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Designing affective haptic experience for wellness and social communication: where designers need affective neuroscience and psychology

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As a central aspect of human physical and emotional experience, affect needs to be incorporated into the discipline of *haptic experience design*, which is emerging alongside the last decade's maturation of *haptic technology*. Meanwhile, *haptic science* fields such as neuroscience and cognitive and social psychology are contributing to knowledge of affective mechanisms and behavior. However, developments in these three areas are often siloed, due to the complexity of the systems being studied or built, diversity of methods employed and distance between the home disciplines of the respective researchers. To facilitate greater bridging, this article offers a glimpse of how practitioners of haptic design conceptualize their work, and ways in which researchers working in these disciplines can jointly identify and fill gaps.

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Introduction

The haptic modality is an important channel in human experience and expression of emotion, on its own or by intensifying or complementing other senses, and playing into our interactions with objects, non-human animals and other people [1,2]. We identify 'haptic' here[1] in the broad engineering sense as encompassing tactile and proprioceptive inputs and outputs across the body, and highlight the role of bidirectionality in affective communication — motor actions, often shaped by perceptual goals [3], as well as perception in its own right.

We are learning more of how humans perceive, process and use affective haptics personally and socially [4] as well as for functions such as physical discrimination and manipulation [3,5]; and how to build technology that supports digitally mediated physical experiences. However, the complexity of haptic science and technology can make them mutually inaccessible, and also impacts the field of *haptic experience design* — a younger discipline that deploys related technology in applications, usually alongside visual and auditory mediums, and is developing its own theories and principles [6–8].

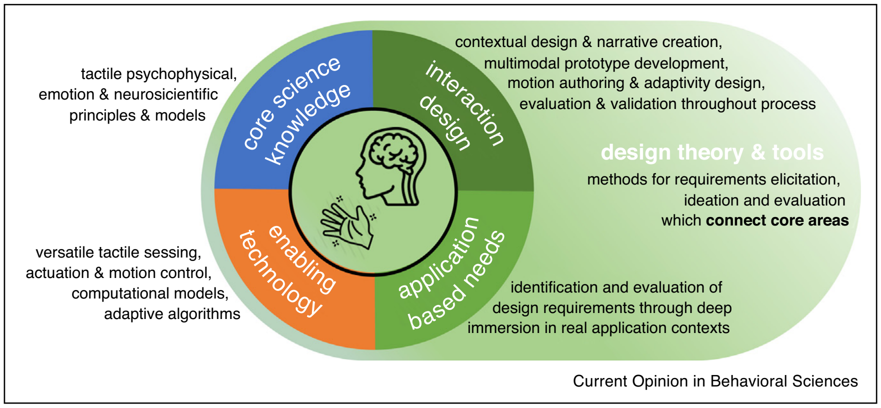
When designers create *affective* haptic experiences, there is a particular motivation for bridging the gap between science and technology: increasing recognition that an affective lens may be a good, perhaps the best, design approach generally because of its centrality to how humans process physical experience [16]. However, haptic experience designers require deeper theoretical foundations than are currently available, to effectively leverage haptic technology's affective potential.

The purpose of this article is to invite an audience of ***affective haptic science*** researchers to consider the places where ***designers*** of haptic experiences (in the field of human-computer interaction, or HCI) and their ***enabling technology*** could benefit from science insights. It offers an illustrative sample rather than comprehensive coverage, and emphasizes developments of the last 5–10 years, the timeframe in which some haptic technologies have matured to the point of commercial viability, and the priority of learning to design with it has grown.

The following sections consider how distinct haptic domains could interact to motivate and inform one another (Figure 1); and explain how haptic experience designers conceptualize their work via the "dimensions" of a design space.

[1] Engineers and computer scientists build and use technology which often acts on both tactile and proprioceptive receptors. Hence, they typically use the term 'haptic' to span these sensations, and to refer both to *active* and *passive* human interactions with objects and materials. Here, we adopt this usage because as designers, we must be concerned with every aspect of experience related to the skin: tactility and materiality, proprioception from the human perspective and the motion and forces that engage it from the device side, in both active and passive engagement. There is not yet a widely accepted term that encompasses all of this.

Figure 1



Domain perspectives informing haptic experience design, comprising the various lenses through which a designer must consider the user's experience.

Domain perspectives that inform haptic experience design

We begin by describing interlinkages between the domains portrayed in Figure 1.

Application needs that can be met through affective haptic experience design

In affectively-informed haptic design, common objectives are to create an experience in which a digitally mediated system might do one or more of *communicating* an emotion to another human; *sensing* a person's emotion; and/or *influencing* their emotional or affective state. These basic building blocks can show up in myriad ways, as in Table 1's examples.

Numerous such scenarios have been proposed and explored, particularly in the space of health, wellness, mental health therapeutics (e.g. anxiety and pain management [2,31••]), and in social touch [4,32]. Notably, many more do not have affect or emotion communication or expression as a primary purpose, but employ it as a trigger of attention or memory.

Affective haptic science

In early days of haptic technology development (circa 1990s), engineers soon realized they required psychophysics to specify haptic technology, including an understanding of human discrimination and control abilities with respect to textures and forces and of the manner in which they couple sensation to motor action. Lederman and Klatzky's seminal work on exploratory procedures contributed an important practical insight into how our manual behavior is shaped by the nature of *functional* information we seek [3]. They showed that we perceive and notice differently when actively exploring and passively receiving and thus instructed designers to approach tasks supported by a tactile display worn on the arm (experienced passively through glabrous skin receptors) differently than those based on devices for active fingertip manipulation.

For haptic designers, understanding and effectively addressing *affect* [13–15] is today's science frontier. We need to understand the emotional language of haptics at the level of the skin and ingrained gestures, so we can sense, interpret and speak it with mediating technology. To some extent we can do this by studying behavioral constructs and relating them to physiological sensing and models [33•]. However, greater knowledge of neurological mechanisms would steer us on more effective paths and spur problem-solving in a range of areas including the following examples.

A touch giver's intent and physical expression

HCI, behavioral psychology and neuroscience researchers use creative means to observe how people express emotional or social intents through touch and the manner in which such expression varies within and between individuals [16,16,34–36,37•]. Such insights, which link internal states to tactile behaviors, are needed by experience designers so they can guide and support touch motivations. Intuition alone tells us that affective intent, whether hedonic, communicative, or discriminative, informs touch-seeking movements along with functional information needs. Can haptic science tell us the mechanisms by which humans balance, execute on and internally reward these different motives?

A touch recipient's interpretation and response

Neuroscientists have learned something about how the pathways by which a haptic sensation resulting from an active or passive touch contribute to a person's internal processing (e.g. as pleasurable, averse or simply conformant to expectations) and their reaction to a touch

Table 1

Examples of affective design objectives: contexts in which we may want to communicate, sense, or influence an affective or emotion state

Purposes with affective intent
Affective communication: Send or receive an emotionally rich, nonverbal message to a remote person or virtual entity [17–19].
Comfort and calming: Utilize visceral affective display to directly reduce stress or pain experience [20–22].
Emotional self-regulation: Use haptics as an intuitive biofeedback modality to help an individual recognize intensive emotion states and learn to self-calm [9,11,23,24].
Using affect as a means to a non-affective (e.g.functional) purpose
Functional social touch: Coordinate joint tasks and convey urgency with a remote person or team, a co-located robot or virtual partner, in a manner that – to be effective – channels a real person and therefore needs to reflect human communication norms [25–27].
Functional messaging: Use affect in tactual signal perception as a parameter with which to make signals easier to differentiate, learn, and recall [28,29].
Valence and amplitude messages: We easily associate harsh versus soothing sounds as 'Dangerous/Stop' or 'Good/Okay', respectively. A valenced tactile signal can be similarly used alongside signal intensity — for example stridently unpleasant versus pleasant [30].

interaction [5,38,39,40•]. Some have attempted to fuse this knowledge with that from other areas, including cognitive and social psychology and cultural anthropology, to imagine how we could model or predict responses [35]. Such insight is sorely needed to develop dynamically responding interactive devices.

Context

What toucher and touchee know or believe about the nature of the touch contributes top-down to these experience. For example, emotion interpretation of physical gesture in a robot is influenced by narrative frame [12]. Reaction to a touch is mediated by the touchee's belief about the toucher's identity [41]. Haptic designers would like to understand the underpinning mental processes (e.g. adding to Ref. [42]) so they can better predict and steer a user's perceptions.

Enabling haptic technology

Haptic technology development has been dominated by simply overcoming the challenges of providing digitally controlled haptic stimuli to the human body, or receiving its manual input. The skin is a highly dispersed reception site, in contrast to our eyes and ears, and haptic technologies require physical contact. Thus, design practice and theory have become relevant only more recently.

Haptic technology is typically classified as either *tactile* or *force feedback*. The first acts predominantly on the skin by, for example, providing textures or patterns to be felt through the fingertips, or strokes on the arm. The latter focuses on proprioception, supplying forces that are usually computed in response to the user's own movement and perceived via muscle, joint, and skin mechanoreceptors. This includes, among others, grasping a handle on a robot linkage to feel forces in a virtual environment or sensing the expressive physical breathing motion of a robot animal through a hand laid on its back. Tactile processing is also involved in most force-feedback interactions, since forces are transmitted through the skin. Force-feedback devices generally must be "grounded" or anchored to the world, in order to provide reaction forces to the user – for example, bolted to a table or attached to a different part of the user's own body. In contrast, tactile feedback technology does not require physical grounding.

As an indicator of haptic technology diversity, the Haptipedia taxonomy classifies over 100 grounded force-feedback devices as of this writing. This is just one of many approaches to providing physical sensations to the body, yet it alone requires a high-dimensional space to capture its range (Haptipedia.org, [43]). Huisman and colleagues elaborate a number of technologies used in social touch specifically [4].

The basic problems that haptic technology needs to solve are *sensing* and *recognizing* nuanced human-generated movements and forces (going beyond force and contact position to shear, pressure, torsion, squeezing, fluffing and complex grasp); *modeling* and *computing* some kind of interaction construct (e.g. a virtual environment, or interpersonal communication system); and *rendering* tactile or force sensations somewhere on the body. Generally, this must be done at an order of magnitude higher update rates (1 KHz is typical) than computational graphics or sound, because of human sensorimotor system considerations and robot stability. It must also be integrated with other computational and display processes. In recent years, gesture recognition, intent modeling and rendering have utilized other computer science advances, for example, machine learning and adaptive algorithms [44,45,46•].

Affective haptics add new technical requirements to those defined by sensorimotor psychology. For example, the pressure with which we stroke, rub, tap or squeeze a surface (whether a handheld phone or a furry robot) is emotionally informative [47,48]. Yet, current spatial tactile sensors are generally limited to measuring position (e.g. Ref. [49]). How does touch *gesture* (the motion, speed, and changing pressures of a touch, all of which a system can directly sense) relate to changes in the *emotion*, which the toucher feels or is trying to convey? New computational methods are needed here, such as artificial intelligence and machine learning algorithms that are informed by findings in affective science.

HCI: the affect-based haptic interaction design space

What do affect-inclined haptic interaction designers need to consider? Their purpose might be dictated by an application need (e.g. adding a physical component to remote interpersonal communication, or a tool for emotion regulation). Alternatively, it might be to create an environment in which we can scientifically observe and try to understand a human mechanism. For example, in collaboration with haptic science they may tackle how and to what degree different haptic stimuli regulate emotion.

Haptic designers draw on a rich body of methods used in human-centered design generally. Briefly, these include full-design-cycle frameworks, such as "design thinking": a problem-centered approach which begins by 'empathising' with the situation faced by users, defining the problem, and ideating, prototyping and testing solutions [50]. There is also a plethora of specific techniques to observe and understand individual or group needs, tasks, constraints and social structures [51], and to evaluating affective interfaces specifically [52].

A trademark of most HCI design techniques is deep involvement of users and other stakeholders [51,53]. In the example of a child's therapeutic emotion regulation above, stakeholders might be patients, clinicians, and parents. We ideally begin with a grounding in theory about the role of haptics in emotion regulation. The clinician would describe a therapeutic goal, and our work with patients could examine ways to engage haptics in an intervention that would be accepted and thereby more effective. We could then ideate on technological forms to implement this, which might include defining how a robot companion could work.

Constraints: what the designer must work with

Human capabilities and current technical limitations constitute the principal walls of any interaction design space. Designers must additionally consider distinctive aspects of the various physiological elements contributing to haptic sensation (broadly defined), their variations across the body, neural processing, and relation to other sensory modalities, memory and attention, all of which are informed by haptic and multimodal science and psychology as discussed above.

Of particular import to affective haptic design are *social factors*. These include the individual's momentary or chronic *state* (e.g. with respect to mood, pain or stress), their situational *context*, *social norms* about body site and others' touch [54,55••], and *proxemics* (e.g. conveying a sense of interpersonal distance). To illustrate the last, one approach is to use skin stimuli to reinforce a virtual percept about distance (e.g. time-of-flight in a game of virtual ping-pong [56]).

While basic aspects of the humans psychophysical apparatus tend to be fairly uniform, there are subtle differences that affect individual aesthetic preferences, desire and need for social, hedonic or functional touch, and learned associations of a specific kind of touch to meaning or memory [57]. This can complicate one individual's knowing or sharing of what another is experiencing, even when exposed to an apparently identical stimulus such as when designing or sending an affective message. Personalization is therefore often necessary [19].

We generally think of basic human capabilities, including sensory, motor, and cognitive function, as relatively immutable. In contrast, social behaviors, tendencies and skills vary across culture, sex, gender, family birth order, socioeconomic status, age, and recently, by generation.

For example, today's 'digital natives' (young people who have grown up in the digital age, in close contact with computers, the Internet, streaming video and digital social media) may "share fundamental properties and drivers of human behavior, cognition and emotion' with their parents" [58]. However, ubiquitous virtual social contact during their development in childhood and adolescence [59] has led some to a profoundly different need for co-presence and social physical contact than what their parents experience [60]. Their immersion in digital social media (primarily text and video based) may have reduced their exposure to and developmental experience with physical social touch from both family and peers [61]. Their experience of play may have moved from in-person and physical (e.g. playground, board games) to digital and virtual-reality gaming, where often players are not physically co-present. Physical touch is key to social development and mediation of social perception [62], and adolescence is an important period for learning social skills [63]. The touch deprivation associated with the move to online socializing may have important consequences in their adult social habits.

Haptic technology is on the move, with movement sensing and recognition advancing at the greatest rate. Nonetheless, for the foreseeable future we will live with its greatest limit: stimulus production systems can only accommodate a small part of the full scope of real direct touch, in terms of qualitative range of sensations conveyed, fidelity, spatial extent and expressive range and more. We must be creative about illusions and interaction paradigm, making the most of what we have. For example, we can convincingly stroke a virtual surface through a stylus or fingertip, when full-hand interaction cannot be managed.

Grounding: in direct-touch experience, or completely new?

Haptic designers must balance leveraging the intuition of familiar "direct touch" situations (e.g. social touch as studied in naturalistic situations [64]), with new modalities of interaction now made possible through digital advances, such as advanced networking, virtual and augmented reality, robotics, sensing and display technology [32].

Self-ness: user's concept of the interaction entity

The designer needs to choose a construct for how the user thinks about the thing they are interacting with, then ensure that its behavior reinforces this. Do users regard it as a robot, an appliance, or an extension of themselves (e.g. a tool, or clothing)? To what extent does it have agency and personality? Are users willing to pretend that the robot is alive in some way, and attribute/project ideas and feelings onto it? Does the robot directly portray another being (e.g. person, pet), acting as an expressive avatar; or does it simply connect the user to that other, like one's phone when we text someone? Do users own or control the robot or does the robot belong to itself or someone else? In emotion expression, are users conveying their own, or trying to elicit or achieve an emotional result with another (e.g. to calm a robot companion which is evincing distress, as a pathway to self-regulation) [65]?

The role that haptics plays within a multimodal interaction

Most haptic interaction designs are multimodal. Roles that haptic sensations will be particularly suited to must contribute within the context of a multisensory partnership. In the framework defined by [10], these include *providing* an environment, *notifying* of changes, and *guiding* through an experience. It can *reinforce* the same information as another modality, or *complement* the construct with independent elements. It might be the *primary* focus of the experience, or a *secondary* factor; temporally it might *initiate* it, or be part of the *followup*.

User control

Will the user engage actively or passively in the interaction, or both (e.g. stroking versus being stroked)? Active interaction is usually manual and can involve manipulation. It is an opportunity for force feedback as well as purely tactile acts, which are entirely different experientially.

Opportunities for passive involvement are often worn, or encountered in the world (e.g. seats, appliances, tools). They can address more body regions and be spatially distributed as well as single-site. Vibrotactile feedback remains the most common technology, due to convenience. Its limited expressive power can be enhanced via combination with other submodalities like temperature, pressure, shear, and more. Some researchers are studying how human social-touch gestures such as stroking can be recreated with a robot, and their reception by humans [66•].

Creating expressive sensations and movement

The need for expressive power, which is the ability to intelligibly display a wide range of sensations [67], is common to many haptic design needs. For many affective applications, designers further need to construct generally recognizable emotive behaviors or stimuli such as vibrotactile rhythms, zoomorphic or humanoid robot emotion display. While some approaches can rely on brief or periodic formats for expressivity that are feasible to hand-craft (e.g. vibrotactile icon design [68]), others will require skills akin to expert graphic animation artists for both visual and felt movement (e.g. behavior of a cuddly emotional robot [69]). Such design can employ parameters like proxemic approach/withdraw behaviors, drawing on disciplines of dance [70], and needs to consider narrative context [12,71].

Future directions: science-informed design theories and tools

We need additional paths to translate affective haptic science findings into actionable frameworks that can be systemically assessed in application-inspired contexts, thus leading to strengthened understanding as well as pinpointing needs for technical innovation. This includes formulating science-informed design theories and emotion models on which we can build interaction frameworks for social-emotional regulation.

Haptic interaction design is a relatively new field, and most designers do not yet consider affect if the application does not seem explicitly emotive in nature. This will change with the introduction of design tools that put this attribute forefront [28,29].

Conclusions

Figure 1 centers on an HCI perspective. It could instead be customized for researchers of any of these four facets by depicting their respective pie-wedge as a full, inner concentric ring that bridges and links the remaining three facets to the human user. Those working primarily within each domain can and should see themselves in a central influential role. All disciplines work directly with the humans we are trying to understand and empower.

However, an HCI perspective provides a unique bridging quality: it is able to provide the ecologically rich and valid context, often inspired by application needs, that can reality-check science findings by evaluating them in lived-experience context and inspire specific technological innovation. Inventors can be directly informed by knowledge about how people engage in and process affective touch. Similarly, HCI designers can deploy and test psychological or neuroscientific models of emotion [72] for purposes like touch-centered emotion regulation.

In summary, affective haptics is a prime opportunity for heightened interdisciplinary research, interconnecting the primary facets of haptic science, technology, applications and interaction design, with each benefiting by the inspiration, focus and context provided by the others.

Conflict of interest statement

Nothing declared.

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