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Multisensory Experiences in HCI

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The use of vision and audition for interaction dominated the field of human-computer interaction (HCI) for decades, despite the fact that nature has provided us with many more senses for perceiving and interacting with the world around us. Recently, HCI researchers have started trying to capitalize on touch, taste, and smell when designing interactive tasks, especially in gaming, multimedia, and art environments. Here we provide a snapshot of our research into touch, taste, and smell, which we're carrying out at the Sussex Computer Human Interaction (SCHI—pronounced "sky") Lab at the University of Sussex in Brighton, UK.

Multisensory Design

Multisensory experience design—a novel approach that considers the different human senses and their interrelations when designing experiences—can have a major impact on society and consumer markets. It can lead to the creation of new product and service experiences and open up opportunities for novel forms of immersive storytelling and users' engagement with content. Looking beyond HCI, we can learn from the sensory experimentations done by contemporary artists.

For example, Jenny Tillotson has introduced the idea of an interactive scent outfit, a smart second-skin dress that mimics the body's circulation system and emits a selection of scents depending on a person's mood (see www.escent.ai/fashion-tech). Such concepts show the potential of combining sensory research with biometric sensors for a more natural interaction, supported by recent technological advancements in mobile, sensor, and wearable technologies.

Similarly, there is a growing international interest in more immersive media (multisensory) experiences, particularly in the film and gaming industries. However, efforts to use smell in audiovisual media have faced a number of challenges. For example, during the smell-enhanced screening of *Iron Man 3*, people were left exhausted rather than enthralled by the new sensory stimulation.[1] The reason that the intended effect wasn't achieved is because there's a lack of knowledge about people's multisensory experiences, and researchers have thus far made only tenuous links between sensory stimulations and experiences.

Multisensory experience design has always been of particular interest for museums and art galleries hoping to engage audiences, convey meaning, and enhance the overall user experience. For example, Mark Harvey and his colleagues have shown that multisensory stimulation, along with interactive components and dynamic displays, has a strong influence on the visitor experience, especially in terms of the visitor's sense of flow and immersion.[2] Another intriguing example can be found at the Jorvik Viking Centre (http://jorvik-viking-centre.co.uk), where multisensory stimuli is used to enrich the experience of a tour concerning the Viking past of the city of York. This experience lets the visitor touch historical objects (Viking Age artifacts); taste the unsalted, dried cod of the Viking diet; smell the aroma of the corresponding displayed objects; see the animals and inhabitants of the Viking city; and listen to the Viking sagas.

Another example can be found in the work of Yiorgos Loscos and his colleagues and their Museum of Pure Form,[3] where visitors can see virtual 3D artworks (such as statues). A device connected to the user's right index finger provides haptic feedback, enabling users to feel the artwork as if they were touching it.
More recently, the SCHI Lab team was involved in Tate Sensorium, a six-week multisensory art exhibition at the Tate Britain art gallery in London. The project team selected four paintings and carefully designed

multisensory experiences to support the artworks in a dedicated area in the museum using lighting (vision), soundscapes (audition), mid-air haptic feedback (touch), scents (olfaction), and a complex chocolate taste (gustation). This was a collaborative project led by Flying Object (www.weareflyingobject.com), a creative studio based in London. The SCHI Lab team provided general advice on multisensory experience design and was mainly responsible for the design of the tactile experience using mid-air haptic technology (a novel touchless interaction modality[4,5]) and the accompanying user study (see Figure 1). We collected feedback from 2,500 visitors through questionnaires and 50 interviews, providing insights into the visitors' experiences of the sensorial enhanced artwork. We were particularly interested in capturing the visual liking (of the painting itself); overall liking (painting integrated with sensory stimuli); and emotional reaction (arousal). Overall, participants responded positively to the sensory enhancement of art through the different senses. We found significant differences between the visual liking of the paintings and gender. Male participants rated the visual liking of all paintings on a 5-point Likert scale (3.80 ± 0.98) slightly higher than female participants (3.72 ± 1.05) ($p < 0.05$, Cohen's $d = 0.7$). No significant interaction between factors in the model was found.

Figure 1. The tactile experience using mid-air haptic technology was iteratively designed and tested in the SCHI Lab before it was integrated into the Tate Sensorium—a six-week multisensory art exhibition at the Tate Britain art gallery in London. Each user was presented with tactile sensations on the hand while looking at a painting (a poster printout for the lab testing) and listening to synchronized sound.

Challenges in HCI

Although our knowledge about sensory systems and devices has grown rapidly over the past few decades, we still don't fully understand people's multisensory experiences in HCI. By understanding the ways in which our senses process information and relate to one another, we hope to create richer experiences for human-technology interactions.

There are specific actions the HCI community must take to meet this challenge:

- determine which sensory experiences we can design for and how to meaningfully stimulate them when people interact with technology;
- build on previous frameworks for multisensory design while also creating new ones;
- design interfaces that take into account the relationships between the senses (for example, integrating taste and smell when it comes to flavor); and
- understand what limitations come into play when users must monitor information from more than one sense simultaneously.

Scientists have advanced the field of multisensory perception over the last 50 years. Most recently, neuroscientists have made new discoveries that have increased our understanding of the sense of taste. For example, there is now a gustotopic map linking taste receptors to brain regions,[7] and we have learned new insights into the human ability to discriminate between olfactory stimuli.[8] Despite these scientific advances, we still lack specific design frameworks that will let HCI researchers and designers exploit touch, taste, and smell as novel interaction modalities. The SCHI Lab systematically investigates peoples' sensory experiences in HCI to inform the design of future interactive technologies.

Exploring New Senses in HCI

While our sense of touch belongs to the category of physical senses of humans (such as sight and hearing), the sense of taste and smell are chemical senses. Studying these three senses is highly challenging.

Sense of Touch

The sense of touch is fundamental in most of our day-to-day interactions. When we squeeze an avocado to see whether it's ripe, or when we receive caresses from loved ones, we're—at a physiological level—

processing a broad variety of information related to our sense of touch. At the SCHI Lab, we focus on using touch to communicate emotional content. In a recent work, we proved that users can use ultrasound mid-air haptic stimulation to reliably communicate their emotional state (see Figure 2). In a current project, we are building a new device combining temperature and vibration patterns to let users communicate emotions in real time though touching.

Figure 2. Exploring the communication of emotions through a haptic system that uses tactile stimulation in mid-air.[5] *The study focused on specific design implications based on the spatial, directional, and haptic parameters of the created haptic descriptions and illustrated the design potential for HCI. (See the video at www.youtube.com/watch?v=OBOxuFmsxBY.)*

Communicating emotions is not trivial. Emotional content can be delivered through multiple senses. Imagine you are watching a horror movie. Both the music and images elicit fear in viewers. In our Lab, we use physiological recordings and self-assessment measures to model (and ultimately predict) the emotional responses of a user under multisensory emotional stimulation. A better understanding of emotional communication will be crucial in creating new, "affective" HCI interfaces and immersive media experiences.

Sense of Smell

Our sense of smell has been defined as the "poet of sensory systems."[9] Smelling is much more than the simple detection of chemical molecules. Our olfactory system is deeply connected to structures in our brain that relate to our emotions and memories, and smell is one of the first senses to be developed. In the last few years, olfaction has gained increased attention within the field of HCI.[10] A variety of innovative devices are emerging (see Figure 3), but unfortunately they make only superficial use of the extraordinary power of the sense of smell.

Figure 3. AromaShooter—an example for a smell-delivery device with six scent cartridges that's connected through USB (developed by Aromajoin). Here, a user is viewing a demo and can select different scents on a tablet connected to the AromaShooter.

For example, some of the innovative devices present in the market do not account for the complexity related to humans' olfactory perception (habituation, threshold perception, and so on) or for the interaction that smells can have with other sensory information (designing experiences with multisensorial integration, for example). Only by combining knowledge in HCI with other disciplines, and their understanding of the sensory system (such as in psychology, neuroscience, and sensory science) will we be able to open up new design opportunities for future smell-based interactive technologies. Those knowledge-based advancements are relevant in a variety of contexts, from entertainment to rehabilitation to immersive experiences in virtual reality.

Our goal at the SCHI Lab is to develop guidelines for creating scent delivery technologies and for classifying smell experiences, shedding light on the interactions between smell and other senses and directing designers to systematically and fully realize the potential of exploiting our sense of smell. As a first step, we investigated the role of olfactory experiences in everyday life and created a higher-level categorization of those experiences expressed in form of "smell stories."

Sense of Taste

With respect to our sense of taste, another SCHI Lab study[11] investigated the characteristics of the five basic taste experiences (sweet, salty, bitter, sour, and umami) and suggested a design framework. This framework describes the characteristics of taste experiences across all five tastes, along three themes: temporality, affective reactions, and embodiment. Particularities of each individual taste are highlighted in order to elucidate the potential design qualities of single tastes (Figure 4).

Figure 4. Three characteristics of taste experiences combined for each of the five basic tastes. Temporality (the duration of the taste experience indicated from left to right); affective reactions (green pleasant, red unpleasant, and orange neutral experience); and the embodied mouth feeling for each of the five tastes.

For example, sweet sensations can be used to stimulate and enhance positive experiences—but only on a limited timescale, because the sweetness quickly disappears, leaving one unsatisfied. It's a pleasant taste but one that is tinged with a bittersweet ending. The sour taste is also short-lived, and it often comes as a surprise due to its explosive and punchy character. This taste overwhelms with its rapid appearance and decay, and it leaves one with the feeling that something is missing.

Our framework could, for example, be useful to improve LOLLio,[12] the taste-based game device that currently uses sweet and sour for positive and negative stimulation during game play. Our framework provides designers with more fine-grain insights on the specific characteristics of taste experiences that could be integrated into game play. For example, when a person moves between related levels of a game, a continuing taste—such as bitter or salt—could be useful based on the specific characteristics of those tastes. However, when a user is moving to distinct levels or is performing a side challenge, an explosive taste, such as sour, sweet, or umami, might be more suitable. The designer can adjust specific tastes in each category to create different affective reactions and a sense of agency. Noteworthy, the sense of taste is practically never stimulated alone, so understanding the interactions between taste and the other senses in HCI is a crucial future direction for research.

As a community, we need to further explore and understand the possibilities behind sensory stimulation and develop design frameworks that provide both quantitative and qualitative parameters for sensory stimulation. Studying these underexploited senses and their interactions will enhance the design scope of multisensory design for future interactive technologies, multimedia applications, virtual reality systems, and beyond (think, for example, about multisensory technology for future space explorations[13]).

Here, we've highlighted that there are opportunities to enhance designers' and developers' abilities to create meaningful interactions and make use of the whole spectrum of multisensory experiences. However, there are still many challenges when studying taste and particularly smell, especially related to the intersubject variability, varying olfactory preferences over time, and cross-sensory effects.

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