

# SurfSync: Towards the Design of Wearables to Enrich Surfing

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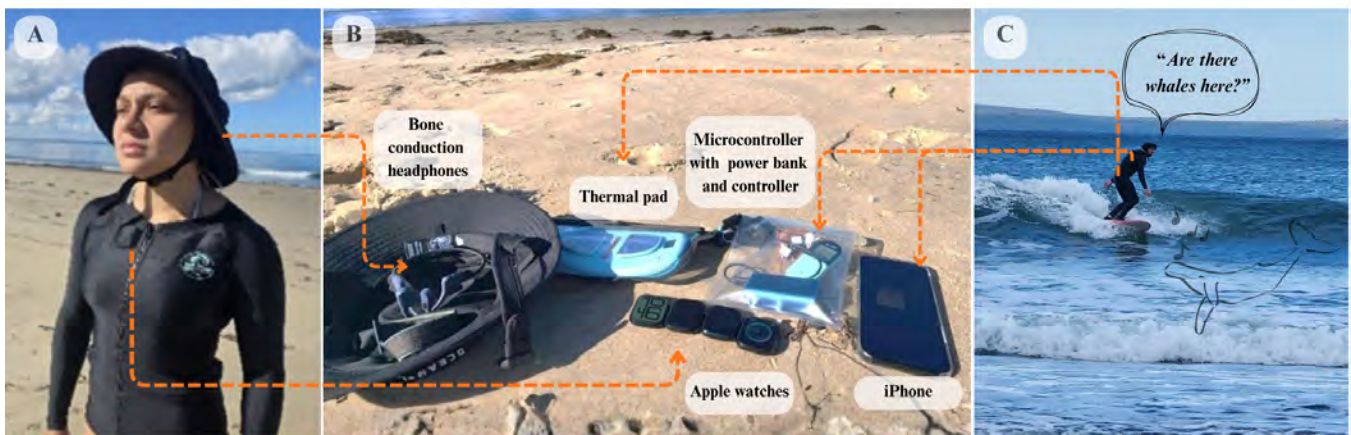
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**Figure 1: Overview of SurfSync: A wearable system that aims to enrich surfing experiences. A) Person wearing SurfSync, consisting of a surfing rash vest and a surfing hat with embedded haptic and audio actuators. B) Actuators embedded in SurfSync: Bone conduction headphones, thermal pad, and vibration actuators, controlled by a microcontroller and smartphone app. C) Participant experiencing SurfSync's playful cues – such as digital whale sounds.**

## Abstract

Surfing, like many water sports, offers a unique opportunity to experience natural environments, yet the design of interactive technologies for water activities – “WaterHCI” – so far prioritised athletic performance over experience. To explore this opportunity, we designed SurfSync, a novel wearable system in the form of an actuating vest and a hat that provides oceanic information through



sound, vibration, and heat actuation, aimed at enriching the surfing experience as a playful encounter with the ocean. We studied SurfSync in an ocean-based field study with eight surfers. Through thematic analysis of interviews, we articulated the surfers' experiences, indicating how they made sense of playful cues while in the ocean. By reflecting on our soma design process and the surfers' experiences, we provide six design strategies to enrich the surfing experience. Our work contributes to the emerging field of WaterHCI by providing insights into how wearables can enrich human-water experiences outdoors.

## CCS Concepts

• **Human-centred computing** → **Interaction paradigms.**

## Keywords

Surf, surfing, surfers, ocean connection, interactive technology, soma design, playful design, WaterHCI, NatureHCI

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## 1 Introduction

WaterHCI is an emerging subfield of human-computer interaction (HCI) that designs interactive systems for water activities [113]. WaterHCI has primarily focused on wearables to support athletic performance, such as improving swimming technique or kayak training [12, 54]. In contrast, experiential aspects: attunement, play, and connectedness, remain underexplored [79, 113]; when they have been considered, the context is limited to indoor activities (e.g., [67, 99]). With advances in waterproofing technologies – e.g., some smartphones can now be taken surfing [94] – we see an opportunity to design interactive technology that enriches the experiential aspects of outdoor water sports.

We focus on surfing because it is one of the most traditional water sports, characterised by experiential aspects that shape its practice [96, 118]. Famous surfer Bethany Hampton put it like this: “Surfing is the purest form of self-expression and the ultimate connection to nature” [1, 55]. This quote reflects how surfing foregrounds strong experiential aspects, which social science research has previously highlighted as deserving closer attention [56, 89, 121]. Yet, like prior WaterHCI research, wearables for surfing have largely emphasised athletic performance. For example, prior research demonstrated how surfing technique can be enhanced with wearables [31], and mobile apps influence surfers' decisions about when to surf [16]. In contrast, limited research has examined how technology might support surfing's experiential qualities [71]. We know surfers appreciate experiential aspects without the help of technology, including time for self-reflection and to “be one with the sea” [2, 88], but we also know that they face barriers to these experiences, such as gender-based judgement and performance anxiety [89, 90]. We believe interactive technology has the potential to enrich the surfing experience and overcome such barriers, so our research question is:

### How do we design wearables to enrich the experiential aspects of surfing?

We explored this question through a soma design process [42], where the first author engaged in bodily experiences in water, including surfing; explored different materials, such as haptic actuators; and performed slowstorming reflections with the design team to contrast first-persons' views [42]. Soma design was chosen to highlight the lived body in water [67] and avoid technological solutionism [6]. Our design process was also informed by playful approaches to sport [114], which highlights how experiential aspects can be supported through wearables [63, 87]. We developed “SurfSync”, a wearable system in the form of a surfing vest and hat. SurfSync provides audio stimulation and haptic actuation through vibrations and thermal stimuli, reflecting ocean dynamics to playfully engage surfers with the ocean. We conducted a field study with eight surfers who used SurfSync in the ocean at a local surf spot. Reflexive thematic analysis [7, 8] of interviews revealed three themes articulating surfers' experiences: sensemaking of information while surfing, supporting ocean connectedness, and SurfSync as a social mediator. We discuss these themes to propose six design strategies for future designs of interactive systems aiming to enrich human-water experiences outdoors. Our work offers the following contributions:

- A novel WaterHCI system, developed through a soma design process, which can inspire WaterHCI, SportsHCI, NatureHCI and soma designers to create actuating wearables that foreground experiential qualities.
- Empirical evidence from an ocean-based field study. These insights, articulated as themes, can serve as a valuable resource for user experience researchers seeking to better understand how people make sense of actuated cues during activities in dynamic water environments.
- Practical knowledge in the form of six design strategies to support the experiential aspects of surfing. This framing provides insights that could guide designers when creating wearables that enrich the experience of outdoor water sports.

Ultimately, we aim to highlight how wearables can support the experiential aspects of water activities and facilitate the many associated benefits of engaging with aquatic environments.

## 2 Related Work

We detail prior work on the experiential aspects of water-based activities and the interactive technologies designed for outdoor water sports and surfing.

### 2.1 The Experience of Practising Water-Based Activities

As we are interested in the opportunity to enrich the outdoor water experience, we define “experience” as “the orientation toward life as lived and felt in all its particulars”, according to experience-centred design [65, 123]. By studying experience holistically, wherein the intellectual, sensual, and emotional stand as equal partners in experience, we can understand people's interactions and relations with technology [65, 123]. Hence, our interest is in the experience of practising water-based activities.

Water-based activities offer a rich and multifaceted experiential dimension, blending physical activity, connection with nature, and psychological benefits. Research reported enhanced well-being [35, 92], satisfaction [14, 73], and a sense of meaningful engagement [121, 126] as core aspects of such practices. Furthermore, studies showed that water activities shape identity, belonging, and place [85, 122]. However, this body of work rarely examines the role of technology in influencing the experience of water-based activities. Thus, we know little about how interactive technology could enrich experiential aspects of being in water. Prior WaterHCI work has shown how interactive technologies can enhance experiential aspects of indoor water-based activities, such as floating in water [70] or playing games in swimming pools [19]. For example, prior research showed us the potential of providing feedback about heart rate using water to facilitate relaxation [67], and sound-based instructions to create social interactions during repetitive swimming [17]. These potentials inspired us to use haptics and sound. However, investigations into the use of these types of devices to enrich outdoor water activities are limited.

Particularly for surfing, experiential aspects such as self-reflection, being present and community building are reported in prior work [2, 26, 56, 88]. This research has shown that a core component of its experiential dimension is ocean connectedness [2]. Although prior HCI work has used terms such as “connection” [120], “relatedness” [125] and “connectedness” [64] to describe an individual’s subjective experiences with the natural world, we borrow “ocean connectedness” from social science literature [4, 83], to describe the emotional and cognitive facets of personal connectedness with the ocean [86]. While prior HCI work [62, 86] and social science work [4, 83] have studied ocean connectedness to foster positive attitudes toward sustainability, there are limited investigations into the use of technology to facilitate ocean connectedness, itself [71]. Surfers enjoy experiential aspects without the help of technology, but they may encounter barriers to ocean connectedness [56, 88], as our first-hand experience surfing has also shown. We believe that our work has the potential to facilitate these experiential aspects, as also derived through our design process (Section 3).

## 2.2 Interactivity in Outdoor Water Sports

Research in NatureHCI [120] and OutdoorsHCI [46] highlighted the difficulty in balancing how technology distracts from versus enriches the experience of being in nature [120]. Recent investigations have found that reaching a balance can facilitate connections with nature. For example, according to Jones et al. [44, 45], designers can amplify nature’s restorative effects by fostering connections with a natural place. Similarly, Kobayashi et al. [49] showed how wearables can help users feel “one” with a forest beyond physical distance. While these works inspired us to explore wearables to support the experiential aspects of being in nature, they are focused on on-land outdoor activities. Consequently, similar investigations remain largely absent when it comes to outdoor water activities.

Interestingly, researchers have developed simulations of outdoor water experiences to highlight experiential aspects [28], including engagement with the ocean [62], connection with cultural heritage [9], affective social interactions [108], and mindfulness experiences

[112]. In contrast, sports science and WaterHCI have studied outdoor water experiences mostly focusing on improving the athletic performance of practitioners. Researchers have used smartwatches and trackers during outdoor water sports such as open-water swimming, rowing [20, 119], kiteboarding [104], and surfing [31, 61, 66] to provide feedback on technique. Only a few investigations have explored the potential of interactivity to enrich the experiential aspects of being outdoors in water. For example, [100] introduced a human-robot team competitive game, where autonomous surface vehicles and human-piloted motorised kayaks worked together in a shared environment to capture a flag. This work shows that designing outdoor water interactions could go beyond the screen, since simple auditory feedback (as used in the capture-the-flag game) could create playful open water experiences.

Another example showcasing the potential of interactive technology to enrich outdoor water activities is the use of underwater augmented reality (AR) to enhance the experience of divers [9]. Bruno et al. [9] demonstrated that a waterproofed tablet could offer AR visualisation to enhance the diver’s experiences. This system showed us that using off-the-shelf devices and simple waterproofing techniques enables the introduction of interactive technologies to outdoor water environments. Additionally, the inertial measurement unit (IMU) sensors in such devices can be used in open water to track users’ orientation without disrupting their activity. Thus, inspired by this work, we also used IMU tracking in our design.

## 2.3 Use of Interactive Technologies for Surfing

The exploration of interactive technologies for surfing has often been led by practitioners. Examples of “surfboard hacking”, e.g., adding digital devices such as sonar [101] and movement trackers to surfboards [74], have become popular according to surfing blogs. This demonstrates practitioners’ interest in enriching their ocean experience. Some of these explorations have been commercialised, for example, 3D printed surfboards [40] and LED-enhanced boards [11]. However, there is no empirical evidence about how surfers engage with them and how they influence the experience of surfing; hence, our work is highly relevant to provide insights into surfer experiences with interactive technology.

Research on surfing has proliferated, focusing on the use of surfing-related information, for example, works on pre-session weather tracking, the usability of weather apps [38], and the potential for mobile apps to support safety [115]. However, we argue that there is limited research on the design of interactive technology for in-situ use during surfing [15, 116]. As a case in point, in 2015, Red Bull investigated the implementation of bodily trackers and augmented glasses for real-time tracking of two elite surfers [41]. Similarly, Microsoft has been supporting the training of the USA national surfing team with the AI post-training video analysis [22]. While these investigations are performance-focused and have not provided empirical evidence on how the surfers experienced the systems, they demonstrate the potential of adapting traditional on-land trackers (e.g., smartwatches, phones) for surfing. Our work builds on these explorations by providing empirical evidence from investigating how surfers interact with technology while in the water.

Finally, our prior WaterHCI work [71] showed that interactive technologies could facilitate these experiential aspects and enrich the overall surfing experience. We previously suggested enhancing the surfing experience via haptic actuators and playing sounds over headphones. Although we evaluated these prototypes in a preliminary study conducted in a swimming pool, we learned that interactive technology could enhance environmental and bodily awareness during simulated surfing scenarios. Hence, we expanded the design space to include haptics and headphone-based sounds to enrich the surfing experience, extending our prior work through an evaluation in the ocean.

Taken together, despite social science research on the experiential benefits of water-based activities and the emerging use of interactive technology in outdoor water sports, there remains a limited understanding of how interactive technologies could be designed to enrich the experiential aspects of human-water experiences outdoors. Particularly, there is no empirical evidence or focused research on how wearables can be designed and evaluated in-situ to enrich these core, non-performance-centric experiential aspects of the surfing practice.

### 3 Design

We introduce our positionality and then describe our process, drawing on soma design practices and playful design thinking. Next, we present the resulting prototype: SurfSync.

The first author, as the main designer, is a female Latina with 1 year of experience in surfing, having delved deeply into the surfing world through documentaries, movies, and informal conversations with surfers [25, 57, 105]. She has a vast track record of sports practice, with 8 years as a semi-professional rugby athlete and several years of experience in seasonal practices of other sports, including swimming, free diving, CrossFit, and handball. She has 8 years of research experience in HCI and 4 years of design experience with soma design. Second, third, fourth, fifth, sixth and seventh authors are also active HCI researchers, with experience practising sports such as running, hiking, climbing, cycling, lifting, and pole dancing. Notably, the last author has surfed for 10 years and has been an HCI researcher for over 20 years. We conducted the design process within the southern part of Australia, which features numerous surfing beaches and a vibrant surfing community.

#### 3.1 Soma Design and Playful Design

We employed a soma design process [42] since this method has been shown to highlight the felt and lived experience of being in water, from pleasure to fear [67, 69]. Soma design rejects solutionism by unpacking assumptions, adjustments made, and value clashes [6]; we know that surfers value ocean connectedness, so we determined that soma design would help pull out experiential aspects without technological solutionism. We followed this design process guided by prior work [42, 43, 68, 111].

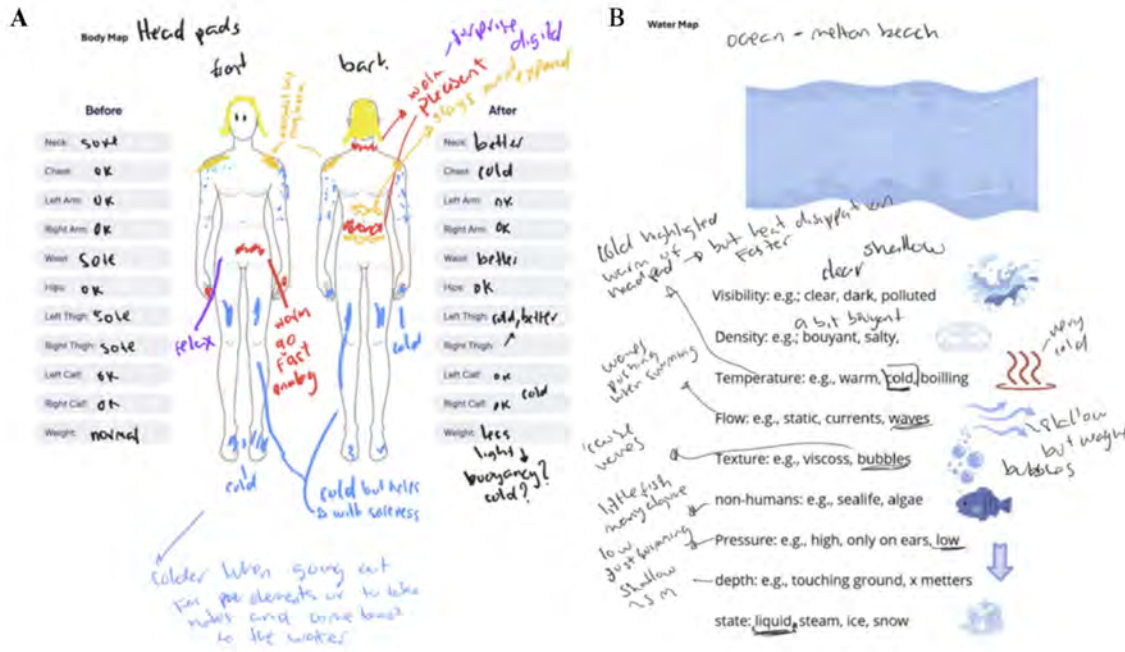
The first author, as the main designer, continued her surfing sessions as a bodily practice and conducted material explorations while surfing and in simulated pool sessions. She documented this process with video and audio recordings and photos when possible. She also used body maps [3, 80] to trigger reflections (Figure 2).

Similar to a body map, she created a *water map* to reflect on the different water qualities and affordances while engaging in water.

This water map was compiled based on analysis of different qualities of water, following prior work's suggestions [79, 113]. For example, "Visibility" aimed to trigger reflection on whether the water is clear, cloudy, or polluted, and, together with the body map, shaped a concise picture on how this made her feel bodily (e.g., feeling bubbles on the feet, goosebumps on the arms), but also emotionally (e.g., fear of the unknown in the darkness beneath, worry for sea life when the water was polluted). This water map was inspired by her practice as a soma designer and the idea of the "body of water", a consideration of the water with agency from social science theories [4, 83]. It aligns with the approach of designing with water not only as a material but as an active medium [71, 72, 124].

Moreover, the main designer complemented the somatic explorations with inspiration from playful design. Playful design is often used to emphasise open-ended, imaginative, and flexible experiences [60, 114], which aligns with our design goal of highlighting the experiential aspects of the outdoor water experience. Additionally, we found that prior work in sports has leveraged playful design to highlight the experiential aspects of practising sports, support enjoyment and reduce performance anxiety [95, 114]. Surfing is a sport that carries prominent risk, so playful design thinking could provide a lens to understand the experiential aspects that come with the competitiveness and dangers of surfing, such as performance anxiety and fear of drowning. Based on this literature, we decided to draw inspiration from the PLEX framework [58, 59], a framework proposing 23 playful qualities that facilitate the emergence of a playful attitude. We considered the playful qualities of PLEX that we believe were more prominent when surfing, including *Sensations* (bodily awareness of water feeling), *Discovery* (exploring ocean dynamics and its hidden patterns), and *Relaxation* (periods of rest and self-reflection). Although surfers often experience a thrill, which can also lead to a playful attitude, we focused on more positive playfulness, seeking positive encouragement rather than encouraging surfers to take more risks.

We conducted slowstorming sessions after the somatic explorations to reflect on how these playful qualities could enrich the experiential aspects of surfing. Slowstorming is a soma design reflection technique used to thoughtfully reflect as a design team on the somatic experiences explored in the design process [42, 50]. This technique allows designers to share experiences within the design team, contrasting first-persons' views of past experiences without the rush of brainstorming [42, 50]. In these sessions, the main designer shared her reflections and findings with the rest of the design team, allowing them to complement the first-person reflection, especially from the last author's perspective, with substantial experience surfing. The documentation and body maps (Figure 2) helped recall details of the sessions, making it easy to link back to the playful qualities from the PLEX framework, especially *Sensations*, *Relaxation*, and *Discovery* [58]. We discussed how these explorations could be materialised into a design concept towards answering the research question. For example, we found ourselves thinking about how facilitating a playful *Discovery* or *Relaxation* attitude could create a sense of connectedness with the ocean.



**Figure 2: Example body and water maps used in the initial design process. A) A body map on which the main designer documented her bodily feelings when exploring thermal pads B) A water map on which the main designer documented her perception of water while exploring thermal pads in the ocean.**

In the next subsections, we present the somatic explorations discussed during the slowstorming sessions and the associated outcomes as observations.

**3.1.1 Swimming Pool Material Explorations.** The main designer deliberately did not include common types of visual feedback during the material explorations, as prior work suggests this may overload visual awareness during sports [10, 84]. She began exploring sound and haptic-actuated systems in water, inspired by prior work [71]. She experimented with pre-recorded natural sounds (e.g., crashing waves, outdoor rain, bird sounds, whale sounds) and vibration patterns of an intimate vibrator on the feet, lower back, neck, and upper chest, while being submerged in water (Figure 3).

- **Observation 1 – Sound congruency:** hearing natural sounds (e.g., birds) while resting on top of the surfboard could transport her conceptually to the origin of the soundscapes (e.g., forest), and induce relaxation, aligned with prior work [70]. Moreover, the sounds related to water, such as ocean crashing and whale sounds, evoked an oceanic presence congruent with the feeling of being submerged in water. Conversely, when moving (i.e., paddling or standing up on the surfboard), the same sounds felt surprising (and even entertaining) due to the incongruence with the movement. The whale sound was aimed to encourage calm, yet she was performing an exerting and cyclic movement.

- **Observation 2 – Synchronised vibrations:** she found that the perception of haptic stimuli was significantly different between outside versus in water. The vibrations on her body while in water evoked a sense of resonance, creating a feeling of synchrony when watching the water move. These perceptions were more pronounced close to the upper chest and feet, in which rhythmic vibration patterns were easily recognised. These sensations, which she considered “pleasant”, directed her attention towards her bodily movement.

**3.1.2 Ocean Material Explorations.** In the ocean, the main designer explored thermal and haptic actuators, as well as sound playback and smartwatch-based haptic actuation while surfing.

**Thermal pads:** She used both an analog head pad (a chemical hand warmer) (Figure 4A) and a digital thermal pad (a remote-controlled device for period pain relief) while floating and swimming in the ocean. She explored the pads’ perception in her hands, feet, lower and upper back, neck, and abdomen. The pads were secured and waterproofed using a plastic bag and a hermetic sling bag (Figure 4B). The analog hand warmer provided an estimated temperature of 37 °C, which dissipated heat for 8 hours. The digital pad maintained a remotely controlled chosen temperature (45 °C, 55 °C, and 65 °C) until its battery ran out (after 9 hours).

- **Observation 3 – Surprise and prolonged enjoyment of water thanks to warmth:** Initially, the analog head pad provided a

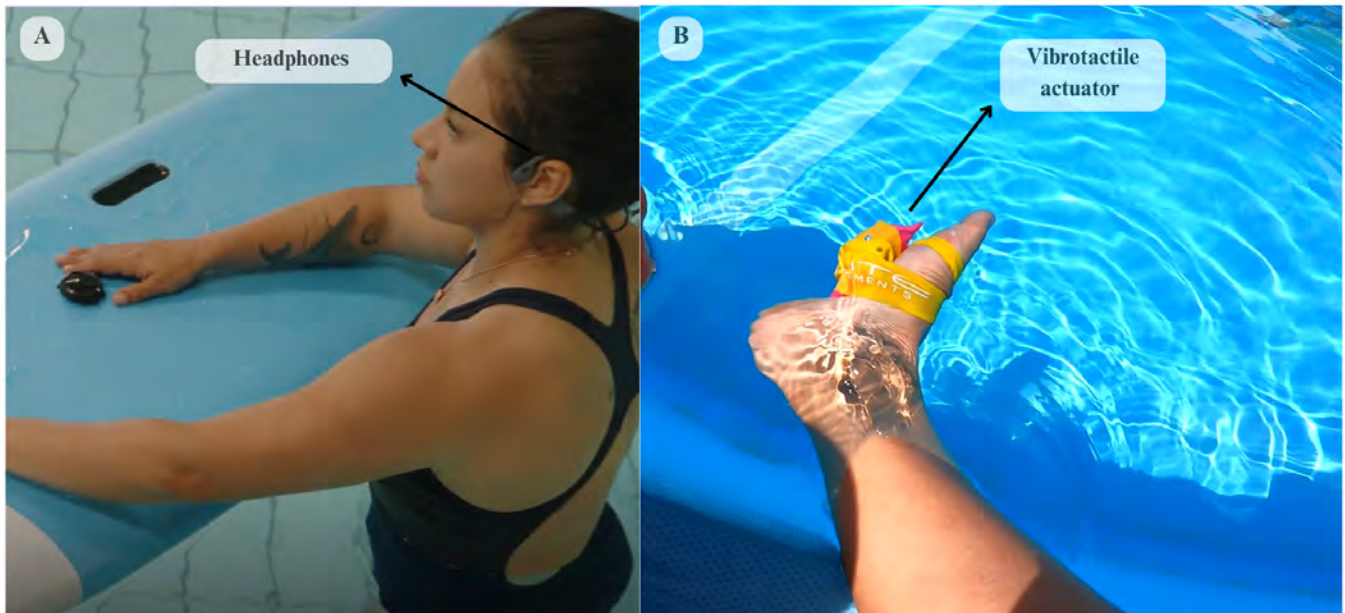


Figure 3: A) Exploring sound stimuli in a swimming pool simulating surfing, wearing bone conduction headphones to play different natural sounds. B) Foot in the swimming pool, exploring an intimate vibrator as a vibrotactile actuator attached with a rubber band.



Figure 4: A) Analog heat pad in a plastic bag. B) Analog head pad placed on the back. C) Phone in a sling bag used to play pre-recorded sounds while surfing. D) Analog head pads placed on the leg. E) Samsung smartwatches placed on the arm are used as vibrotactile actuators. F) Exploring the sounds provided by the phone while surfing.

pleasant but short-lived warm sensation, which was more notable in the hands and feet, but facilitated a relaxed mood

when placed in the lower back and neck (Figure 2). Apparently, the cold water highlighted the warmth perception.

However, this perception disappeared after about five minutes, likely due to heat dissipation. The digital pad retained warmth longer and, when briefly turned off and then on, produced a sudden warmth that surprised her and refocused her attention from movement-focused to her bodily sensations. Finally, she noticed that both pads helped her withstand the ocean cold and experience other ocean qualities (i.e., moving freely, relaxation), while it was also more enjoyable due to the pleasant warmth.

**Smartwatches:** The main designer used two smartwatches while surfing, secured underneath the surfing rash vest. These functioned as displays (for weather and movement data) and as vibration actuators placed on the abdomen, lower back, and clavicles. She was inspired by prior work highlighting that other actuating modalities, such as sound and haptics, could convey environmental information and create novel perceptions in water [71].

- Observation 4 – Smartwatches as displays: She found the weather information displayed on the smartwatch useful, but she also noticed she checked it only once or twice during the one-hour session during rest periods. Then she checked the watch’s movement tracking after the session to understand how much she had moved. Although she found the numeric information interesting, it held little meaning for her, as she was not seeking to quantify her training.
- Observation 5 – Smartwatches as vibrotactile actuators: The vibrations were distinguishable (left vs. right) but uncomfortable on the abdomen during paddling; they worked better on the lower back or upper chest. Moreover, she noted that the rhythmic vibrations appeared to suggest a particular paddling rhythm and were more noticeable when placed in the upper chest, probably due to the proximity to the movement of the upper body. This led her to imagine the vibration array indicating directional cues (left/right). The vibrations felt more pleasant during resting periods, supporting bodily awareness and imagined ocean information, but were less interpretable during active wave-riding.

**Sounds:** She used a waterproof mobile phone (CAT S62), while surfing: The mobile phone was secured using a portable bag and placed on her back under the wetsuit (Figure 4C). It was programmed to play sounds, either congruent (e.g., whale songs) or incongruent (e.g., horse gallops) with the ocean environment, chosen based on the swimming pool explorations. The mobile phone automatically played one of the randomly selected sounds when its acceleration exceeded a threshold. This was implemented using a simple application made in Unity3D using the built-in mobile phone’s IMU sensors.

- Observation 6 – Sounds for playfulness and reflection: The main designer noted that the whale songs felt relaxing and believable, while horse gallops evoked humorous disbelief. The automatic activation of the sounds generated surprise and playful questioning (“Was I really hearing this?”). She noted that although the system was bulky, the phone was not obstructive, and the placement on the back did not add considerable weight.

**3.1.3 Design goals.** Based on the outlined observations, we started prototyping guided by the following design decisions:

- (1) Convey ocean information through haptics: Instead of providing information about the surfer’s movement, which could reinforce a performative mindset, we decided to communicate ocean data to facilitate surfers’ reading of the ocean state and possibly enhance their relatedness to the ocean. This was inspired by the main designer’s explorations of imagining ocean patterns as vibrations in the body, backed by prior work highlighting the potential of vibration to convey oceanic information [71], and by surfers’ reliance on ocean state to make decisions [51]. Moreover, this is aligned with PLEX’s *Discovery*, since surfers often find pleasure in exploring the ocean dynamics and the surrounding sea life.
- (2) Facilitate playfulness through congruent sounds and warm sensations: We decided to use nature sounds related to the ocean to facilitate playfulness via PLEX’s *Relaxation*, since, in our explorations, being surrounded by water enhanced the feeling of relaxation when combined with congruent sounds (e.g., whale sounds). Moreover, we sought to evoke playfulness through “make-believe” [23], hypothesising that sea life sounds might prompt reflections on the local sea life presence. Perceiving the warm haptic stimuli proved both surprising and pleasant, so we integrated it into the prototype to elicit a playful attitude via PLEX’s *Sensations*. We aimed to create a warm bodily sensation to facilitate a prolonged interaction in the ocean, avoiding the uncomfortable cold.
- (3) Use off-the-shelf devices instead of self-fabricated waterproofing: Contrary to prior work showing the cumbersome process of waterproofing Arduino sensors and actuators from scratch [65], we opted to use simple waterproof techniques for off-the-shelf devices. We also adapted the functionalities of other devices that are already waterproof from manufacturing. For example, we decided to use smartwatches as vibrators, and we waterproofed a remote-controlled thermal pad using a hermetic waterproof sling bag.
- (4) System aesthetics congruent with surfing gear: Taking advantage that most local surfers use rash vests and wetsuits all year long, and the use of hats is common, we decided to embed the devices into surfing gear. Also, we considered the importance of adhering to cultural values regarding surfing dress codes and avoided outrageous clothing [71].

## 3.2 SurfSync

SurfSync is a wearable prototype embedding off-the-shelf devices in a surfing vest and a surfing hat, based on design decisions #3 and #4 (Figure 5)

**3.2.1 The wearable.** We created four surfing vests of different sizes to accommodate different body types (Figure 5). The vests featured the same custom-sewn pockets: three on the upper chest to secure three smartwatches (Apple Watch), and one on the upper back (in the middle of the shoulder blades) to secure the waterproof sling bag that contains a smartphone (iPhone 16), a microcontroller (ESP32C), and the thermal pad controller. The vest also had a sewn leash in the lower bag to secure the digital thermal pad inside a waterproof

slung bag (Figure 5). We created two hats to accommodate a variety of head sizes, and we attached waterproof bone conduction headphones with straps sewn on and plastic ties. The built-in leash of the hats helped secure their placement.

**3.2.2 Smartphone app.** The devices were networked using Bluetooth via a mobile app we developed in Unity (Figure 7A). The app integrates real-time body direction tracking and provides haptic and audio feedback, as explained next. The app offers configuration options designed to be used only by the researcher, not the surfer.

- **Body orientation tracking:** The app leveraged the smartphone's built-in IMU orientation system (gyroscope and accelerometer) to capture three-axis motion data. This data was captured to communicate oceanic data through haptic cues on the body (design decision #1). Euler angles were derived from the gyroscope to determine whether the user is facing the ocean or the shore. We calibrated these angles based on the surf spot's geolocation. This orientation is critical because a surfer's "left" and "right" change depending on the direction they are facing; what is to the right when facing the ocean becomes the left when facing the beach (Figure 6). In this way, the app established a consistent reference relative to the body's orientation. Additionally, it uses calibrated ranges on the three-axis motion data for vertical alignment to determine whether the surfer is paddling or sitting on the surfboard.
- **Ocean data acquisition and haptic stimulation:** As we decided to provide swell direction and swell period through vibrations (design decision #1), the app retrieves environmental data from the local surf spot using Stormglass<sup>1</sup> API. The app periodically (every minute) requests swell direction and swell period data at this specific fixed location. The app then uses this data to calculate a direction value based on surfer's bodily orientation (facing the ocean or the shore), so the swell could be described as coming from their left or right. The system then classifies the swell period (consecutive waves), using a fixed threshold of 5 seconds; for example, below 5 seconds indicates fast-period waves, and above 5 seconds indicates slow, successive waves. By combining left/right direction and fast/slow classification, the system selected one of four vibration patterns: fast wave from left, fast wave from right, slow wave from left, slow wave from right (Figure 6). The app sent this pattern to the microcontroller, which triggered the vibrotactile stimulation via the smartwatches. They were triggered only when the surfer's orientation changed and the swell period and direction changed, allowing for moments without activation.
- **Auditory and thermal stimulation:** Following our design decision #2, the app played sounds through the headphones and triggered the thermal pad via the microcontroller. The app randomly played prerecorded nature audio clips, including rain, crashing waves, dolphin, whale sounds, and seagull sounds, at stochastic intervals between 1 and 5 minutes. Similarly, the heat pad activation was triggered between 1 and 5 minutes randomly, but the heat stayed on for 2 minutes

to be noticeable. This triggering pattern was chosen based on the main designer's explorations, which elicited surprise upon first encountering heat and comfort after prolonged exposure to heat.

**3.2.3 Smartwatch app.** We developed a custom-made app using Xcode (Figure 7B). The app enables Bluetooth connectivity with the microcontroller, allowing simultaneous activation of multiple watches. We developed this app because multiple connections are not natively supported on Apple smartphones.

## 4 Study Design and Data Analysis

We conducted a field study to understand the surfers' experiences with SurfSync (approved by institutional ethics). All the sessions were conducted at a local surfing spot. We chose this surfing spot because it is a commonly patrolled surfing beach, has stable phone coverage, access to showers, and online swell direction and period data.

### 4.1 Participants

We recruited participants through our social media surfing channels and email lists. We offered monetary compensation to cover the fuel costs. Eight surfers with at least 2 years of surfing practice and prior experience surfing in the local surfing spot volunteered. These criteria ensured understanding of the local ocean environment (rocks and reefs) and reduced the risk of injury. Four participants identified as women and four as men, none as non-binary or self-described, with an average age of 46.75 years old  $\pm$  8.56 years old (Table 11). All participants completed a single session with SurfSync as outlined in the next subsection. Given the exploratory nature of our research and the early stage of our prototype, we conducted a single surfing session, consistent with prior work on bespoke prototypes for novel outdoor sports experiences [75, 77]. We hope our work can scaffold future studies examining use across repeated sessions.

### 4.2 Procedure

After obtaining signed consent, we scheduled a session with each participant based on their preferences and weather conditions, asking them to bring their surfboard and surfing gear. We provided an overall description of SurfSync and instructed participants that the actuations they would experience were not intended to alter their surfing decisions but rather to enrich their surfing session. We clarified that the vibrations were intended to indicate the swell's direction and period, but the participants could decide what to do with that information. Finally, we reminded the participants that their safety was their responsibility, but in case of an emergency, the research team was ready to seek assistance from the local life-saving club.

**4.2.1 Onboarding:** Once we met the participant at the surf spot, we asked them to don their surfing attire and gave them 10 minutes to perform their own warm-up and rituals, if any.

**4.2.2 Participant's device setup:** We assisted the participant in donning the system under their wetsuit, including helping them adjust the vest and hat. We provided guidance on its safe handling in and

<sup>1</sup>Stormglass is a web service that provides direct access to the world's most accurate weather forecasts. <https://stormglass.io/>



**Figure 5: SurfSync component: a surfing vest with custom-made pockets embedded with a thermal pad and smartwatches controlled with a mobile phone app and a microcontroller, connected to bone conduction headphones embedded in a surfing hat.**

**Table 1: Participants’ demographics and details. Note that “S.L.” is “Skill Level” (“Nov.” = Novice, “Inter.” = Intermediate, “Adv.” = Advanced, ), followed by years of surfing. “S.L.” and “Experience” are self-reported. “Digital Tech.” addresses participants’ responses to their experience using digital technology while surfing.**

ID	Gender	Age	Occupation	S.L. (years)	Experience	Digital Tech.
P1	M	41	Electorate Officer	Adv. (20y)	Lifelong surfer	No
P2	W	51	Manager	Adv. (25y)	Lifelong surfer and director of surfing communities	No
P3	W	56	Retail Assistant	Inter. (7y)	Started surfing when turned 50 y/o	Yes: Garmin, Watch, GoPro
P4	W	41	Manager	Inter. (4y)	Surf Instructor	No
P5	M	53	Engineer	Adv. (48y)	Wave pool designer and researcher in surfboard shaping	Yes: FlowState Cameras, GoPro
P6	M	38	Police Officer	Adv. (26y)	Lifelong surfer	No
P7	W	23	Architect	Nov. (4y)	Surfing regularly	No
P8	M	60	Retired	Adv. (50y)	Lifelong surfer	No

out of the water, such as lowering the volume of the headphones or re-adjusting the hat.

**4.2.3 Surfing session:** We encouraged participants to hold a 1-hour session, surfing as they usually do, but wearing SurfSync.

**4.2.4 Offboarding:** After 1 hour, we assisted participants in taking off the prototype, waited until they got changed, and held an interview for approximately 30 minutes. The questions focused on participants’ prior surfing experience, including their motivations and challenges, as well as their experience using SurfSync, covering its potential to enrich their surfing sessions and support them in overcoming experiential challenges.

### 4.3 Data Analysis

We transcribed and reviewed the interviews, ensuring accuracy while familiarising ourselves with the content. We followed a reflexive thematic analysis (RTA) in Nvivo (without AI tools)<sup>2</sup>. Two coders, the first and third authors, who had previous RTA experience, worked independently coding the data. Because the subjectivity of researchers is a valuable research resource in RTA [7, 8], we note the coders’ positionality as explained in the design section. The two coders systematically coded each transcript, treating all

<sup>2</sup>NVivo 15. <https://lumivero.com/products/nvivo/>

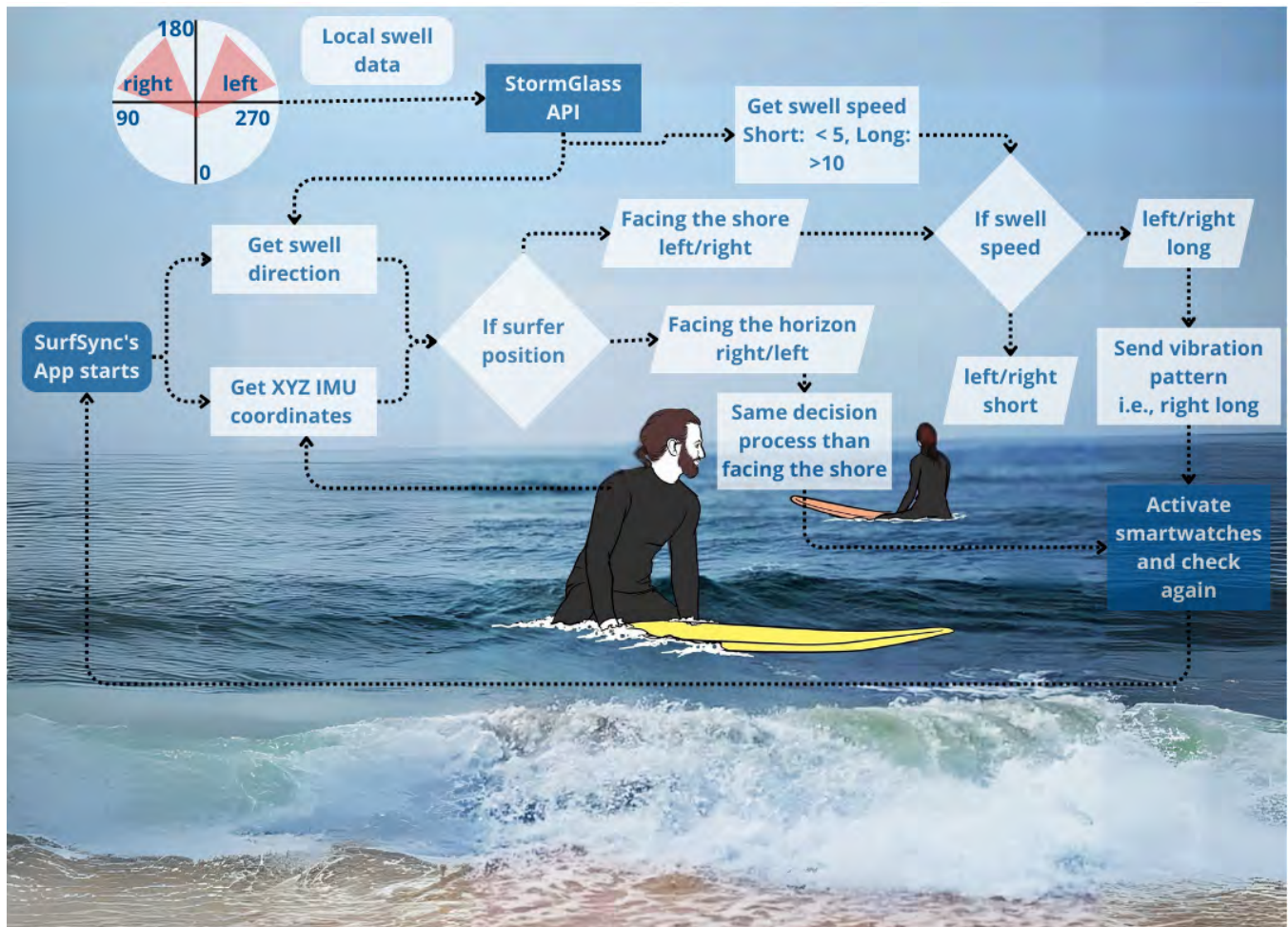


Figure 6: Smartphone app’s logic diagram. The app fetched swell direction and period data from StormGlass. This data was compared with the IMU data of the surfer’s orientation: looking at the horizon or looking at the shore. This comparison allowed us to classify the right and left directions triggered by vibration patterns. If the swell period was long or short, the vibration pattern was accordingly slow or fast.

data items equally. Each “unit” of data is a single coded quote (following prior work practices [67, 93, 117]). High-level codes were iteratively clustered into themes upon collaborative agreement. The themes were presented to the rest of the authors, and we worked together to refine them into the final themes presented in the next section.

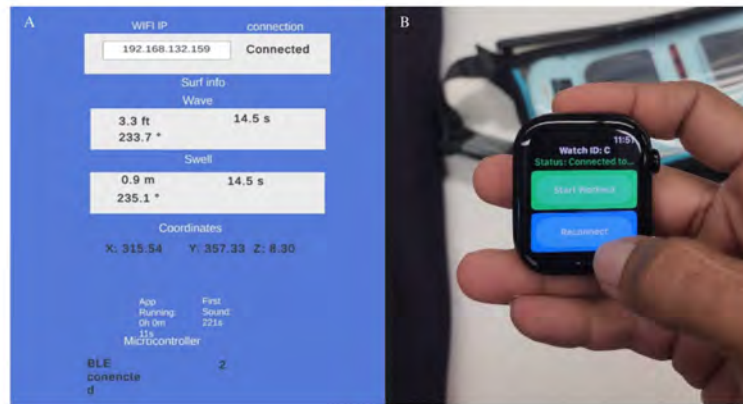
## 5 Results

Overall, participants described using SurfSync while surfing as “interesting” (P2, P8), “fun” (P1, P4, P8), and “relaxing” (P3, P5, P7). SurfSync appeared to allow users to shift between different modes of awareness, moving their attention from themselves to the ocean and to others. Based on this, we present our results in three themes and 10 findings (F1-F10): Sensemaking of information (134 units), Supporting ocean connectedness (68 units), and SurfSync as social mediator (57 units).

### 5.1 Sensemaking of Information: From self-awareness to Ocean-Awareness

This theme describes how participants reported that their bodily awareness changed in response to SurfSync’s different features and how they made sense of the actuations to become aware of the ocean.

5.1.1 F1. Subtle Vibrotactile Sensations on the Chest Enhanced Bodily Awareness. While four participants enjoyed the vibrotactile sensation provided by SurfSync, for another two, these sensations were not noticeable, and the rest “did not pay attention” (P3). Those participants who were aware of the vibrotactile sensations, reported that it helped them to be “more in tune with your body” (P1). For example, P6 stated: “I think it’s that connecting you with your body again. It’s just that reminder that you got these focus points on your body that are reactive.” P4 reported that in the middle of the session, she “wanted more” vibrations. It seems for these participants the



**Figure 7: A) SurfSync Smartphone app’s display, showing, from top to bottom, connection to WiFi to fetch swell direction and period data, three-axis relative orientation coordinates, sound triggering information, and active Bluetooth connection. B) SurfSync smartwatch app’s display, from top to bottom, watch ID, connection status, start button, and reconnect button.**

sensations were enjoyable because they were subtle “like a light vibration” (P1), different to the ones provided by other devices: “I actually turn this off on my phone on my watch and my phone because I can’t handle it, it’s too much, it’s overbearing, whereas this one was a nicer feeling.” (P6) This was interesting, as we used the same smartwatches in our SurfSync’s prototype; hence, the position on the body mediated by the rash vest seems to make a significant difference for these participants, as exemplified by P4: “Because a smartwatch vibration is annoying. whereas that felt nice, it’s where it was placed on your shoulders, and it felt like nurturing as opposed to stressful.” This suggests that position and the mediation of clothing turned “stressful” signals into pleasant sensations.

**5.1.2 F2. Vibrotactile Stimuli as Ambiguous Cues for Predictive Sensemaking of the Ocean.** Although four participants enjoyed the sensations created by the vibrations, others struggled to interpret them, with P1 noting “I was trying to work it [the vibrations] out, but I couldn’t get my head around it.” Particularly, P5 found the positioning of a watch was “obstructing” his paddling position because the vest did not fit him well. Despite these sensemaking challenges, participants commonly framed vibrotactile feedback as potential cues for anticipating swells. For example, P2 felt that vibrations gave an “alert to when the swell was coming, when the waves were going to be bigger, and I really liked that.” Likewise, P7 explained: “I was waiting for the signal, maybe if the next swell will come, I can feel something.” Participants suggested that the utility of the vibrotactile cues could emerge over a learning period, as explained by P7: “I’m dealing with so much information, so don’t know (what it means), but if you are familiar with the system then you know if there’s a vibration coming to your left, then you paddle to the left.” By contrast, P8, an experienced surfer, was more sceptical: “Information would not be important for me while in the water,” noting confidence in reading the ocean directly. These findings suggest that the vibrotactile stimuli were perceived as ambiguous but potentially learnable, with their value potentially depending on prior surfing experience to build meaningful associations.

**5.1.3 F3. Evocative Natural Sounds as Prompts for Ocean Awareness.** Some participants mentioned that SurfSync drew their attention to the ocean. They described the sound stimuli as a reminder to re-engage with their surroundings. Rather than conveying specific information, these stimuli encouraged a broader awareness of the ocean and the animals within it. For example, P4 explained that whale sounds prompted him to look into the water: “I was looking for the whales or just looking down, like ‘what’s going on out there?’ — which I never usually do.” P7 similarly noted: “it was a little reminder for me to be, like ‘Look at your surroundings, check the peak and look at the people.’” For some, this heightened awareness fostered a sense of ocean connection, “when I’d normally be a bit less connected. It probably connected me more because the sounds relaxed me.” However, P2 said it sometimes disrupted her usual way of connecting: “When I’d normally relax and breathe deeply and look at the horizon, I probably didn’t do that as much because I was listening to the sounds.” In contrast, P7 suggested layering in ocean facts to expand awareness: “Each time I’d love a bit of educational information about the connection between all of this, maybe even about real-time environmental issues [...] because I think 90% of surfers really care about the environment and the ocean.” Overall, these findings suggest that sound stimuli have potential as an attentional scaffold for noticing and reflecting on the ocean instead of as an informational cue.

**5.1.4 F4. Audio Pass-Through as a source of Blurred Reality.** Participants frequently reported uncertainty in distinguishing between system-generated and real-world sounds, particularly with the bone-conduction headset, which allows environmental audio to remain audible. While the animal sounds were participants’ favourite feature, described as “nice” (P4), “cute” (P8), “fun” (P6), “awesome” (P1), and “unusual” (P2), they made participants question whether they were real. For example, P4 recalled: “When I heard the whale, I was like: ‘What is that?!, Oh, it’s just a rock.’” Similarly, P5 said the rain sound blended with the ocean: “I don’t even know if that’s the sound in my ear, or if that’s the waves breaking.” This blending of audio sources led participants to actively question and interpret

their sensory experience, sometimes resulting in misattributions: P2 associated the rain with swell prediction, *“I felt like the rain kind of alerted you to when the swell was coming [...] I don’t know if that really happened.”* For P7, with less surfing experience, the rain was initially disorienting: *“As your brain is trying to deal with real-time information, it was a little bit disoriented at one stage, so I thought, why is it starting to rain?”* Some participants wanted additional auditory cues to match the environment. For example, P5 reported he was asking himself: *“What’s going to happen now? Is there more sound signalling what’s happening?”* Interestingly, P2 raised a concern about unintended consequences: *“How is this interacting with the shark? Are they picking up the electronic vibration?”* These findings highlight how audio pass-through introduces reality negotiation among surfers, fostering curiosity but also enabling misinterpretations. This suggests that such cues for reality ambiguity should be further investigated to understand the impact of our technologies.

## 5.2 Supporting Ocean Connectedness: From Comfort to Presence

In this theme, we describe how SurfSync helped participants feel comfortable and present in the ocean.

**5.2.1 F5. Calming Natural Sounds Reduced In-Surf Anxiety by Amplifying the Ocean’s Tranquillity.** Most surfers indicated that one of their primary motivations to surf is the mental health benefits. P2, who participated in a surf mental health program, said: *“I was in the program where 11 of us, veterans, were surfing at the pools.”* While the ocean typically offers a sense of calm, feelings of anxiety can prevent individuals from profiting from the wellbeing benefits. P3 reflected on how the ocean itself can create anxiety and said, *“I’m not the only one, but I can get very anxious out in the surf, especially if there’s a big crowd, if it’s big waves and all the variables.”* P5 had similar thoughts about the anxiety of doing things in the future: *“You often worry about what to do after getting out of the water and the tasks waiting for you at work.”* Participants reflected on their prior surfing sessions, noting that the sounds of SurfSync seemed to amplify the ocean’s calmness and reduce their anxiety levels. P3 said, *“Yesterday felt overwhelming, and I was anxious. I believe wearing those headphones would have helped me avoid overthinking.”* P5 was also calmed by the sounds: *“The rain sounds were quite calming. I’m not sure what it was, but it was playing in the background and was very soothing.”* P1 indicated that one reason for this calming effect was the consistent theme of water: *“The rain and the sound of the water accentuated the sound of the waves.”* P6 also noted the congruency of the system’s sound with natural sounds from the ocean: *“It was easy to be in tune with the rain sounds that were almost cathartic and relaxing.”*

Interestingly, participants reported that moments of silence were also important to facilitate relaxation. P5 said, *“It was quite effective to go sound and then a period of silence. Especially when you had silence, but with the heat, then you could relax into the heat feeling.”* P3 compared SurfSync’s effect with the calm she gets when drinking natural medicine: *“I actually take a natural tonic, a natural tonic for my naturopath to calm the nerves, and I found that with that background noise of the rain, it was calming. I felt very calm out there today.”* P2 envisioned a future feature: *“People could use it when*

*you’re surfing by yourself and you want it on to calm you down.”* P7 added to these future visions and said, *“Like a personal little therapy that tells us to: ‘Keep going, you’re fine. The next wave is coming. You can still have fun.’”*

**5.2.2 F6. Localised Heat on the Lower Back Improved Comfort by Relaxing Key Muscles Used in Surfing.** All the participants found the heat stimuli very comfortable and useful during the surfing sessions. For example, P5 noted: *“The warmth on the back was very pleasurable, it was a nice sensory feeling”,* and P2 said: *“The heat was weird, because you are used to feeling cold, but it was a comfortable sensation.”* P4 noted that the heat was on and off for periods of time: *“I felt on and off. I didn’t feel it like hard, fast on-off. But I was definitely warm when it was on. And then I cooled down when it wasn’t on.”* The ability to switch between on and off modes seemed to make individuals become more aware of the heat. P5 said: *“I felt the heat pad really helped relax my lower back, and therefore relax the body, right into the supple and smooth my pop-up.”* Some participants pointed out that the heat could positively influence performance and safety, and even be a “lifesaver” (P7). P3 reflected: *“Sitting in cold water can stiffen your back, harming your performance and increasing the risk of injury if you fall from a wave.”* Although the local weather tends to be cold and *“every little bit of extra comfort you can get is a luxury in the water here sometimes”* (P6), participants mentioned it could also be comfortable in tropical weather: *“Even in Indonesia if it’s a windy day and you can still get quite cold even if the water is hot”* (P5).

**5.2.3 F7. Non-invasive Auditory and Tactile Cues Helped Users Stay Present.** A recurrent remark from participants was that SurfSync helped them to be “present” in the ocean. Particularly, the sounds were helpful, for example, P4 mentioned: *“I was surprised at the response that I had to the whale sound. It definitely brought me back into being present.”* Beyond helping the participants stay present physically connected with the ocean, the system helped them to stay connected when, mentally, they might drift off, as stated by P5: *“The sound of the rain brought you back to the ocean, keeping your mind from wandering.”* Participants suggested that the matching of the natural sounds with the quietness of the moment facilitated this presence: *“Having those seabird sounds and whale sounds, it keeps you in the moment. You can almost do with the relaxation of it, even though, like wind sounds and that sort of thing, in the moment of that quietness.”*(P5) Additionally, three participants reported that the vibrations also helped them to feel present due to the tactile sensations: *“I was focusing on: ‘Why is it feeling so nice?’. So, it did bring me back to being present.”* (P4) Similarly, P6 said: *“That light vibration it’s just a reminder that you’re present, I think, it’s like shocking you back into the present.”* Apparently, the non-invasiveness of the prototype played a crucial role since it avoided distracting them from the ocean, as exemplified by P3: *“I find GoPros distracting and have missed many waves because of them. The prototype I wore today is better; it’s hidden underneath and not invasive, allowing me to focus on my surfing.”* While participants reported it was non-invasive, they mentioned it was “bulky”(P4, P8, P6) and expressed their desire for an “all-in-one” (P5, P6) device.

### 5.3 SurfSync as a Social Mediator: From Companionship to Solitude

In this theme, we describe how SurfSync acted as a social mediator in three main ways: supporting companionship, facilitating solitude, and fostering social interactions.

**5.3.1 F8. The System's Actuations Created a Sense of Companionship.** Some participants described SurfSync as a surf companion because the actuations made them feel less alone. As P4 put it: *"I like the concept of it feeling like a companion. You definitely don't feel alone when all [the actuation] was going on."* Participants also suggested that the sounds could increase confidence, particularly for women. P3 noted that *"Being a woman in the ocean is still a barrier,"* while P7 explained: *"Because I'm not a confident surfer at all, especially as a female, it can be like an empowering sound [...] a little reminder to say: 'You are okay, you are enough, you are not competing, just be with yourself.' Sometimes we do need a reminder."*

Others suggested the actuations could help solo surfers by reducing anxiety. P6 reflected: *"Surfing on your own can be daunting and intimidating, so having that extra sensory perception just gives you something else to focus on and bring your anxieties down."* Some even noted its potential for self-training, with P7 explaining that the sensations could communicate what language could not: *"The instructor can tell you 'Go, there's the wave next to you.' But I'm dealing with so much information. The sensational experience is not something that can be communicated by language."* These reflections highlight how SurfSync's continuous sensory presence could act as a companion, empowering less confident surfers and offering reassurance in situations where language or social support is absent.

**5.3.2 F9. Auditory Actuation Facilitated a Sense of Personal Solitude by Masking Distractions in Crowded Spaces.** The participants suggested that SurfSync helped counteract the frustration of overcrowded surf spots by creating a sense of isolation. P5 explained: *"In a way, it gave you a sense of quiet isolation, because it makes you a little bit more isolated from everyone else, because you're just listening to the sounds."* Several noted that the natural sounds reduced their awareness of others. P2 reflected: *"Sometimes when it's crowded, I'm a bit too aware of the other people and where they are. So [the natural sounds] might make you just focus a bit more on yourself and the ocean, cut down the distractions of other people."* Similarly, P1 attributed this effect to the qualities of natural soundscapes: *"I think it would definitely help because you have those sorts of natural sounds."* This ability to carve out solitude was valued in contrast to the stress of overcrowding. As P1 explained: *"When it's overcrowded, you can feel the tension in the water, which is not a nice feeling. I'd rather surf waves that aren't as good on my own, but at least there are fewer people."* These reflections suggest that immersive auditory stimuli may support personal solitude by masking social distractions and allowing surfers to focus more fully on themselves and the ocean, even in crowded conditions.

**5.3.3 F10. SurfSync's Appearance Acted as a Social Object, Sparking Conversations with Others.** While SurfSync supported positive isolation, most participants noted that it did not interfere with their social interaction. P3 observed: *"99% of surfers don't care about anyone else but themselves [laughing]. They don't notice you, they don't*

*look at you, they don't, yeah, they are just so focused on what they're doing."* Similarly, P4 described an expectation of *"no talk on the line"*, with only occasional small chats when waiting for waves. In these situations, participants suggested that the system was not noticeable to others. As P1 explained: *"I don't think they realised at all. The other guy I was chatting to also had on his earplugs, so he probably just thought I was just with another earplugs."*

By contrast, some participants felt that when SurfSync was noticed, it created a "nice point of conversation." For instance, P6 reflected: *"I'm sure they notice it because it's a bit unusual paddling out in a hat on a day like that [cloudy day]. And I did speak to one of the guys out there about what I was doing."* Participants also highlighted that adjusting or pausing the sound was important for being able to engage in these interactions. As P6 added: *"Having an understanding of the technology and you can turn it up and down, which is handy. I felt like I could listen to the noise and communicate fine. It was just the volume."*

The pass-through nature of the headphones was seen as helping maintain connectedness with other surfers, even though some participants still preferred the idea of on-ear earplugs for practicality. However, the constant actuation could sometimes feel overstimulating, as described by P4, who has Attention-Deficit Hyperactivity Disorder (ADHD): *"It was tough to communicate with people, which is what I normally do. Focus on the sounds, try to turn them all down, try to work out what I'm doing, and then look at the wave. So I actually became quite overstimulated. But it could just be me. Like I've got ADHD. I'm so overstimulated all the time."*

These reflections suggest that while SurfSync could blend into typical surf interactions, its eventual noticeability could also serve as a conversation starter, though its sensory load needed careful management for inclusivity.

## 6 Discussion

Our findings suggest that SurfSync enriched the surfing experience by shifting participants' awareness between the self, the ocean, and other surfers. Our findings align with prior social science research that identified key experiential qualities in surfing: self-reflection, connection with the ocean, and community building [26, 91]. This resonates with prior research that positions ocean connectedness not as a singular state but as an assemblage of embodied, social, and ecological relations [2, 56]. In the next three subsections, we discuss in detail the enrichment facilitated by SurfSync: Enriching Surfing through ocean connectedness (6.1), enriching surfing through reduced anxiety (6.2), and enriching surfing through rough social mediation (6.3). In each subsection, we present associated design strategies to provide designers with practical guidance for enriching the experiential aspects of surfing and insights into how wearables can enrich human-water experiences outdoors.

### 6.1 SurfSync Supported Ocean Connectedness through Comfort, Awareness, and Presence

In this section, we will discuss how our study suggests that SurfSync facilitated experiences of "ocean connectedness", referring to the emotional and cognitive facets of personal connectedness with the ocean [86], as explained in related work. Based on our results, SurfSync facilitated a restoration of surfers' ocean connectedness

when they faced anxiety and overcrowded spaces [5, 21]: natural sounds were described to anchor attention to the present moment (F7); thermal cues made surfers feel more comfortable in cold waters (F6); and tactile cues reminded surfers to be aware of the ocean (F2, F3, F4).

These results extend prior HCI work that has aimed to facilitate nature connectedness [52, 106] and ocean connectedness [62, 86], engaging users in VR simulations of the natural environment. In our work, we show how interactive technology can also be used in-situ, in the real ocean, to amplify ocean connectedness. Moreover, our findings also extend prior social science work demonstrating how surfers achieve ocean connectedness, by showcasing how interactive technology can also facilitate this state when experiential barriers appear.

Particularly, the work by Anderson [2] describes the ocean connectedness while surfing using two terms: “*assemblage*” the connection that emerges when surfers, boards, and waves as distinct elements, are temporarily linked to form a unified whole during the ride, and “*convergence*” the connection that emerges when the wave becomes a place where these elements are not merely connected but merge, their boundaries dissolving into a single, fluid entity. We argue that feeling *present in the moment*, feeling *comfortable* in the ocean, and *being aware* of the ocean could be dimensions of ocean connectedness that interactive technology can facilitate. Such dimensions seem to sit between what Anderson [2] describes as assemblage and convergence. Hence, we can represent a connectedness gradient as shown in Figure 8.

First, we position *comfort* in the ocean just to the right of the assemblage, as an advanced stage of it. *Comfort* emerges when the surfer’s body, surfboard, and the surrounding ocean environment begin to align in a way that reduces strain and fosters ease. This embodied ease can prolong users’ engagement and open emotional receptivity towards the ocean. In this sense, *comfort* can be seen as a transitional state: it deepens the assemblage while preparing the ground for convergence, to start reaching a state fully synchronised into a cohesive and pleasurable whole.

Second, we position *awareness* of the ocean at a midpoint between assemblage and convergence. Awareness involves perceiving and interpreting the ocean’s dynamics (e.g., swell direction, wind shifts, rip currents, animal presence). *Awareness* requires attunement to interdependencies; how one’s own position, movement, and decisions are already co-shaped by the ocean. This is still an assemblage (discrete entities interacting), but *awareness* leans toward convergence because the surfer starts to recognise their co-constitution with the ocean: *awareness* of tides or migratory cycles alters behaviour, acknowledging that the ocean is an active partner.

Thirdly, we position the sense of *presence* in the ocean just before convergence. *Presence*, defined as being immersed in the moment [34, 106], is a precursor of the convergence state. As the literature describes, this is not just “feeling in relation to the ocean” but being subsumed into the surfed wave [2]. *Presence* could mark the shift from assemblage’s interrelation of parts to convergence’s blending, where the surfer no longer feels like a separate entity on a wave but “one with the ocean” [2, 78]. This is where surfers report timelessness, catharsis, or merging with the medium, not only while riding the wave but also while waiting for it.

Furthermore, we noted that SurfSync’s actuation occasionally competed with the surfers’ established rituals of horizon-gazing or breathing, echoing Anderson’s point that ocean connectedness is a dynamic convergence that can be both intensified and disrupted [2]. To aid future design practice, in the next subsections, we present design strategies for these stages based on our craft knowledge from designing the prototype and on how ocean connectedness was experienced by our participants.

**6.1.1 Designing to Support Physical Comfort in the Ocean.** Participants reported that thermal stimuli provided *comfort*, pleasant sensations, and reduced lower back muscle tension, even contributing to safety by keeping the bodies supple in cold water. While thermal stimuli are very popular in traditional sport science research and physiotherapy to induce muscle relaxation [33, 81, 98], in prior HCI work, this modality has been used to guide bodily awareness during introspective slow experiences, such as lying on the floor [107] or guided walking [27]. We extend this work by showing that in-situ thermal stimuli can allow immediate muscle relaxation and support surfers’ performance by “loosening” their lower backs. Although most surfers rely on thick and specialised wetsuits to keep warm in the ocean, this solution does not provide localised heat. Moreover, the cyclic on/off warm stimuli were noticeable to surfers and enhanced the comfort of being in the ocean, especially during long stationary wait times. Furthermore, we extend prior HCI research by demonstrating that intermittent thermal stimuli can support comfort during exertion, such as in water sports, which were previously used only for slow-paced activities. This could offer new possibilities to address interaction challenges in SportsHCI [29].

**Design strategy #1:** Consider localised and subtle haptic stimuli (thermal or vibrotactile) to support both bodily comfort and muscle tension relief during inactive periods in the ocean. Such physical comfort could improve trust in the aquatic environment and reduce attentional load, enabling a more fully engaged experience.

**6.1.2 Designing to Encourage Ocean Awareness via Playfulness.** SurfSync’s audio pass-through (using bone-conduction headphones) appeared to guide participants’ attention away from worries towards the surrounding water environment. Occasionally, the natural sounds of rain, whales, and seabirds appeared to make participants believe the sounds belonged to the real world, sparking their curiosity (F4). This behaviour is related to our design decision to include playful make-believe features [24], such as adding sea life sounds, to create wonder and surprise. Our findings suggest that make-believe emerged through the use of an audio pass-through system, which created a mixed reality sound: it enabled hearing the digital sound while the auditory channel is free to hear the real-world sounds. We believe this effect would not have been possible with other audio technology, such as noise-cancelling headphones: sound quality would have been better, however, make-believe would not have emerged. Our work is a response to prior work calling for the implementation of playful features during sports [76, 114]. Thus, we expand this prior knowledge by showcasing how playful features, as presented in the PLEX framework (specifically *Discovery*) [59], could direct surfers’ attention to their surroundings by simulating hidden features of the ocean, such as sea life.



**Figure 8: Gradient of ocean connectedness during surfing.** The gradient starts with an “*assemblage*”, where the surfer feels connected to the ocean while riding a wave, yet can still differentiate between their bodies, the surfboard, and the wave. The gradient ends in “*convergence*” where the surfer feels “one” with the ocean, and they act as a single entity of human-surfboard-wave.

By highlighting the hidden features of the ocean, we aimed to position this environment as an active agent in the interaction, responding to prior works that called for designs that consider water’s agency [71, 79, 124]. We extend this work by showing how hidden ocean qualities, such as sea life, can shape surfers’ practice and awareness. Our design process, including the water map, supported reframing the ocean from a passive medium to an active participant. This consideration aligns with recent more-than-human (MTH) work and NatureHCI research studying human-environment relationships [18, 48, 110]. These prior works provide agency to things, animals, and robots thanks to different MTH design approaches. Our work extends these prior studies as little work has considered the environment where the interaction takes place (e.g., the forest, the lake, the mountain) as an active agent in the interaction. Thus, the findings from SurfSync showcase how the ocean can also be an active participant in the interaction.

**Design strategy #2:** Consider using audio pass-through stimuli to facilitate playful make-believe features that enhance users’ ocean awareness by sparking their curiosity. Reveal the presence of out-of-the-ordinary hidden elements of the ocean to facilitate wonder and encourage exploration of the surroundings.

### 6.1.3 Designing to Facilitate Ocean Awareness Through Information.

It appears that our design decision to inform participants about the swell direction and period through vibrations was not readily understood (F1, F2). These findings contradict results from a prior surfing simulation in a swimming pool, which suggested that vibrotactile cues had the potential to communicate directions in the ocean [71]. SurfSync’s vibrotactile cues were not distinguishable for most participants during ocean surfing. For participants who did notice the vibrotactile cues, it seemed the intended direction did not come across. Future work could explore increasing vibration strength, various sizes of vibration arrays (e.g., a simple left/right [103], different positions on the body (e.g., feet [30]), or linear actuators [37]). Despite SurfSync’s implementation limitations, vibrotactile feedback remains promising: participants found it pleasant and a meaningful reminder to stay present. They also expressed interest in richer stimuli that convey the ocean’s dynamics; for example, some linked rain sounds to swell prediction, even though this was not the intended function. However, we also note that users’ limited

understanding of how technology functions in open water may introduce new anxieties, as one participant worried about electronics attracting sharks (P2).

**Design strategy #3:** Use ambiguous yet evocative (vibrotactile) cues that stimulate surfers’ awareness and interpretation of ocean states during resting periods. Explore the potential to strengthen sensemaking by adjusting the placement of the actuation, or expand the tactile vocabulary with patterns for different environmental features.

### 6.1.4 Designing to Facilitate a Sense of Presence While in the Ocean.

All participants reported how the sounds “brought them back into being present” (P4), and some identified how subtle vibrotactile actuation has the potential to support surfers’ presence in the ocean (F7). Our findings suggest the importance of natural sounds (e.g., rain, ocean waves) blending with the real soundscape (F7). This aligns with prior NatureHCI work that showed how designs often blend natural and artificial elements, creating hybrid spaces where technology augments outdoor experiences [120]. Our results extend this work, showing that merging naturalistic digital sound with the real soundscape can go beyond augmentation to facilitate a sense of presence in the natural environment. Furthermore, our findings suggest that the presence was facilitated by vibratile actuation, aligning with research in VR that showed how haptics can heighten a sense of presence [36]. This aligns with HCI work that has focused on designing simulated water environments to make people feel present in the ocean [62] and while floating in static water [67]. We extend prior presence research that explored how to make people feel present in VR by suggesting that subtle vibrations could make people feel present in the physical world. More specifically, our findings suggest that SurfSync’s actuations were “invisible” (not visually noticeable) to participants most of the time, which might have prevented distractions from being in the present moment. We deliberately decided to embed our actuators in the wetsuit so that the technology would not be noticeable to others. This hidden nature appeared to support a sense of presence. Taken together, these findings underscore how technological mediation could facilitate presence while in the ocean. This has potential for water sports, as feeling present in the ocean may be hindered by factors such as uncontrollable weather [26, 89].

**Design strategy #4:** Consider integrating subtle digital elements overlaying the aquatic experience to facilitate a sense of presence while in the ocean. This could be achieved via audio (utilising technology like bone conduction that allows natural sounds to be perceived) or small haptic actuators on specific body parts that enable the user to perceive many other haptic sensations from nature. Prioritise non-invasive integration into existing gear, ensuring the technology remains unobtrusive.

## 6.2 Enriching surfing through reduced anxiety

Our findings suggest that SurfSync enriched the surfer's experience by supporting them in managing anxiety in the ocean, simultaneously amplifying calmness (F5) and fostering psychological empowerment (F8). Prior research on blue spaces (research about the human relationship with lakes, rivers, sea, etc) showed that reducing anxiety and physiological ease in the ocean leads to restoration, increased mindfulness, and a deeper connection with nature [97, 122]. Our findings suggest that by reducing internal noise and anxiety, SurfSync enabled surfers to be more confident in the face of wave unpredictability and other uncontrollable variables.

*6.2.1 Designing to Amplify Calmness During Anxious Scenarios in the Ocean.* Our results suggest that SurfSync's water sounds (rain and ocean waves), were congruent with the natural soundscape of the ocean and helped calming surfers during moments that would normally provoke anxiety (F5). We attribute this effect to a combination of three factors: First, water sounds have associated relaxation effects (e.g., [97, 122]). Second, participants perceived the augmented sounds as "merged" with the existing ocean sounds. And third, the fact that the sounds were triggered intermittently with periods of silence, creating a rhythm that enhanced relaxation rather than requiring overwhelming attention. These findings align with prior work on VR nature environments and ocean simulations for wellbeing, mindfulness, and anxiety reduction [47, 53, 62, 82, 112] in which researchers augmented the relaxing virtual environment with immersive sound. We extend this work showing how, in dynamic natural environments, sound-to-context congruency and alternation between sound and silence are key for facilitating calmness during anxious moments. In virtual simulations of oceanic environments, systems often provide constant digital ambient sound to enhance users' immersion and the relaxation that the ocean can naturally produce. In contrast, our results suggest that in nature, the role of digital sound is to highlight nature's relaxation potential and augment the soundscape, with congruency between the types of sounds and the rhythms of triggering. Moreover, as participants reported feeling psychologically empowered, we believe facilitating calmness during surfing could be particularly beneficial for surfers who are less experienced or feel vulnerable in the ocean, such as women surfers. Indeed, prior work has shown that women surfers search for surf buddies and join women's surf clubs to find companionship that supports overcoming low confidence and intimidation [89, 90]. Our work extends this research by showing the potential of interactive technology to empower surfers.

**Design Strategy #5:** Consider using aquatic-congruent aligned sounds, alternating with silence, to help users manage anxiety during overwhelming scenarios in the ocean. Using rhythms of

sound/silence that mirror natural cycles could create space for relaxation.

## 6.3 Enriching Surfing Through Social Mediation

Our findings suggest that SurfSync mediated how participants related to other surfers, although the ocean remained central during their social interactions. For some participants, SurfSync provided a sense of isolation, creating a protective bubble in overcrowded line-ups (F9). This finding aligned with Schaffer's observation that surfers often negotiate solitude and collectivity in their encounters with the ocean [102]. SurfSync influenced how surfers balanced solitude and community in the ocean, showing that social mediation is deeply entangled with how surfers connect with the ocean.

*6.3.1 Designing transitions between solitude and companionship.* Prior work suggested that interactive technology can support solitude in sports by supporting practitioners who enjoy being alone [32, 45]. Our research extends this work by providing evidence that auditory cues can support solitude in crowded ocean environments, rather than encouraging surfers to be alone. According to our results, auditory cues have the potential to provide a sense of isolation and distract surfers from other people's presence. This perspective aligns with prior work re-conceptualising solitude from "being alone" to the concept of "noncommunication" [13]. Conversely to supporting solitude, SurfSync also acted as a social initiator, sparking conversations, reinforcing the communal dimension of surfing as a shared ocean experience [121]. During some of these social interactions, SurfSync was a barrier, and participants who experienced this would have liked more control over the sounds to reduce this obstacle. This aligns with prior NatureHCI work that suggested more agency to enable unobtrusive interactions in Nature [39].

**Design Strategy #6:** Enable flexible transitions between social isolation and connection by providing control over sound intensity or triggering sound only when no talking is detected. This could allow users to shift from an inward focus to social engagement when desired. Consider an appearance that can communicate both a private mode, supporting "noncommunication" and solitude, and a public mode, sparking curiosity and conversation when revealed.

## 7 Limitations and Future Work

While our field study is one of a kind, as it is among the few that evaluate interactive technology during surfing, several limitations must be acknowledged. Firstly, the sample size and diversity of surfers were limited. Although the number of participants is in line with prior HCI research [23, 71, 109], we acknowledge this may affect the generalizability of our results.

Secondly, we only studied surfing with our system in one location, mostly due to logistical reasons (easy access for our participants, patrolled beach, stable phone coverage, access to showers, reliable ocean data, etc.). Although surf conditions varied, other surf sports might reveal additional information, complementing our results. Thus, future studies can learn from our single-session procedure to ensure safety logistics for longer exposure studies, and from our results to propose future lines of inquiry.

Thirdly, although our results strongly suggest SurfSync enriched the surfers' ocean connectedness, we acknowledge that a single session with the system may have induced a novelty effect. A single

session also limits the implications of our results in terms of the prolonged effect of SurfSync in surfers' perceptions and preferences. For example, studying longer-term engagement could have revealed how the surfer's sensemaking of embodied cues would evolve over time, as well as how their emotional response, such as reducing anxiety, would be affected by habituation. Hence, longitudinal studies can learn from our initial work and lead to further insights. We also acknowledge that we have yet to investigate how surfers would appropriate our design if they had access to it on their own surf sessions: Once waterproofing of interactive technology becomes more advanced (as called for in prior WaterHCI work [79]), we might be able to develop prototypes that surfers themselves can tinker with, potentially leading to additional insights that could complement our findings.

## 8 Conclusion

We introduced SurfSync, a soma-designed wearable that uses haptic and auditory actuation to enrich surfing as an experiential practice rather than a performance-driven one. Through an ocean-based field study, we showed how SurfSync fostered bodily self-awareness, reduced anxiety, and deepened surfers' sense of connectedness with the ocean. The articulation of the findings in three themes contributes to WaterHCI by demonstrating the potential of interactive technologies to foreground experiential qualities such as exploration, attunement, and reflection in dynamic natural environments. Beyond the empirical insights, we discuss our findings in comparison with prior work to provide design strategies for creating wearables that scaffold diverse ways to enrich surfing. In this way, our work contributes to NatureHCI and WaterHCI, showing how technologies can transform the natural environment from a passive medium into an active participant. Looking ahead, we see opportunities for future work to extend the proposed design strategies to other water activities and further explore technologically mediated human-water relations at scale. Ultimately, through our work, we aim to inspire other HCI researchers in relevant areas, such as OutdoorsHCI, to explore the design of interactive technologies that support people in benefiting from engaging with the ocean.

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