm. In the early phases of my meditation practice, I was not always able to match my breathing to the tapped rhythm, but after a few months of regular use, I found I was able to entrain to the desired breathing patterns. This entrainment often led to successful meditation sessions.

I designed the parameters of the thermal cues — **rhythm**, **duration** and **direction** (e.g. heating or cooling) — to be adaptable (Figure 6), recognising that thermal comfort and affective tone are seasonally and contextually variable (e.g., contextual heat from the environment, or bodily stress can reduce sensitivity to warming cues, or make them unpleasant). Through *Window*, I explored key dimensions of affective interaction: the comparison between passively receiving and actively interacting with thermal patterns; the multisensory interplay between thermal cues and environmental conditions; and the affordances of different thermal delivery media for introspection-focused practices (see Figure 6).

5 Findings

This section presents the results of our analysis of data recorded over the course of the 18-month design process — journals, memos, design sketches, photos and reflective writing recording my design and emotion regulation practices. The results are organised around four key themes and illustrated with reference to the design cases described above (section 4). Together with the design space schemas, they are the basis of our design space illustrated in Figure 9.

5.1 Traversing the Gap Between Experience and Design: Language, Practice and Know-how

In conceptualising and implementing thermal technologies for emotion regulation, I observed a constant, back-and-forth negotiation between the evocative, subjective language required to capture affective experiences and the precise technical specifications needed for implementation. Translation between affective experience and design parameters meant finding the right language at different stages of design. Approximating experiences via thermal cues didn't end when I found stable, standardised parameter ranges, but relied on know-how-based adjustments (see Figure 9).

5.1.1 *Use the "appropriate" language for describing thermal patterns.*

Throughout the process, I found language is essential for me to make sense of experience, bring them to awareness, and create pivot points between experience, iterative design, and implementation. Different stages of design demanded different language to effectively capture and translate the intended emotional experience for design purposes. In the early stages of ideation, I relied on figurative and rhetorical language to capture the embodied and affective qualities of an experience I was designing for. For example, in case 1 (*Tomato*), I first used simple labels like "calm" or "anxious", to describe the states I felt or wanted to attain. However, I soon realised that these words did not adequately capture my feelings and experiences — I was simply following established terms from previous work on affective design. I instead began to use phrases like "lingering warmth" or "intrusive and dominating feeling". This more expressive language better articulated the specific moment-to-moment, affective qualities I wanted to capture in design: the agency, activity and physicality of the feeling (Table 2). This was essential for me to connect the abstract perceptual quality to concrete, bodily sensations and allowed for more nuanced design exploration, going beyond simple dimensions of valence and arousal.

Later, however, as I moved toward prototyping and iteration, this evocative language became frustratingly unworkable. Rather, I needed different language for different stages of design. As I moved towards a working design, I needed to gradually translate experiential qualities into technical parameters. I began to use engineering terms like **magnitude, direction, rate of change (RoC), duration, and interval** to model the intended sensory textures. Sometimes this translation was relatively simple: in case 2 (*Clare*), a "lingering warmth" became a small magnitude and a low RoC. Other experiential qualities (e.g., *perceived intrusiveness* in case 1, *Tomato*, or *the cadences of wheat moving in a field* in case 3, *Window*) required more complex combinations of parameters, e.g., duration, direction, interval, and magnitude. Examples of such translations are illustrated in Table 2.

This shift in language reflected a basic tension in designing for affective thermal experience. I needed to be fluent in the rich, subjective language of affective experience to describe the design's purpose, and precise, technical language to instantiate this in a prototype. Technical language, while critical for precision and accuracy, was inherently limiting for capturing the full, messy quality of affective and bodily states. Conversely, while figurative language was vital for introspection and deep conceptualisation of affect, it failed to provide a concrete blueprint for technical implementation. In this sense, forms of language became instrumental, like buses heading to different destinations — one toward introspection and affective resonance, the other toward precision and implementation. Getting on the right "bus" at the right time is crucial for aligning affective expression with technical implementation.

5.1.2 *Navigation and adaptation requires practice and know-how.*

Having translated an experience into the language of parameters, I found I frequently encountered a discrepancy between the perceptual qualities I aimed to approximate and the actual sensory experience from that approximation. Mappings between experience and objective technical specifications were not linear and direct, but non-linear and complex. A minor perceptual shift or change in context could dramatically alter a cue's affective impact, making a subtle cue weak and ineffective, or an assertive cue unexpectedly intrusive. Navigating this required know-how and practice.

In an early design iteration of case 1 (*Tomato*), for example, I attempted to create a sudden, attention-grabbing, sensation to support anchoring (see section 4). I turned to parameter ranges in prior literature [e.g., 118] to design sharp thermal bursts: a cue 8°C above ambient temperature, with a rapid RoC of 2°C/s, mediated by a plain woven linen cover. Unexpectedly, this cue was far more intrusive than intended. Yet, despite not matching my intentions, this intrusiveness proved very effective for anchoring: sharply and forcefully pulling my attention away from intrusive thoughts.

Not all such discrepancies were positive. In case 3 (*Window*), I specified a thermal pattern of gentle pulses intended to approximate a calm and supportive rhythm for breathing regulation. Again, I began with parameters drawn from previous knowledge [e.g., 99, 118] specifying a ramp up to 4°C above skin temperature with a RoC of 1°C/s, held for 2 seconds, before dropping back down for 4 seconds (Figure 7, top). The results felt weak and sluggish. Pulses blurred together, lacking the clear rhythmic quality necessary to serve as a rhythmic cue. Likely, this was affected by latency in my thermal perception and the way contact between my skin and the heating module prevented the skin from fully cooling during the interval. Having recognised that the problem lay in the pulse's lack of definition, an adjustment to timings solved the problem, creating a clear, defined rhythmic cue, effective for meditation practice (Figure 7, bottom).

Much work on thermal interaction has studied the effects of precise parameter ranges [e.g., 44, 100], yet technical parameters are not direct proxies for feelings. Rather, knowledge of parameter ranges provides a starting point for careful, practical adjustment, which (as discussed further below) must be sensitive to a range of contextual and multisensory factors.

5.2 Considering the Body: Sensitivity and Vulnerability

Unlike sight and sound, where sensation is localised with particular organs, thermal sensation occurs across the entire body and differs from site to site. During design, I found that the location of thermal stimulation on the body profoundly shaped its affective quality and regulatory function. I came to understand body location not simply as a site for sensation, but as a design material in itself — affectively loaded, socially situated, and technically constrained. My choices of where to apply thermal stimulation were defined by considerations of **perceptual sensitivity** and **vulnerability**.

Regarding **perceptual sensitivity**, I found that more thermally sensitive areas, such as the forehead and the thenar eminence of the hand, offered a wider expressive bandwidth. These areas were sensitive to even small changes in temperature, meaning lower RoC and shorter durations were perceived as relatively abrupt or affectively salient. When designing for the "anchoring" strategy

Table 2: Translation from experience to technical approximation and the design implementation.

Experiential descriptions	Technical approximation	Implementation
Case 1: “Momentary intrusive and dominating feeling, like a water balloon exploding in a splash.” “A burst of sensation.”	**Duration**: 4 seconds **Amplitude**: 8°C change **RoC**: 1-3°C/sec **Direction**: heat up and cool down **Interval**: self-determined	**Actuator**: Peltier module rests on a ceramic heat sink. **Control board**: Teensy 3.2. **Material**: ceramic surface of the peltier module. **Form**: pocket-size cube.
Case 2: “Companionship: Lingering warmth of a bronze censer.” (a bowl for burning incense) “Gentleness: Spring breeze waves the willow’s hair.” “Atop bare branches, the Cotton-rose unfolds—a flush of silk against the chill mountain.”	**Duration**: designed for long-term display, in response to holding and stroking. **Amplitude**: varies depending on the season and ambient temperature. Max up to 45-50°C. **RoC**: 0.2°C/sec **Direction**: heat up	**Actuator**: flexible heat pad. **Material**: synthetic fleece with low thermal conductivity. **Control board**: Arduino UNO. **Form**: hand-made crow-shaped soft toy.
Case 3: “The candlelight pulses warm against my palms.” “A gentle cadence, the sway of wheat fields.” “The puppy sleeps in my arms, its belly rising and falling like a tiny tide lapping against my arms.”	**Duration**: 4 seconds ramping up before cut-off, then 2 seconds of ramping down. **Amplitude**: varies. **RoC**: 1°C/sec **Direction**: adaptable, both heat up and cool down. **Interval**: 6-second interval from the cut-off.	Actuator: **Peltier** module with heat sink and supporting structure. **Control board**: Teensy 4.1. **Material**: ceramic surface of the peltier module. **Form**: cobblestone sized hand-held cube.

Note: Experiential descriptions are examples. Each case drew on a constellation of such descriptions, with technical approximation and implementation translating the whole constellation rather than any single account.

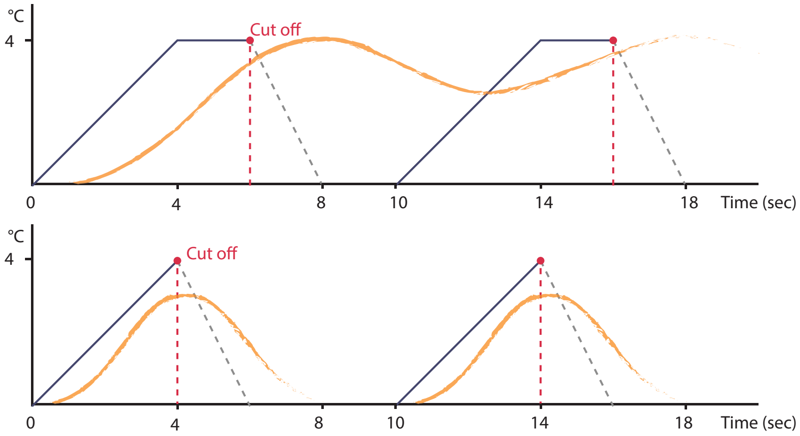


Figure 7: Layering subjective perception on a designed thermal profile with technical specification. Curves in yellow are depictions of how the signals were subjectively felt with the thenar eminence area on the hands. The red dotted line represents the signal cutoff, and the grey dotted line represents the thermal dissipation on the device’s surface.

in case 1 (*Tomato*) (Figure 4), I often focused on these sites, since they let me design fast cooling or heating bursts that felt immediate, sharp, and attention-grabbing. In contrast, when designing more immersive, backgrounded cues (e.g., for slow attunement or mood modulation) I targeted less thermally sensitive areas such as the abdomen or lower arms. This allowed thermal patterns to “settle into the background”, creating a felt presence that was more ambient and lingering than targeted or directive (c.f., cases 1 and 2, Figure 5).

Meanwhile, **vulnerability** shaped not only how thermal cues felt, but also what they meant. Thermal cues on more private body areas (e.g., chest, ribcage, inner thigh) often produced a stronger sense of emotional intimacy or vulnerability. When paired with slow temperature changes, such placements could evoke a subtle sense of companionship or care. I speculated that this may be because they resemble forms of social thermal touch, like cuddling or being held. However, more abrupt cues at the same locations could trigger discomfort or self-consciousness. This was especially true when I was already experiencing negative affect, as when using Tomato. Then, the thermal cues often felt intrusive and raised my alert. These experiences foregrounded the complex interaction between the vulnerability of the location and the affective context.

Location also carried social consequences. Many of my wearable concepts required direct skin contact, limiting where and how I could wear them in public. Off-the-shelf actuators often demanded thick wiring and heat dissipation elements, making the devices bulky, rigid, and attention-drawing. Wearing these in everyday social environments was not only physically cumbersome but also socially uncomfortable. I felt the visibility of Tomato and Clare risked inviting unwanted attention, comments, or even judgment. I connected this to a broader stigma around support for emotion regulation and the implicit binary many people perceive between being emotionally "functional" or "dysregulated" [see e.g., 60, p. 4]. These social dynamics shaped when, where, and how I chose to engage with these technologies. They pose important design challenges around discretion, wearability, and cultural perceptions of mental health. In designing thermal experiences for the body, I learned to think beyond the "what" of sensation and attend to "where", "when", and "how" it is encountered. Thermal design combines the anatomical with the experiential, relational, and social. Cues are not simply delivered to a body but move through the emotional and social ecology of the body's lived experience.

5.3 Designing Temporal Features of Thermal Cues for Emotion Regulation

I found that the temporal features of thermal cues — duration, rhythm, intervals, and rate of change (RoC) — played a key role in shaping affective meaning. I illustrate this in three different patterns of emotion regulation activity I observed in my practice.

Situation 1: Intentional up- or down-regulation of emotion. **Intentional regulation** describes situations where I was aware of my emotional state and deliberately sought to up- or down-regulate it, to navigate a situation. As described in subsection 4.1, my therapy introduced me to "anchoring", a technique to (as my therapist put it) "broaden my perspective" away from affective overload. When I found myself stuck in a loop, focused on affective reactions, anchoring aimed to shift my attention to sensory qualities (e.g., colours, textures, scents) in the environment. These sensory "anchors" were intended to help me stay stable in an "emotional storm".

Case 1 (*Tomato*) was developed for this purpose, using thermal cues that were strong and abrupt, even intrusive and dominating [31, p. 2808]. To achieve this, I experimented with short-duration cues (3–5 s) with a fast RoC (1–2 °C/s), varying within this range to convey different levels of dominance (Figure 8, teal). I found that a sharp cooling cue on my palm and neck felt more intrusive and attention-grabbing than an equally sharp warming cue (i.e., of the same magnitude). The cold cue more effectively grasped my attention, "shocking" me out of my fast-rushing river of thoughts. Compared to warm cues, far shorter durations of cooling cues were sufficient for me to drop an emotional anchor.

Situation 2: Retrospective reflection on bodily reactions I could not connect to an emotion. Case 2 (*Clare*) was designed to address situations where I am not consciously aware that I am experiencing an emotional reaction, yet find myself experiencing puzzling bodily responses such as goosebumps, or shaking legs. Clare supports **retrospective reflection** to help me learn to connect these sensations to affective states and contexts. Here, the thermal cues were intended to serve as a gentle companion, not an intrusive anchor. I explored slower changing cues, influenced by stroking, that I connected to homely, vital yet gentle experiences: the lingering warmth from a bronze incense censer, or, when feeding crows in winter, they came close enough that I could feel their body warmth.

I found Clare especially helpful before and during reflection sessions to settle into a reflective mindset. I settled on cues with a ten-second temporal envelope and a 'just noticeable' RoC (0.3°C/s mediated with a fleece material), while the interaction was designed to allow me to sustain the temperature at a fixed level for as long as I wanted; so long as I continued touching *Clare.* This created a steady thermal presence that invited attention without demanding it, and remained within my control. In practice, I tended to maintain the temperature for around five minutes (Figure 8).

Situation 3: Mindful attunement to inner states. In meditation, my goal is proactive rather than responsive or retrospective. I do not aim to manage or interpret specific emotions, but to cultivate attentiveness to bodily states and broader affective awareness. In the early phase of my meditation practice, I often struggled to control scattered thoughts and irregular breathing (common experiences when beginning meditation, as I later learned [71]). Once I got "on track", my attention and breath stabilised, and I found it easier to remain attentive to my inner states.

Case 3 (*Window*) was designed to support this transition into focusing, using thermal cues as temporal scaffolds. Again, I did not use preset cue lengths. I designed cues to respond to tapping, allowing me to define and adapt my breathing tempo. In practice, I tended to tap out breathing cycles of roughly eight seconds in duration (Figure 7). The onset of each cycle ramped up slowly, not demanding focus but creating a subtle background presence. Over repeated use, the rhythmic intervals acted as temporal anchors, easing me from cognitive turbulence to embodied awareness.

As these examples show, temporal features differed significantly between design cases. The duration, rhythm, intervals and RoC were key to defining the *quality* of thermal cues — their texture, how they felt — and also their *function* — how they supported my emotion regulation. I also found it necessary to change the *responsivity* of patterns. In some cases, I needed them to respond to my bodily and experiential rhythms. In other cases, I needed them to enforce their own rhythms and patterns — to *dominate* and *induce* experiences rather than to support my own *reflection* or *augment* my existing experiences.

Beyond thermal binaries: temporality and agency. A further important consideration was the agency that designs afforded, in shaping thermal cues over time. I did not find that certain bodily locations, or thermal-temporal patterns were always and in all situations more effective than others. Instead, different contexts called for different temperatures and patterns. As such, the three designs deliberately avoided predefined, static forms of thermal feedback (on/off, hot/cold). They were designed to be adjusted to regulatory needs and situational demands. Over the months that I used the three designs, the agency this afforded supported both contextual and long-term adaptation. *Tomato* and *Clare* in particular were used in a variety of contexts. Over the weeks that I used them, long-term progressions or patterns in how I used them were hard to discern. Instead, the agency afforded by their thermal design helped them adapt to each context of use. *Window*, meanwhile, used in more controlled contexts, supported long-term adaptation, though again supported by moment-to-moment agency in controlling the cues.

Beyond the Hot/Cold binary. The thermal feedback of *Tomato* responded to the force and duration of my grasp. Sometimes, the initial cue did not feel strong enough to anchor spiralling thoughts. In these cases, I could tighten or prolong my grasp to increase the temperature intensity. Seasonal conditions also shaped how I

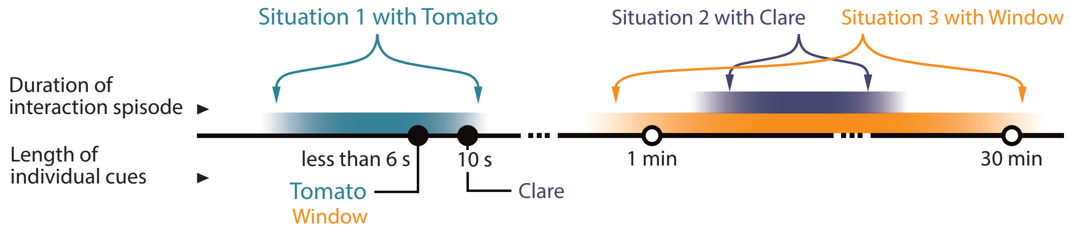


Figure 8: Timescales for the three interaction situations, and the prototypes (cases) used in each. (Below) the duration of thermal cues were all relatively short, while (above) lengths of interaction episodes varied more widely. Only in case 1, where the technology was designed to provide a brief stimulating "anchor" did interaction episode align roughly with length of cue. In other situations, I continued engaging with and triggering the cues for longer periods of time.

worked with the cue: in the Nordic summertime, to help cues stand out, I adjusted cues to cool to below skin temperature. At other times, I adjusted warming or cooling to ambient conditions. As well as influencing the sensory salience of the stimulus, these small choices involved me in the process, reinforcing the sense that the anchor was co-constructed and intentional.

Beyond the On/Off binary. The design of (*Clare*) moved further beyond a simple "on when held, off when released" interaction. The interaction design (responding to my holding and stroking) encouraged a longer, slower interaction, while the material's high thermal inertia mediated the rate of change and duration of the warmth. This created a slow thermal envelope that gently adapted to my handling, operating less as a switch, or event, and more as a temporal contour shaped through touch. I found that this supported retrospective reflection without prescribing its timing. In case 3 (*Window*), I created a different kind of adaptive temporal contour, adapting cues to the rhythms of mindful attunement. Moment-to-moment, I could modify the timing to (re-)synchronise with my breathing when entrainment felt difficult. Across weeks of practice with different rhythms, I moved towards a relatively stable breathing rhythm (a roughly 4-second: 6-second inhale-exhale pattern) that afforded introspective comfort. By contrast, when this adaptivity was absent, I found myself "chasing after" the pulse, attending to an external marker rather than turning inward. The ability to shape the rhythm preserved the sense of agency necessary for mindful attunement.

Taken together, these examples illustrate that moving beyond binary patterns — whether hot/cold or on/off — is not merely about adding nuance to thermal actuation. It is a way of designing with and for regulatory agency, treating thermal interaction as a co-evolving, adaptive *process* rather than a static, externally imposed *stimulus*.

5.4 Considering Sensory and Perceptual Qualities

Thermal cues are abundant in everyday life and often entangled with wider, multisensory, experiences. Sitting by the open window in my flat on a hot day, for example, I could feel warm air brush against my skin while the scent of greenery from the nearby park diffused into the room. Such experiences were thermal, tactile, olfactory, and affective, and the thermal information — the sense of heat — arrived through all of these senses. Building on this foundation, while my designs focused primarily on the haptic dimension of thermal cues, I was also attentive to how these experiences were mediated by materials I touched, by my sensory capacities, and by other sensory channels.

5.4.1 Mediating the perceptual qualities of thermal cues with materials. Material mediation emerged as a particularly important factor in my design practice, with materials placed between the thermal source and the skin often drastically altering meaning and affective quality of the cue. For example, direct contact with the ceramic coating of *Tomato*'s Peltier module conveyed temperature changes very abruptly and clearly, while introducing a layer of brushed cotton softened this and the overall emotional tone of the cue. These effects were not only due to material differences in thermal conductivity or heat capacity, but also to the way mediating materials shaped other haptic qualities such as texture, weight, and compliance (cases 1 & 2). For instance, for *Clare*, I experimented with rice wrapped in cloth — a common way of applying slow heat [84], to create a heavier, more solid texture. Yet, I found the scent of rice distracting and incongruent with the design's crow imagery, while the texture beneath the skin gave an impression of ill health. The black fleece finally chosen did not provide the same comforting weight or shape the thermal cue so strongly, yet its smooth, furry feel felt more congruent and affectively positive. Such examples made me aware of the rich networks of sensory and thematic correspondence that designers navigate when choosing materials for thermal technologies.

5.4.2 Working with perceptual abilities. Other examples in my design process revealed how design for thermal cues must accommodate the nature of our perceptual abilities. For example, I found that prolonged exposure to a stable temperature could reduce my ability to perceive changes and potentially dull the affective impact of a sensory cue. To counter this, I intentionally used contrast to preserve perceptual salience. For example, in case 2 (*Clare*), I used *spatial contrast* between different areas of the body, applying warmth only where *Clare* was held or stroked, while keeping surrounding areas cooler. This allowed subtle, slow increases in temperature to remain noticeable. In other cases, I used *temporal contrast*: In *Window*, changes in temperature followed a predictable rhythm, synchronised to breathing pace. In *Tomato*, I used abrupt changes to increase salience and create a more disruptive effect.

Across all cases, achieving the right balance required tuning parameters such as amplitude and RoC (see Table 2). These adaptations were more than mere technical workarounds for a sensory limitation. Working with **perceptual sensitivities** became part of the design space, allowing me to subtly guide attention, sustain engagement, and shape emotional tone. In *Clare*, for example, delivering the thermal stimulus at the site of the activating stroking gesture created a positive focusing feedback.

5.4.3 Multisensory or monosensory? More is not always better. In my RtD process, I explored how other sensory modalities could enhance the emotional resonance of thermal interactions. The promise of multisensory technology in HCI is well-documented [e.g., 113], with prior work pursuing the use of combined modalities to heighten salience, deepen affective engagement, and enrich meaning [e.g., 76, 86, 104]. Yet, my own practice demonstrated that the benefits of multisensory design are not guaranteed. Sometimes the addition of other sensory modalities yielded subtle, enduring contributions to emotion regulation. Other times, they collapsed into redundancy or distraction.

Sometimes, multisensory approaches were effective. *Clare's* thermal cues responded to a reflective holding and stroking gesture. The pattern was slow, subtle, and prolonged, aiming to gently ground my bodily state in moments of affective reflection. Later, I added a contrasting feature: a short, "wiggling" movement initiated by stroking Clare's beak (inspired by seemingly happy, relaxed, movements I observed in crows near my home). This juxtaposition of slow warmth against sudden motion felt effective, combining sensory pleasure with meaning. The sensory interplay seemed to work because each modality carried a distinct temporal and affective signature; complementing, not competing.

Multisensory designs were less successful in early prototypes for *Tomato*. Following multisensory design principles and my desire to experiment with a rich sensory palette, I combined thermal bursts with vibrotactile pulses to increase engagement and focus [76]. However, I found the thermal cue overpowered by the vibrotactile pulse, rendering it redundant. Staggering the onsets of the two modalities did not resolve the issue; vibration still dominated. Eventually, I created separate mono-sensory designs, one thermal, one vibratory. Each had distinct, practical advantages: the vibratory design required fewer batteries and was easier to carry, while the thermal-only version was quiet and discrete.

This led me to a broader reflection: multisensory design is not inherently valuable, and augmentation with additional sensory modalities should not be a default design choice. This is especially true for technologies used in environments already rich in sensory information. For example, multisensory experience while using *Window* often arose not from the artefact but from the surrounding context: the dramatic shifts of Nordic daylight, the scent of incense, the soft rustling of leaves outside my window. Sometimes these contextual stimuli augment the thermal experience, sometimes not: that depended on my affective background, motivation, and progress in emotion regulation practice. These emergent results were often far richer than anything I could have designed in advance, and more under my control. This was enabled by simpler, monosensory designs which left space for my in-context agency. This points to an approach to multisensory design that is less about stacking features and defining stable sensory correspondences, and more about creating subtle interactions that the user can integrate into the broader ecology of their sensory and emotional context.

6 The Thermal Affective Design Space

We constructed a thermal affective design space by synthesising the design space schema from all design cases (including the three presented), together with the findings reported above. This design space has four interrelated components: **Affective Experience**, **Design Parameters**, **Engineering Technology** and **Physical Configuration** (shown in Figure 9, with mappings to our design cases), capturing the interplay between factors that must be navigated when designing for thermal-affective experience and emotion regulation.

Affective Experience concerns the experiential dimensions of thermal cues relevant to emotion regulation practice: perceptual sensitivity, material quality, perceived temporal features, etc. Making these dimensions explicit allows designers to identify which qualities matter for a given practice, and to trace how they might be enacted through design decisions. We found that making this dimension available as a design material required work to make experiences clear and conscious: careful introspection (subsection 5.3), sensitivity to bodily vulnerability, sensory abilities (subsection 5.4), and the experiential context (subsection 5.2), and rich language, capable of connecting experiences to the contexts and associations that gave them meaning and texture (subsection 5.1).

Affective experiences cannot simply be implemented directly in technology: experiences and feelings are not inherently parameterised in the way demanded by technology. Designing for affective experiences thus required *translating experience* into the **Design Parameters** necessary to implement sensory and affective cues — modality, magnitude, rate of change, direction of temperature shift, and so on. Careful tuning of temporal parameters was often necessary when approximating desired experiences and effects (subsection 5.3). When considering parameters and their ranges, designers should consider perceptual sensitivity and vulnerability, and the pitfalls of over-complex multisensory cues (subsection 5.4). The experiences that can be addressed and how closely they can be approximated is determined by the current available parameter space: the parameters we can control, and the values they can take. For example, what materials are available to mediate heat, and how rapidly and precisely can we vary temperatures? Only when we attempt to formalise experiences in such design parameters do we understand the limits of this parameter space. These limits come from **Engineering Technologies** and **Physical Configuration**.

Engineering Technologies marks out the modes of thermal transfer and actuation methods designers can use to approximate experiences. Choice of technologies will be informed by the kind of experiential quality designers want to realise. At present, this means primarily resistive heating and thermoelectrics, but as explored in previous work, radiant and conductive heat sources offer quite different possibilities for affective and thermal experience [31]. Finally, **Physical Configuration** concerns matters of form and ergonomics: physical affordances, fabrication methods, forms and materials. These configurations both inform and constrain how design parameters can be implemented and how they are ultimately

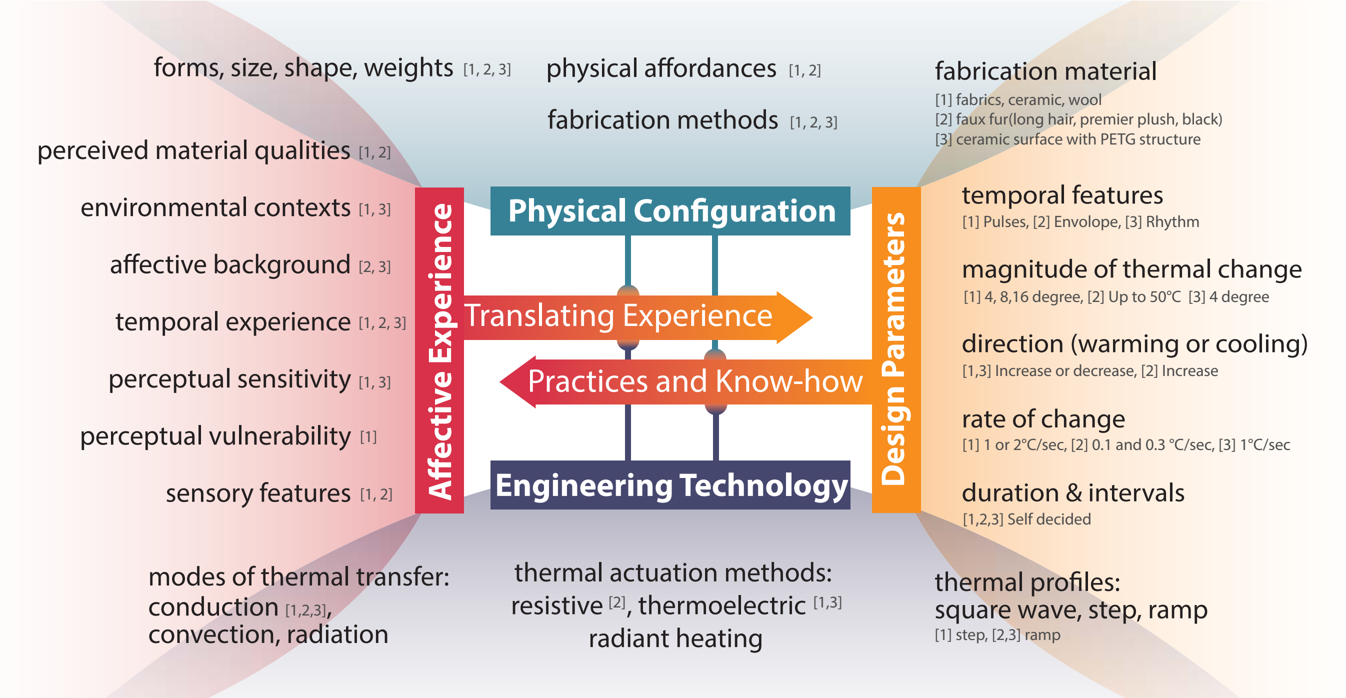


Figure 9: Our thermal-affective design space, with four overlapping aspects: Affective Experience, Design Parameters, Engineering Technology and Physical Configuration. We emphasise an iterative design process: translating experiences of affect and sensation into design parameters via rich descriptive language, then refining these design parameters via practices and know-how to approximate the intended experience. Engineering technologies and physical configurations serve as both constraints and enabling factors on this process, and on resulting design solutions. Here, we map the three design cases to this design space ([1]*Tomato,* [2]*Clare,* and [3]*Window*), illustrating how it can be used to analyse existing designs.

perceived. A change in material, for instance, may alter not only thermal conductivity but also texture, weight, or symbolic meaning by modulating the affective qualities of the cue. While these factors constrain the space of currently available Design Parameters, this is never final: as new technologies emerge, these constraints will change, extending the design space.

In design, none of these components can be considered alone since they all influence and constrain one another. As shown in Figure 9, movement between Affective Experience and Design Parameters structured the thermal-affective design process. Traversing this gap relies on **translation** — to move from experiences to specified design parameters — and **practices and know-how** — to move back from specification to well-crafted experiences (subsection 5.1). Progress in both directions was both enabled and constrained by Engineering Technologies and Physical Configuration.

7 Discussion

The four components of our design space illustrate the layered negotiation between experience, parameters, available technologies, and physical format. This schema, together with our wider findings, makes clear that thermal affective design cannot be treated as a straightforward linear mapping between measurable affect and definable parameters. Rather, it is an iterative interplay, where choices at each level continually reshape what is possible at the others.

This design space differs from prior approaches. Unlike experience-focused frameworks that primarily offer vocabularies for conceptualising affective thermal experience [31], or technological typologies that organise existing applications by actuation type [59], our design space brings these perspectives together to offer guidance for the complex navigation and negotiation back-and-forth between these perspectives. As our findings illustrate, this back and forth is essential for moving beyond propositional knowledge about experiences or technologies, and towards effective experiential design. While our design space is grounded in design for emotion regulation, its focus on affect, qualities of experience and support for reflection points to broader applicability. The considerations and principles we outline are relevant to the design of a broad range of thermal and affective technologies. In the discussion below, we outline the key challenges and opportunities for thermal design indicated by our findings. We then discuss the contribution of the design space schema approach, surfacing and organising decisions throughout the design process.

7.1 Thermal Cues as a Design Material for Emotion Regulation: Challenges and Opportunities

7.1.1 *Challenge 1: Moving from know-what to know-how in design.*

The first challenge identified in our analysis was the movement from knowing to doing when navigating between Affective Experience and Design Parameters. We found that articulating design requirements often relied on explicit, propositional knowledge: the "know-what" of scientific knowledge about perception [e.g., 12] and technical knowledge about engineering [e.g., 61]. The act of shaping interactions, meanwhile, relied on tacit know-how: the kind of practical, situated, inner-knowing that Polanyi refers to when he writes "we can know more than we can tell" [88, p. 136].

To illustrate, the literature offers rich information about thermal perception: the behaviour and distribution of thermoreceptors and mechanoreceptors, for example. This know-what clarified possible design *directions* (for example, treating body location as a parameter and the thenar eminence as a promising location), but offered little guidance for the more granular, concrete aspects of design. In practice, this gap was bridged through an iterative process of clarifying impressions, identifying and adjusting parameters — all guided by propositional knowledge, but instantiated through skilful adjustment and practical reflection. This meant a lengthy process of experimentation with materials and temporal patterns, identifying issues (such as time lags between thermal actuation and perception), until eventually the desired effect was achieved. Importantly, the results of this process did not always align with initial intentions, and sometimes this misalignment was generative. In the design of *Tomato*, for example, the most effective thermal cue was far sharper and more intrusive than initially anticipated (see Table 2) in a way that proved highly effective. Iterative practical engagement and self-testing made it possible to discover, recognise and capitalise upon useful outcomes that sat beyond or between the data points of propositional knowledge (see subsection 5.1).

For design research, such observations raise the question of how we might better scaffold this movement between know-what and know-how. In our practice we found language was a key tool in this process: clarifying and anchoring perceptions in meaningful associations and providing a pivot between felt experience, design intention, and parameterisation. Some prior work, in somaesthetics for example, [55], has emphasised the limitations of language, arguing that embodied awareness, felt experience, and sensibilities are essential to cultivating designerly know-how. We do not see this as inconsistent with an important role for language in design, but rather a caution against a sole focus on language, or allowing language to become disconnected from experience and know-how. As in our process (see Figure 2) designers may wish to draw on language alongside a range of other modalities, including sketches, gestures, photographs, and verbal articulation to bridge propositional and practical knowledge. Still, we see potential for more hands-on means of sharing the experience of moving between know-what and know-how.

Opportunity: Translational design toolkits. One promising direction for communicating know-how is the development of interactive translational toolkits combining experiential and design knowledge, with exercises and practical resources. By combining easy to use tangible and interactive devices and components (as in [119]) with theoretical resources and exercises, these can allow designers to move more fluidly between parameter testing and perceptual verification. This can reduce reliance on unguided trial-and-error and make tacit design understandings more shareable. Our design space and findings offer a conceptual frame, process guide and a source of translational exercises for the development of such toolkits. For example, a tangible thermal toolkit could operationalise the translational approach we describe, allowing designers to experiment with and prototype experienced rhythms of thermal change. Interactive devices, implemented in open-source hardware (e.g., Bela [78]), can incorporate high-level control principles to enable more direct, intuitive interaction with temporal patterns without the need to implement low-level code. This can help designers iteratively implement, experience, and refine affective thermal experiences in a structured way, forming design intuitions and connecting perception to theory. Other relevant resources could be drawn upon in developing such a toolkit, including work documenting mappings between design parameters and Finnish sauna experiences [81], classification of actuation methods [59] and design cards [32] that articulate design principles for thermal experience design and sense-making.

7.1.2 *Challenge 2: Accessibility of thermal actuators.*

A second challenge concerns the Engineering Technology and Physical Configuration aspects of our design space. At present, navigation between Affective Experience and Design Parameters is constrained by limitations in the configurations and form factors of standardised components and the availability of off-the-shelf thermal actuators. While the first author intended to explore a range of actuation methods, availability constraints limited implementations to just two kinds of actuator (details provided in technical reflections in Appendix A): thermoelectric modules in *Tomato* and *Window*, and resistive heating pads in *Clare*. While these components enabled quick prototyping, this came with trade-offs. For example, thermoelectric modules require rigid mounting, external heat sinks, and high power consumption, requiring cumbersome, specialist power supplies. This limits their integration into flexible, wearable forms and raises concerns around sustainability (see subsection 5.2). Heating pads, by contrast, were simple and accessible but came in fixed forms, making them difficult to adapt.

Technical limitations also shaped the user experience. Early designs for *Window* focused on wearable technologies for meditation, yet this soon ran into a dead end. Properties of the available components resulted in considerable setup before each meditation session: e.g., adjusting power supplies and managing heat dissipation. This recurring effort proved a barrier to incorporating the system into mindfulness practice, and even a source of stress. As such, despite its promise, this design direction was abandoned. Such practical barriers always pose a challenge when prototyping wearables, but they are perhaps particularly acute in the case of emotion regulation. Therapies such as Acceptance and Commitment Therapy (source of the *anchoring* strategy) emphasise the need to reduce barriers to performance [see e.g., 47]. Practical barriers can pose a particular challenge for neurodiverse people who often experience behavioural inertia and task-switching difficulties [11] that may be exacerbated by the need for setup and adjustment.

Opportunity: Customizable thermal actuators and open-source hardware. This reveals an opportunity to develop more adaptable, user-centred thermal components. A wider range of forms and materials can support designs that promote agency (see subsection 5.3) and "highly respectful" integration into users' routines and preferences [2, 110]. For example, shape-customisation of resistive heating elements, or affordable, customisable flexible Peltier modules, could enable use of these actuators in more diverse interactive forms and contexts. While HCI and fabrication researchers increasingly investigate the fabrication and customisation of low-level components to support the design process [e.g., 15, 45, 83, 94, 95], to date, no such work has addressed thermal design. Such components (particularly if integrated into open-source toolkits, as in opportunity 1) could broaden the design space for affective thermal interaction and lower barriers to self-use, personal appropriation, and DIY exploration [see e.g., 87]. Ultimately, they could support what Gaver calls the "ultimate particular" [37]: design tuned to specific users, purposes, and situations.

7.1.3 Challenge 3: Synthesising knowledge from multidisciplinary research. A third challenge was the difficulty of synthesising knowledge from very different epistemic traditions. Researchers approaching thermal design from an engineering perspective often begin with technical descriptors such as square waves, ramps, or amplitude changes and the reliable control of thermal stimuli [99]. In terms of our design space, such approaches focus on defining Design Parameters and expanding capability via Engineering Technology. By contrast, other research — often grounded in phenomenology, embodied design or somaesthetics, for example — tends to begin from the felt body then extrapolate towards design [62]. In terms of our framework, they begin from Affective Experience, and often focus on expanding the possibilities of Physical Configuration. Neither approach is "better". Each reflects its own disciplinary priorities and design goals, and each is essential to understanding the design of technologies for experience.

In the design process described in this paper, we sought to bridge and translate between these two perspectives. How does a square-wave thermal pulse feel in use? How does that feeling change at different frequencies? Conversely, what engineering possibilities exist for approximating a subtle experiential quality such as "warm, gentle pressure experience" [62, p.111]? Arguably, the challenge lies not in a lack of knowledge but in a lack of handshakes between different ways of knowing. A set of waveforms [99] tells us little about the qualities of experience they might evoke, while experiential accounts of the "felt body" [62] offer few clues about how they might be implemented. For design research, this makes it hard to build cumulative knowledge or integrate insights across engineering-driven and experience-driven approaches.

Opportunity: Translational works for sensory design. This points to the need for translational works that facilitate communication across epistemic boundaries. By combining careful analysis of first-person experience with technical prototyping (subsection 5.1), our work makes efforts in this direction (see subsection 5.4). There are many routes forward here. Micro-phenomenological interviews may be used to investigate the intricacies of lived experience, and map experiential descriptions more precisely to design principles [50, 122]. Equally, constructive design approaches may be used to articulate vocabularies and design patterns that translate experiential qualities into possible design activities [31]. More systematic efforts could take the form of shared research toolkits, multi-disciplinary workshops to develop shared language, or empirical studies that explicitly link engineered signal profiles with reported experiential qualities. Such translational methods can support richer collaborations between HCI designers, experience researchers, and technology innovators, not only advancing thermal and affective design but multisensory design more generally.

7.2 Using the Design-Space Schema to Construct Intermediate-level Knowledge

A recurring discussion in HCI is how design practice contributes to theoretical knowledge [19, 43, 65, 91]. One common contribution is a design space: an intermediate-level knowledge contribution that structures options, dimensions, and trade-offs for future work [25]. Yet in many prior cases, the process by which design spaces are constructed remains implicit: we are often shown the outcome without the reasoning that shaped it [e.g., 69]. We used the Design Space Schema approach [7, 24] to make our process of synthesising a design space more explicit. This both helped organise our large body of documentation , and encouraged us to articulate and organise the reasoning behind expansions and reductions of our design space: why certain aspects were included, and why others were pruned.

Explicating reasoning in this way has several benefits. First, it clarifies how diverse sources inform the design space, including insights from therapy, theoretical framings of experience, and technical limitations of actuators. Clarity about these sources helped us to be more precise and conscious about design constraints (e.g., the unavailability of flexible actuators) and to see them not only as obstacles, but also opportunities for innovation (see subsection 7.1, above). Further, explication of the process can enhance rigour. As Zimmerman et al. argue, rigour in RtD depends on providing enough detail that "the process ... employed can be reproduced" [124, p.499]. By revealing both the "what" and "why" of design knowledge, we aimed to support work to extend, critique, and test our work, and adapt it to new technological, scientific, and sociocultural developments. For instance, availability of flexible and customisable Peltier modules could expand the options for "body location", allowing the expansion of the design space as technologies and practices evolve. In this sense, our design space should not be a fixed artefact but a living structure.

Intermediate-level knowledge can take multiple forms. Beyond "design spaces" [75], previous work has described "strong concepts" [56] and "bridging concepts" [19], for example. The design space approach best supported our translational goal: moving from lived, affective experience toward actionable design parameters. As discussed in subsection 3.3, the design space schema approach helps structure attention to design judgements, experiences and actions, making them explicit and analysable. In our case, this helped us to become aware of how experiential qualities were instantiated in technical and material choices, and to present this as a structured landscape of possibilities rather than a set of singular exemplars. This is consistent with our goal of offering designers a navigable structure to connect felt experience with implementable design decisions.

However, no one approach can serve all goals. Design spaces clarify options and relations across the design process, yet they do not capture the depth of phenomenological experience nor the narrative nuance of personal practice captured in other approaches. As we have articulated above, we see broad opportunities for future work to extend our findings here through a range of methodologies and forms of knowledge, including microphenomenological studies and autoethnographies more focused on the evocation and articulation of experience.

8 Conclusion

This paper presents a design space for thermal affective technologies that articulates thermal cues as rich, expressive design materials for emotion regulation. The design space grew out of an 18-month, autoethnographic, Research through Design inquiry, combining therapeutic practice with iterative prototyping. Its four interrelated components— Affective Experience, Design Parameters, Engineering Technology, and Physical Configuration — describe the key factors that must be navigated when designing thermal technologies for emotional support.

Our design space provides structured guidance for thermal interaction design, highlighting the central role of translation between experiential qualities and technical implementation. Second, by using the Design Space Schema approach we make our design reasoning explicit, contributing process knowledge for developing intermediate-level theory in HCI. Third, our autoethnographic RtD surfaces rich, first-person insights difficult to capture via second- and third-person methods. We discuss how these insights are essential for design in affective contexts where experiential nuance, bodily awareness, and contextual sensitivity are central.

While developed for emotion regulation, this design space and our methodological insights have broader applicability for thermal interaction design and experience-focused HCI research, providing resources to advance technology design for affective experience in a range of contexts.

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A Choosing Between Forms of Thermal Actuation

Relevant to the integration of thermal cues with other modalities, heat can be transferred in three broad ways: by conduction (direct surface contact), convection (air movement), or radition (electromagnetic waves). Though the presented finished design cases focus on conduction, all three modes were explored in my design process, using a range of actuators, from fans, to Peltier modules, to resistive heating pads. I found that each afforded distinct possibilities for design. While previous work has categorised and surveyed technical options for thermal delivery [e.g., 59], I found few accounts of how designers reasoned through such choices from a design or experiential perspective. As such, here I reflect on these choices in my design process.

Due to their availability and common use I primarily made use of resistive heating actuators . These convert electrical energy into heat by resisting electrical current (e.g., using nichrome wire). I found that off-the-shelf resistive heating pads were easily integrated with fabrics and deformable designs (such as Clare) due to their flexibility. However, their inability to stretch limited my use of these pads in wearables, especially near joints and other mobile body areas. Further, they limited my design choices to heating, not cooling, while their plastic outer layer (required to electrically insulate the heating element) reduced the immediacy of their thermal cues.

To expand the expressive range of thermal cues I often used thermoelectric actuators based on the Peltier effect. These can both heat and cool, creating faster, more controllable thermal transitions. This bi-directionality allowed me to design more dynamic emotionally expressive cues. However, commercially available Peltier modules are difficult to integrate into deformable or irregular interfaces, being rigid, square-shaped, and ceramic-coated. Further, their requirement for additional heat dissipation (e.g., via heatsinks or fans), resisted quick prototyping and created barriers to use of the prototypes, particularly as wearables.

I also explored radiant heat sources, such as infrared emitters and natural sunlight, to support "non-contact" thermal interaction [59] and a sense of immersion. In case 3, I used sunlight as an ambient facilitator for emotional reflection — demonstrating the potential to leave space for users to integrate designed sensory cues with their already-multisensory environments (see section 5.4.3). However, I found their directional nature and slower response made them less effective for localised or responsive feedback.

Beyond electrical heat sources, I explored other forms, including induction, mechanical, and chemical heating in early prototyping and ideation, but proved difficult to integrate into design. Mechanical thermal sources, for example (e.g. running motorised wheels against surfaces) offered unique temporal-spatial patterns but added mechanical complexity and noise. Meanwhile chemical heat elements (such as sodium acetate hand-warmers) were low-cost and self-contained, but lacked controllability and reversibility, making them unsuitable for interactive or responsive applications.

B Auxiliary Materials

https://osf.io/spktx/overview