Drone Chi: Somaesthetic Human-Drone Interaction

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ABSTRACT
Somaesthetics—motivated by improving life quality via appreciation for bodily and sensory experiences—is increasingly influencing HCI designs. Investigating the potential of drones as a material for somaesthetic HCI, we designed Drone Chi: a Tai Chi-inspired close-range human-drone interaction experience. The design process for Drone Chi has been informed by the soma design approach and the Somaesthetic Appreciation concept from HCI literature. The artifact expands somaesthetic HCI by exemplifying dynamic and intimate somaesthetic interactions with a robotic design material, and body movements in expansive 3D space. To characterize the Drone Chi experience, we conducted an empirical study with 32 participants. Analysis of participant accounts revealed 4 themes that articulate different aspects of the experience: Looping Mental States, Environment, Agency vs. Control, and Physical Narratives. From these accounts and our craft knowledge, we derive 5 design implications to guide the development of movement-based close-range drone interactions.

Author Keywords
Drones; human-drone interaction; movement; soma design; somaesthetics; Somaesthetic Appreciation; Tai Chi.

CCS Concepts
•**Human-centered computing** → **Empirical studies in HCI;** *Gestural input;* Interaction design;

INTRODUCTION
Somaesthetics is motivated by improving one's quality of life through cultivating a sophisticated appreciation for bodily and sensory experiences [66]. In HCI, somaesthetics has been gaining traction as a theoretical foundation for designs that engage with the human body [62, 9, 46, 68, 30, 28, 32, 5]. Current somaesthetic design exemplars often feature a calm and rather static nature; soft, malleable forms or materials; and haptic interaction [62, 5, 9, 37, 68]. For example, they are often covered in fabrics [62] or plush materials [5]; input is typically captured through contact [62], pressure [9], inertial [62], or deformation [5] sensors; and actuation occurs via light [62, 68], sound [9], heat [37, 68], or slow-moving motors [5]. In contrast, the potentials of somaesthetic design using robotic materials and whole-body movements in 3D space are relatively under-explored.

Concurrently, autonomous flying drones have been flourishing as a design material [12, 20, 7]. Recent literature [18] suggests—and our experiences corroborate—that the drone is a promising material that can embody somaesthetic qualities in synergy with body movements. With high-performance motion sensing, drones can also figure in intimate interactions—within the "intimate space" of an approximately 0.5 m-radius around the body [26]. We see an opportunity for investigating how drones can be a material for such "intimate" interactions with somaesthetic qualities.

To explore this opportunity, we present Drone Chi:[1] a Tai Chi-inspired human-drone interaction (HDI) experience based on co-movement with a drone. Drone Chi builds on recent HCI literature where the bearing of somaesthetics has crystallized into generative theoretical constructs: created through a process grounded in the "soma design" approach [28], the resulting design instantiates the "Somaesthetic Appreciation" strong concept [30]. Informed by Tai Chi and meditation, Drone Chi is meant as an exploratory prototype to investigate a somaesthetic design opportunity. Our work expands somaesthetic HCI by contributing a dynamic and intimate somaesthetic interaction design with a robotic material using movements in expansive 3D space.

In what follows, we describe Drone Chi and its design process. Based on an analysis of participant accounts (N=32) which

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[1]The *Chi* in Drone Chi is pronounced as in *Tai Chi*.

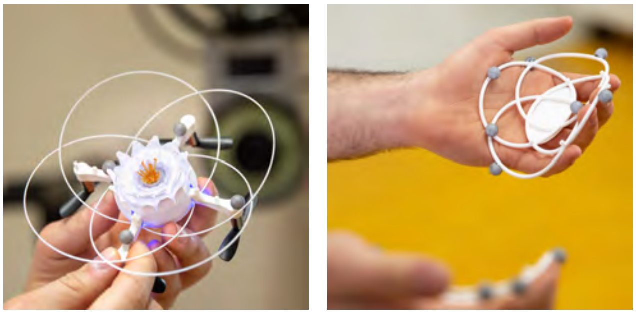

Figure 1: The Drone Chi drone and hand pads.

integrate explicitations on bodily phenomena, we present 4 themes that articulate aspects of the Drone Chi experience. We then present design implications from our research, which may inform future movement-based close-range HDI designs.

We contribute:

- A HDI design artifact which instantiates the Somaesthetic Appreciation strong concept [30], created via a soma design-based process [28];
- An empirical study and thematic analysis to articulate aspects of the Drone Chi experience; and,
- Design implications that aim to inform future close-range HDI designs.

RELATED WORK

Interactive Autonomous Drones

HCI research on autonomous interactive drones has been flourishing recently [12, 20, 7]. Here, we unpack specific aspects of how these works relate to ours.

Studies with interactive drones point to propeller noise and airflow as significant pain points [13, 14, 16, 36, 42, 75]; while smooth and stable flight is appreciated [40, 63, 70]. These considerations influenced our material selection. We based Drone Chi on a micro-quadcopter platform that is significantly smaller and quieter than most commodity drones, flown under closed-loop control via a high-precision, low-latency motion capture (mocap) system (see Section 4).

Previous work has investigated how a drone can figure in close-range interactions, confirming the viability of the concept. Experiments with drones as "tactile" objects that can be touched, held, and manipulated point to the significance of exterior design elements and noise minimization [1, 42, 78, 10, 22, 23, 57]. In addition, sports and exercise appear as a promising context for close-range HDI, where even unruly system behavior may contribute to experiences [52, 3, 56, 78].

Many studies have explored how conventions grounded in human sociality can guide HDI design. Among different functions and roles—e.g. "assistant" or "toy"—a "pet" metaphor often emerges as relevant for HDI [13, 38, 40, 53]. Recent work has capitalized on these findings by using human- and animal-inspired features like "eyes" on drones [58, 71]. These works suggest a broader theme: grounding HDI designs on animate creatures. Expanding this theme in a different direction, Drone Chi features a floral aesthetic. Our drones are covered with a delicate hull modeled after a lotus flower; and they are docked to a charging station that resembles a vine (see Fig. 4).

Another strand of research concerns performative HDI where interactive drones take part in artistic performances. Kim and Landay (2018), for example, report on a "drone-augmented" dance performance [41], where the creative process and aesthetics draw on design principles for "technology-augmented dance" [24]. More recently, Eriksson et al. (2019) have used somaesthetics, postphenomenology [35, 72], and intercorporeality [51] as theoretical devices to access subjective experiences (in particular, those of the choreographer/dancer) of producing and staging human-drone co-performance. These works point out desirable qualities for HDI that is coupled to body movements, and they informed our methods for understanding the user experience.

HDI focused on the body and introspection has been proposed and demonstrated previously by utilizing drones in meditative movement exercises [44, 43]. However, these conceptual and technical publications do not report on any empirical studies. Here, using a technological platform that is similar to this previous work [44, 43, 8], we contribute an empirical study that articulates human experiences, situated within somaesthetic HCI.

Somaesthetic Appreciation and Soma Design

Somaesthetics is a field of scholarship and practice that studies and promotes "the soma – the living, sentient, purposive body – as the indispensable medium for all perception" and "sensory appreciation (aesthesis)" [65]. It is motivated by the idea that a sophisticated appreciation for bodily and sensory experiences can contribute to quality of life. In HCI, somaesthetics informs various "experience-centered" approaches [46, 74], providing a theoretical basis for design scholarship with subjects ranging from art installations [47, 61, 62] to everyday artifacts [19]. Broadly, somaesthetic HCI aims to use technology for "engaging participants in deepening the experience of their own felt bodily sensations and movements," rather than for mediation or for optimizing one's body according to external criteria [32].

Recently, the role of somaesthetics in HCI design and scholarship has crystallized in two theoretical constructs. The first is the Somaesthetic Appreciation strong concept [30]—a kind of "intermediate design knowledge," i.e. a generative step from abstract theory to concrete design instances [31]. The crux of Somaesthetic Appreciation is 4 qualities that characterize artifacts and guide design processes: (1) "subtle guidance" of attention to bodily and sensory phenomena via design, rather than explicit direction; (2) "making space"—both physically and mentally—to support reflection, by way of evoking feelings of safety and protectedness through design aesthetics; (3) an "intimate correspondance" between the body and the artifact via immediate, congruous interactive coupling; and, (4) a means for "articulating experience" by making bodily sensations explicit through visualization and verbalization,

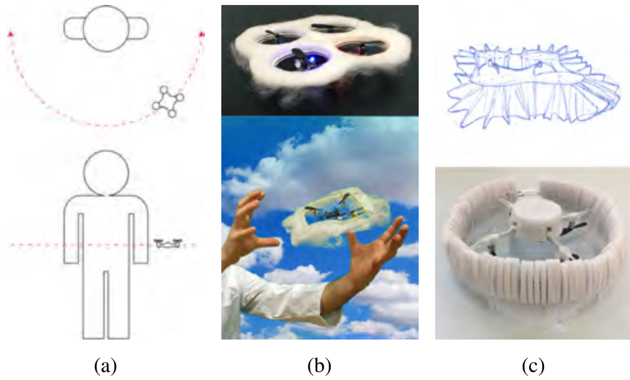

Figure 2: Specimens from the year-long design process: (a) initial non-interactive prototype diagram; (b) "cloud" claddings; (c) sketch and prototype on radial symmetry.

both during and after the experience. Artifacts that instantiate Somaesthetic Appreciation include the Soma Mat and the Breathing Light [68], Sarka [9], and SWAY [6]. Drone Chi also intends to instantiate Somaesthetic Appreciation, as we tried to integrate the requisite qualities in our design process and in the artifact.

The second way in which somaesthetics has crystallized in HCI theory is the "soma design" approach detailed by Höök [28]. To inform concrete design processes, the book compiles a selection of skills (e.g. autoethnography and somatic connoisseurship), and methods (e.g. slowstorming and embodied sketching). The design process for Drone Chi is based on this approach, as detailed in Section 3 below.

THE DESIGN OF DRONE CHI

Our design process was based on the soma design approach [28]. Soma design advocates that designers of somaesthetic experiences should themselves engage with soma-focused practices (e.g. Feldenkrais [59], horseback riding [27]...) to inform design work. In our case, the design (as well as the name) of Drone Chi was primarily inspired by the martial art of Tai Chi [45, 73]. The first author, who is also the principal designer, took regular Tai Chi lessons over 6 months to learn the practice and develop appreciation of their body as a design material. We also consulted the "somatic connoisseurship" ([28], p. 154) of the Tai Chi master who gave the lessons, by involving him in a 2-hour co-design session and engaging with the drones together.

Soma design recommends ideation methods like slowstorming ([28], p. 158) and embodied sketching (ibid, p. 161). Slowstorming—as opposed to rapid brainstorming—promotes ideation via slow, reflective, and iterative engagement with materials. Embodied sketching uses the body to act out design ideas in situ, capturing them on media like video as they unfold in time [49, 34]. We applied these methods in reflective encounters with our materials ([28], p. 162; [64, 67]) over a 1-year "research through design" process [76, 77, 21].

Early concepts drew on the "active ingredients" of Tai Chi [73]—e.g. "imagery" which "alter intention, belief, and expectation." We also studied the "technology-mediated attention-regulation process" proposed in literature on meditative HCI [60, 54], which advocates the use of non-judgemental feedback to highlight slow movement that in turn brings attention to the body.

To investigate these ideas in conversation with the drone as a material, we first built non-interactive prototypes. The first was a drone that oscillated in a horizontal semi-circle around a person at waist level (Fig. 2a). The drone was covered with fluffy cladding to promote imagery of being amongst clouds and embodying cloud-like movements (Fig. 2b). These drones did not sense the body; rather, we used the feeling of physical synchrony with the drone as the only means for feedback. We investigated the viability of the material through formative sessions with participants, quickly discovering that the experience was distinctly different to Tai Chi and therefore required a theory that encapsulates both somatic awareness and interactive digital materials. Soma design theory provided a grounding from which we could see these drones as a socio-digital material [28].

Drone Aesthetics

Our design investigations led to *radial symmetry* as a formal criterion, based on three observations: (1) radially symmetrical forms—as opposed to bilaterally symmetrical or directional—are less conducive to anthropomorphism—a concept we considered incongruent with the intended experience; (2) radial symmetry fit the innate form of a quadcopter; and (3) ambiguous drone orientation opened up a degree of freedom for movement and attention. Subsequent drone prototypes drew on radially symmetrical flora and fauna, e.g. fungi, jellyfish, and dandelions (Fig. 2c). We sketched and fabricated over 30 iterations with the intention of finding an overall form that was not visually dominated by straight arms and sharp propellers. For example, we considered where the gaze is drawn to when looking at the drone. These iterations culminated in a custom 3D printed hull with petals modeled after a lotus flower. We used concentric and intersecting circular elements to draw the eye to the middle of flower. We also inverted the drone's propellers, moving them down—into the background—to further aid this.

After arriving at the final design, a flock of 12 drones were produced. Following the floral theme, we built a docking station for the entire flock from a plastic vine, which integrates charging cables (Fig. 4). The narrative of 'picking a flower drone from the vine' emerged from this design. When the drone is removed from the vine and turned on, it emits a melodic beeping sound and spins each of its motors once; LEDs at the center of the drone's 'petals' begin to glow white, which adds an animate element to the experience.

Hand Tracking and Interaction

Hand tracking solutions were explored concurrently with drone aesthetics. Initially, gloves with markers were considered, which gave the us the freedom to 'grasp' the drone by curving fingers slightly. However, at times, this left our fingers feeling vulnerable, despite the innocuous nature of the propellers. A prototype that used square cardboard pads on the

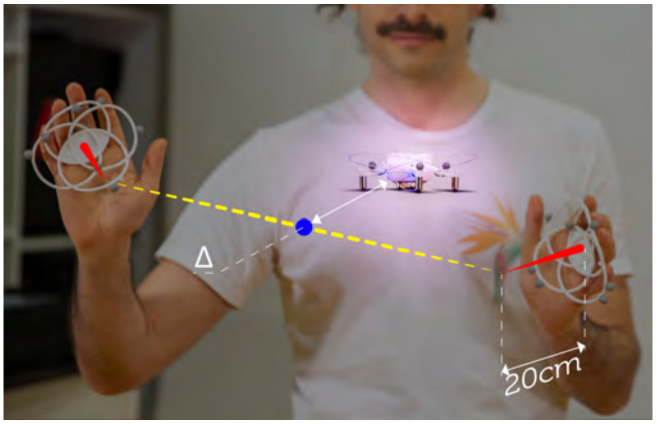

Figure 3: A diagram of the offset-midpoint mapping between the drone and the hands.

Figure 4: The drones dock to charging points integrated in a vine, which complements their floral design.

palms emerged as a preferable solution, as they were quick to take on and off. However, the rigidity of this design prevented the aforementioned 'grasp' action, and the pads completely eliminated the feeling of vulnerability, making the drone feel 'distant' to us. The final design strikes a balance by virtue of a curved form and large open sections (Fig. 1). The slender features printed from PLA plastic also feel delicate and somewhat fragile in the hands, resonating with the delicate materiality of the drones.

Through embodied sketching and reflective iterations, we arrived at an *offset-midpoint* measure for the correspondence between the hands and the drone. Based on mocap data, we first compute two offset points that reside on imaginary rays shooting perpendicularly out of the palms, at 20 cm away from the pads. We then compute the midpoint of the line segment straddling the two offset points—the offset-midpoint. The distance Δ between the offset-midpoint and the drone drives the interaction. The LEDs on the drone glow with an intensity based on this measure; providing "intimate correspondence" between the hands and the drone, and "subtle guidance" towards a state of focus. The glow intensity L, between 0 and 1, is computed based on the following formula:

$$L(\Delta) = \begin{cases} 1 - \Delta/20\text{cm} & \text{if } \Delta < 20\text{cm} \\ 0 & \text{if } \Delta >= 20\text{cm} \end{cases}$$

Inspired by the notion of "making strange" [48], and to further extend "subtle guidance" through different ways, we designed the interaction experience to unfold in two stages. First, the drone is 'followed' with the hands, its movements occurring on a circular flight path. The flight circle grows in size as the interaction progresses (Fig. 5a). The design of this flight path was based on multiple iterations. For example, early designs involved a circle in the horizontal plane, but we noted that as the drone moved away from the body, we tend to follow by walking forward—a familiar movement. By assigning the growing flight path to the vertical plane the knees and the torso had to be engaged, prompting an unfamiliar movement that requires attention to coordination and pace. In the second stage, the user 'leads' the drone, free to perform different movements while maintaining the same qualities (fig. 5b). In 'lead' mode, the drone will follow the hands as long as the offset-midpoint is within 20 cm of the drone. In both modes, the drone's air speed is limited to $2\,\text{m}\,\text{s}^{-1}$, mimicking the smooth, slow, and focused movements in Tai Chi.

To subtly delineate the lead mode from follow, an LED ring on the drone was programmed to change slowly from white (in 'follow' mode) to pink (in 'lead' mode). In 'lead' mode, if the drone breaks its speed limit or the hands are out of range, the light slowly turns back to white as the drone slowly drifts away from the body. Subsequently, the design elements in the curved hand pads and offset-midpoint mapping evoke a feeling of 'recapturing' the drone.

TECHNOLOGICAL MATERIALS

The Drone Chi technical setup is based on apparatus for HDI research that is described in the literature [8]. We built on the Bitcraze Crazyflie[2] micro-quadcopter (approx. 10 cm motor-to-motor) platform. We used a Qualisys[3] mocap system to detect the positions and orientations (in 6 degrees of freedom) of the drone and the hand pads, via infrared-reflective markers attached in asymmetrical formations. Object positions are processed on a host PC, and the drone is kept under closed-loop control at 100 Hz to interact responsively with the hands. Our software is based on the open source Crazyflie client.[4]

EXPERIENCE STUDY

Participants and Environment

32 people—13 who identified as male and 19 who identified as female, with ages ranging from 21 to 72—participated in the study. Participants were recruited through snowball sampling as well as posters around our facility. 15 of them had 3+ years of experience in practices involving bodily skills, e.g. dance, yoga, or martial arts. 20 participants had never flown a drone

[2] bitcraze.io
[3] qualisys.com
[4] github.com/bitcraze/crazyflie-clients-python

(a) 'Follow' mode

(b) 'Lead' mode

Figure 5: Representative movements in 'lead' and 'follow' modes, captured through long exposure photography.

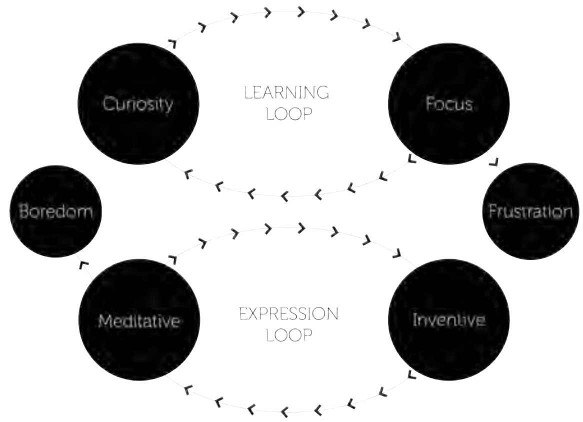

Figure 6: Six mental states that occur as part of learning and expression loops.

before. 11 were studying or working in fields related to design, architecture, or HCI. This demographic mix was intended to sample both naive impressions and those influenced by prior experience. All were native or otherwise fluent English speakers, and the study was conducted in English.

The study was conducted within one month in a laboratory setting, in a space measuring 5 m × 5 m × 5 m. The drones were programmed to remain within a space measuring 3 m × 3 m horizontally, between altitudes from 0.8 m to 1.8 m, to ensure they are seen by the mocap cameras at all times.

Procedure

Participants first completed an informed consent form and demographics questionnaire. They were then shown the apparatus and explained that the drone's lights respond to the hands. They were informed that they will go through two 6-minute sessions. At the beginning of the first session, participants were instructed only to maximize the glow, and were allowed to experiment with the interaction between their hands and the light as the drone hovers in stillness. Between the two sessions, the experimenter explained the technology and the control mapping in detail. Thus, we aimed for each participant to have a naive session influenced only by prior experience, as well as an informed session with an accurate mental model of the system. We took care to give as little verbal instruction as possible during the sessions, in order for the design itself to influence the experience and direct attention. Instructions were limited to safety-related events such as transitions between different modes, e.g.: "Now the drone will start making circles."

Data and Analysis

We used a fusion of three qualitative data sources to arrive at a rich articulation of the experience. First, the experiences were recorded on video. Second, participants annotated *body sheets* after the sessions. Finally, semi-structured interviews were conducted, supported by explicitation [50] where participants viewed the session videos and reflected on the body sheets. The information on the videos and body sheets was thus integrated to the interviews, which were recorded and transcribed into a text dataset to be analyzed systematically.

Body sheets are blank outlines of a human form printed on paper, used to reflect on feelings and sensations associated with different body parts during an experience (Fig. 7). We provided participants with two outlines on a sheet of A3 paper, which represent the first and second sessions. We asked them to freely draw and/or write on the sheets with colored markers, representing their feelings and sensations during the sessions. This method was informed by previous work in soma design research where body sheets were used as non-verbal means to "articulate experience" [30, 68]. Body sheets for both sessions were annotated after the second session, as we wanted to avoid influencing attention towards bodily sensations during the experience.

Interviews lasted from 20 to 30 minutes, including time spent viewing and reflecting on the video, and discussing body sheets. They were then transcribed into a text dataset with 2,043 extracts of participant statements. We employed thematic analysis [11, 4, 25] to build themes that consolidate aspects of experiential qualities expressed by participants in diverse ways. Following this approach, each data extract was assigned descriptions by the first author and two researchers independent from the study. The descriptors were iteratively developed into three sets of codes by each researcher, before being consolidated into subthemes and clustered into themes.

FINDINGS

Our analysis of the data has culminated in 4 themes that describe different aspects of participants' experiences.

T1: Looping Mental States

The data suggests that participants were in a flux between six mental states as they went through the Drone Chi experience, which can be characterized by a *learning loop* and an *expression loop*. This phenomenon is depicted on Figure 6, and said mental states are described below as subthemes.

The *learning loop* describes participants trying to familiarize themselves with the interaction, where participants alternated between states of *curiosity* and *focus*. Occasionally, an error, misunderstanding, or unexpected event could push the experience out of this dyadic condition, into a state of *frustration*. The learning loop was commonly associated with accounts of the first trial, while during the second, participants seem to be attracted to an *expression loop* characterized by *meditative* and *inventive* mental states. Here, on occasion, the experience could fall into a state of *boredom*.

The body sheets revealed how the loops were associated with distinct bodily sensations (Fig. 7). The learning loop typically related to rigidity and restriction, whereas the expression loop corresponded to fluidity and freedom. P22 explains: *"I was still learning how the drone would respond to movement. I was keeping quite stiff. But in number two I felt a lot more relaxed so that's why felt like I could move my arms a lot more freely and my knees up and down a lot more. So I felt like I could be more fluid."*

Furthermore, the body sheets indicated that the first session produced more reflections on the hands and the shoulders while the second session produced reflections on a wider variety of body parts. Participants realised that although the hands control the drone, coordinating movements of the whole body produce smooth moving hands. For example, P23 recognised the need to *"move from the legs instead of the hips and that sort of gets you into a better movement"*.

Curiosity State
Participants were often curious about particular aspects of the system, trying to understand, through reasoning, why it behaved in a particular way. P22, for example, was trying to figure out: *"is the drone following this hand or is it being pushed by this hand?"*

Focus State
In trying to figure out a particular aspect of the system, participants would become very focused, investigating the question in action. As P1 explains: *"my brain was very active. I was trying to puzzle it out. I was definitely focused on what my body was doing and how it was corresponding to the device." "It really requires your concentration, if you really want it to move in the direction you want it to move. You really need to focus on it,"* said P7. Participants would cycle between the curiosity and the focus states while they became more and more attuned to the exercise.

Frustration State
In a small number of instances, frustration was expressed. As P31 explains, *"At times it would stop working for some reason that I didn't understand. And that really frustrated me but then it will also take me back to interesting. Because I was trying to understand again exactly how it works and why it wasn't working."*

Inventive State
At some point, participants developed a good understanding of how the system works, and begin exploring what more they can do with it. As P15 explains: *"I understand how to make it work and after that it becomes routine. You start to think about what else can you do to stretch my knowing of this thing". "Understanding the way that you had it set up and the triangulation of it that made it easier for me to move it around and become a little more imaginative,"* noted P32.

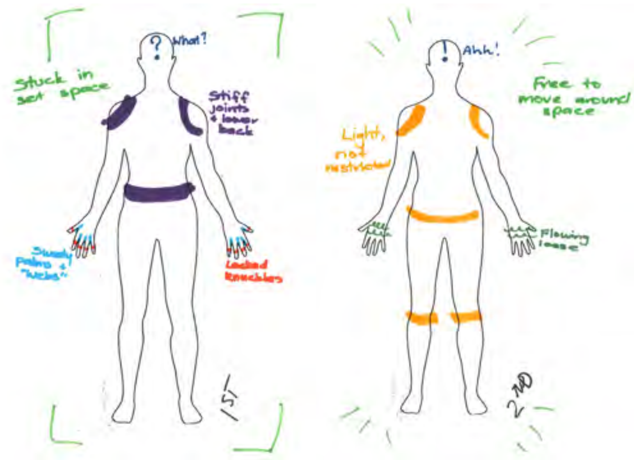

Figure 7: The body sheet completed by P9, which illustrates bodily associations with the learning and expression loops.

Meditative State
The expression loop involved a state of meditation, which was often found to be easy and instinctive. Quoting P29: *"I think when I was into it, there was less thinking and more moving [laughs]."* Some, however, thought that effort was necessary to stay in this state, *"It took distinct mental and physical effort to kind of monitor my body, and what was going on to remain in that zone"* (P24). Either way, participants were rewarded with *"feeling good and feeling relaxed, those positive feelings"* (P24).

Boredom State
The majority of participants did not express any boredom, as they were driven to expressive use. A small minority showed signs, with one participant even asking to land the drone and conclude the session before completion.

T2: Environment
The experience occurred in a certain environment—both physical and affective—that was perceived as immersive, non-judgmental, and spacious; granting participants with the patience to learn and the confidence to explore.

Immersive
Participants found the experience very immersive, as P2 corroborates: *"I lost track of time. It takes you, I feel like there's a little trick to it and you're trying to figure out exactly how it's doing, what it's doing."* The movement of the body contributed to immersion, as P16 notes: *"It's physically engaging, obviously, because you're standing up, you're not standing back with a controller."* The level of engagement enabled participants to block out distractions, such as feelings of self-consciousness: *"I was really thinking about the drone and how my body was moving. So I got into the experience, and that was the most fun part, because I forgot about the fact that I was being filmed"* (P29).

Non-judgemental

Expectations or judgement were not prominent in the experience, as noted by P28, *"It reminded me of like chasing butterflies where you move without a specific purpose because it's just fun and easy, to move like a kid."* P27 noted enjoying the lack of goals: *"Quite often I feel really stupid around technology. It wasn't like pressurised activity and so it wasn't like playing any video game where you have to achieve any kind of goal. You just have to explore how to make it move and it also did not move very fast."*. The initiation of the experience in follow mode has helped P26, *"because it just helped ease into figuring out how it works so you couldn't fail, I really liked that."*

Spacious

A physically spacious environment with no obstacles was appreciated by participants. P20 explains that they made more use of the space after learning how the offset-midpoint worked, *"after the second stage of the experiment, I realized that it was in 3D land, which makes so much sense because we live in a 3D world"*. P14 used the space to try and move the drone through *"three movement planes at once or something, once I worked out how to fly it."* However, this expanse was not favoured by all, P21 realised how big the space was after moving into the lead mode and felt overwhelmed: *"I think [it is] in some ways worse. So I was sort of a bit more overloaded with, um, not being able to focus as much in one area."*

The experience gave participants the figurative space to recognise the effects of their movements on their somas. For example, P25 said: *"I also told myself quite a few times to remember to breathe because I noticed that I was holding my breath."* P14 realised that their *"footwork was weird"* and that they were shuffling awkwardly, causing them to step more purposefully. P24 recognised their fevered movement and was *"telling myself to be patient"* as a result.

T3: Agency vs. Control

Participants felt the "intimate correspondence" between themselves and the drone, for example P13 was able to *"feel as one with the system."* However, their interpretations of this intimate relationship were different.

Object to Control

It was common for participants to articulate their relationship with the drone as if it was an object to control. For P25, this was a highlight; they especially enjoyed leading the drone - *"the part where I was able to take control."* P9 described the consequence of crashing the drone as *"more about losing control of it"* than breaking it. Control also featured in the way participants learnt and expressed with the drone, likening it to objects like a motorbike, bicycle, or car. P27 compared the requisite coordination to learning how to ride a motorcycle: *"I had to step on gears, steering [laughs] I can remember all the things I need to do to learn"*. P24's explanation was also object oriented, *"you just want to play with it, play around with having it close and having it far"*.

Subject with Agency

Participants could also relate to the drone as a subject with agency. P18 thought that *"it is sort of a small pet. I speak to my plants, birds around me so this is something that's often an experience that I can of build a relationship with all of the things that come into my house."*, P29 said *"I could play with it, and teach it pet tricks"*. P4 drew parallels between initial interactions with the drone and meeting a person: *"It's like when you meet a new person, you can have an overall idea but you need time to understand the things that annoy them, how you need to talk to them, how not to offend them."*

Intercorporeality

Some participants approached an intercorporeal understanding with the drone [18, 51], as they learned the motor skills to move the drone smoothly whilst also experiencing an affective bond. P27 explained the physical connection, *"like connecting with it and understanding how it reacted to my movements and how my movements affected it."* Conversely, P21 captured the affective relationship: *"I really enjoyed that kind of process of connecting with the drone. It felt like the drone was relying on you to do something."* P32 realised mid-interview that they were referring to the drone and the hand pads interchangeably: *"I was very conscious of the drone and that was I guess where the majority of my concentration was. Yeah. And by the drone I guess I'm referring to the units I had in my hand as much as the drone."*

P23's account straddled different interpretations of the nature of the human-drone relationship, likening the experience to horseback riding when describing how they re-captured the drone after losing connection: *"There is an element of satisfaction in flicking your hands and getting back under control again, it is like you are on a horse, and you are kind of riding the horse, and the horse gets a little ooh ooh ooh ow, and then you are like ok come back, ok we're good, we're good, keep going, keep going."*

T4: Physical Narratives

This theme describes how different aspects of the physical artifact evoked different narratives with consequences in terms of affect and user experience.

Touch and Feel

The drone made little sounds and movements when turned on in participants' hands, which added to the experience of it feeling "alive:" *"When it came live it made the [imitates the drone beep sound] and like the slight vibrations there and just the sense that this thing is going to be connected with me now"* (P26). For some, the action of picking a flower drone from the vine added value and meaning to the experience: *"There are lots of flowers that you can choose from but you choose one, and that's the one you can control, it has a spirit inside there"* (P30).

Building Trust

The physical nature of the experience induced a need to build trust in the system. P30 could only start to explore after feeling sure that the drone will not crash and break: *"I tried to push it high. Like it's got a limit right? So I go lower and find the lower limit. So I go, okay, it's got a limit so I feel safe now."* P24 found *"the drone was very responsive, it felt like you just put the point there and it could just go to it,"* which motivated them *"to get physically more close to it, and look at* *it more closely, and to feel the force of the rotors coming off it as well."*

Something Worth Protecting

Participants said the delicate form of the drone inspired a want to protect and guide it. P20 explains: *"Working with the drone and being very delicate and guarding of it I suppose. So I might try and guide as opposed to try and control in the hands."* Even after understanding that the drone is more robust than they thought, P1 was still concerned: *"I didn't want the device to crash. It looks delicate so you think if it crashes it's going to break, which may or may not be true at that velocity of fall."* Corroborating with these accounts is the video footage which show most participants rushing to place their hands underneath the drone after a sudden and unexpected drop in altitude in an effort to prevent its fall.

Positive Noise

Most participants were not bothered by the drone's noise, with some noting surprise at how little it affected the experience (P16, P23, P28), as P28 explains: *"I came with the expectation that the sound would be annoying but this one was softer than what I was expecting"*. Some found the sound relaxing, as P23 reflects: *"I think the fact that is was constant, when you are trying to do something relaxing, it is nice to have a constant sound."* In P27's case, we observed that they even stood still with the drone and just concentrated on the sound for a while.

Validating Movement

Participants noted that the physicality of a moving drone added meaning and validation to bodily exercise, compared to performing the same movements unaccompanied: *"when you are doing Tai Chi you are always imagining some kind of something there, whether it is Avatar the last air-bender, or water bending, or holding the ball, but actually having something you can see, and actually being responsive to what you are doing, I think that was really relaxing"* (P23).

Implied Softness

Participants often described a sense of softness, despite the artifacts having no soft materials at all. P26 and P31 described a *"softness in the hands"*, and the diffusion of the light through the petals *"did soften it in a way"* for P25. The form of the drone was *"soft and spherical"* for P20 who contrasted it with typical *"hard and square"* drones. Finally, P18 described picking the drone from *"mother nature [...] a very soft but divine experience"*.

DESIGN IMPLICATIONS

We present 5 design implications we derived from the study of Drone Chi and our felt experiences during the design process. These implications are meant to inform the design of movement-based close-range HDI, and demonstrate the benefits of a soma design approach. We also discuss pointers for future research that are revealed by these implications.

Design for both simplicity and mastery.

The Drone Chi interaction is based on a single mapping between hand positions and the drone: the offset-midpoint. This interaction design proved simple enough to be intuitively usable by novice and naive users, but at the same time, supported mastery through experience and sophisticated understanding.

For example, some participants interpreted the mapping as a purely proximity-based relationship, and limited themselves to rudimentary gestures like pushing and pulling the drone. As the study progressed, participants developed a better apprehension (via their physical experience) and comprehension (via the experimenter's explanation) of the mapping. Subsequently, they began performing more sophisticated movements such as articulating the wrists and playing with the distance between the hands.

For close-range HDI, we recommend simple, intuitive control mappings; but the same designs can reveal new subtleties and possibilities in time. In current HDI research, continuous and subtly sophisticated control mappings are a relatively nascent topic, while many studies (e.g. [13, 17, 15, 55]) focus on discrete semaphoric or iconic gestures [2].

Allow exploration one dimension at a time.

Drone Chi introduced participants to the interaction design gradually, one dimension at a time. The first interaction was one-dimensional: the drone hovered in one point, as the participant experimented with the light and their hands. The 'follow' mode involved the drone flying in circles on a 2D plane. Finally, in 'lead' mode, participants could transfer the qualities of focus, coordination, and pace that they cultivated into free movement in 3D space. Thus, they gradually developed an understanding of how to move their bodies, with minimal explicit instruction.

The body sheets, video footage and interviews suggest that initially the hands were demanding the most attention. By the second session most participants were moving more fluidly, coordinating the whole body to produce smooth moving hands. So while the idea to move in this way was not explicit in the design, some participants figured this out during the experience. We attribute this engagement of the whole soma to the gradual introduction to the experience combined with the exploratory mindset facilitated by the environment.

Support fragility to facilitate intimate interactions.

For close-range HDI, the idea of fragility was used to encourage intimate (close-range) [26] interactions. The fragile floral aesthetic proved effective in communicating this idea, evidenced by participants' regular willingness to bring the drone close to the body and to feel the airflow from the propellers. However, it was important that this notion was supported by other design elements that engaged the soma. For example, the feeling of gently 'holding' the drone via the hand pads evoked curiosity and care from participants. The offset-midpoint mapping bound the whole body movements to the fate of the fragile drone, evoking a sense of inter-dependency which heightened the awareness of both the drone and the participant's movements. Other aspects of the experience outside of flying supported the idea of fragility, such as picking the drone from the vine, feeling its delicate petals and sense of animism when turning it on. This led many participants to recognize that their movements have direct and physical consequences.

Drone noise can be used constructively.
Previous empirical studies on close-range HDI indicate, with a high degree of consensus, that propeller noise and airflow are undesirable [13, 14, 16, 36, 42]. Even in studies where user experiences are reportedly favorable, noise and airflow consistently emerge as pain points. In contrast, participant accounts with Drone Chi point to the low level of constant propeller noise as a calming, focusing aspect of the experience. Thus, we argue that in HDI there are opportunities for using mechanical noises constructively.

While the constant humming noise contributed to the experience in itself, we have also observed that noise in Drone Chi functioned as an effective feedback modality, giving "subtle guidance" to smooth and slow movement. When the participant's (and the drone's) movements were soft, smooth, and calm, the propellers also emitted a smooth and quiet noise. In contrast, any sudden movements by the participant could cause slightly jarring noises. Future work might explore HDI designs that modulate mechanical noises for interaction.

Imply softness through form and movement.
Previous somaesthetic HCI designs have predominantly featured soft materials that invite touch. In contrast, most drones cannot be touched in flight. However, the design of Drone Chi nevertheless evokes softness through design elements like smooth lighting animations, slow movement, quiet propeller noises, and a floral look. Thus we propose *implying softness* as a design tactic for close-range HDI, and more generally, somaesthetic interaction design. Even with design materials that do not afford touch, softness and tactility can be evoked by leveraging responsive and multi-modal feedback, as well as attention to details of form.

DISCUSSION

While the findings and implications point to ways Drone Chi allows a participant to engage with their own soma, it is difficult to determine any changes in somatic awareness and appreciation over the course of a lab study. This limitation contributed to our decision to use the body sheets exclusively after the experience as opposed to before and after. As evidenced in the findings, the body sheets from the second session depicted reflections on a wider variety of body parts than the first, as many participants recognised the need to engage the whole body to move the drone. Compounding this limitation, the batteries on our drones only allowed for flight times slightly more than 6 minutes. We acknowledge the need for longer-term studies to investigate somatic changes and appreciation.

A common theme among many somaesthetic design artifacts [39, 33, 68, 69] is playfulness [29]. This is often a consequence of moving in a manner that has not been repeated since infancy or childhood (ibid). The relation to the drone as a subject or an object was bridged by the idea of play. This is demonstrated by participants' different usages of the term 'playing' when explaining why they thought the system was playful (see Section 6). P29 used the term as if the drone was a subject with agency whereas P24's description was more object-focused. When relating to the drone, participants described varying proportions of agency and control. For those who related to the drone primarily as an object, the sensory experience seemed to drive their description: concepts such as *balance*, *rotation*, *pushing*, *pulling* featured prominently. For those who saw the drone more as an agent, the perceptive experience seemed to dominate: *negotiating*, *guiding*, *competing* were common descriptors. In previous work on movement-based HDI, a satisfactory balance between agency and control has been described as an "evocative resistance" [18] which is achieved by "somaesthetically attending to the drones."

CONCLUSION

This paper presented Drone Chi, an intimate (close-range) HDI experience that builds on somaesthetic HCI theories. By presenting an overview of the design process, situated within somaesthetic HCI, we aimed to expand the horizon of this field by exemplifying dynamic and intimate somaesthetic interactions with a robotic design material and body movements in expansive 3D space. While inspired by Tai Chi and meditation practices, we opted to position Drone Chi as an exploratory somaesthetic prototype rather than a tool for meditative exercise. This paper foregrounded the design process, and articulated the qualities of the Drone Chi experience via themes derived from participant accounts integrating explicitations on bodily phenomena. Thus, Drone Chi illustrates the potential of drones as a design material for somaesthetic HCI. We also see our work as a precursor to opportunities for how drones can figure in novel experiences around exercise, play, meditation, and the body in general. We hope that the experiences and design implications we presented will be valuable in realizing these applications with positive consequences.

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