Designing Interactions Beyond Conscious Control: A New Model for Wearable Interfaces

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Recent research in psychology distinguishes levels of consciousness into a tripartite model - conscious, unconscious and metaconscious. HCI technologies largely focus on the conscious pathway for computer-to-human interaction, requiring explicit user attention and action. In contrast, the other two pathways provide opportunities to create new interfaces that can alter emotion, cognition and behavior without demands on attentional resources. These direct interfaces connect to cognitive processes that are in our perception but outside our conscious control. In this work, we feature two sub-categories, namely preconscious and metasomatic within the tripartite model of consciousness. Our goal is to provide a finer categorization of cognitive processes that can better help classify HCI research related to activating non-conscious cognitive pathways. We present the design of two wearable devices, MoveU and Frisson. From lessons learned during the iterative design process and the user studies, we present four design considerations that can be used to aid HCI researchers of future devices that influence the mind. With this work we aim to highlight that awareness of consciousness levels can be a valuable design element that can help to expand the range of computer-to-human interface devices we build.

CCS Concepts: • **Human-centered computing → Interaction design theory, concepts and paradigms**; **HCI theory, concepts and models**.

Additional Key Words and Phrases: wearable computing, design methods, interaction design

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1 INTRODUCTION

Fundamental questions about whether perception and action are rooted in conscious awareness, and whether they are generated primarily in the mind or the body, have important implications for researchers building technologies for behavioral, cognitive and affective interventions. The search for the genesis of action – decision to wear purple today, autonomic eye movements while reading this paper or meta-awareness of these eye movements –

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in the cognitive sciences has revealed that much of our perception and subsequent action are generated below the level of attentive, conscious awareness. Perception and action can be either a subliminal process, a conscious process or a meta-aware process (i.e., being aware of being aware) [77] and a user's actions can be influenced by each of these processes.

Cognitive frameworks which help elucidate the origins of behavior can help frame intervention design for researchers in Human Computer Interaction (HCI) community who are interested in developing affect modulation and behavior change technologies. Persuasive technologies aim to influence behavior and action through wearable or ubiquitous computing devices [30]. Many of the current behavior change interventions utilize design protocols that require user's attentional resources and primarily engage their explicit cognitive capacities, for example, beeping to indicate bad posture. Adams et. al. [1] proposed the idea of "mindless computing" based on psychologist Daniel Kahneman's dichotomy between fast, instinctive and emotional thinking (System I) versus slower, more deliberate and logical thinking (System II). They call for design of new types of persuasive technologies that do not rely on explicit attention and user motivation, with the goal of overcoming some limitations of the existing persuasive technologies [1]. Their work is further inspired by the research in psychology and behavioral economics that has successfully demonstrated use of System I thinking for promoting subtle changes in behavior while the user is unaware [1]. This paper builds on work in Mindless Computing by Adams et. al. [1], with emphasis on using the body as an interface to the non-conscious mind. As we expand from dual process model into more nuanced consciousness models, we observe the influence of sensory memory on the mind, neither exclusive to System I or System II. Since sensory memory is enacted throughout the body, we prioritize the body as an interface to the expanded aspects of awareness. All levels of consciousness, from implicit to explicit awareness, are grounded in the physical body [55] and are thus physically exposed to be accessed through wearable electronics.

Manfred Clynes' vision of the cyborg, a union of human and machine that extends into the human's unconscious self regulatory control and does not require conscious control, serves as an exemplar for seamless integration of a human and technology [13]. This work aims to showcase non-invasive pathways of "writing to the body" as a step towards that seamless integration. We propose a design framework for targeting different levels of consciousness through the body. Our framework provides an alternative to the present day interaction design paradigm that prioritizes explicit user attention and action. To do so, we dig beyond the dichotomy of conscious-unconscious thought (now a 50 year old theory). We build on the updated tripartite distinction of levels of consciousness that includes unconscious(below level of awareness), conscious(being aware) and meta-consciousness(being aware of being aware) [77]. We expand the tripartite model's classification into five distinctions by including preconscious and meta-somatic as two new levels (Figure 2). The preconscious level is derived from prior work that shows that awareness of a stimulus is considered to be preceded by conscious information processing [90]. The meta-somatic level is derived from research in neuroscience that explores the brain's influences on bodily functions and the effects of reflection on sensory input on behavior and cognitive functions [10]. Thus, the five pathways of information processing are: (a) completely unaware or subliminal, (b) peripherally aware or preconscious, (c) aware, actively thinking and perceiving or conscious, (d) meta-aware or meta-cognitive, and (e) reflecting and projecting on body sensations or meta-somatic. We argue that while bodily sensations can form aware and conscious thought, many of the sensations remain outside the fovea of attention. We believe these sensations, often considered inaccessible, offer a host of design opportunities for research in influencing user action, thought, judgement, emotional awareness, or behaviour. And since these sensations do not become part of user's conscious experience they do not demand high attentional cost or rely on explicit motivation.

The goal of this paper is to highlight the novel design opportunities for HCI researchers that become available by targeting the different levels of consciousness via the body.

This paper provides three main contributions:

- Bringing insights from the tripartite model of consciousness to HCI by featuring two sub-categories, namely preconscious and metasomatic within the tripartite model.
- A framework for the design of seamless interaction technologies that modify user affect, cognition, and behavior without requiring explicit attention or motivation.
- Design considerations for technologies that take into account the non-conscious mind.

2 MALLEABLE MIND

We begin by outlining the key role that the environment and the body play in the generation of thought and action. This in turn serves to highlight opportunities for wearables which influence the mind by interfacing with the body. Traditionally cognitive science has viewed the mind as an independent information processor [32] with emphasis on abstract symbol processing. However, there is a growing body of research that aims to understand the mind in relationship to the body as it interacts with the physical world [95]. Proponents of this idea argue that cognition is embodied, it takes place in the context of a physical environment, and it inherently involves perception and action. This change in thinking places emphasis on the role of the body in the framing of thought, suggesting the presence of cognition distributed in peripheral sensory input as well as motor output. Our thoughts, simulations and intentions are constant conversations between the physicality of our bodies and the sensation of the environment. Mental activity is grounded in the mechanisms of sensory processing and motor control, that have evolved over millennia for translating thought into a real world event, and vice versa.

2.1 Processing Pathways

The mind works collectively with the body towards making sense of the world. The process involves sensation – gathering of information; perception – analysis of gathered information; cognition – synthesis of the information; and generalization – representation of the information. This sequence is referred to as bottom-up processing [49].

Information coming in from the sensory modalities directly influences mental representations and modulates emotions, thought and behavior. It starts with the sensory receptors transmitting nerve impulses to the brain. These impulses become part of sensory memory that can hold incoming data momentarily. Our visual sensory memory or iconic memory lasts < 1 second [21] holding high density data whereas our auditory or echoic memory lasts for 4-5 seconds [18] for sequential processing. The next stage is working memory that holds a maximum of 7±2 symbols simultaneously [57], and is considered as the main center for conscious information processing, reasoning, decision making and as a prime determining factor of our cognitive capacity and fluid intelligence [89]. After the working memory, information could get stored in long term memory as mental representations which help us learn, form concepts and develop generalizations.

Information flowing from bodily senses through sensory memory into working memory transforms the process of sensation into perception as the sensed stimulus becomes a part of the conscious experience. However, limits of working memory have been linked to fundamental limits of human cognitive capacities [44] and perceptual abilities [31]. Sperling's experiments from the early 1960s [80] showed possible information funneling from sensory to working memory and its implications of cognitive constraints arising due to visual iconic memory surpassing working memory capacity [61]. Information that does not make it to the working memory stage is generally thought to be lost. However, it has been shown that information held in the sensory registers also influences active cognitive function [35, 93, 97] bypassing working memory. Furthermore, it has been found that information flow is not strictly a feed-forward mechanism. Top-down processing provides feedback in the information flow system, modulating mental computation and storage based on previous mental models of the world [9] i.e., top-down processing modulates the way incoming information from the senses is interpreted in the mind and could lead to generation of affect as shown in Section 2.5.

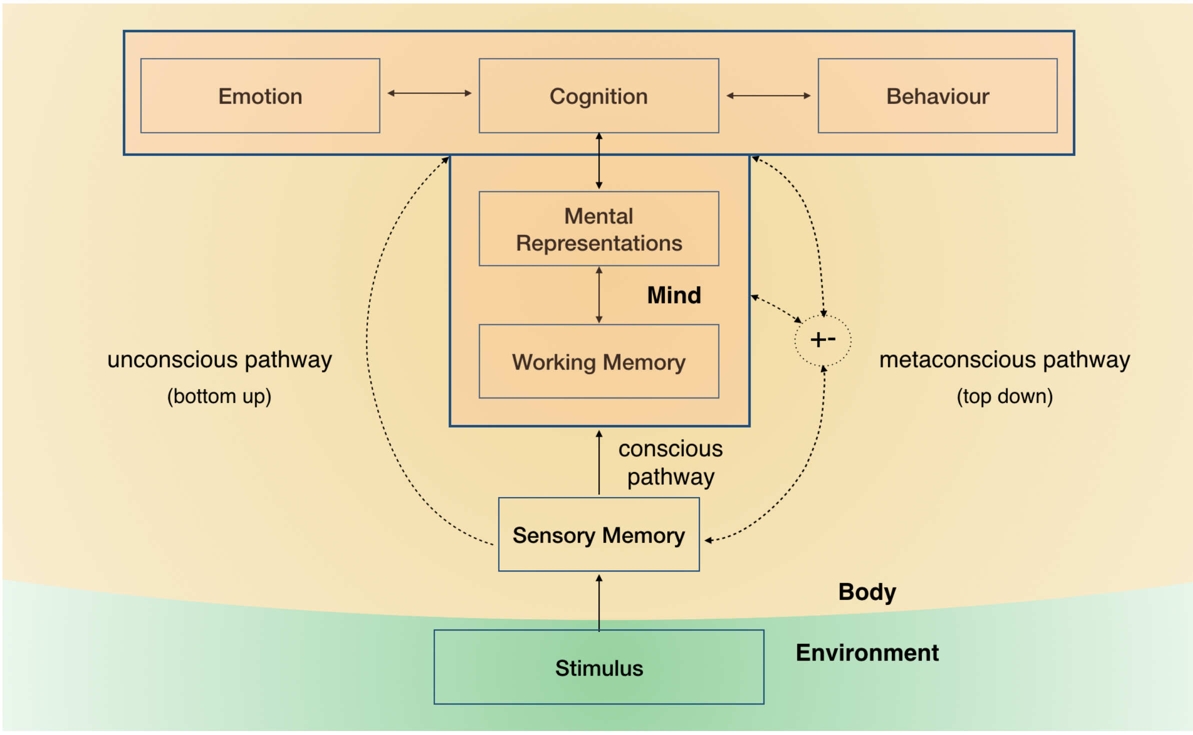


Fig. 1. Cognitive processing stages and pathways for external stimuli from the environment to the mind

HCI has traditionally used conscious sensory stimulation techniques to influence conscious awareness of the user. Our framework identifies new pathways from sensation to processing by outlining non-conscious, body-based pathways which can influence higher order cognitive processes such as emotion and behavior. Such pathways can be either unconscious in nature with bottom up processing or metaconscious with top down processing as illustrated in figure 1. The new pathways help in reducing the active information load on working memory by bypassing the active perception and conscious information processing stages

2.2 Tripartite Model of Consciousness

The process of perception, cognition and generation of mental representation described above can happen under various levels of awareness. A recent tripartite psychological model provides insight into the distinction between three levels of consciousness, namely the unconscious, conscious and the metaconscious [77]. This model expands beyond the dual process theory [42], suggesting potential grey areas between System I and System II that could be influenced at various levels and thus allowing for more subtle manipulation of cognitive processes. The tripartite model defines consciousness as the subjective state of mental content whether it is perception, thought, or feeling. This means the individual is directly engaged with the contents of their mental state (e.g, happiness) and can subjectively evaluate it. Active mental content of working memory is part of the conscious process and hence contributes directly to the attentional and cognitive load of the individual. Stimuli and processes below the level of awareness are part of the unconscious process whereas explicit reflections of conscious mental content are part of metaconscious (being aware of being aware) processes.

The following sections 2.3-2.5 showcase examples of sensory processing pathways at each of the levels of the tripartite model. Our mind is influenced on a daily basis, and these examples demonstrate the malleability of the mind and highlight opportunities for creating new technologies using body-based interfaces to the mind.

2.3 Prenoetic Determinants of Action

Our body structures our thoughts before we are even aware of intending to act. These prenoetic processes define what is a possible thought outcome that remains below the level of conscious awareness [8]. Our decision to grab is defined by our having hands, redirection of eyesight is determined by the range of our vision, decision to jump is made within the framework of our physical capacity. To see is not only to see something, but also to see from somewhere, that is, under conditions defined by the position and postural situation of the perceiving body [79]. Thus physiological processes are not passively produced by incoming stimuli, but rather, the body meets stimulation and organizes it within the framework of our own pragmatic schemata.

Every one of these prenoetic frameworks is an opportunity for HCI engineers to influence and interface with cognition. By altering the body and its interaction with the environment, and understanding the the role of body in cognition, we alter basic cognitive processes. Experimental alterations of the postural schema (for example, by asymmetrical body tension induced by experimental tilting of the body) lead to perceptual shifts and changes in task performance [7]. Simply turning the head upside down changes perceived size and perceived distance, yet few of us are aware that standing upright is a prenoetic determinant of the size of objects we are seeing now [39]

2.4 Implicit Sensations

Our thought is structured by our constant stream of information on body position (proprioception) and sensations coming from inside the body (interoception) as well. Interoception and proprioception are well known examples of internal senses of the body that can operate outside the level of awareness and influence our daily cognitive processes. Interoception, the sense of the internal state of the body, helps ensure the survival of the organism [17] by driving behavior through feelings such as hunger, thirst and respiration. Interoceptive signals are increasingly being recognized to have a pervasive (as yet incompletely characterized) impact on cognition, emotion, perception, decision-making, and memory [86].

Proprioception is defined by neurologist Oliver Sacks as "... that continuous but unconscious sensory flow from the movable parts of our body (muscles, tendons, joints), by which their position and tone and motion is continually monitored and adjusted, but in a way which is hidden from us because it is automatic and unconscious" [45]. It relies on populations of mechanosensory neurons distributed throughout the body, collectively referred to as proprioceptors. Proprioception is partly unconscious, such as the central nervous system registering limb position and providing afferent feedback on limb movement: you are not consciously aware of how bent your leg is, but nonetheless could stand without consciously registering limb position. This is distinct from conscious proprioception, where one is paying active attention to one's limbs as they move in space.

Both interoception and proprioception can be understood as being part of the unconscious process in the tripartite model. At the level of experience, these two are necessarily intertwined [34]. For instance, studies indicate that there is "close linkage between eye posture or eye movements and the spatial organization of the whole-body posture" [70]. Vibration of extra-ocular muscles results in body sway and shifts in balance. Changes in the movement of the eyes induce changes in environmental and embodied experience. Vibration-induced proprioceptive patterns that change the posture of the whole body are interpreted as changes in the perceived environment. Subtle changes in body position and sensation can thus be used to engineer cognition and perception (see Section 5).

2.5 Reflection On Sensation

Metacognitive reflection on the sensory stimulus received from implicit and explicit sensations also plays a key role in modulation of cognition and emotion. The two factor theory by Schacter and Singer [16] posits that emotion is based on cognitive labels assigned to physiological arousal–that the mechanism in the body precedes the mind. Emotion therefore involves following physiological arousal with a search in the immediate environment for cues to label the arousal. We can thus imagine engineering emotional reactions to an environment by creating physiological sensations using wearable electronics and allowing users to label them. For example, we can change user's perception of their heart rate using false heart rate feedback and expect an arousal [15] or fear-related cognitive label through interoception. Since the labelling is part of a reflective process, this phenomenon would be classified as a metaconscious or meta-aware process.

3 THE DESIGN SPACE OF CONSCIOUSNESS

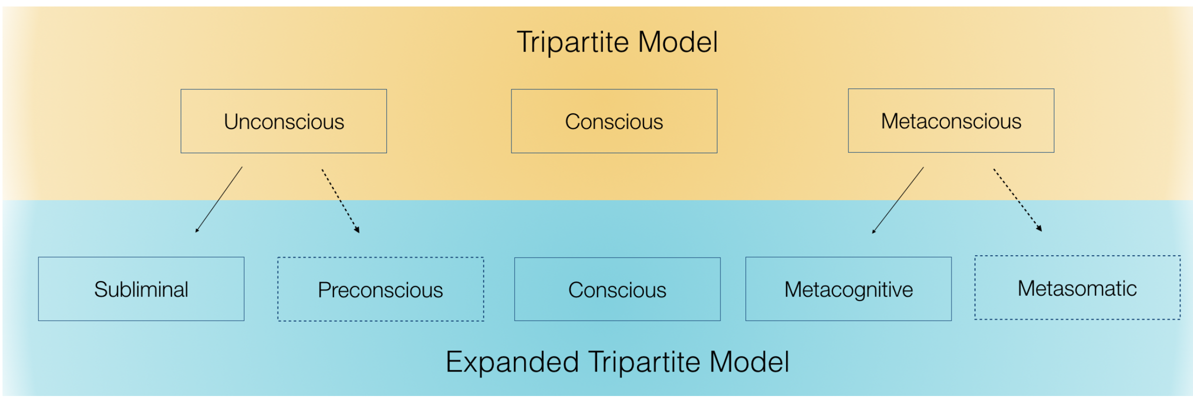


Fig. 2. Including two new levels of pre-conscious and meta-somatic to expand the tripartite model of consciousness.

Building on the understanding that many determinants of cognition exist in the body outside of the locus of attention, we bring insights from the tripartite model of awareness to support the design of HCI interfaces that can enable greater control of our internal processes and behaviors. We feature two additonal sub-categories within the tripartite model. The five subcategories presented are: Subliminal, Preconscious, Conscious, Metacognitive and Metasomatic (Figure 3). Our model expands upon the tripartite model by distinguishing preconscious and meta-somatic processes as independent, sub-categories of unconscious and metaconscious processes respectively (Figure 2).

Stimuli and processes below the level of awareness are considered part of the unconscious process. It is possible to focus attention on some unconscious processes which would elevate them to the level of conscious processes. This subcategory of unconscious processes form the preconscious process. Because preconscious processes demand and utilize part of our cognitive capacities in contrast to strictly unconscious or subliminal processes, which cannot become part of subjective experience at all, we present them as a separate consciousness level in our proposed five-level model of awareness. For example, both subliminal and supraliminal priming aim to influence behaviour unconsciously[25] but supraliminal could become part of the conscious experience of the user while subliminal cannot. Similarly, the third level of awareness in the tripartite model is the metaconscious process that involves an explicit characterization of conscious mental content i.e. being aware of the thoughts. Since the reflection could either be upon psychological or physiological mental content, we classify them separately as metacognitive and metasomatic stages. The proposed expansion is illustrated in Figure 2.

This expansion of the tripartite model into the five level model facilitates understanding of perception processes and stimuli's influence on cognition. This can help researchers and designers to more clearly identify the mental pathways involved in information processing. Preconscious and meta-somatic pathways offer opportunities for the design of new interaction technologies, with examples included below (see Section 5). We take inspiration from the design of "Implicit Interactions" [41] that occur without the explicit awareness of the user. Since four out of the five modes do not demand much conscious cognitive resources, new interfaces designed according to this framework would allow users to direct mental processes that are in their conscious perception but outside of conscious control.

In this work, we refer to stimulus as change in the external environment sensed through the body's physiological sensors and processed via one of the pathways as shown in Section 2.1. Stimuli influences the body by physical, chemical, electrical or biological means and has the potential to influence the mind.

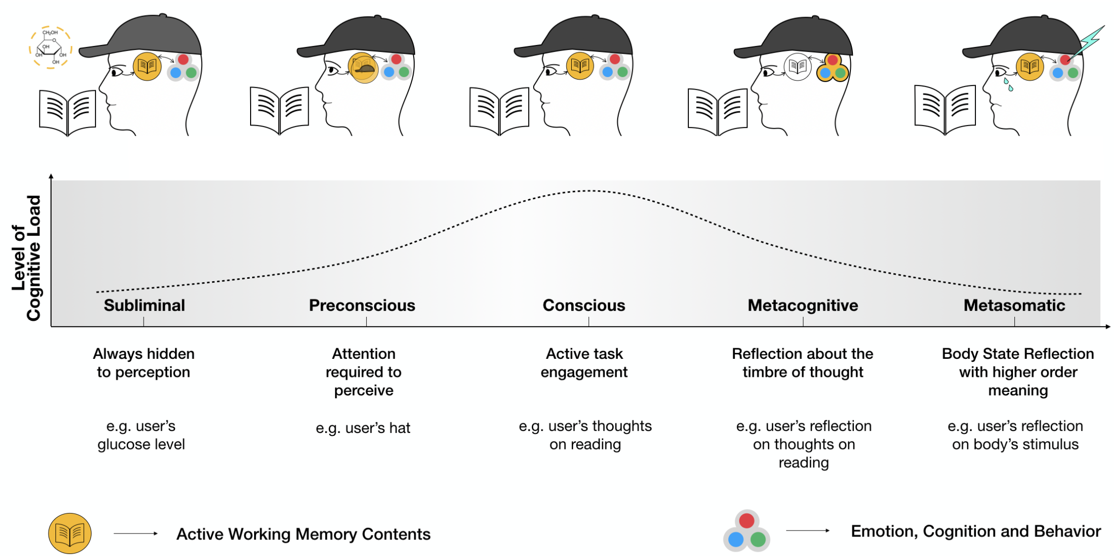


Fig. 3. Cognitive load at each level of consciousness in the five-level model. When reading, (a) glucose levels are hidden from the user's perception. The user is also unaware of word frequency or other linguistic features. (b) The user may peripherally notice the hat they are wearing. (c) The user's active thoughts and engagement with the text content. (d) The user's reflection on their thoughts and understanding of the content. A possible rereading of confusing text. (e) The user's stimulated emotions by somatic intervention while reading. In all non-conscious levels, the user may be peripherally aware of the stimulus but the main cognitive load is taken by the active task the user is engaged in (in this case of reading).

3.1 Subliminal Processes

An subliminal stimulus is a stimulus completely outside of the user's perception. This includes cognitive and bodily processes that are below the level of awareness with no potential to become part of conscious thought. There is no associated cognitive load as there is no perception. For example, insulin levels are actively maintained by the body but they are not perceivable by the user naturally and do not incur any demand on cognition. Medicinal influences, drugs, gene editing, subliminal priming, masking, and environmental effects, also fall into the subliminal processing category as none of them enter conscious perception even though they influence task performance. Brain stimulation techniques used for conditions like depression (electroconvulsive therapy) or epilepsy (vagus nerve stimulation) fall into this area of mental processing. The user is not consciously aware of any mental process alterations though the outcomes/effects are in their conscious perception.

3.2 Preconscious Processes

The stimuli which naturally operate below the level of awareness but can be made aware given enough attentional resources are referred to as part of preconscious processes. The main distinction between the subliminal and preconscious is the potential of a preconscious stimulus to become part of subjective experience given enough attentional resources. These stimuli have higher cognitive demands than subliminal processes but lower than the conscious processes. For example, your shoes may not be in your active perception but paying attention to it as you read this will make it part of your conscious experience.Similarly, people tend to mimic the physical posture or facial gestures of those they are interacting with without consciously intending to or being aware that they are doing so. This unconscious imitation has been shown to increase liking and serves as "social glue" [5]. Interoception and proprioception are prime examples of preconscious processes. MoveU (see Section 5) demonstrates how uncomfortable bodily sensations like nausea and dizziness may be mitigated by stimulating vestibular sensory input that is processed by the preconscious mind.

3.3 Conscious Processes

Cognitive processes that occur at the level of awareness are referred to as conscious processes. These stimuli are actively experienced but are not reflected upon. For example, as you read this paper, you may feel some sentiment about the meaning of the text. However, you do not actively reflect upon why you are reading this paper as you read it unless pointed to. The visual imagery, sounds, and sensations of dreams present another class of experiences that involve conscious content but not explicit reflection [66]. Other examples include active mind wandering without the realization that one's mind is wandering. Nudging and task related haptic interventions also fall into the category of conscious processes. Haptic interfaces have the potential to break the flow of ongoing cognitive processes through demands for user attention, for example, smartwatch vibrations, while a peripheral nudge, can take a user away from their primary task. Persuasive technologies have traditionally focused on the conscious mind requiring active user engagement for supporting behavior change with varying degrees of success. Mindless Computing [1] aims to shift the focus of persuasive technologies to System I thinking or the automatic mind to lower cognitive load on the user and not rely on explicit user motivation while successfully supporting behavior change.

3.4 Metacognitive Processes

The active conscious reflection on conscious experience is a metacognitive process. It is a type of conscious experience where focus of thought is turned onto itself. For example, as you know you are reading, you may become aware and start reflecting on the way you are reading. Metacognitive processes aid in task engagement and planning, and influence mood and emotion [65, 76]. Responding to questions like, "What are you thinking right now?" would require metaconsciousness. There is a significant distinction between conscious and metacognitive processes as the latter carries behavioral consequences of value in the design of new interfaces. Mindfulness and meditation techniques fall into this category and have been extensively explored in HCI research along with several consumer applications that are available for mobile devices as well as VR headsets. We present specific examples in the Technology Review section.

3.5 Metasomatic Processes

The automated mental reflection on bodily sensations which have an embedded cognitive meaning, such as the physiology of an emotion (e.g., a smile is the physical manifestation of an emotion) are meta-somatic processes.

Reflecting on what your body feels, connects these sensations to meaning, each associated through past emotion-action associations like those that link an expression of smile and enjoyment. For example, a stretch in facial muscles to form a smile can lead to the generation of a happy emotion in the mind [82]. The main distinction between metacognitive and metasomatic is that the former reflects on stimulus generated in the mind whereas the latter reflects on bodily stimulus. This has been explored in some HCI research where electrical muscle stimulation is used to actuate the physical body [50] which in turn can have an impact on the user's mental content. Frisson (see Section 5) demonstrates how the meta-somatic process can be used to induce a bodily sensation that causes downstream effects in the mind.

4 TECHNOLOGY REVIEW

Majority of HCI research falls into the category of conscious processes. In this section we classify examples of previous HCI work and phenomenon in cognitive sciences that fall in the other four categories, namely subliminal, preconscious, metacognitive and metasomatic. Figure 4 classifies existing stimulants and processes into each category. We focus on these four categories as they exist outside the locus of attention and highlight new design spaces for HCI researchers. Through these categorized examples we hope to make evident the distinction between the levels of non-conscious awareness as applied in prior work.

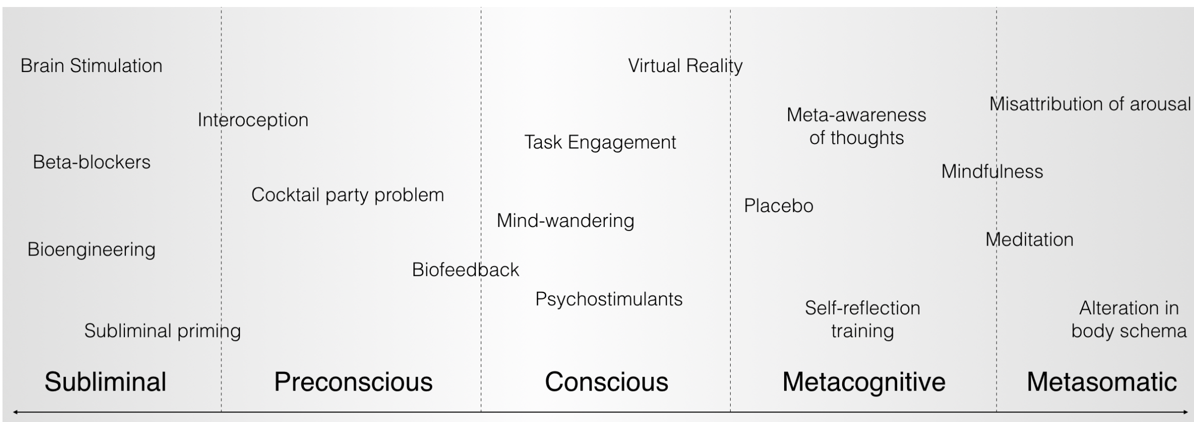


Fig. 4. Classification of example interaction techniques, mental phenomena, and research areas related to the body and the brain, in the five levels of consciousness.

4.1 Subliminal

Several works demonstrate the effect of unconscious influence on conscious task performance. One classic example is "blindsight," where patients with a damaged primary visual cortex (V1) are able to discriminate visual features by pointing and guessing without being aware of the stimulus being presented to them [93]. A similar effect is seen in the mechanism of subliminal priming wherein a brief stimulus lasting for a few milliseconds and outside of visual perception affects task performance [28]. Despite an absence of conscious visual awareness, subliminal visual and textual content can activate the related semantic and affective mental processes [35]. Subliminal priming has been shown to enhance semantic and affective categorization performance, mathematical task performance [19], and facilitation of goal pursuit [4]. An subliminal effect on emotions was demonstrated through the impact on beverage drinking behavior after watching faces displaying different emotions [97].

In HCI, subliminal interactions have been explored with the main motive of injecting information when the user's information capacity is full and no capacity is left to transfer information in a traditional way [67]. Several Non-conscious behaviour change interactions have been explored using subliminal interaction techniques. These explorations use an unconscious stimulus for applications of behavior modification [62]. Subliminal auditory cueing is also found to induce a change in affect [83]. Subliminal cues have also been explored in learning and memory recall scenarios where cueing facilitates intuition without being in a user's conscious awareness [11][20].

4.2 Preconscious

Attentive user interfaces [91] are those that are aware of the user's current intention and focus. These interfaces adjust information delivery to minimize disruption and maximize usefulness. Calm technologies [92] and ambient interfaces [88] present information peripherally, requiring little explicit attention. They often use other modalities than those used for the primary task, making it possible for a user to multi-task with minimal disruption.

Embodiment is at the centre of a type of philosophical thought called phenomenology that rejects the "Cartesian separation between mind and body" [55]. Inspired by phenomenology, embodied interfaces [23, 29] and tangible interfaces [40] make use of spatial and tangible modalities to aid task performance. Proprioceptive interfaces, on the other hand electrically stimulate muscles [50] or use body pose in space [81] to provide eyes-free access to information. These systems focus on minimizing disruption and enhancing task performance by communicating through modes that require minimal user attention.

4.3 Metacognitive

The primary way to influence by metacognitive process is by enabling self-reflective behavior which can cause further downstream effects. Research has shown a positive effect on behavior and task performance with an increase in self-reflection. For example, mindfulness training has been shown to reduce biases, stereotypes [85], and mind-wandering [98]. Self-reflection training exercises have been shown to alter user perception of external stimuli as well as internal emotions [76]. Discrepancy in the ratings of strawberry taste was found to be decreased between participants and experts when participants were engaged in self-reflective behavior [96]. While by being metacognitive includes an explicit characterization of what is currently being consciously experienced, it has significant behavioral consequences [77]. For example, being meta-aware of anger can help attempts at improving self-control.

PsychicVR [2] aims to increase mindfulness by providing visual feedback based on EEG activity to trigger reflections on focus. Lucid Loop [43] presented a virtual reality (VR) experience for practicing lucid dreaming by bringing forth the user's biovitals to aid in self-reflection. Mind Maps are a well known tool used to promote meta-awareness and improve productivity through reflection on active mental thoughts [27].

4.4 Metasomatic

Metasomatic interaction is based upon manipulation of a user's physiology to effect the user's psychology. The manipulation causes a misattribution of arousal as the user reflects upon their bodily physiology. Experiments have shown to increase romantic attraction to confederates by increasing the user's heart rate through exercise [94]. Other experiments have manipulated various forms of bodily generated signals to manipulate specific emotions [47] such as changing facial muscles to influence affective responses [82] or producing feelings of fear, sadness, anger, and happiness [24, 82].

HCI researchers have utilized false heart rate and respiration feedback to create technologies for emotion manipulation that do not require conscious cognitive resources [59]. Although numerous physiological responses are related to emotion, heartbeat is the easiest to implement and understand. Nishimura et al., enhanced affective feelings towards others by presenting a pseudo heartbeat as tactile stimulus to the user [60]. Costa et. al. [14]

showed how modulating heart rate can help control anxiety in EmotionCheck and demonstrated improved performance of false feedback in math tests [15]. VR experiences have used false feedback to generate and intensify fear [87].

5 DESIGN EXPLORATIONS

The two projects presented in this section demonstrate using different levels of consciousness to transfer information from the body to the mind. *MoveU* uses electrical stimulation to modulate low level sensory input to the inner ear and helps mitigate motion sickness. *Frisson* uses thermal input to mimic the bodily response of aesthetic chills and provides information transfer through the mind's reflection on bodily signal. From lessons learned through the iterative design process in each project and the user studies, we present four design considerations in Section 6 that can be used to aid HCI researchers of future devices that aim to build a computer-to-human interface.

5.1 An Example of Preconscious Interface: MoveU

Preconscious interfaces utilize sensory channels that usually operate below the level of awareness but become part of user's conscious experience with attentional resources allocated to the channels. In our daily life, typically vision and audition utilize the majority of attentional resources while other sensory modalities like olfaction, proprioception, gustation, equilibrioception, or somatosensation remain in a preconscious state. Depending on an ongoing event, each preconscious sensation has the potential to change into a conscious sensation and add to user's cognitive load. For example, a strong smell can trigger olfaction and alter cognitive processing [71].

The MoveU project showcases stimulation of a sense in preconscious i.e. proprioception to prevent condition of nausea/disgust.

5.1.1 Motivation. Preconscious interfaces present opportunities to manipulate low level sensory inputs that work on the periphery of a user's perception. The sensory channels provide continuous information to the brain to build a mental map of the user's immediate environment without the user being consciously aware of the information. A detected mismatch between sensory inputs causes the brain to send signals to the body to respond to the perceived environmental threat. One such example of sensory conflict is motion sickness caused by a mismatch between vestibular and visual sensory inputs where motion is felt but not seen[64]. It is most commonly experienced in moving vehicles such as cars, ships, or airplanes where the eyes and the inner ears perceive motion differently, as well as in virtual reality. The poison theory [58] states that as a result of the discrepancy in input signals the brain concludes that the cause is poison ingestion and thus responds by inducing physiological symptoms like stomach uneasiness or vomiting to clear the supposed poison. In cases of virtual media, the user is often stationary and no motion information is transferred via the vestibular afferents. The mismatch with virtual visual motion causes a condition called cybersickness [38]. Nausea generated from these conditions can cause a disruption in the user's active task and break the flow. *MoveU* shows the stimulation of the vestibular afferents in congruence with the visual sensation of motion to reduce motion sickness and prevent emotion of disgust without requiring conscious user input, attention or action.

5.1.2 System. MoveU is a small and lightweight wearable device that stimulates the vestibular labyrinth by passing a small amount of current (Figure 5) through the inner ear of the user. It has a six-axis inertial measurement unit (IMU), three voltage controlled current drivers, and physiological sensors. The electrodes are attached to the user's mastoids and one extension on the forehead. A small amount of current is passed via electrodes (+- 2mA) to stimulate both the otoliths and semicircular canals in the vestibular system. Resulting changes in balance are passed onto the brain via the vestibular afferents. For example, for stimulating roll, the electrodes are attached behind each ear on the mastoids (Figure 5) and current direction, intensity and duration are manipulated for the

Fig. 5. The MoveU device showing placement of three electrodes, two on the mastoids and one on the forehead. Electrode placement along with current intensity, direction and duration determines the sensation felt.

desired effects. For stimulating pitch, a third electrode is attached to the forehead (Figure 5) and direction of flow of current is altered in succession.

5.1.3 MoveU in VR. Our initial exploration involved using MoveU to add vestibular feedback in VR for reducing visuo-vestibular conflict [81]. The experiment involved a virtual roller coaster experience where the device provided vestibular stimulation with specific intensity, direction and duration to match the virtual roller coaster turns. We invited 20 participants (12 female, age range: 18 to 42) for a within-subjects design with participants trying the experience. The experiment involved trying with and without the MoveU device in a random counterbalanced order. Data was collected using the Simulator Sickness Questionnaire (SSQ), the Slater-Usoh-Steed Presence Questionnnaire (SUS) and the Game Experience Questionnaire (GEQ). Results indicated reduced physiological outcomes like nausea and dizziness (Table 1) and a much higher sense of presence (Table 2) when using the device than without. 85% of participants predominantly preferred the virtual experience with the device than without [81].

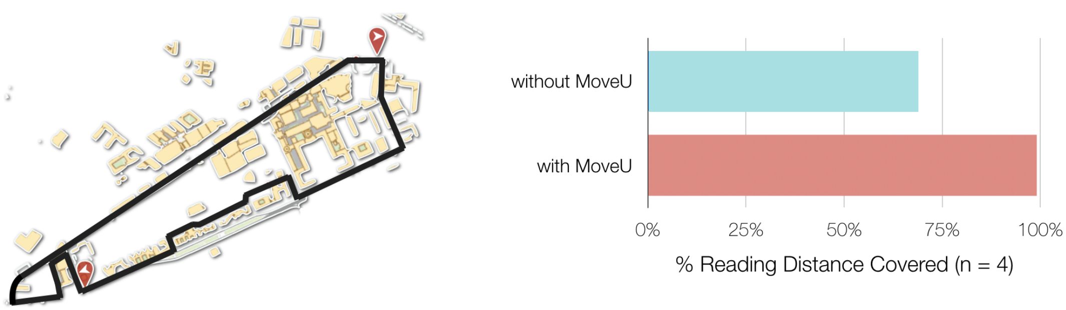
5.1.4 MoveU in a Vehicle. Motion sickness in moving vehicles when a person is reading is due to non-availability of visual motion cues but transmission of vestibular motion data to the brain. In this experiment we stimulated the vestibular system to suppress motion data going to the brain in order to match the stable visual data. The stimulation counteracted vehicle motion data accessed using the device IMU in real-time. The pilot experiment involved riding the back seat of a campus shuttle bus with four participants susceptible to motion sickness, one at a time. All participants did both trials, with and without the MoveU device in a counterbalanced manner. They were tasked with reading excerpts from a book during the ride and took a 20 minute break between rides. During the ride, the participants reported their status after major turns (Figure 6) and were asked to stop reading if they felt motion sick. Each trial took 25-35 minutes. All four participants were able to successfully complete the trip with the MoveU device. Without the device, 3 of the 4 participants reported feeling motion sick and stopped

Table 1. Mean scores of evaluation and results of a pairwise Wilcoxon test for with-MoveU and without-MoveU conditions showing impact of sensory input to the preconscious level of awareness causing physiological output.

Data	Trial	with-MoveU	without-MoveU	Wilcoxon Test
Nausea	Pre	4.08 ± 5.58	1.90 ± 2.56	$V = 29, p^* = 0.046$
	Post	8.05 ± 11.28	15.52 ± 20.22	
Oculomotor	Pre	5.67 ± 7.54	4.60 ± 5.97	$V = 13, p^* = 0.025$
	Post	4.64 ± 5.46	8.09 ± 8.30	
Disorientation	Pre	5.72 ± 7.75	5.62 ± 9.72	$V = 22, p^* = 0.033$
	Post	9.91 ± 7.83	23.71 ± 26.13	
Total	Pre	5.90 ± 6.19	4.51 ± 5.81	$V = 21, p^* = 0.009$
	Post	8.04 ± 7.08	16.32 ± 17.82	

Table 2. Mean scores and results of a pairwise Wilcoxon test between with-MoveU and without-MoveU conditions for Presence, Positive and Negative Affect, and Flow.

Data	with-MoveU	without-MoveU	Wilcoxon Test
Presence	3.60 ± 2.16	2.40 ± 2.19	$V = 110.5, p^* = 0.027$
Positive Affect	3.03 ± 0.88	2.55 ± 1.12	$V = 135, p^* = 0.032$
Flow	2.72 ± 0.82	2.37 ± 1.03	$V = 134.5, p^* = 0.034$
Negative Affect	0.59 ± 0.63	0.86 ± 0.84	$V = 37.5, p = 0.21$



(a) (b)

Fig. 6. (a) The map indicates the shuttle route taken during the pilot study and highlights two areas where the shuttle took sharp turns. (b) Results showing the distance participants were able to read for in the moving shuttle with and without the MoveU device.

reading at one specific location where the shuttle took a sharp turn while one participant stopped reading on a straight section of the shuttle route (Figure 6).

5.2 An Example of Metasomatic Interface: Frisson

Metasomatic interfaces utilize imitation of physiology of affect or behaviour to lead the mind into interpreting the effect as being generated by its own mechanisms. The effect has been found true of several emotional sensations [14, 59, 60, 87]. Metasomatic interfaces focus on influencing physiology to drive the psychology. As a metasomatic interfaces, we investigated replicating Frisson, a sudden strong feeling of excitement or fear [53]. Frisson is typically characterized as a shiver going down the spine when a user is exposed to a poignant stimulus like art or music. Theoretical models have described it as an effect of meaning construction by the mind. A high correlation between the perceived stimulus and the mental models of the stimulus can lead to generation of positive chills and have a positive valence [74].

5.2.1 Motivation. Frisson or Aesthetic Chills are described as universal emotions, interpreted similarly across all cultures [53]. Of the five main personality traits – OCEAN (Openness, Conscientiousness, Extroversion, Agreeableness, and Neuroticism) – chills are very closely associated with Openness [53]. Previous studies on aesthetic chills demonstrate their modulatory effects on stress, pleasure, and social cognition [75]. Chills have been described as a physiological marker of salience [72], a self signalling mechanism allowing the cognitive system to orient its attentional resources toward evolutionary relevant stimuli [51]. People with more openness to feelings and a greater sense of empathy are likely to have more chills when exposed to appropriate stimuli. Such a strong emotion has the potential to momentarily alter personality and even modulate behavior depending upon the situation. In this project, we investigated the potential to generate aesthetic chills and its subsequent downstream effects such as empathy towards a stimulus.

5.2.2 System. Frisson is a localized and non-invasive wearable device built to modulate the sensations which underlie the embodied emotion of aesthetic chills (i.e., goosebumps, psychogenic shivers) by simulating traversing cold and vibration sensations down the spine [73]. The device consists of three Peltier elements and vibration motors placed at different spatial locations on the back (Figure 7). The actuators are controlled by a Bluetooth enabled control board. The entire device is cast in silicon to conform it to the body. The device delivers thermal feedback in a manner closely resembling an internal chill. An accompanying Android application activates the device in sync with the stimulus, determined by the researcher and kept constant across all participants. We tested the device in a series of preliminary experiments, and improved the design based on participant feedback to reproduce the sensation of chills. The final device delivered thermal feedback in a manner closely resembling the internal chill, a traversing cold temperature from top to bottom for a period of 3s and a short burst of tingling vibration at the top of the back for 1s.

5.2.3 Experiment. In order to evaluate whether the device can elicit chills, we did a user study involving 21 participants (7 female, age range: 18 to 46). A speech excerpt from the Charlie Chaplin movie "The Great Dictator" was used as the stimulus. In the within subject study, each participant did the experiment twice: once with the device and once without, for the same stimulus. To account for learning effect, participant order was counterbalanced. Subjective data was collected through surveys after each trial. Questions included reporting on the number of chills experienced, the intensity of the chills experienced, time points in the stimulus that elicited the chills, whether participants shared the speaker's viewpoint, and whether the participants shared the speaker's feelings. Participants were told that the study examined the relationship between temperature and cognition, and were given the definition of aesthetic chills as psychogenic waves of cold as opposed to external cold stimulation from device, and asked to report only the former. The stimulation device was placed on their back and a flex sensor was wrapped on their right hand's index finger. Participants were told to clench their hand if they experienced aesthetic chills at any time during the film, so that the flex sensor could collect a count of chills. The subjective questions were asked on a Likert scale of 0-10. Once the experiment was finished, the

Table 3. Mean scores and results of a pairwise Wilcoxon test between with-Frisson and without-Frisson conditions for Intensity, Empathy and Pleasure respectively per row.

Data	wDevice	woDevice	Wilcoxon Test
Intensity of Chills	5.62 ± 2.44	4.33 ± 2.56	$V = 104$, $p^* = 0.033$
Sharing speaker's feeling	8.00 ± 1.73	7.19 ± 2.40	$V = 74$, $p^* = 0.015$
Pleasure rating	7.67 ± 1.28	6.95 ± 1.66	$V = 38.5$, $p^* = 0.032$

experimenter disconnected the sensors and provided the subject with a questionnaire. Finally, the subjects were thanked for their participation and fully debriefed. Each session lasted about 20 minutes.

5.2.4 Results. Analysis of the data (Table 3) shows that the device significantly increased the number of chills experienced by the participants (Figure 8). Four people who did not feel any chills without the device, experienced them with the device. The data indicates that artificially induced chills were perceived as internal chills with a higher intensity ($p = 0.033$). The measure of empathy (sharing speaker's feelings) also showed a significant increase ($p = 0.015$). There was also a significant increase in pleasure experienced with the device ($p = 0.032$).

Both *MoveU* and *Frisson* present an example for using preconscious and metasomatic pathway respectively. In the next section, we present four design considerations towards developing non-conscious computer-to-human interactions.

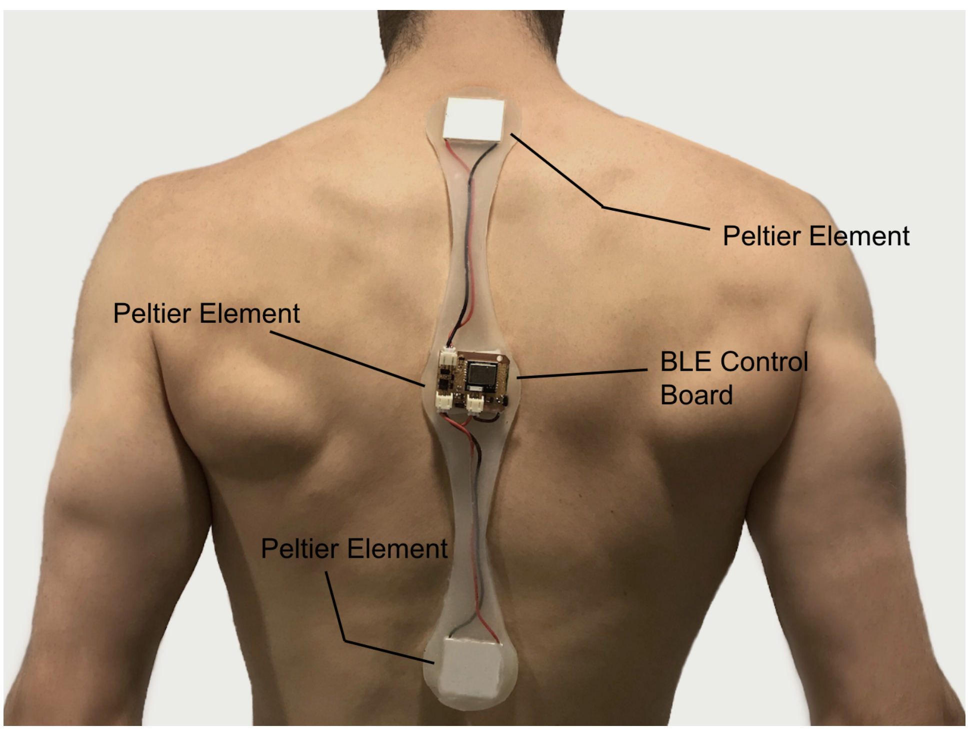


Fig. 7. Frisson wearable device showing the Peltier elements and their placement on the back to elicit aesthetic chills.

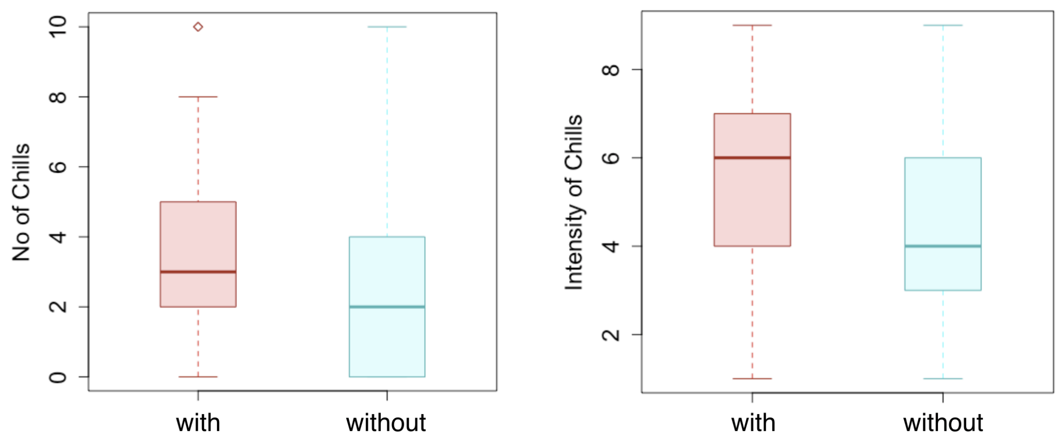


Fig. 8. Number of chills and intensity of chills experienced by participants is significantly higher (p=.0021) & (p=.0.033) respectively when using the Frisson device.

6 DESIGN CONSIDERATIONS

Thus far we have identified new mechanisms for influencing the mind that do not require explicit user attention. We showcase five levels of awareness with respect to their demands for cognitive resources. We also presented two example technologies that use alternate paths to target emotion and cognition by targeting the preconscious and the metasomatic processes. Here we provide directional cues and considerations that can aid in the design of such body-to-mind technologies.

6.1 Targeting the Senses

The brain is difficult to access, and extremely difficult to effect with specificity. Current brain stimulation technologies are either prohibitively invasive or not specific enough to be useful. The body, on the other hand, has exposed interfaces to the world and provides well studied links to the brain. For example, we can target the olfactory bulb through the nose or the color vision area (V8) with colored light.

The first step in *writing to the body* is the identification of possible bodily input channels through which information can be transmitted. The main sensory channels we can use are vision, audition, proprioception, touch, taste, and olfaction. Each of these acts as an interface to the outside world and is a primary influencer in the brain.

Sensation involves three steps:

- Sensory receptors detect environmental stimuli.
- The stimuli are transduced into electrical impulses and sent to the brain for processing.
- Electrical impulses travel to parts of the brain where they are processed into information (perception).

All senses have perceptive thresholds, for example, we can only hear up to a certain distance or frequency, we can only see light of a specific frequency range, or perceive smell beyond a certain level of concentration. Each sense has distinct characteristics that can help researchers pick the appropriate target sense for their design. For example, usually vision and/or audition based interactions demand a significant amount of cognitive attentional resources [52] but are the most common ones used in interaction design. Olfaction provides opportunities for interfacing during sleep [6] as it is not routed through the thalamus which relays motor and sensory signals to the cerebral cortex. Hence researchers exploring sleep related interface designs can benefit from using olfaction. Somatic senses include the sense of touch, proprioception, and haptic perception [68]. These can be used to design both conscious and unconscious interfaces. Touch has a high degree of sensitivity and resolution allowing it to sense a range of input from pressure to texture, pain, temperature and vibration. This is useful for the design of haptic feedback devices that reside in conscious awareness as well as those that target metasomatic processes, like *Frisson* (see Section 5). Other peripheral internal sensors operate inside the body to help maintain homeostasis. For example, baroreceptors for detecting changes in blood pressure, sensors for tracking blood glucose levels, heart rate etc. Most of these bodily sensors work at either the subliminal or preconscious level of awareness but some processes, like heart rate, can be manipulated through reflection on external stimuli [14].

6.2 Effect Validation

Effect validation becomes challenging when designing body-to-mind interfaces that target non-conscious processes. Researchers need to be aware that evaluating the technologies simply based on self-report questionnaires at the end of the study could provide misleading results [69]. Pre- and post-surveys used together could help to better evaluate the difference in user's psychology or physiology caused by the intervention. Another option would be to collect just-in-time feedback, where the evaluation can be done close to the input time, given that the effect could deteriorate very quickly. This type of evaluation could be done using physiological data, voice analysis, optical facial expression analysis etc. Users need to be made mindful of their baseline and normal conditions before they begin an evaluation in order to have more accurate self-reports. A randomly ordered counterbalanced within subjects design is preferable to other study designs as every user has different sensitivity and perceptual baseline of the world. In evaluation of technologies that alter the user's physiology, we suggest researchers to be mindful of of carryover and habituation effects. For example, in MoveU, participants experiencing the without-device condition first generally developed more motion sickness symptoms that were carried into their with-device trial. While this could be resolved with a longer gap between the study conditions, oftentimes it is realistically not possible to ask the same users to return to the study on a different day. Furthermore, senses are susceptible to habituation which can lead to sensory response saturation and decrements in the intended effect of the intervention. For example, studies show users reaching sensory saturation with continuous vestibular stimulation applied over multiple 30+ min long sessions [3, 22, 33].

6.3 Ethics

Technologies working at levels of consciousness that are not in the fovea of attention mean users have limited capacity to discriminate between options, outcomes, and possibly high degrees of suggestibility. As we build tools like *Frisson* for influencing the mind through the body, we must design ways to inform users about how the device could influence them outside their conscious awareness. Users need to know which mental processes are being targeted and what effects they could expect to feel. Beyond informing users, designers can give the user complete control over their experience by building devices that can be customized, and operated by the user. Another option is to provide a transparent reflection interface for such technologies that, for example, enables users to keep track of changes made to their mind to help them "see" the influence through the non-conscious cognitive processes. We envision in all of these considerations is that the user voluntarily chooses to use the functionality and is involved in setting preferences and choices in the setup phase of the interaction. Users may also be given interfaces to review afterwards about when and how the system intervened, its effect on user's physiological and psychological data. Users would have an opportunity to modify or end the operation of the system any time. While HCI technologies such as those described in this work could conjure thoughts of science fiction like mind control, especially if the user is not aware of the influence, the same could be said of advertising or medical treatments. With increasingly powerful and targeted interventions for mental illness and neurological disorders, researchers are calling for new safeguards for brain-focused therapies that can manipulate mental states [48, 54]. For example, drugs for Parkinson's disease boost motor function but can also make patients more impulsive. By including a section on Ethics in our work, we hope to inspire other researchers who work on designing technologies, medical or otherwise that can influence the user's mental state, to start including a discussion of ethics as part of their work.

6.4 Target Application Areas

6.4.1 Intervention Technologies. Body-based interfaces open up the design space for developing assistive and rehabilitative technologies. Similarly, non-conscious just-in-time feedback systems have the potential to help regulate embodied cognitive functions without disrupting user's task engagement. Panic attacks, depression, and insomnia, all present symptoms simultaneously in the body and brain [12, 46, 78]. Systems such as Emotioncheck [14] provide aid in controlling user's anxiety by providing tactile false feedback user's heart rate using metasomatic intervention. Recent study also shows use of unconscious neural reinforcement for conditioning fear response in users [84]. Targeting the preconscious and metacognitive states which contribute to disorders through body-based interfaces could provide new opportunities for the design of clinical interventions that are not as attentionally costly as cognitive behavioral therapy.

6.4.2 Augmentation Technologies. Body-based interfaces can potentially augment user cognitive capacities. In affording greater control over cognition that typically operates outside the conscious domain yet guides behavior, these interfaces can enable users to make more informed decisions and take more intentional actions. Researchers have shown augmentation of creativity by dreams control [37], enhancing pro-social behaviour using scents [36], memory recall using subliminal priming [20]. The devices also augment innate capacities (e.g., MoveU for mitigating motion sickness), entertainment and other visceral experiences similar to how Frisson enhances the experience of watching a speech excerpt from a movie.

6.4.3 Research Opportunities. Research in embodied cognition and emotion regulation has furthered our understanding of the brain-body link and created new paradigms for diagnosis and treatment of disorders [56]. Creating tools that are designed to engineer emotions based on theories of embodied cognition allows us to ask new questions about how our psychology and physiology are connected. Wearable and ubiquitous devices can ask those questions with ecological validity, in the wild. These could give us new windows into how emotional nightmares manifest in the body, how panic attacks are tied to physiological changes, how our brain generates our body schema and more.

7 LIMITATIONS

Our classification system has a few limitations that are worth mentioning. In this work, our goal was to identify non-conscious pathways for conveying information to the mind that have not been explicitly included in prior models of levels of consciousness. While we presented a five level model that is focused for HCI research, it may not be the appropriate model for other work nor are the five levels an exhaustive list of the levels of consciousness or showcase linearity among the levels. For example, new levels of consciousness could be conceived based on concepts from social cognition and theory of mind. Our classification attempts to place cognitive processes, as shown in the example projects, in the appropriate levels though cognitive processes are not strictly confined to specific levels and the boundaries between the levels are fluid. For example, interoception predominantly exists in subliminal and preconscious levels but research in body awareness demonstrates its effects on emotional behavior and the user's mental health [26, 63], thereby spanning multiple levels.

8 CONCLUSION

Over the years, many HCI technologies have been designed and developed with a focus on the conscious mind and an expectation of active user interaction, requiring attention and cognitive resources. The success of persuasive technologies has depended not only on user participation but also user motivation. However, if the user is not aware or motivated about behavior change, such technologies will likely fail.

In this paper we show that novel interface technologies can be designed in ways that are not demanding of explicit user attention. We propose a higher granularity in the levels of consciousness than previous dual and tripartite models. The five-levels of awareness provide the backbone for a design framework of technologies that use the body as an interface to the mind. To this end we introduce the concept of *writing to the body* and present two examples to demonstrate the concept. The first example is MoveU, a head or neck-worn wearable device that uses electrical stimulation to reduce motion sickness without requiring conscious user input, attention or action. The second example is Frisson, which leverages metasomatic processes to elicit aesthetic chills through a back-worn wearable device with peltier elements and vibration motors.

Finally, building upon the tripartite model of consciousness and the technologies designed to access the non-conscious levels of awareness, we provide a set of design considerations that can be used to guide the development of body-to-mind interfaces. We hope the work presented in this paper will inspire others in designing novel technologies that are seamlessly integrated with our body and mind, and inspires HCI researchers to explore work in psychology, neuroscience and related areas to create new lenses with which HCI work can be viewed.

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