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Discomfort: a new material for interaction design

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We present discomfort as a new material for HCI researchers and designers to consider in applications that help a person develop a new skill, practice, or state. In this context, discomfort is a fundamental precursor to a necessary adaptation which leads to the development of a new skill, practice, or state. The way in which discomfort is perceived, and when it is experienced, is often part of a rationale for rejecting or adopting a practice. Factors that influence the choice to accept or reject a practice of discomfort create opportunities for designing interactions that facilitate discomfort. Enabling effective engagement with discomfort may therefore open opportunities for increased personal development. We propose incorporating discomfort-as-material into our designs explicitly as a mechanism to make desired adaptations available to more of us, more effectively, and more of the time. To explore this possibility, we offer an overview of the physiology and neurology of discomfort in adaptation and propose three issues related to incorporating discomfort into design: preparation for discomfort, need for recovery, and value of the practice.

KEYWORDS
discomfort design, adaptation, Inbodied Interaction, tuning, health, wellbeing, performance

1. Introduction and motivation

We are wired to thrive via discomfort. That is, we have evolved such that our learning, physical wellbeing, and even social interaction all develop across a gradient of what Mattson et al. (2018) have termed *intermittent challenges* ranging from hunger, to heat, cold, fatigue, and cognitive challenges like skill acquisition. In other words, we thrive *from* bouts of discomfort. What's more, stacking discomfortable challenges has been shown to amplify the benefits. For example, where most of us experience even a slight hunger pang as discomfort, Mattson suggests that people who engage in extended fasting experience certain adaptations:

> [E]merging findings are revealing remarkably complex and coordinated adaptations of the brain and body that enable the individual to maintain and even enhance their cognitive and physical performance for extended time periods in the fasted state.

Mattson also notes the benefits on cognitive performance when combining physical challenge and fasting together.

> Cognitive challenges performed during exercise result in levels of enhancement of synaptic plasticity, as well as learning and memory, greater than either challenge alone. ... [F]rom an evolutionary perspective, it is noteworthy that precise navigational decision-making (cognitive challenge) while rapidly traversing the landscape (running) in a food-deprived and/or fasted state would be critical for survival.

In our related work on Inbodied Interaction (Schraefel, 2020) we highlight the physiology of our bodies as the site of constant adaptations to context. This refers to non-stop adaptation to whatever is our current environment – both internally and externally. Our internal processes of metabolism are constantly responding to adaptation cues, from digestion going on inside of us, to changes in our environment's temperature going on around us, all in order to maintain our internal state – our homeostasis.

Discomfort is almost always a predictable feeling associated with the experience of our metabolism attempting to process a novel or sufficiently infrequent interaction wherein we need to process more energy/use more resources than typical to maintain that current internal state. Being too hot and sweating ortoo cold and shivering are experiences that initially induce a discomfortable experience. That is, while triggering an adaptive response metabolically to reduce the cost of repeated doses to that experience, we experience discomfort. In some contexts, we take this signal of discomfort as a threat signal: we attempt to get out of that situation as quickly as possible. People who are more introverted may seek to leave a social gathering as quickly as possible because of their physical discomfort. This is understandable when one lacks understanding of either their reaction or the skills needed to cope with this situation – and make small talk with their neighbor. But adaptation is possible – and happening all the time. If we are regularly exposed to bouts of cold, over time, we notice that our discomfort in that context is less. We become, physiologically, more cold-adapted (Castellani and Young, 2016) or, in the opposite temperature range, we become more heat-adapted (Siquier-Coll et al., 2023). If we start to run, mixed with intervals of walking, with repeated bouts, we walk less and run more. As we practice more problems from statistics, with better success, topics like ANOVAs become less daunting and more usable. That is, our bodies – including our brains - have adapted internally to support these processes with less metabolic cost, and thus less discomfort. What was once "difficult" - and discomfortable – is now easier.

Despite the ubiquity of discomfort and associated adaptation across a range of experiences, we rarely talk about the experience of discomfort explicitly as a largely necessary part of that progress. We have not found work that frames discomfort explicitly as a normal, necessary component of an adaptive process where we wish to get better at something: to learn a new skill, to gain strength, burn fat, speak in public, or interact better at parties. Instead, the focus is typically on the adaptation effect at the end rather than the experience in between. Lift weights regularly and over time you get stronger. Eat less every day and over time you will burn more of your stored fat. And yet, all of us know, these experiences are not just fun especially initially.

Given our interest in Human-computer interaction (HCI) in experience, we suggest that engaging directly with physiological discomfort-for-positive-adaptation offers new pathways for HCI to help people better engage with desired processes – like better skills, better health, and better quality of life. In addition, our experience as and around professional health and strength and conditioning coaching is that we have seen potentially positive healthful processes abandoned in the past because discomfort was experienced as a roadblock, or a signal that something was not safe. We have seen how lack of preparation for discomfort and an understanding of how to anticipate and work with it can lead to giving up on any other practice for fear of repeating the same experience. Also, discomfort interpreted as threat or signal of lack of capacity or failure can also break trust with any guide, potentially including interactive technology for education or coaching.

In this paper, we therefore propose Discomfort Design: a design approach to engage with discomfort explicitly to better support exploring experiences to support positive adaptation. In the following discussion, we present more of our rationalization to explore discomfort as a design material; we situate it within the closest approximations within HCI and related literature. We look at how discomfort, while often used interchangeably with the term "pain", is different from it. We offer some of the physiology of adaptation and discomfort's role in these complex processes to demonstrate how an understanding of these processes can make the desired post-discomfort experiences more accessible. From these sections, we offer an initial set of five considerations that designers can use to better incorporate discomfort into their artifacts: preparation for discomfort, support during discomfort, micro-rewards, support for recovery, and role of the practice. We also propose dimensions of discomfort that support thinking about discomfort as a new material in design. Our intent in offering this approach is to invite the community to explore, test, and further refine these parameters toward a generalizable "discomfort design framework" to help us, as a community, design better tools to support health, wellbeing, and performance.

2. How HCI's "ease of use" fits with embracing discomfort as a design material

Our technologies - not least our digital technologies – have been increasingly designed to move us toward alleviating the briefest feeling of immediate discomfort for more immediate gratification. There are costs to this exchange. The trade away from short bouts of discomfort has meant the experience of slower development but longer lasting chronic pain and illness, Chronic daily enabled sedentarism for example is tied with long-term musculoskeletal pain and cardiovascular disease (Nijs et al., 2020). Cheap, immediately accessible, highly palatable calories are tied with metabolic syndrome and chronic inflammation. Even lighting puts off rest to enable non-stop entertainment, which distorts our cellular clock rhythms, inducing stress, fatigue, and cognitive decline.

Given the essential role of discomfort in adaptation, discomfort designers ask: how do we design systems to help people embrace the associated discomfort as a temporary, necessary part of a health, skill, or learning process? In HCI, we might say our discipline is designed fundamentally to avoid discomfort. Our focus is often to make engaging with a task or system as effortless as possible. Our systems rarely engage the physiologically and functionally necessary aspects of discomfort toward improvement outside one interesting example: games culture. Games require skills development to succeed: in classic video game interaction, one must embrace the frustration of repeated "virtual deaths" to improve performance. And yet, each level is progressive. The intriguing history of game hacking to learn hidden secrets to make different levels accessible – not least in pursuit of larger rewards or greater status – also demonstrates our desires to find short cuts in progress. Game hacking can accelerate speed of access to decrease time in work. These hacks may also show that progressions from one level to the next are not always best designed to demonstrate skill adaptation. It may just be that the designers unintentionally did not leave enough traces to support solving a particular problem beyond luck.

On the other hand, there are games like the notoriously difficult interface of QWOP[1] that are designed to be frustrating. Knowledge, skills, and practice for life are discomfortable enough as material for discomfort design so there is no need to add frustration to artificially create discomfort. Likewise, our intent is to leverage the body of work in HCI to create usable and useful interactions that support people to anticipate and engage with the associated discomfort in support of the positive adaptations they seek. In physical training culture, an expression is "everyone needs a coach." Discomfort is not avoided *per se*; a great coach helps increase the value of the time spent in discomfort to develop the skills to achieve the next level of performance. The discomfort therefore becomes more meaningful—and, in HCI terms, more useful and usable.

In that sense, we would offer discomfort design as *both* a departure from and an affirmation of usability. It departs from usability by deliberately foregrounding the locations of discomfort in a practice. It affirms usability by employing HCI principles to make the discomfortable aspects of a practice as effective, meaningful, useful, and usable as possible.

Before getting into detail of this proposed approach, it is important here to make clear what we are *not* addressing when we talk about discomfort. Our focus in discomfort design is on *the physiological responses to demands for adaptive responses in context*. This is a distinct area where ""discomfort" has been framed as politically and socially constructed sites of discomfort, which the neuroscience literature frames as intermittent challenges, described above.

In user experience design, HCI designers like Sondenrgaard have drawn on Haraway's concept of "staying with the trouble" (Haraway, 2016), which "requires learning to be truly present" as "mortal critters entwined in … configurations of places, times, matters, meanings" (Søndergaard, 2020). Examples of designing to deliberately trigger these kinds of situated, social discomforts include Helms and Fernaeus' "troubling care" (Helms and Fernaeus, 2021), the exploration by Almieda et al. of women understanding pelvic fitness DiSalvo's (2015), and (Almeida et al., 2016) adversarial design.

These examples of "staying with the trouble" might be seen as similar to our concept of "engaging with discomfort." However, the similarities largely end there. And that's ok. In the above examples of experience design and design more broadly, there is a critical focus on the making apparent the social construction of, in these cases, women's bodies, the viewing of women's bodies, and the social/cultural construction of the physiological processes of women's bodies. These designs are deliberately provocative to challenge the deliberate actions of making the being-ness of the female body in contemporary culture invisible and nasty. An object of the work may be to provoke discomfort in order to then provoke an emotional or intellectual response. The designs ask why this sight makes you uncomfortable. While this question is crucial for interrogating cultural norms, it is not our question or orientation in treating discomfort as a material.

Likewise, we are not situating our work on discomfort as something in contrast to "flow" as described by Csikszentmihalyi (2000). Flow is presented as a state of bookended boredom. One is bored if something is either too easy or too hard to be engaging, whereas in Flow, the challenge is just right. One might see boredom as a type of discomfort, but it is distinct from the type of discomfort we are describing. In experiences to support flow, boredom is to be eradicated as useless for flow, as if something is too easy or too hard it will never be engaging, and that engagement is necessary for creative growth and expression.

Finally, our concept of discomfort does not include inconveniences or annoyances that have no purpose. For example, an itchy sweater might cause discomfort in the sense that it is unpleasant to wear or a shoe that is too small might cause discomfort while walking. The difference between these experiences and the kind of discomfort we describe is that these experiences are not part of an intentional practice designed to trigger intended physiological adaptations.

In our case of discomfort as sign of physiologic adaptation, discomfort is not to be escaped, but understood, and used as a material for building knowledge, skills, and practice. In the work presented here, therefore, we consider how to understand the features of these processes and to learn to use them as a design material.

3. Background

As noted, our consideration of discomfort is situated within the context of Inbodied Interaction. Inbodied Interaction (Schraefel, 2020) fundamentally suggests that, by considering the physiological processes that take place across all 11 of the body's organ systems, we will be in a place to better *align our designs* with how we function optimally as complex systems of complex systems, operating in environments/contexts that are also complex. Discomfort Design was first proposed as a part of this Inbodied Interaction consideration at a Ubiquitous Computing Workshop in 2019 (Schraefel et al., 2019) and a follow-up paper (Schraefel et al., 2020). In that workshop and paper, a key consideration for discomfort was how what we might frame as more global processes of discomfort is necessary for positive adaptations. How, the workshop participants explored, might this kind of beneficial discomfort be embraced in terms of relations to our individual and social wellbeing and sustainability - from food consumption to housing (Tyler et al., 2019)? What these questions on this macro level have raised about using discomfort as a design material that need to be clear for design include, beyond a sensation of varying degrees of intensity, what *is* discomfort? How is it the same as or different from pain? What role does something seemingly negative serve in being so fundamental an enabler in health to growth? And how can we use these understandings more deliberately in our designs to enable these benefits more deliberately in our interactive technology designs? It is from this context - of attempting to better understand the properties of discomfort as material - that we present the following sections: that discomfort is distinct from pain, that recovery from discomfort of adaptation

1 See https://www.wikihow.com/Play-Qwop.

is needed for adaptation consolidation, and that long-term value motivates engagement in short-term discomfort.

Given that discomfort is interlinked with a desired adaptation, we ask what can we learn about discomfort itself and how might we more deliberately embrace and deal with discomfort within our designs? In Inbodied Interaction, we call the parameters of adjusting practices to support adaptation "tuning" (Schraefel and Hekler, 2020). That is, how can we connect knowledge, skills, and practice (KSP) with a clearer awareness or perception about how a particular intervention affects us. For example, a sedentary person may be asked to explore standing up from sitting, then sitting down and standing up again. Effectively, they are asked to repeat a movement they already do (sitting/standing) to trigger a new adaptive response to deal with this new demand. This body weight movement may be uncomfortable because of the harder breathing induced in the moment of the activity, and also the next day with sore muscles. Although without this novel stress of both the respiratory and muscular systems, the body will not produce the necessary adaptations for the person to become stronger, and thus build up their health (Dent et al., 2023).

Tuning includes making these variables of action and their effects available, explicit, and moderatable in order for them to be manageable and successful. Similar considerations are necessary when designing for more cognitive-based activities like problem solving and concentration, where new skills, and neurological/endocrinological responses and paths – physical processes all – are developed. The philosophy of discomfort design is simple: by designing *with* and for discomfort awareness, we can help mitigate its negative effects on achieving aspirations.

4. The anatomy of discomfort

All processes and experiences are mediated by the body, even cognitive, social, and emotional ones. They are all experienced in the body, where the state of the body (including the brain) affects how we perceive and react to any experience at any time. Thus, discomfort is both a physiologically mediated process and a perception. Discomfort is associated with physiological processes invoked by stimuli, and our perception of discomfort is complex. We will consider both process and perception below. We appreciate that the following sections are largely explanatory but necessary as this science of discomfort is new territory for most of us in the HCI the community. Therefore, in order to suggest how we can use these processes to inform a design material, we offer the following as an overview of properties of discomfort for interaction design.

4.1. Brief overview of the physiology of adaptation

In order to understand discomfort, we need to understand something of the fundamental physiological process to which it is attached. That is, adaptation. To expand on what we touched on above from an inbodied interaction lens, the body is primarily the "site of adaptation" (Schraefel, 2020). It manages this adaptation as part of a triple process: a trigger or context that requires a physiological response, via metabolism, to maintain homeostasis. In brief, homeostasis refers to the internal environment of the body that must be maintained within strict ranges in order to function. We can track these states via measures like blood pressure, Ph, temperature, fluid levels, and so on. Metabolism is the conversion of incoming resources, like nutrients, into fuel to power other metabolic processes, like generating new tissues or recycling cells that the body requires to function, all in response to changing external demands, like learning a new skill, or trying to keep warm in a suddenly cold room. These are responses to demands for adaptation.

The key takeaway here is that the body is *constantly* adapting to context, and everything is context. Sitting in a chair, reading this paper, requires a non-stop balancing of internal resources to enable all the demands - from maintaining cognitive focus to physical position over any given period of time – to be met. Those adaptations will be different depending on previous and ongoing adaptations driven by how we sleep, eat, move, think, and engage with others (Schraefel, 2019). They will be affected by how much light we have, the quality of the air, and the microbiome within it – and thus within us. Within these interactions, the body is constantly responding to the requirements imposed by the environment or context both external and internal to the body to maintain its homeostasis - in any context (Kanwetz, 2016). It bears repeating that there is not a single moment when the body is not *on*, when it is not responding to the most subtle shift in states to maintain its capacity to function and to stay alive as effectively and efficiently as possible.

The management of homeostasis is a critical component of the discomfort experience. The metabolic processes triggered to maintain homeostasis is largely managed by the autonomic nervous system (ANS). The autonomics are those processes that happen without requiring conscious attention. The nervous system itself is divided into two main branches: the central and peripheral (Farley et al., 2014; Massadi et al., 2017). The central references the nervous tissue of the spinal cord and the brain. The peripheral references the nerves that connect with every other part of the body. As sensory information like touch, sight, and hearing comes from the periphery (PNS) into the central system (CNS), the ANS receives CNS signals from the brain that automatically moderate peripheral processes, like the beating of the heart, the constriction of blood vessels, and the depth of breathing. Within these changes, when we feel discomfort, these include signals coming from nervous system sensors known as nociceptors and chemoreceptors. The areas of the brain associated with the ANS may interpret these signals as pushing us toward a threshold affecting homeostasis. At this point, we may be making a decision on whether we can keep going or need to pause, slow down, or stop what we're doing – if only for a moment.

Recent work has shown that physical effort is gaited by volitional decisions to quit well before we would actually cause ourselves harm (Noakes, 2012). Thus, signals that we interpret as discomfort – and the amplitude of those signals - is contextual and experiential. If an experience is less familiar those signals may seem much louder. An easy example to explore is referred to as "air hunger drills." If we expel our breath and then close our mouth and hold our nose we will after a minute or so experience a sense of needing to breathe. This signal is really a signal to exhale rather than inhale to rid the body of building-up carbon dioxide that is keeping oxygen in the blood from getting to cells. This signal can be suppressed Parkes (2006, 2012). Initially, however, when we are not used to it, we may panic especially if we feel something external is interfering with our breathing. During COVID, a considerable issue for people on ventilators was around this experience of air hunger and associated panic that they were suffocating (Worsham et al., 2020). It is far from pleasant. Use of air hunger drills – moving through the discomfort toward skills to manage suppression – has been shown to have a variety of positive adaptations such as improving ventilatory capacity (stroke volume) (Woorons et al., 2021) and red blood cell development (Persson et al., 2023); it also has positive adaptations in the brain (Tseng et al., 2010).

4.2. Discomfort and adaptation

We might ask here, if we are constantly adapting to context, why are we only occasionally discomfortable? We might think of the lack of discomfort this way: the body's metabolism is able to maintain the requirements for more or less familiar physical and cognitive and social demands without requiring a significant or new range adaptation. Discomfort is generally associated with the experience of pushing the body into a state that challenges its current threshold at which it can maintain homeostasis. That limit will be different for different people in different contexts.

Consider someone running as fast as they can to catch a bus pulling away. We may notice that the person slows in about 7–9 secs - and stops before the bus starts to leave; they are huffing and puffing, hands on their knees, though they may only have been moving at a pace not much greater than what is considered walking speed (2–4mph). For that commuter, their discomfort is associated with an unaccustomed effort that has taxed a particular energy system [the phosphocreatine system (Saks, 2008; Guimarães-Ferreira, 2014)] that can provide a burst of energy for <10 s by which point they could physically keep moving, albeit slower [another system, glycolytic, dominates at this time (Baker et al., 2010)] but, they have told themselves to stop from fear that this unfamiliar pounding in their chest may be a heart attack. Recent work suggests that this discomfort and fatigue that induces quitting (Ishii et al., 2014) is both physical and mental (Cutsem et al., 2017). Their heavy breathing is both rebalancing the gases their body needs for homeostasis, and also panic - a response to a perceived threat rather than actual physiological harm [we often over-breath in recovery from an effort (Woorons et al., 2016)]. Often when one is not prepared for or familiar with discomfort associated with a new effort, they will – not unreasonably - interpret it as pain, or boredom, and thus as a signal to stop, rather than as a signal that greater than usual adaptation is actually being invoked right at that moment. Building a skill, building strength, and shedding fat are more obvious cases of adaptation often associated with discomfort: we speak of the amount of discipline and motivation required to keep someone "on task" to put in the "work" required to build new capacity. We talk about the need to break a plateau in a current skill or state by "getting out of our comfort zone." Discomfort, as a precursor to progress through adaptation, is not optional; the way we experience that discomfort, however, is, and that experience is where we see opportunity for HCI design/research.

4.3. Discomfort and pain

A question that comes up when we discuss discomfort is: what is the difference between discomfort and pain?

A general heuristic that our work draws on for separating discomfort from pain is that discomfort is an uncomfortable sensation that one can move through and with, without it being debilitating; pain, on the other hand, may include feeling uncomfortable but will also inhibit performance. Both discomfort and pain happen in the brain; both are signals. As Melzack (1999) described the complexity of pain as a "neuromatrix" (Melzack, 1999; Visser and Davies, 2010), pain is multifactorial.

Discomfort signals enabling adaptation; pain signals limiting performance. Sometimes, in some contexts, the brain may not allow signals for either state to reach perceptual areas of the cortex. For example, an athlete in the middle of a game may experience a hit or a fall, and feel no pain, get up, and keep going. After the game, the athlete may start to feel pain, and find that they have broken a bone. The brain in these cases related to a perception of threat and survival stops the signals that would turn on pain perception while it prioritizes other tasks that are perceived to be more critical - like catching a football. That physiologic interaction is informed by context. When we feel pain or discomfort it is related to context. Physical pain can be assessed by how it limits speed, range of motion, or load. This assessment might apply equally to a migraine as to a movement. With a migraine, the pain limits our capacity to move at any speed.

As noted, physical markers of pain are related to how they limit performance. After an injury, for example, the protective inflammatory response (Koh and DiPietro, 2011) to the injury may cause pain signals if trying to move the affected area. That pain is a protective mechanism to keep that area mobile while the healing processes take place, from clearing out infection, to scaffolding and building new tissue.

This process is known as an acute response to an acute injury. Pain in these cases can often be described as sharp, and also specific. A person can point clearly to where they feel that pain. Other types of pain that last well past the time of healing processes have completed are called chronic pain (Borisovskaya et al., 2020), and are usually more general in sensation than a sharp or clear pain in a particular location. They are also deemed as serving no functional purpose. More recent research frames chronic pain more like a treatable disease condition rather than a response to an injury (Cohen et al., 2021). One other frequently reported kind of pain is *referred pain*. That is, pain is occurring in one organ/area and is perceived in another area. A heart attack felt as pain in the left arm is a classic example. There is also emotional pain. We may call this pain only cognitive - but that is actually impossible: these responses are all physiologically mediated in terms of hormonal signals of stress and fight or flight reactions. Affect itself is physically locatable across numerous and very physical areas of the brain. Pain as a signal produced in the brain is, as soon as it becomes conscious, both psychological and physical, but a key takeaway is that physiological state underpins our interactions with context.

Indeed, as we offer throughout this paper, all sensations and experiences are mediated by the body, physiologically. We see this in our own experience: if we are lacking sleep, we are more likely to respond with more anxiety than if well rested (Kayser et al., 2022).

Discomfort absolutely has similar components to pain, as we will see below, but the difference between sensations that we categorize as either pain or as discomfort is that they move capability in opposite directions. If an action produces pain, as we have said, actions that involve that system will be limited in terms of range of motion, speed of action, and amount of load. The more we carry out a painful action, often, the greater the pain will become, and the greater the associated injury. Indeed, continuously moving an area when in acute pain will often inhibit healing. With discomfort, we see the opposite effect: doing the same action over repeated bouts causes the discomfort to be reduced as we adapt to it.

Consider going for a run again: we may get to a point where our breathing rate goes up, our muscles feel fatigued, and we just cannot move as fast. We feel ""winded" and so we slow down to catch our breath. And we can go again after this brief period well named "recovery". That is, using a discomfortable experience to create positive adaptation. We note that we can recover from the event and repeat. With pain, that ability to recover and go again would not enable that continuation. It is likely clear here that one can push past discomfort into pain, and cause injury, which will require different kinds of recovery. Discomfort and pain can be part of a continuum. The challenge because of this similarity is how to help designers differentiate between the necessary level of discomfort for positive adaptation and that same discomfort signal as a pain signal and therefore a stop sign? Discomfort is also nuanced. It is practiced or habituated. Hunger is a great example of this: hunger is also a multifactorial experience, but it is strongly associated with a particular hormone, ghrelin, that fires based on habituation - feeding times - rather than around physiological need (Massadi et al., 2017). As a person extends the period in which they are not eating those signals of discomfort - of the need to eat - change too. In research on fasting, we see leveling out of ghrelin levels that occur through fasting associated with decreased experience of hunger (Massadi et al., 2017). A challenge many experience - and hence an opportunity for design - is attempting to get through those pangs "cold turkey", that is, without gradual adaptation. That can be challenging and a cause for abandoning a practice as "too hard" when really it is too much discomfort for current adaptive capacity to maintain. It is worth repeating: discomfort, unlike pain, does not limit range of motion, speed, or load of the activity. But it can cause us to quit. Like recent research on fatigue, quitting almost always has a mental or cognitive choice within discomfort, rather than being only metabolic exhaustion (Marcora et al., 2009).

A review of the use of the terms "pain" and "discomfort" in several databases of medical publications found that, in the medical literature, the term "pain" is used as a source of discomfort, but that pain is not the only source of discomfort (Ashkenazy and Ganz, 2019). Discomfort, as proposed here, is a signal of *incremental challenge* leading *to positive adaptation.* Pain is a signal for change due to injury in acute instances, and potential dis-ease in chronic care – in each case these kinds of pain limit rather than enable progressive positive adaptation. In other words, our distinction between pain and discomfort is based on the impact on the individual's future capability. We believe our distinction will be more useful in interaction design because our distinction invites designers to consider the impact on future capacity and to focus on experiences that will increase capacity.

4.4. Recovery from *intermittent challenge* - completing the cycle of discomfort

Physiological adaptations that are usually related to discomfort can be categorized as demonstrating a need to adapt from our body's current *state to another,* which may in turn cause a metabolic *threshold* to adapt. For a state adaptation, we can say that we have the current physiologic and metabolic capacity to support us as we move from one state to another. Consider changing states from static to active, like going for a walk on a cold day. We dress such that we will likely be a little cold at the start of the walk, coming from a warm indoor space and heading out into a cold outdoor space, but we know that, as we move, we will literally warm up. This process begins with what is hypothesized as "allostasis"" - an autonomic nervous system response (that is, not volitional or even conscious) that, based on patterns of practice with this experience of going outside, actually begins to anticipate what will be needed to keep our bodies functional in this climate shift. These are metabolic processes. They include hormonal signaling moving through the blood stream to trigger increased respiration and constriction of certain blood vessels to support more circulation to the limbs as they "warm up" - quite literally – from movement. Initially, shivering may also be triggered as a physiological mechanism to generate heat. We will notice that the initial discomfort of our body feeling cold / shivering dissipates as we move and warm up.

In our walk, we may even begin to feel discomfort from the other end of the temperature scale – needing now to shed clothing, to help us shed heat being built up, in order to help maintain a temperature balance relative to our movement state. After some practice, we gain experience on both how to endure the short period of discomfort and initial cold and to adjust to growing warmth. Our predictive allostatic responses become more refined in their adjustments: the more frequently we practice, our discomfort decreases. Throughout this process of adaptation, our metabolism is active in adjusting our heart rate, circulatory system, and air flow to ensure we do "adjust" to the temperature relative to our effort. As part of these positive adaptations, our tissues may be changing as well to adapt to the cold: the organelles in our cells that can produce heat as well as energy (mitochondria) tend to multiply (Ortega et al., 2017), both as heat producers to help us stay warm and as energy generators to help us run with less perceived discomfort/effort.

Where we often see greater discomfort in terms of this physiological/psychological experience is where demand approaches physiological thresholds of current capacity. If we use a familiar example of someone building muscle strength, research over the past several years has made clear that, more than anything else, the muscles must be pushed to fatigue - to a point of discomfort where they cannot complete another movement with the same speed, load, and control of form. Fatigue is *necessary* for strength building. Close to what is known as pushing oneself toward *failure*, more so than traditional thinking that load or number of repetitions of a movement matter most. Getting to fatigue is the principle (McIntosh et al., 2023). To get to fatigue consistently and repeatedly in a workout means managing discomfort (Jorgenson et al., 2020; Stokes et al., 2021).

Based on current models, lifting loads that are beyond a person's norm causes "microdamage" in the body. As a result of this damage – which is often not experienced as pain until the next day – the body responds, as part of the repair process, by creating new tissue – including new muscle fibers. More fibers mean more capacity for tension to lift greater load, like adding strands to a rope to make it stronger. It is important to note that this repair process happens during recovery – post damage – and when that recovery is insufficient so is the adaptation. This constant cycle of demand requiring physiological response is the role of metabolism to bring together the necessary materials to support the adaptation to maintain homeostasis. For our purposes, the strength building example is important for the aspects of both discomfort and pain that it elicits, and a question for design in terms of how to prepare a participant for this experience.

First, the sense of fatigue itself is not pleasant – it can be uncomfortable to push oneself to perform sufficient repetitions to achieve fatigue. That in itself is demanding. That activity in itself, however, will also create an adaptive response over time as the person learns how their body responds to this kind of stress.

On the other side of this experience is the delayed onset muscle soreness that is felt in the next 24–72 h, which can be experienced as significant pain (Heiss et al., 2019) - we see that range of motion, speed of motion, and loads that can be moved are all limited by one's experience of pain in these muscles. Pain here is doing exactly what we have described its role in performing: limiting risk to the repair process underway by making movement of that area difficult. This experience post exercise is exactly what can keep people from coming back to a strength routine: the initial routine may not have been fun and now afterwards they are experiencing pain. It is important to note that not all DOMS' experiences are painful rather than uncomfortable by our definition. DOMS' assessments frequently show that, while the worked muscles feel sore, that load, speed, and range are *not* impacted. So, while DOMS often follows new, particularly eccentric, movement work, it does not always result in pain rather than discomfort. The challenge for designers is, therefore, how to help someone get the balance right when the discomfort experience is not necessarily a guide for the degree of DOMS after the experience?

A similar process occurs for distance running to become experienced as less effortful: one's capacity for bringing air into the lungs, and also for the body's cells to adapt to be able to make use of more air, is also stimulated by carrying out what is known as "threshold training" (Li et al., 2013; Ní Chéilleachair et al., 2017; Pla et al., 2019). This kind of work is often very demanding. Imagine doing a series of 50–100 m sprints, at near your maximal capacity, resting only briefly and doing a set of them again. And then again. The practice is uncomfortable, but this discomfort is part of a signal for the body to build new capacity such that this same amount of effort over time can be invoked with less cost to the body – in other words, so that the process induces less discomfort. That new capacity is built during periods of recovery between training sessions. Physical training programs typically build in *progressions.* The Couch to 5K protocol is a popular embodiment of that acknowledgment that capacity to carry out a new physical activity is built up over time. What few of these programs address explicitly however is *how* that capacity is being built as a response to a demand on our homeostasis.

This adaptation is critical as a response to demand. Not adapting would mean that the system cannot maintain homeostasis – it cannot repair the challenges to its homeostasis. Research on aging and extending healthy lifespan frames aging in terms of a system's decreased capacity of one's metabolism (Guarente, 2011) to meet the repair and recovery challenges. Similar research is showing that these effects can be mitigated and, in some cases, reversed by engaging in activities that induce autophagy constantly and cause our systems to need to refresh, repair, and recover (Mizushima and Komatsu, 2011; Hajd et al., 2023).

4.5. A volitional/perceptual/inhibitory aspect of discomfort and its relation to adaptation

We can frame discomfort as having both *physiologic* and *perceptual* components. Practicing holding one's breath in air hunger drills has physical components of discomfort as the urge to breathe grows. But it also has a different discomfort as we deal with a fear associated with running out of air and suffocating. We propose to call this type of discomfort *perceptual.* For example, we may always feel similar physical discomfort with air hunger drills, but the perceptual discomfort of fear or panic, research shows with free divers (Fitz-Clarke, 2011), can and does subside with experience. Engaging with perceptual discomfort before, during, and after discomfortable activities so that it does not unduly inhibit us from exploring a desired practice toward a desired achievement seems a large opportunity space for HCI design research.

It is likely clear from these examples that discomfort can also be experienced from non-physical sources, but whatever the source, discomfort will be experienced physically—as all experience is mediated via the body. A difficult high-stakes ethical challenge, for example, may cause physical responses of associated discomfort such as lack of sleep or poor digestion. These responses may over time challenge our capacity to maintain homeostasis. Challenge homeostasis for sufficient time or intensity, and we become ill: a failure of homeostasis to adapt to the discomfortable demand.

Perceptual discomfort can also be *anticipatory*. These anticipatory and perceptual discomforts do not always inhibit an action or lead to illness. In the physical circumstances outlined in the above sections, like going for a walk on a cold day, we will anticipate discomfort. Based on our familiarity with that discomfortable experience, however, as the expression goes, we may "suck it up" in order to achieve the associated adaptation we seek.

Sucking up generally means that we *choose* to carry out a practice despite the anticipated and/or perceived discomfort. We keep walking in the cold, because (1) experience tells us we will adapt in a short period and (2) that we can withstand the cold for that long without damage while we warm up. We are balancing perceptions of cost/harm with benefit/adaptation. This process of up sucking discomfort can, however, cause damage from the misguided because of the popular conceit of "no pain no gain." This is a false corollary. Pain and discomfort as we described above may have similar feeling starting points, but their process and purpose go in near opposite directions. As noted above, pain limits capacity; discomfort, perhaps especially perceptually, seems to be largely a signal for us to pause and reflect on whether this activity is safe to pursue. That is, *how much of a risk to our homeostasis is it?* If we do pursue it, if we do "suck it up", that pursuit will also induce adaptations; our capacities and our thresholds will adapt to these new demands, if done appropriately. Designing discomfort doses that are both safe and effective to support positive adaptation again seems a new opportunity for HCI design. If the discomfort dose is too small, positive adaptation is not likely to take place. If the discomfort dose is too large, the dose becomes pain which reduces capacity.

4.6. Seeing the future – key to deliberate discomfort interaction

Culturally, beyond HCI, given all our individual technology designs and social infrastructure to avoid even a moment of immediate physical discomfort, we may well wonder how these discomforts could have been – and indeed continue to be – so successful for positive adaptations not just for survival, but for thriving.

One possibility we may imagine is that there has been a very long period of time in the 350–450 thousand years of homo sapiens on the planet where dealing with discomfort has not been a choice: to eat meant to dig or hunt, out in the wind and rain, no matter how one felt. The desired outcome from this effort is greater than the immediate gratification of making the discomfort stop. In other words, we have a capacity to make decisions based on present perceptions of future value – on *prospection* (Bulley and Irish, 2018). How far and how accurately we can see into that next moment of discomfort, and past discomfort, is based on our KSP of that experience. Our willingness to go there may be based on our understanding of how that discomfort is associated with our desired outcome.

In evolutionary biology, this seeing into the future is usually pinned to the actual parts of the brain that support motivation and reward (Sapolsky, 2018): to be able to see that the discomfort of the present practice toward an adaptation will support a value that is worth more than the discomfort. All of us who have experienced the cost of committing to a project, working to translate the results, having setbacks and recovering from them (including the cycle of publication submission/rejection/revision) are regularly weighing the discomfort of various experiences of a process toward a particular goal. In the CNS, we have reward signals that are triggered within particular kinds of efforts, seemingly to help keep us going. We have in our bodies opioid production, not unlike the effects of marijuana, that is triggered during a run, for example, at a certain period and intensity (Boecker et al., 2008) that can help keep us going. Recent work suggests other kinds of euphoric hormonal triggers like dopamine are set off during intellectual pursuits (Marvin et al., 2020). It is important to note, however, that these reward circuits are not tripped without first going closer to thresholds of capacity – these may be endurance, speed, accuracy, power, or, for some, thrill (Chen et al., 2019; Schmitt et al., 2019) - what the popular press of late calls "dopamine addiction" (Waters, 2021). In other words, in physical environments, we do not seem to be wired to get the euphoric hormonal rewards without approaching maximum effort. The social media/dopamine experience is like the sugar of reward: micro suffering for micro hits. On the other hand, we have also evolved to enjoy rest so that sustained discomfort without rest is not motivating either.

Micro Reward Proximity Indeed, recent work around motivation shows that the proximity in time of a reward to the cost of an effort is germane to how much effort a person will put into that effort (Grogan et al., 2020). For our purposes here, this means that a possible discomfort design vector is to explore how close we can bring an appropriate reward related to the aspiration to the current discomfort effort. For someone who already accepts that effort/discomfort will be a part of becoming stronger in lifting weights at the gym, simply lifting something heavier than the previous day, no matter how hard that experience is, may be its own micro reward on a larger quest for bigger biceps. It may also result in injury for having an approach to practice more likely to push too hard too fast. Patience can also be discomfortable. How to design to support appropriate but smaller discomfort doses with micro rewards that lead toward larger aspirations is an interesting challenge. In an ongoing study in exploring strength building while at work, we have been looking at the power of "one more rep" each time a particular movement sequence is practiced. Within 7 min going back and forth between two movements, five repetitions at a time, the aim is to add one more rep each day. Usually, beginners will get more than one more rep each time as the first 4 months of any strength program for new participants is usually neural conditioning – that is – the body learning how to do the movements. Likewise, the inevitable delayed onset muscle soreness (Hotfiel et al., 2018) from 7 min of new movement work is less than a typical 20–30 min initial session in the gym. Micro discomfort, during and after, that can be anticipated, we see is bearable against valued, demonstrable improvement like "getting stronger and feeling better".

5. Designing with discomfort

After summarizing key insights from pain research and deliberate practice, we present design considerations and material dimensions for discomfort. Material dimensions for discomfort invite the designer to think about how discomfort will be both experienced by a person and impact an interactive experience.

5.1. Key insights

While pain and discomfort, we argue, are different, we can draw design inspiration from pain research strategies to help chronic sufferers manage and lessen their pain. Particularly around dealing with intermittent pain – like migraines - or ongoing chronic pain, pain researchers have focused on the role of models about pain processes to help people better anticipate and manage their pain, and thus lessen it (Moseley and Butler, 2015). These models are not the only mechanisms, of course. Exercise, diet, and sleep are also part of pain interrogations, but modeling pain is seen as particularly helpful for managing the emotional responses that can amplify a pain experience (Ridder et al., 2021). A potential takeaway for designers is the value of being explicit about possible discomfort experiences, clarifying what is happening to create the discomfort, and how to manage it rather trying to eliminate it.

One framing around anticipating, managing, and potentially embracing discomfort is Ericsson (2020) "deliberate practice" that we touched on above. In deliberate practice, every training session includes a deliberate effort to push oneself beyond the current comfort level: moving from repeating tasks that are easy to consistently engage with to tasks that are (currently) perceived as difficult and require struggle. Success of adaptation is measured in quantifiable progress of performance. That quantifiable improvement is another design cue for us. Overall time spent in discomfort (deliberate practice) is correlated with degree of expertise built. This work assumes there will be discomfort but not *what kind or degree* of discomfort, or the cost of perceived discomfort to engagement or persistence. It seems very much of the "suck it up" school of discomfort coping. This approach definitely does not work for everyone: how might designers mitigate that demand?

They also suggest this work requires a teacher to support feedback necessary for progress. What kinds of feedback, potentially associated with better enabling progress, might we offer in our designs? Just from these examples, we can see opportunities for explicitly preparing for discomfort, detailing the anticipated experience, offering a model of the adaptation processes being cued and the benefits from this, supporting quantifiable measures of progress each session, and offering feedback on technique to support the adaptation better based on current performance.

5.2. Design considerations for using discomfort

These key insights suggest several considerations for incorporating discomfort into design. Table 1 lists several considerations along with a brief explanation of each. In this section we will discuss the discomfort associated with jogging as an example. For clarity, we will refer to the user of this design as "Bob".

The first Discomfort Design consideration is to help the person prepare for discomfort through planning and understanding. Planning for discomfort involves making specific plans for engaging with the discomfortable situation. Preparation may decrease anxiety about the upcoming discomfort and increase the chances of beginning and completing the discomfortable task. Understanding discomfort means understanding how the experience will feel and what will happen in the body during and after the experience. In the case of an interactive system that supports Bob jogging, preparation for discomfort might involve making a specific plan for when, where, and for how long he will run. Preparation for discomfort might also include helping Bob understand the impact of increased running load on the muscles, tendons, and ligaments in his legs. Bob is likely to feel as he enters the room such as an increased heartrate or increased perspiration. Understanding what is likely to happen during and after running may help Bob stick to his plan. People regularly abandon resistance training activities because in the days *after* lifting – not at the time – they experience intense soreness which can take days to get over. And so, understandably, they abandon the activity [this abandonment cycle is reflected in the health belief model (Rosenstock et al., 1988)]. And yet, this delayed onset muscle soreness (Heiss et al., 2019) is a well-known phenomenon. Correctly understanding that muscle soreness is an expected indicator of positive adaptation may prevent early abandonment of the activity.

TABLE 1 Considerations for working with discomfort as a material in design.

Design consideration	Meaning
Preparation for discomfort	Reduce resistance to discomfort through planning and understanding
Role of practice	Making the role of discomfort explicit
During discomfort	Support to endure through the planned experience
Micro rewards	Connected to the purpose of the experience.
Support recovery	Allowing time for the body to adapt.

Another consideration for design is to make explicit the anticipated role of the practice. The role of the practice includes both the role in generating adaptation triggered by the imposed load during the discomfort and the subjective value assigned to those adaptations by the person engaging in discomfort. While two people may experience similar adaptations triggered by similar discomfort, they may assign different values to those adaptations based on their personal goals or motivations. For Bob training as a runner, the direct value of the practice will be specific changes to his muscles, tendons, ligaments, and bones as well as adaptations to his cardio-vascular system. Bob wants to place in his age group at a local 5 km race in a few months. Based on that goal, the subjective value of adaptations in Bob's body is that he will get faster and become more competitive on race day. A different runner motivated by getting in shape in order to improve overall health will find a different subjective value while experiencing the same (or similar) direct role of training. Making the role of the practice explicit may motivate Bob to persevere through the discomfort in both the long and the short term.

Design can also explore ways to provide support during discomfort. Support during discomfort can include support for remaining engaged, avoiding pain, and staying connected to the purpose. Remaining engaged means enduring to the end of the planned experience and not giving up early. Avoiding pain means avoiding experiences that reduce rather than increase function. Avoiding pain might involve knowing when to stop based on symptoms felt in the body or knowing to stop even if feeling really good during the experience. Staying connected to the purpose involves staying connected with both direct and subjective values associated with adaptations triggered by the discomfort. These purposes will likely align with the roles of the practice. For Bob the runner, remaining engaged means continuing through the entire run with good form and pace. Bob may need reminders if his pace falls below a threshold. Avoiding pain means that Bob ends his run at the prescribed distance even if he is feeling particularly good that day and it means that Bob knows to stop if he begins to feel specific indicators of overuse injuries, such as persistent pain on the outside of his knee which may be a symptom of iliotibial band syndrome. Finally, remaining connected with the purpose includes both reminding Bob that this discomfort will trigger adaptations in his muscles, tendons, ligaments, and cardio-vascular system that will increase his capacity to run. Remaining connected also means reminding Bob that discomfort will help him get faster for the 5 km race he plans to run in the future.

Micro rewards connect practice with indicators that point toward desired long-term adaptations, thus strengthening the connection between present discomfort and future value. Micro-rewards are given during discomfort, not after. Many issues need to be resolved in making this connection explicit during discomfort: Is encouraging more effort now (and possibly more discomfort) supporting the adaptation sought or is it too much effort and becoming painful which reduces function? Is the micro reward explicitly connected to the desired adaptation strongly enough to trigger motivation? For Bob, micro rewards given during a training run might be that his heart rate is lower during this run than the previous run or that his pace is gradually falling which means that his finish time in the local 5 km race will be lower.

A final consideration is supporting recovery. Adaptation occurs not in the effort but in the recovery. Pacing out practice to interleave effort with recovery (and positive adaptation such as skill building) requires patience and that patience itself can be discomfortable. Impatiently, or naively, replacing recovery with additional effort creates pain, which limits ability. A misguided “no pain, no gain” mentality compounds the problem. Connecting the benefits of recovery to the value of the practice may sustain motivation across periods of inactivity. For Bob, supporting recovery means encouraging Bob to take time off between runs and to gradually build his weekly running effort—even if he is feeling good and knows he can go longer or harder in a given week. Support for recovery also includes support for keeping hydrated between runs and eating a diet that will support recovery. Several questions arise: How long should the recovery period last? How are the benefits of recovery communicated? How is enthusiasm to act impacted by the need to rest? How is recovery connected to long-term value? We might consider how to design to support feeling the benefits of recovery as a mitigation for the discomfort of waiting. In endurance training, for example, there has been work using HRV as a measure of recovery. How might that be internalized/validated against interoceptive awareness to best anticipate when work/training is next best used? Or similarly, when one is not interested in training, because the anticipated discomfort of hard effort is off-putting, how might skill deterioration from not embracing that discomfort be reflected? These questions may also be asked around cognitive skill building.

TABLE 2 Five dimensions of discomfort as a material for design.

Dimension	Range of values			
Current capability	None	Some	Significant	Expert
Latency	Seconds	Hours	Days	Years
Engagement duration	Seconds	Minutes	Hours	Days
Engagement frequency	Minutes	Hours	Days	Years
System use during	None	Infrequent	Frequent	Constant

5.3. Dimensions of discomfort

In this section we suggest dimensions for conceptualizing discomfort as a material in design. Dimensions and their levels are shown in Table 2. We give an ordered list of values for each dimension. We do not give units or precise numerical values for each dimension as the suggested list is likely precise enough for thinking about discomfort as a material. Because different people experience discomfort in different ways, the first dimension, current capacity, describes the person experiencing discomfort. Values assigned to these dimensions by a designer can be thought of in either a *descriptive* or *proscriptive* sense. Descriptive values measure what is actually happening in a given practice. Proscriptive values describe what a designer thinks or imagines should or could be happening. Proscriptive use allows a designer to imagine discomfort in ways that are not tied to current practice. We define each dimension below and use running or jogging as an example to better explain each dimension. We will leave our fictitious runner named Bob out of this section to focus on discomfort as a material independent from a specific person.

Current capability means the person’s current capability in situations that generate a given kind of discomfort. Different people will experience discomfort in different situations based in part on their capacity to perform the activity. This dimension of discomfort describes the capability level at which discomfort is generated. Current capability matters because it changes how the designer might think about each of the design considerations listed in the previous section. For example, supporting engagement with discomfort for an Olympic-level marathon runner is likely different from supporting engagement with a person who has never run 5 km at once. Current capability will also change the other dimensions of discomfort. The difference in capacity will impact preparation for discomfort, communicating the value of the practice, support during discomfort, micro-rewards, and support for recovery. Olympic-level runners engage with discomfort for longer and more frequently than new runners.

Latency describes the amount of time between when a person realizes that discomfort is coming and when the discomfort actually begins. Latency of a few seconds means that a few seconds pass from the time at which a person begins to anticipate discomfort to the point at which they feel discomfort. Latency is important from a design perspective because it impacts the amount of time available to help a person prepare for discomfort. Latency is typically high in running because runners typically plan training runs days or weeks in advance. Few people decide to run and are running within a few seconds or minutes of that decision. However, a designer might take a more proscriptive approach and decide that latency for running should drop to hours or minutes. Thinking about the latency of discomfort on that time scale may lead to different ways to support engaging with discomfort. Discomfort in other settings beyond running may have different latency than running. For example, latency in social encounters might be a few seconds if the discomfort comes from social situations that happen unexpectedly.

Engagement duration means the duration of engagement with discomfort. Engagement duration might be a few minutes, a few hours, or a few days. We chose not to include durations beyond a few days because days of continuous discomfort seem unlikely to produce positive adaptations. In running, engagement duration is the amount of time a person spends running. In some cases, the intensity of discomfort may vary over the engagement duration. Engagement duration changes how a system supports a person during discomfort. If the discomfort lasts a few seconds, support may not be as important during discomfort. If the discomfort lasts a few hours and is intense, support may be critical. Engagement frequency refers to how frequently the person will engage with discomfort. Frequency of a few minutes means that a person is engaging with discomfort every few minutes, as might arise during a weightlifting session in which each set of motions produces discomfort with intentional rest in between. In running, engagement frequency is typically on the order of days rather than hours, weeks, or years. At different phases of their practice, people may engage with running at different frequencies such as twice a day during periods of peak training or a few times a week for new runners building up their capacity. Engagement frequency impacts how much time is available to prepare for discomfort and how much time is available for recovery.

System use during discomfort refers to how much a person will use an interactive computing system during periods of discomfort. In some settings, a person never uses a system during discomfort, while in other settings system use is constant. It is also possible that the system itself is the cause of discomfort. System use during discomfort impacts what a design can do during discomfort to support engagement. When running outdoors, most people likely have infrequent engagement with an interactive system. However, a proscriptive approach to running might begin by deciding that people should never engage with a system while running. A system predicated on non-use during running will be different than a system intended for infrequent use.

6. Conclusion and future work

We propose that discomfort as material in HCI can be understood with two particular attributes – like warp and weft – of physiological discomfort and perceptual/anticipatory discomfort. Both strands are related to how the body adapts, and particularly how the body adapts to discomfort to create greater capacity to be able to maintain homeostasis better and for longer in more challenging contexts. Triggering these adaptations involves discomfort rather than pain and includes periods of recovery. Successfully engaging in discomfort and recovery is motivated by connections to perceived long-term value.

These principles suggest new approaches to design that include preparation for discomfort, communicating the future value of discomfort, and support for recovery. We suggest that framing discomfort as an explicit design material enables us as researchers and designers in interactive technology to consider more deliberately how discomfort acts to affect engagement with a practice, and thus engagement with designs that support practices. For designs particularly focused on health, wellbeing, and creativity – in other words all aspects of human performance – discomfort is therefore a critical, operative factor for such designs. We have sketched out five issues for consideration in discomfort design. These issues range from preparation to recovery. We have also defined five dimensions for sizing discomfort as a material in interaction design.

Questions about how a design can help one reflect on the balancing of degree of discomfort and the degree of recovery needed, and how to recover from both perceptual and physiological discomfort, are uncharted territory. But we suggest that this territory has much to offer to help more people access more knowledge, skills, and practices to support their brilliance and resilience. We look forward to developing this exploration of discomfort as material here with the inbodied community, toward broader uptake in the general HCI research and design communities. Our goal is to have discomfort embraced as a design material and to take steps toward a useful and usable general framework for discomfort-embracing designs.

It may seem odd to design for discomfort when being comfortable is such a desirable and easy state of being. We seem to *naturally* seek comfort and to remain in that state for as long as possible. However, seeking and remaining comfortable can be destructive for our health and wellbeing in a world in which we are surrounded by an over-abundance of modern comforts such as plentiful food available with little effort in great variety all year, constant streams of sedentary work and entertainment, and indoor climate control. These aspects of our physiology that cause us to seek comfort were likely advantages in our recent evolutionary past. However, until our physiology catches up with modern comforts, a healthy long-term lifestyle is likely to involve intentionally seeking and appreciating discomfort for health, for learning, and for social connection. HCI has a significant opportunity to help us connect, purposefully, and to interact with these practices for our health and wellbeing – our discomfortable wellth ("wellth" is a portmanteau of "wellness" and "health" intended to convey a different kind of wealth).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ms and MJ contributed to the conceptualization of discomfort as a material for interaction design. ms led in the discussion of the physiology and neurology of adaptation due to discomfort. MJ led in the formation of issues to consider when incorporating discomfort into interaction design. All authors contributed to manuscript revision for the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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