# Articulating Mechanical Sympathy for Somaesthetic Human–Machine Relations

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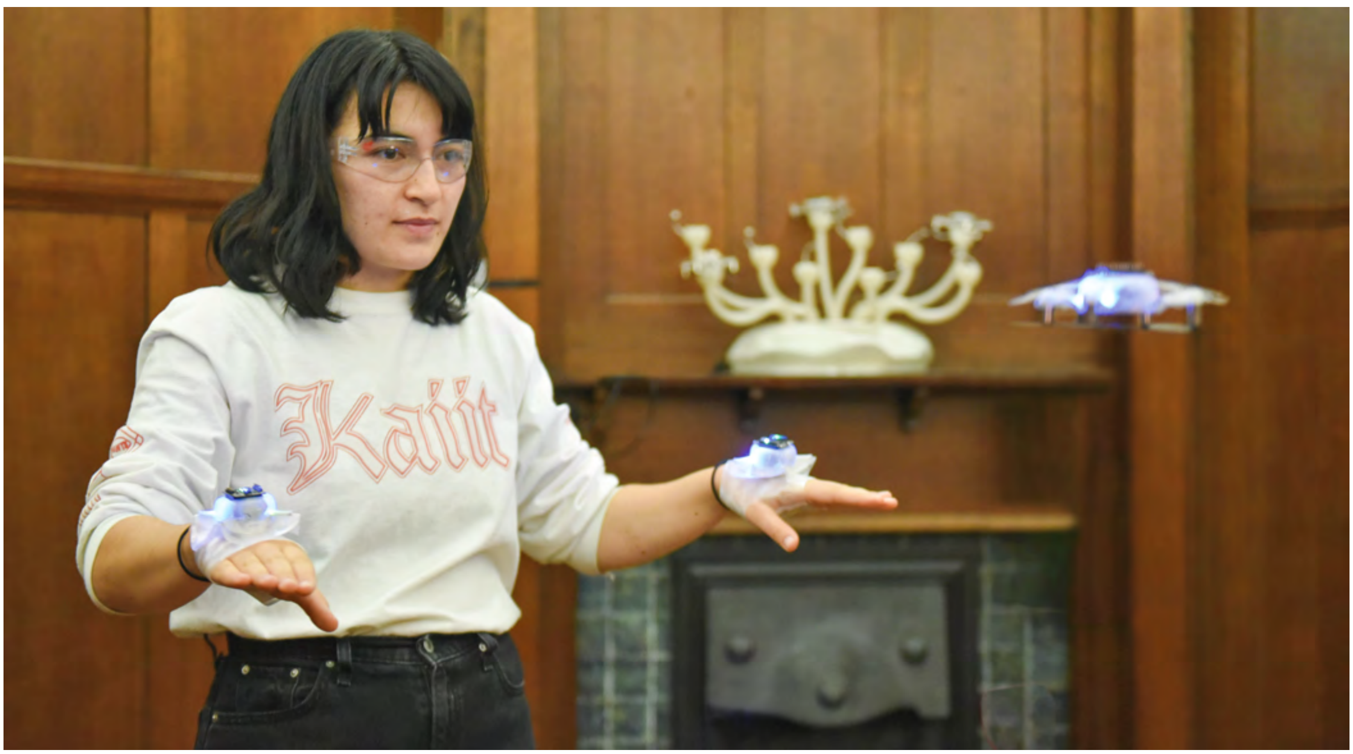


**Figure 1: How to Train your Drone: Nora, one of our co-creators, wears hand sensors while flying the drone. The charging dock rests on the mantle in the background.**

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*DIS '24, July 1–5, 2024, IT University of Copenhagen, Denmark*

## ABSTRACT

We present mechanical sympathy as a generative design concept for cultivating somaesthetic relationships with machines and machine-like systems. We identify the qualities of mechanical sympathy using the design case of *How to Train your Drone* (HTTYD), a unique


ACM ISBN 979-8-4007-0583-0/24/07
https://doi.org/10.1145/3643834.3661514

human-drone research product designed to explore the process by which people discover and co-create the somaesthetic potential of drones. We articulate the qualities – (i) machine-agency, (ii) oscillations, and (iii) aesthetic pursuits – by using descriptive and reflective accounts of our design strategies and of our co-creators engaging with the system. We also discuss how each quality can extend soma design research; conceptualizing of appreciative, temporal, and idiosyncratic relationships with machines that can complement technical learning and enrich human-machine interaction. Finally, we ground our concept in a similar selection of works from across the HCI community.

## CCS CONCEPTS

• **Human-centered computing → Interaction design theory, concepts and paradigms**.

## KEYWORDS

somaesthetics, soma design, machines, drones

**ACM Reference Format:**
Joseph La Delfa, Rachael Garrett, Airi Lampinen, and Kristina Höök. 2024. Articulating Mechanical Sympathy for Somaesthetic Human–Machine Relations. In *Designing Interactive Systems Conference (DIS '24), July 1–5, 2024, IT University of Copenhagen, Denmark.* ACM, New York, NY, USA, 18 pages. https://doi.org/10.1145/3643834.3661514

## 1 INTRODUCTION

The design of machines typically stems from a culture of standardization [14, 18], control [49, 101], prediction [48, 76] and human behaviour models [47, 100]. Such design principles often emerge from the development of machines for military, industrial, or commercial contexts (e.g., aviation, factories) where the motivations and goals are relatively well-defined and a successful design might be evaluated by metrics such as error rates, predictions or through standardized qualitative evaluations [55]. This culture has impressed upon other design practices – notably those in human–robot interaction (HRI) and human–drone interaction (HDI) – a tendency to converge on generalizeable design frameworks or metric-driven solutions [43, 44, 83]. For example, in HRI, interactions are often evaluated on parameters such as safety [65], trust [15, 66], and emotion recognition [57]. However, as novel technologies increasingly migrate into domestic and social contexts [8, 35], it is becoming apparent that these research trajectories are not flexible enough to absorb the reality of our complex and dynamic relationships with machines [10, 33, 129]. While some in HRI have approached this complexity through participatory [4] and ethnographic methods [16, 30, 31, 68], here, we identify space for a somaesthetic approach to the design of machines and machine-like technologies.

We are human–computer interaction (HCI) designers who are interested in designing for human–machine relationships. For our purposes, we focus on *machine-like systems*, including robots and drones that are machine-like in form rather than strictly humanoid or zoomorphic [2, 93]. Through soma design [51], we consider the somatic and appreciative relationships that can evolve with such machines, and how we might design to cultivate such relationships within increasingly intimate human-machine entanglements [32]. We identify *Mechanical Sympathy* as a process that leads to a cumulative appreciation of a machine; a synergy with, or bodily understanding that someone can develop of, a machine that mutually shapes how the human and machine can act together. Mechanical sympathy as a concept embraces the dynamic and intractable complexities of human–machine interaction and allows for explicit shaping of a given human–machine relationship. This, we argue, can be a fruitful and generative design concept when designing for deep somaesthetic relationships with machines.

We extend the soma design program with the design concept of mechanical sympathy. We articulate the qualities of mechanical sympathy using the design case of *How to Train your Drone*[1] (HTTYD), a unique human-drone research artefact designed to explore the process by which people discover and co-create the somaesthetic potential of drones See Figure 1). We describe three qualities of mechanical sympathy: (i) machine-agency, (ii) oscillations, and (iii) aesthetic pursuits. We also identify five ways the concept of mechanical sympathy can contribute to soma design practice by conceptualizing the somatic relationships between humans and machines. Further, we reflect on how designers might set the conditions for experiences of mechanical sympathy to evolve with machines. Finally, we ground the concept of mechanical sympathy in similar and tangential works from across the HCI community.

## 2 RELATED WORK

Here, we present an introduction to somaesthetic interaction design, the pop-culture origins of the term mechanical sympathy, and connect to related works in human–machine interaction.

### 2.1 Soma Design

Somaesthetic appreciation is a cornerstone of somaesthetic interaction design – or soma design; a design practice that centres on the living, purposive, sentient body [51]. It adopts the philosophical perspective of somaesthetics, which argues that by attending to our bodies and enhancing our capacity to experience the world, we can enrich our capacity for rich, meaningful experiences [104]. We take this to mean that cultivating somaesthetic appreciation allows us to reflect on which experiences hold value to us [37]. In essence, the process of somaesthetic cultivation asks us to reflect on the ways in which we *desire* to live.

Within soma design practice, there are many methods of attending to one's soma that implicitly ask us to reflect on the experiences that hold value to us. This can include extended engagement in a somatic practice [29, 64, 71] that enhances our bodily or somatic expertise, or becoming attuned to somatic experiences such as breathing [56, 118, 120] that might reveal a previously unnoticed habit. Other methods seek to more explicitly foster such reflection, such as by estranging or defamiliarizing a habitual way of engaging with our bodies [9, 69], potentially uncovering more desirable ways of being in the world [37]. Typically, soma designers employ such methods to enhance their own somaesthetic appreciation. This allows them to uncover the potential of their socio-digital materials (the materials and technologies that are being designed) [119], i.e., what experiences do we want to create that are *desirable*?

[1]This name is a play on the popular children's books and feature films *How to Train your Dragon* by Cressida Cowell.

Much work in soma design has focused on creating interactive applications that facilitate this process of somaesthetic appreciation for others, that is, applications where the "*interactions subtly encourage users to attend to their own bodies, enriching their sensitivity to, enjoyment of, and appreciation of their own somatics*" [51, p. 21]. Technologies designed from the perspective of somaesthetic appreciation tend to share a similar set of qualities, namely directing attention inwards to the body, making space for reflection on somatic experiences, an intimate correspondence that follows bodily rhythms, and providing help to articulate certain bodily sensations [53]. Somaesthetic appreciation has proven to be a generative design concept in mental health [127, 128] and women's health contexts [109, 111], as well as in developing interactive [59] and performance art [45].

The *Soma Mat* and *Breathing Light* are two well-known design exemplars [114]: One lies on the Soma Mat and underneath the Breathing Lamp. The Mat gently applies heat to different parts of one's body while a pre-recorded voice invites one to compare the sensations. The dome and low curtain create of the Breathing Lamp enclose one's upper body while the intensity of the light it synced to one's breath. Together they make space for one to become aware of one's own body; and develop an understanding as to why it feels the way it does – and in what ways one might like to change oneself. We draw on this approach here, with a focus on the somaesthetic potential of drones. However, instead of a heavily facilitated approach of somaesthetic cultivation (such as that offered by the Soma Mat and Breathing Light, or even through somatic connoisseurship [94]), we adopted a position more akin to somatic co-creation [51]. We offered a somaesthetically designed artefact but left the details of the interaction more ambiguous [38], with the intention of allowing our co-creators to undertake their "own path" to uncovering the experiences they found desirable.

Finally, we understand the soma as *"living, purposive, sentient, perceptive body, in which movement, body, emotion, cognition, perception, and sociality are tightly interlinked"* [51, p.14]. This way of understanding ourselves rejects the idea that the mind controls the body and embraces instead *"our double status as object and subject"* [104, p. 28]. It is this resistance towards dichotomies that opens avenues for soma design to traverse the boundaries between *self-and-other* or, in the case of our work, *body-and-technology* [52]. There is an emerging body of work that seeks to explore this relational perspective to our soma and experiences. Höök and colleagues show how the interconnectedness between perspectives is key to engaging with the soma in design practice [52]. Karpashevich and colleagues use a postphenomenological lens to understand the entangled perspectives that emerge between humans and wearable technologies [58]. Garrett and colleagues examine how aesthetic and ethical appreciation emerge from a body entangled through intercorporeal and material/technological relations [37]. Finally, Ståhl and colleagues show that engaging in soma design is a matter of "intra-action" [6] or somatic exchange between designers and their design materials [115], and further, that this somatic exchange continues with those who come to interact with such technologies, often leading to transformative experiences [113]. Our work is situated in this space, extending soma design practice using a relational perspective between humans and machines. To this end, we draw inspiration from autobiographic accounts concerning relationships between car, driver and mechanic.

## 2.2 Mechanical Sympathy in Popular Culture

The term mechanical sympathy originates in motor sports. It is loosely used to describe a "felt sense" of how to race a car smoothly, consistently, and at speed. Formula One driver Sir Jackie Stewart described how he felt an attunement to the limits of his car's adhesion to the track, enabling him to corner at maximum possible speed [112]. Peter Brock, an endurance racer, explained that he felt sensitized towards changes in his car, allowing him to anticipate the failure of various components and increase the longevity of his car [23]. These descriptions reflect a tacit knowledge – a way that these drivers "feel" their cars as a way of understanding what they can do, identifying issues to communicate to engineers and mechanics, and describe how they want their cars to feel when driving [80]. It reflects a view that purely technical or mechanical knowledge alone is not sufficient to make one a "good driver" [112], rather it also entails a *felt* sense – mechanical sympathy – towards driving a vehicle. We view mechanical sympathy as a process – something that is developed and enacted through constant engagement with a machine – rather than a talent. It is a cumulative process by which a driver makes sense of what their machine is doing and, in doing so, cultivates a profound aesthetic appreciation of how their machine should "feel".

## 2.3 Human–Machine Interaction

We contrast this perspective to an existing body of work on manual and embodied control for machine design [19, 55, 99]. Though these approaches share some phenomenological similarities to soma design [77, 97, 98], there is little emphasis here on the aesthetic or appreciative relationships that can be cultivated with machines. Much of this research takes place in technologically mature contexts, such as aeroplane cockpits [76], and embodied extensions, such as tele-robotics [99] or robotic prostheses [19]. These contexts have relatively well-defined motivations and measurable goals (e.g., low stress in the cockpit, able-bodied mobility) and the design process focuses on optimisation and error reduction, with complexity seen as a problem to be managed [49]. Despite the tightly coupled relationship between pilot and plane, the emphasis is on standardization [18]. A pilot's experience of the plane, for example, is communicated in a largely objective fashion [40], with little room for the subjectivity and aesthetics of their experiences.

Though there is clearly not a firm boundary between interactions that strive to be functional and the cultivation of an aesthetic appreciation (such as is evident in the example of race car driving), we see an emerging interest across the HCI community – especially among designers who work with robots and drones – to explore more designerly approaches to crafting rich experiences with technologies that have emerged from these cultures of standardized machine development [35]. For example, as drones (originating from a typically military context) have moved into increasingly domestic and social contexts [8], there is a growing interest in exploring the aesthetic potential of such technology. Examples include exploring the role of drones with children in the home [33], as companions [36], and designing drones to engage in somatic practices such as breathing

[34] and tai chi [64]. Though body-based interaction (akin to soma design) has long been of interest to the human–drone interaction community [117], with gesture and touch in particular being explored as a potential modalities of controlling drones [3, 13], such research has often pushed for "natural", effective, and functional interaction rather than delving into aesthetic complexity and nuance. Our research joins a growing body of work that explores the aesthetic potential of interactive drones [27, 36, 61, 62] and their potential role as creative technologies [26, 27].

Here, we delve into a complementary design space for machines and machine-like agents – one that embraces the complexity of machines and the subjectivity surrounding interactions as a resource for rich human-machine relations. Further, we do not see our aesthetic-driven enquiry as distinct from technical skill or proficiency. Looking back to the early days of flying machines, the shape of a plane and its cockpit were yet to be standardized, and data collection was limited to conversations between pilot and engineer. "*Working side by side during design and development and sharing the roles of flight test engineer and test pilot, Wilbur and Orville [the Wright brothers] avoided problems of communication that would in later years mark the interdependence of these roles*" write Harper and Cooper [40, p. 517]. Similarly, many professional race car drivers begin their careers playing both driver and mechanic [80], similar to how any mechanic maintains, restores, or creatively modifies a car [84, 108]. Alongside Sondoqah and colleagues, we argue that somatic engagement with machines can complement and augment other forms of learning [110].

Our exploration and articulation of mechanical sympathy is situated at the intersection of these emerging bodies of work. We adopt a relational perspective towards the soma [52] and interactive technologies [32], and strive to approach machines and machine-like agents – in this case, drones — in terms of their aesthetic and creative potential [35].

## 3 METHOD

To ground our conceptual development of mechanical sympathy, we present the design and deployment of HTTYD; a system where we invited three people to be *somatic co-creators* [51], exploring the creative potential of drones, contemplating potential futures [7], and reflecting on the kind of experiences they desired to pursue. Here, we describe the method by which we arrived at our articulation of mechanical sympathy. This entails (i) our research through design methodology, (ii) a brief overview of design process, (iii) our choice of design outcome - a research product, and (iv) our horizontal grounding of the concept in similar design cases and tangential works. We offer a fuller description of the finished product and its deployment in Sections 4.1 and 4.2.

*Research through Design.* Mechanical sympathy emerged from a research through design methodology [130], wherein part of our contribution develops through the synthesis of related work, part develops from our actual practices of making and designing [88], and part emerges from our co-creators interacting with our artefact-as-enquiry (the HTTYD system) [82]. These three facets are how Fallman and Stolterman characterize rigorous design research – an informed design exploration, a design practice, and a design study – that seeks to explore new directions, new technology and produce knowledge that might broaden the existing design space [28]. Such knowledge can be expressed and articulated in many different forms, sometimes referred to as intermediary knowledge, such as annotated portfolios [70], strong concepts [54], design methods, or design principles. We contribute mechanical sympathy as a design concept with three distinct qualities, which may be of interest to other designers exploring the space of human–machine relations.

*Design Process.* As this paper focuses on the conceptual development of mechanical sympathy, we offer a shorter overview of our design process. (A comprehensive description of the design process is available in [63] and [60].) We began by employing soma design methods [51], such as body storming [78] and embodied sketching [73], to delve deeply into how the drone could move and respond in ways that prompted curiosity and exploration. Once certain movements or responses piqued our interest, we employed technological explorations [119] to see whether they could be designed for with the drone. Certain movements or responses where discarded for not having the right "feel", whilst others where adapted to limitations in the drone hardware (e.g., flight time, in-flight stability). This stage of the design process was guided by first author Joseph's autobiographical accounts of maintaining old cars and racing go-karts, which were recollected and documented prior to the design process. These accounts were rich in tensions between function, performance and aesthetics. We combined this approach with product design engineering methods [20]. The drones were visually inspired by marine life from the deep sea, particularly the *cnidaria phylum* [2], to create a form that expressed equally plant, animal, and machine-like qualities. These visual considerations were combined with the limitations of the drone hardware (e.g., weight distribution, structural integrity). The final design emerged as an ambiguous, almost alien-like body that invites our co-creators to reflect on and interpret its form (See Figure 2).

*Research Product.* The outcome of this process was a research product; an independent, finished artefact designed to be deployed for longer periods without extensive upkeep from researchers [82]. Our approach is inspired by other work where research products have been deployed effectively to investigate the relationships between humans and technologies [41, 42, 72, 124, 125]. The aim of this research product was to invite our co-creators to uncover the aesthetic potential of drones through open exploration. Evidently, the essence of designed artefacts is that there will always be sedimented movements and ways of interacting with it embedded in the design [91, 121], so care was taken to balance scoping the interaction within the limits for the technology (e.g., how the drones could move), pre-defining some aspects of the interaction (e.g., one would control the drone using their hands), and maintaining ambiguity in the interaction (e.g., for what purpose they could use this system) [38]. To aid the reader in understanding the empirical grounding of mechanical sympathy, we describe how one interacts with the research product separately in Section 4.1, and in Section 4.2, we detail the context in which the system was deployed as well as the analysis we used to articulate these qualities.

[2] *Cnadaria phylum* refers to a large group of marine animals including corals, hydras, jellyfish, sea anemones, and many other species.

**Figure 2: How to Train your Drone. Top: The charging station with the different drones and hand-sensors docked on top. Bottom left: The 3D printed material of the charging station. Bottom right: The hand-sensors that can be attached to the hands.**

*Articulating and Validating our Design Concept.* In line with Höök and Löwgren's recommendation [54], as we articulate the qualities of mechanical sympathy in Section 5, we ground ourselves vertically by connecting to theory and existing literature. Finally, we ground mechanical sympathy horizontally in a selection of other works from across the HCI community, including the Very Nervous System [89], Freaky [67], Suspended Circles [5], and Metaphone [106]. We describe these works in Section 6, illustrating how they relate to the design concept of mechanical sympathy.

## 4 DESIGN CASE: HOW TO TRAIN YOUR DRONE

Here, we describe our design case: the HTTYD system and the co-creation process we use to ground our articulations of mechanical sympathy.

### 4.1 System Description

HTTYD consists of a collection of movement-controlled drones that can recognize and respond to certain positions of one's hands. To create a distinct "feel" to each machine, the drones have variations on their flight behaviors; requiring more precision in positioning, needing longer training times, allowing for more freedom of movement, or being quicker to learn and respond. The system also consists of a pair of hand-sensors attached to finger-less gloves that function together within a tracked indoor flight environment. The system operates from a laptop; a client used to track the drones and hand-sensors within the flight space, and a graphical user interface (GUI). A custom-built charging station is used to charge the drones and the hand-sensors. To explain how these parts come together, we divide the description into launching the drone, training it to fly in certain patterns, holding and moving with the drone, catching and realising it, and finally, landing. Further, a video showing the HTTYD system in motion has been included in the supplementary material to this paper.[3]

*Launching.* The tracked flight space is initialised by switching on a pair of infrared lasers that monitor the flight environment. Then, the chosen drone and the two hand-sensors are placed on a flat surface such as a table or floor within the tracked space environment. After switching the drone on, it makes a melodic tone to indicate that the automatic pre-flight check has been successful. The hand-sensors can then be attached to the finger-less gloves worn on the hands. The drone is launched using the GUI. After a successful launch, the drone rises to a specified height and spins in place along its vertical axis while producing a rhythmic clicking sound akin to that of a Geiger counter.

*Training.* Within tracked space, the system constantly monitors the position of the two hand sensors and the drone. Remaining still for a length of time within the tracked space causes the system to save the position of the two hand sensors (relative to the drone) as a *position*. Holding the hands still causes the drone to

[3]The code repositories are is available at [21, 22]

spin progressively slower and coming to a stop while the clicking sound becomes faster and coalesces into a rising tone. Once the position is successfully saved, the drone turns to face the person and hover in place, no longer spinning or producing a tone. We use the word "train" in the spirit of the pop culture reference that inspired the name of the project (*How to Train your Dragon*). The system does not employ machine learning or datasets to facilitate the interaction. Instead, it is "trained" by saving the co-ordinates of new positions. These saved coordinates accumulate around the drone (See Figure 3). This allows for the drone to be "held" in different positions. The points do not change the underlying behaviour of the drone, but they shape the overall interaction by enabling new movement possibilities.

*Holding.* Holding a position means the person is holding their hands close enough to those same relative points that were created when the position was first trained. Multiple positions can be trained with the drone. The position currently held by the person is called an *active position.* Only one position can be active at any one time. When a position is being held, the drone remains hovering in place, facing the person. Any relative positions saved by the system, but not currently being held, are called *dormant positions* (See Figure 3).

*Moving.* Each position is made of two points that are always relative to the drone. These points are surrounded by a "bubble": As long as the hand-sensors remain within the bubble, the drone continues to be held in that position. This enables the person to move without releasing the drone. For example, if the person moves their hands left within the bubble, the drone also follows to the left, changing its position to maintain the relative distance (See Figure 3). This allows the person to move the drone in any direction. The diameter of these bubbles varies for each drone in the collection, changing their interaction characteristics.

*Catching and Releasing.* Moving either hand out of its bubble will release the drone and it will return to spinning in place. This position then becomes dormant. A dormant (i.e. previously trained) position can be found by moving the hand sensors back into the bubbles that surround the two points that make up the position, thereby "catching" the drone.

*Landing.* Once the battery drains, a red warning indicator lights up on the drone. The drone lands itself by descending directly towards the ground. The battery allows a flight time of up to seven minutes. A twin drone with identical positions is available to use immediately. This extends the possible flight time within a single session to fourteen minutes.

## 4.2 System Deployment

The HTTYD system was deployed into a shared house over the course of a month. The system requires that a flight environment be in place in order to fly the drones, which was prepared in a common area of the household, allowing all co-creators to access the system and take turns flying their drones. The study received ethics approval from the Royal Melbourne Institute of Technology, Australia (RMIT).

*Co-Creators.* Our three co-creators were Nora, Justin, and Tom (pseudonyms). Nora is a 29-year-old lead service designer at a mental health care provider. Justin is a 30-year-old operations lead at a biomedical engineering laboratory. Tom is a 30-year-old machine learning engineer at an artificial intelligence hardware company. Each was given a drone with different flight characteristics, shown the basic operation of the system, and told to explore whatever they felt like doing with the drone. This direction was purposefully vague to make space for each to approach the system in their own way.

*Flight Sessions and Data Gathering.* We encouraged our co-creators to begin flight sessions by undertaking a body scan and completing a body sheet. Body scans are employed in soma design as a method of sensitising oneself to their body [119] – through sketching, color, or words – noting down any experiences they found their attention drawn towards [17]. After engaging with the system until the battery was drained, co-creators could continue with another drone (with identical memory) or choose to complete the remainder of their body sheet. Midway through the study, we encouraged co-creators to fly each other's drones. Finally, a comprehensive semi-structured exit interview was conducted. We asked co-creators to record their individual and shared flight sessions on audio and video devices we provided. The final extended interviews were audio-recorded.

*Data and Analysis.* Nora, Justin, and Tom each provided us with six recordings of their flight explorations (five individual and one shared), one short interview before the study (average 15 minutes), one long exit interview at the end of the study (average 60 minutes), as well as reflections captured on camera and periodic conversations with the research team. In total, Nora, Justin, and Tom created 24 body-sheets, 9 hours of interview data, and approximately 5.5 hours of flight footage.

We transcribed the recorded interviews and any conversation/ commentary captured on video. We began by conducting a thematic analysis [12] of the audio, video, and transcriptions. Our analysis was heavily informed by our position as soma designers, as we focused closely on our participants' movements while interacting with their drones, how they articulated and described their felt experiences, and what they wanted to do with the drone. First, the two first authors individually watched the video recordings of each flight sessions, in chronological order from the beginning to end of the study. They then each made a first pass through the interview data, reading and listening to the transcribed interviews in chronological order whilst adding our initial descriptions to the data. Following this, they each watched the video recordings again, using Adobe Premiere Pro to cut and add descriptions to the videos, including notable moments specifically mentioned in interviews or on body-sheets. Example of notable moments included our participants experimenting with new ways of moving their drones or trying to make sense of breakdowns or unfamiliar drone behaviours. They each then made a second pass through the interview data, adding more detailed descriptions and cross referencing to descriptions in the video data. Finally, they each made another pass through both sets of data to group these descriptions together.

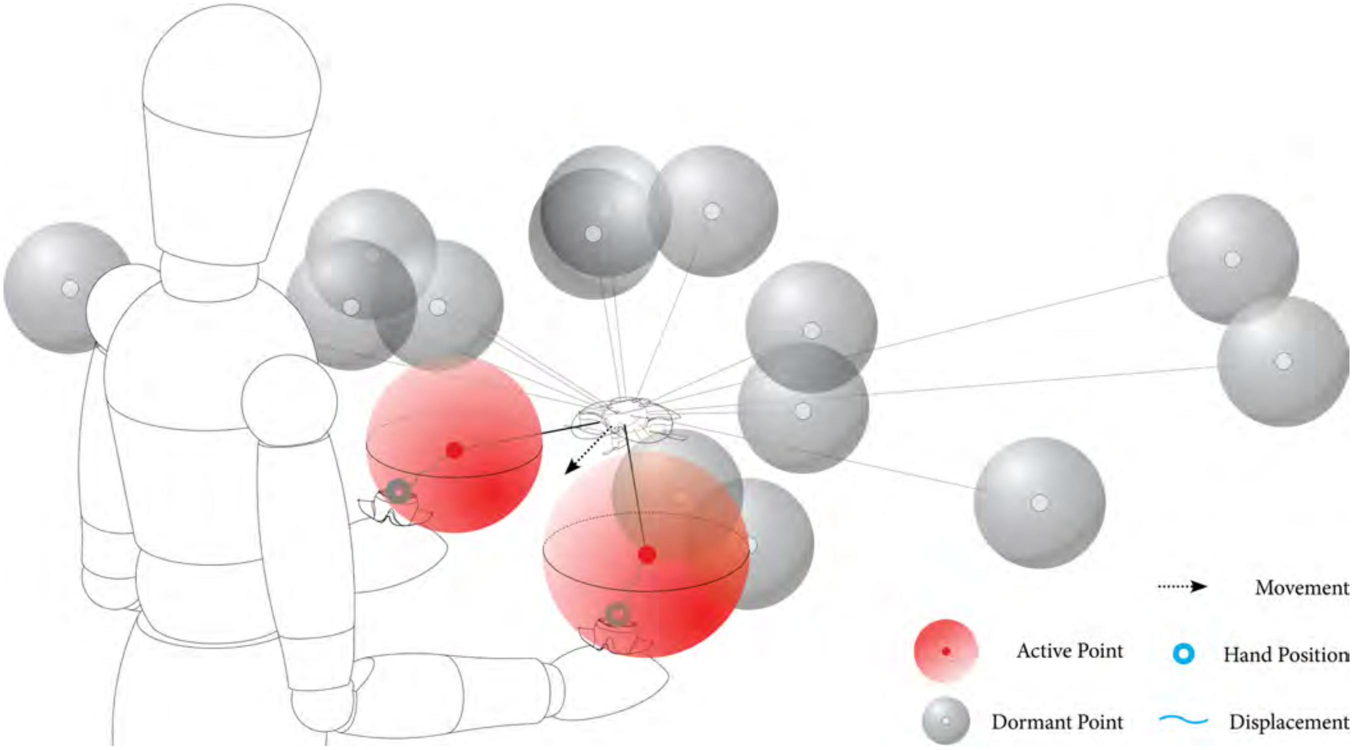


**Figure 3: A figure holds active points (red spheres) and is pulling the drone in towards their body. An accumulation of active points (red) and dormant points (grey) are connected to the drone, and therefore always move with it. The drone aims to minimise the displacement between its active points and the hand position, but only when the hand positions are within the active point's red spheres.**

The third and fourth author contributed to conceptual development by discussing the analysis process and key ideas as the work unfolded.

During this process, we noted that Nora, Justin, and Tom each developed distinct relationships to their drone. Therefore, we grouped these descriptions in two different ways. One set of grouped descriptions focused on each individual's reflections and a second set of grouped descriptions focused on notable commonalities between all the reflections. The first and second author, then, met to compare and discuss their individual analyses, collating the findings, and tightening the individual descriptions. At this point, they decided to shift away from themes as a way to present the findings, and, instead, to draw on storytelling as a narrative methodology [74, 79] to present Nora, Justin, and Tom's individual stories. Storytelling has been employed successfully by Ståhl and colleagues to discuss the transformative potential of somaesthetic experiences [113]. The first and second author returned to the data to construct a story arc for each of our co-creators, each of which was drafted and re-drafted several times. These three stories are intended to uncover the rich aesthetic value of allowing unique and individual human–machine relationships to flourish. Our co-creators reviewed the drafts and affirmed that their experiences were accurately represented. They also consented for their photographs to be used in research dissemination. Finally, all the authors discussed the stories. We draw on extracts from these stories to articulate the qualities of mechanical sympathy.

## 5 ARTICULATING THE QUALITIES OF MECHANICAL SYMPATHY

Mechanical sympathy joins a growing body of work that demonstrates how cultivating somaesthetic appreciation is neither a solely isolated nor inward-looking practice [37, 52, 113, 115]. Rather, cultivating the soma entails a fundamentally relational appreciation of our situated relationships with the people and technologies around us [37].

Mechanical sympathy is a process that leads to a cumulative appreciation of a machine; a synergy with, or bodily understanding that someone can develop of, a machine that mutually shapes how the two can act together, focusing on felt experience, or how a machine comes to be 'experienced from the inside' as opposed to 'controlled from the outside' [50]. We focus deeply on the case of HTTYD, using it to ground and articulate the qualities that characterise mechanical sympathy before we present other similar cases in Section 6. We describe three intertwined qualities – (i) machine-agency, (ii) oscillations, and (iii) aesthetic pursuits – and demonstrate how the design of HTTYD helped to foster mechanical sympathy. In each case, we show how our co-creators cultivated and experienced mechanical sympathy with the system. Finally, we show how this understanding of human–machine interaction can extend soma design as a relational practice and augment the soma design program with a means of conceptualising and designing for a somatic entanglement between a human and a machine or an agent, such as a drone or a robot.

## 5.1 Machine-Agency

The first quality of mechanical sympathy is that a machine exhibits some form of machine-agency, i.e., has a capacity to mutually shape the person using them. Even simple artefacts and interaction can shape one's body [51]. In this way, we find 'agency' a useful to term to describe this capacity without claiming that a machine's agency is tantamount to human agency [11]. Rather, we view an agent as "*anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors*" [92, p.34]. We also do not find that systems need to be autonomous to have machine-agency. In fact, the ambiguity between whether a human or a machine is in control of an interaction can be a fruitful design resource [63]. In the design of HTTYD, we found that accentuating this machine-agency was key to fostering mechanical sympathy. We made purposeful design decisions focused on (i) capabilities and limitations, (ii) change, and (iii) difference. We now describe each in turn.

*5.1.1 Capabilities and Limitations.* **Mechanical sympathy entails cultivating a somatic sensitization and responsivity towards the capabilities and limitations of a machine, which allows for the deconstruction and reconfiguration of the different possibilities for interaction.**

*Designing for capabilities and limitations:* As we previously mentioned, the drones were designed with different flight characteristics that accentuated their machine-agency. Each drone was programmed with different training times, manoeuvrability, launch height, and spin rate, all of which have implications for how each drone moves and behaves. In practice, this meant that each drone had "quirks" that our co-creators would come to appreciate as characteristic of "their" drone, that is, requiring more precision to move or being slower to train. Purposefully accentuating this machine-agency, for instance by making the drone more or less resistant to certain actions, helps create space for mechanical sympathy to be fostered. This is seen clearly in Justin's experience with his drone.

*Justin's story:* Justin was given the drone which was most difficult to move. "*It was interesting*" he reflected after his second session, "*I found that, when moving to the side, it's quite difficult. It's quite easy to move up and down, because the drone doesn't get in the way, but when you're moving laterally, unless [the drone] moves across with you, then you're going to bump your hand into it.*" The limited manoeuvrability of his drone prompted Justin to develop a deeper understanding of how he could move with his drone and also to sensitize himself towards his own movements. Justin came to move his body in a highly coordinated manner. He began to appreciate that, to be able to move with the drone, he needed to coordinate his whole body to support the lateral movement of his hands. To move left, for example, rather than moving from the shoulders or the hips, Justin would cast a pointed left foot out to the side while placing his weight on a firmly planted right foot. He would then slowly shift his weight onto his left foot, keeping his arms still, as his torso glided to the left (See Figure 4). As he explained: "*I have to move very slowly. Otherwise, I lose the drone. I was moving my legs very slowly and very deliberately putting my toes down on the ground in order to stabilize myself.*" Here, we see the enhanced somatic sensitivity that Justin cultivated with his drone (an awareness of its capabilities and limitations) and how Justin came to be shaped by his drone's machine-agency; moving his body in different ways to compensate for the limitations of the drone and, thereby, reconfiguring the possible ways for them to move together.

*First Extension:* A cornerstone of soma design is the understanding that somaesthetic appreciation can yield a greater appreciation of our somatic capabilities and of the limitations of our bodies – and how such capacities can be improved. Some somatic practices, for example, primarily focus on slow deconstruction and reconstruction of certain movements, thereby rendering a greater appreciation of the body, such as the aches, pains, or harmful habits that may constrain the body [29]. This, in turn, allows for the discovery of better ways of moving and enhances our somatic capabilities by reconfiguring the boundaries of what may be limiting our capacity to act. By adopting a relational perspective, mechanical sympathy offers soma design a way to conceptualise, engage with, and design for appreciative relationships with machines. Our somatic capabilities and the limitations of our bodies can be considered as situated within the relationship between human and machine [122], shifting the focus of appreciation from "turning inwards" [53] towards moving back and forth between human and machine perspectives. This makes space, not only for the felt experience of one's own soma, but to experiencing oneself in relation to the machine, as a means of somatically making sense of it, and even as a way of experiencing oneself through it [58]. From HTTYD, we have learned that purposefully accentuating a machine's capabilities and limitations can be a productive design strategy to foster mechanical sympathy.

*5.1.2 Change:* **Mechanical sympathy entails appreciating gradual changes to the machine, which allows for an evolving, temporal, and singular relationship.**

*Designing for change:* The HTTYD system was explicitly designed to enable gradual and accumulative change. The drones were programmed to be trained: to remember, recognise, and respond to different positions of the hands. Our co-creators were offered the option of either searching for and catching a previously trained position or to train an entirely new position where the drone can be held. As points are trained into the system, the drone gradually evolves. This allows for an accumulation of points around the drone, extending and changing the potential for interaction. Over time this results in not only a situated history of how the drone has been held in the past – unique to each individual – but constantly changing options of how to hold it in the future. This is seen clearly in Tom's experience with his drone.

*Tom's Story:* During the study, Tom focused on choreographing a sequence of movements that he could flow through with his drone. His sequence started with the drone at eye level and held at arm's length. He, then, pulled the drone down and inwards towards his

**Figure 4: Justin demonstrating how he typically moves the drone left and right; using his toes to smoothly shift his weight from one leg to another. The drone's position changes very little in relation to his body.**

navel, before pushing it down and up again from head height, then opening his arms outwards to full span, while keeping the drone still in front of his chest, and, finally, closing his arms inwards to return himself and the drone to starting position. Tom's repetitive and structured approach allowed changes to Tom's body to manifest in the drone. For example, during an early session, he highlighted the left side of his upper back, writing "*muscular pain through shoulder blade and trap*". He, then, went to train a position that placed the drone in front of him, with his outstretched hands either side at shoulder height. However, because of this muscular pain, his left hand was further from the drone than his right. In later sessions, Tom would repeatedly use this position to push the drone down. Each time, the drone would move slightly to the left which would, in turn, pull his body further to the left (See Figure 5). He reflected: "*I felt my body mirroring what the drone is able to do. I felt that I'm opening up new vistas and new possibilities to movement. I wasn't expecting it to have that level of control [over me] – actually feeling restricted and feeling quite mechanical in my movements, then that loosening up. It was quite embodied, being so embodied was a surprise to me.*" Here, we see the enhanced somatic sensitivity that Tom cultivated with his drone (an awareness of how the drone changed) and how Tom came to be shaped by those changes to his drone; appreciating that his body could move in different ways as new possibilities opened up to him.

*Second Extension:* Somaesthetic appreciation foregrounds change. Change, in the form of somatic transformation [113] or meliorative improvement [104], can be considered the pursuit of the somaesthetic project and is at the heart of cultivating appreciation. If change can be encouraged, then this appreciation can focus on small changes that reveal the temporal nature of our bodies, different circumstances or contexts in which we find ourselves, and different people or activities with whom we engage. By adopting a relational perspective, mechanical sympathy offers soma design a way to consider the temporal, somatic relationship between a person and a machine. Mechanical sympathy advocates for a slow and unfolding appreciation of the changes to complex systems – whether from design developments, maintenance, environmental factors, or regular use – and how we change with them. This can lead to a deeper understanding of how our machines might shape us in desirable and undesirable ways, and lead to healthier entanglements with technology [123]. From HTTYD, we have learned that explicitly enabling these gradual changes – such that hooks can be used to actively shape the machine – can be a productive design strategy to foster mechanical sympathy.

#### 5.1.3 *Difference:* Mechanical sympathy entails appreciating the differences between machines, which allows for an enhanced appreciation of the unique qualities of a machine relationship.

*Designing for difference:* In the case of HTTYD, programming the drones with different capabilities and limitations, as well as enabling gradual change, allowed for each drone to slowly evolve in a distinct fashion in relation to an individual body. In other words, we made space for them to evolve into 'different' machines. This difference could be considered from two perspectives. First, each point that our co-creators trained into their drone contained 'traces' of their individual body, i.e., the way they held their arms, the set of the shoulders, their height, etc. This meant a different person might struggle to find that point, even when adopting the exact same stance. Second, each co-creator became accustomed to their drone's quirks, or ways of moving, and learned to move accordingly. This meant that a person might struggle to move with a different drone. Encountering a different machine can also foster mechanical sympathy. This is illustrated when Nora tried to fly Julian's drones.

*Nora's Story:* Nora's approach to flying her easily manoeuvrable drone often involved exploring new movements out of curiosity. Her drone had an "elasticity" that enabled this loose, experimental style of moving, allowing Nora to repeatedly bounce the drone in different configurations like a yo-yo. During the partnered session, Nora tried flying with Justin's drone. This forced her to rethink the way she was moving. Despite Justin instructing Nora on how to move, Nora struggled with Justin's less manoeuvrable drone: "*It felt similar to my first or second session where I was trying to learn.*" She also carried herself differently (See Figure 6), reflecting that "*I feel like I have tight shoulders from trying to maintain a lot more control.*" When she returned to flying her own drone, she reflected "*That was so interesting going from one to the other. The difference is just so instantaneously noticeable!*" This experience bolstered her appreciation of the "feel" of her own drone and how it felt to fly. "*I felt like it was more responsive, it encouraged me to move around more, and be about the space I was in because I did not have to think about [the drone's] position. I would not have picked that up until I was able to compare that to someone else.*"

**Figure 5: Tom's drone pulls to his left as it descends, causing him to follow it in a leftward feedback loop.**

**Figure 6: When Nora uses Justin's drone she moves it left and right using a similar weight shifting technique to Justin but instead taking smaller steps.**

*Third Extension:* Soma design advocates for considering our design materials as socio-digital materials: using our somas to discover the aesthetic potential of the physical and material artefacts we are designing [119]. This aesthetic potential emerges at the intersection of the soma and the material [37, 115]. By adopting a relational perspective, mechanical sympathy offers soma design a way to consider individual machines as distinctive and idiosyncratic design materials. As opposed to conceiving of machines as standardized tools [14], mechanical sympathy advocates for designing socio-digital machines that are purposefully evolving and shaping a dynamic relationship [122]. This allows us to not only shape our socio-digital design materials but explore how they might also shape us, thereby cultivating intimate and appreciative human–machine relationships. From HTTYD, we have learned that supporting difference to manifest and be explored can be a productive design strategy to foster mechanical sympathy.

These three focuses – capabilities and limitations, change, and difference – where key to how we designed HTTYD to exhibit machine-agency, or in other words, accentuating the HTTYD system's capacity to help shape co-creation by opening up possibilities for somatic communication, understanding, and appreciation between human and machine.

## 5.2 Oscillations (Perception-Action Sequences)

The second quality of mechanical sympathy is that of oscillations. This refers to perception-action sequences — indicative of a perception-action coupling between human and environments [86] – that characterise sense-making of a machine [110]. Oscillations are characteristic of other processes of embodied sense-making [81], embodied learning [87], or skill acquisition [25, 46]. However, from a somaesthetic perspective, they are also closely tied with traversing the boundaries between the body and technology [52], and employing defamiliarization exercises to extend one's movement repertoire [9, 126]. Here, we use oscillations to describe the process by which our co-creators cultivated mechanical sympathy with their drones: Tom oscillating between movement experiments and experimental movements to decide how to train his drone, Justin oscillating between alternating perspectives to make sense of how to move his drone, and Nora oscillating between the habitual and the unfamiliar when using a different drone.

*Designing to support oscillations:* Though we did not design HTTYD intentionally to support oscillations – rather we observed them retroactively in our analysis – we find that certain design decisions likely supported these perception-action sequences. During the design process, we followed the principle of subtle guidance [53], focusing primarily on how the drone would respond through movement over audio-visual feedback modalities (e.g., lights or beeps indicating a change of state), sparking curiosity and reflection, without overly drawing attention away from the body. In hindsight, this resulted in the drones being somatically "readable" and "writable" [116], wherein perception and action became the primary sensemaking modality. Only later did we consider this larger process of somatic sense-making [81]. Unlike the use of subtle guidance to turn one's attention inwards [114], in the case of HTTYD, it contributed to guiding attention on a path from the co-creator to the drone, and back again.

*Tom's Story – Movement experiments and experimental movements:* Tom created an entire semi-circle of points trailing from

**Figure 7: (Top) Tom tips his body over while holding the drone. (Center) Tom lunges while holding the drone. (Bottom) Tom twists his body from the torso while holding the drone.**

each side of the drone. He moved his hands through this arc of points to the outermost point. Tom, then, employed a movement experiment, incrementally moving his hands left and right probing out where the connection would break. These movement experiments allowed Tom to probe the boundaries of the movement available to him. With his arms now at that boundary, Tom engaged in experimental movements to probe the different possibilities for the next part of his movement sequence. Tom creatively experimented with the different ways he could move his body. He lent to one side like a teapot (resulting in the drone breaking contact); took a long step forward with one foot to drop into a lunge (resulting in the drone moving diagonally); and twisted his torso from the hips resulting in the drone moving in an arc). In this process (See Figure 7), we see an example of Tom making sense of the aesthetic possibilities available to him and reflecting on the ways he wanted to act (i.e., move with the drone).

*Justin's Story – Alternating perspectives:* Justin explored how to move his drone up-and-down and side-to-side. He discovered that moving up or down with the drone was relatively easy, requiring him to rotate his arms vertically from the shoulders while his body set the distance between his hands (making it easier to hold his relative position.) When Justin tried to move the drone laterally, he discovered that this required him to coordinate more parts of his body (rotating his shoulders, extending his elbows, and articulating his wrists). These different movements could easily unfold at slightly different speeds and lose his relative position to the drone. Following this discovery, Justin tried holding his arms in place and rotating his hips, trying to use his body to maintain the set distance between his hands. Making sense of these movements required Justin to oscillate his attention between his individual body parts, his whole moving body, and the movements of the drone, cycling between different perspectives to make sense of how his individual body parts related to the whole of his body and how his body, in turn, related to the drone. He reflected this relationship in his interviews, explaining that in order to move laterally, he needed to consistently be mindful of the *"separation between my hands, number one, and also the separation between myself and the drone."*

*Nora's Story – Familiar and unfamiliar:* Nora's habitual way of moving with her drone was fluid and carefree. When Nora tried to fly with Justin's drone, however, this less manoeuvrable drone would not respond to her. Encountering this estrangement, Nora reassessed her ways of moving, and gradually adopted a weight shifting technique to move the drone laterally. She even had to pay attention to her breathing, as a deep breath could cause her hands to drift from the active position. Eventually, Nora locked her hands at the wrists which stabilised her hands and made it easier to manoeuvre Justin's drone. Nora, then, carried these new movements back to flying with her own drone, using this position to vigorously bounce her drone up and down in the manner that eventually flowed into a ballet-like performance.

*Fourth Extension:* Soma design practice centres on the bodily experience as our primary sense-making modality [51, 97]. Recent work has shown that somatic engagement can be a fruitful path towards "learning" about a complex system. Sondoqah and colleagues demonstrate how intimate, bodily interactions can complement technical prowess in more precisely probing, understanding, and determining the capabilities of a technology such as a drone [110]. We observed a similar understanding in Justin's relationship with his drone: though he was never shown the complete "inner workings" of the HTTYD system, he discovered and reflected to the researchers on tiny technical aspects of the system, such as the inconsistent calibration of tracked space, training times, and flight dynamics. In a similar vein, mechanical sympathy complements a somatic approach to learning about machines, alongside mechanical or technical learning. Further, from HTTYD, we have learned that designing for perception and action sequences – encouraging movement and action as the primary sense-making modality – can be a productive strategy to help foster mechanical sympathy.

## 5.3 Aesthetics Pursuits

The third quality of mechanical sympathy is that of aesthetic pursuits, namely that the relationship with the machine evolves into one that is aesthetically rich and experientially meaningful [24]. Through cultivating mechanical sympathy, each co-creator developed a sensibility towards what they found desirable to experience [37]. This ongoing process of sensemaking prompted the articulation of their aesthetic desires or tacit self-knowledge, and, ultimately, this encouraged reflection on what they found meaningful and fulfilling in their experiences. This reflective process prompted Nora, Justin, and Tom to articulate their meaning-making with the system [102]. They often expressed their explorations using rich, anthropomorphic, metaphorical, or analogous descriptions. Tom used the analogy of poetry to describe his bodily creativity within the limitations imposed by the drone: "*I was trying to minimize the number of points I made because otherwise I think it would remove this interesting constraint from the whole thing which is like trying to lock into these patterns and these paths. If you just had points absolutely everywhere, that would be sort of boring to me, like free form poetry. You have the whole world available to you, so, it is very hard to make a decision about which thing to use, as opposed to when you are constrained by the form can be very creative in that form.*" Nora anthropomorphized the drone as a means of allowing it to participate in her creative process. She reflected on her experience of the drone shifting from being "*an object, to being something that has a personality* while she became "*more familiar [with it] and then being more confident [with it] over time, which then gave me more creative freedom.*" Justin conjured poetic, metaphorical interpretations of the relationships between his felt experiences and the technical parameters of the system: *This is now how I visualize the drone – a mossy stone that is shaped by water flowing over it. The water being like the cascading movements that I make with my hands. And that it is shaped by them. I also feel as if I am made of moss as I enter a really peaceful state of feeling like I am organically interacting with something.* Their articulations shed light on their meaning-making processes with the system and unique forms of appreciation, that is, how they cultivated a relationship with the drone, shaped by their lived experiences, interests, values, and desires [75, 85].

*Designing to support aesthetic pursuits:* This is perhaps the most nebulous quality for which to design. Aesthetic appreciation (appreciating what it means to live well) does not simply emerge from repeated engagement but requires aesthetic willingness. HTTYD is an interaction that requested much from our co-creators, probing the boundaries between designer and user by asking them to put considerable work, effort, and care into the technology before they could uncover the richness of the system. According to Schön, this willingness is critical to meaningful experience: "*I can tell you that there is something you need to know, and with my help you may be able to learn it. But I cannot tell you what it is in a way you can now understand. I can only arrange for you to have the right sorts of experiences for yourself. You must be willing, therefore, to have these experiences*" [95, p. 93]. How we "arranged" a system like HTTYD to offer the "right sorts of experiences" is hard to summarise in a few simple design choices. However, we engaged deeply with the somatic experiences that prompted curiosity and reflection [51], and took care to keep the interaction ambiguous and open-ended [38], which made space for the co-creators to decide what they desired to do. In each story, we find examples not only of our co-creators engaging with the drone in ways that brought meaning and pleasure, but also deeper reflection on ways of living that held meaning and value to them.

*Tom's Story:* Tom's relationship with the drone evolved through purposefulness and premeditation. Tom somatically sensitized himself to his drone, meticulously exploring the different movement possibilities available to him while holding a position. Tom viewed the limitations of the system as adding needed challenge and reward to his experience; having too many possibilities available to him removed the challenge of being creative within boundaries. Tom came to a greater appreciation of how the drone shaped his movements than he had expected. At the end of the study, Tom pondered on the experiences that he might be missing because of his methodical and narrow approach to exploring the system.

*Justin's Story:* Justin's relationship with his drone evolved through highly coordinated movement and playful tomfoolery. He slowly became sensitized to the limited manoeuvrability of his drone, which invited him to re-sensitize himself towards his own movements. In this way, he became somatically aware of his and his drone's capabilities and reconfigured the boundaries of moving together, moving his body in different ways to compensate for the limitations of the drone. Justin eventually stopped trying to force the drone to move and allowed a mutual shaping between himself and the drone. Towards the end of the study, he engaged with the drone in a humorous and absurd manner, moving in nonsensical "locked-limb" poses (to the amusement of his housemates and researchers). Justin also came to appreciate how the drone had changed him, allowing him to move in slower, more thoughtful ways than he usually engaged, explaining how the system made different experiences available to him by forcing him away from his self-confessed fast-paced ways of being and doing.

*Nora's Story:* Nora's relationship with her drone evolved subversive play, performativity, and dance. Nora probed the limitations of the drone – trying to uncover different ways of tricking the system – as opportunities for creative expression. She allowed for the connection between her and her drone to be broken, letting the drone spin alone whilst she danced around it. This allowed the drone to fuel her creative process. In one session, the housemates placed "stage curtains" on each side of the researcher's video camera. The curtains drew apart to reveal Nora standing with the drone held at chest height while tinny applause rang out from a nearby speaker. As the melody of "Dance of the Sugar Plum Fairy" began to play, Nora lifted the drone high above her head and it broke free from her hands, spinning in place. Nora spun gracefully beneath the drone. She then leapt to retrieve the drone, in time with the music, bringing the drone down whilst smoothly dropping to her knees. Nora continued to break and reconnect with the drone rhythmically for the duration of the two-and-a-half-minute performance, whilst Justin made a cameo as a comedic sugar plum fairy, sprinting across the "stage" before leaping out of frame. At the end of the study, Nora spoke about how she found joy in performing and how a playful learning experience offered her a kind of exploration that she had not engaged in since she was child.

*Fifth Extension.* The ultimate goal of somaesthetics – the philosophical project drawn on by soma design – is that of somaesthetic appreciation and self-stylization [105]. Through enhancing our capacity for somaesthetic appreciation [104], we can enhance our capacity for experience. Subsequently, one will develop richer perceptions, sensations, judgements, and feelings – all of which open new meaning-making possibilities and aspirations for how one might desire to live. Shusterman roots this meliorative process in the body, and, therefore, a matter of deep somatic engagement [103]. By adopting a relational perspective, mechanical sympathy offers soma design a way to cultivate meaningful somaesthetic relationships with machines. Mechanical sympathy advocates cultivating the soma, not only as a tool for appreciating the world [104], but as a constitutive part of a human–machine entanglement, that is, seeking methods to somatically experience ourselves and our technologies as interconnected and transformative [123], and the role we play together in cultivating meaningful and fulfilling human–machine relationships. From HTTYD, we have learned that – though fostering aesthetic willingness is difficult – leaving room for the machine to play an active role in shaping somaesthetic experience can be a fruitful strategy to foster mechanical sympathy.

## 6 GROUNDING HORIZONTALLY

Finally, we ground the qualities and design strategies for mechanical sympathy in a selection of other works from across the HCI community: the Very Nervous System [89], Freaky [67], Suspended Circles [5], and Metaphone [106]. We have chosen these as illustrative examples to demonstrate mechanical sympathy with a variety of machines and machine-like interactive systems beyond drones.

*Very Nervous System.* An exemplative account of mechanical sympathy can be found in David Rokeby's *Very Nervous System*. Very Nervous System was an installation that employed video cameras, an artificial perception system, and a synthetiser to translate body movements into sound in real-time [89]. Rokeby spent a considerable amount of time – 18 to 20 hours a day – iteratively refining the installation, using his own body movement to develop the system. He recounts: "*After setting up my installation in Vancouver, I was astonished by the fact that it did not seem to respond properly to other people, and sometimes didn't notice people at all. I didn't really understand the problem until I saw videotape of myself moving in the installation. I was moving in a completely unusual and unnatural way, full of jerky tense motions which I found both humorous and distressing. In my isolation, rather than developing an interface that understood movement, I'd evolved with the interface, developing a way of moving that the interface understood as I developed the interface itself*" [90, p.3]. This account succinctly captures the qualities of machine-agency; namely how the capabilities and limitations of the system evolved alongside Rokeby as he shaped the system; the gradual change that cumulatively evolves into a unique human–machine relationship; and the stark differences that emerge when others attempted to interact with the system.

*Freaky.* Other accounts are found in Leahu and Sengers's *Freaky*, an artificial companion attached to one's chest. The system was trained to monitor a user's heart rate and to "freak out" if it perceived them to be experiencing "fear" by beginning to vibrate and emit intensified sounds [67]. After Freaky reacted to one participant, Uma, meeting a friend, she reflected "*I remember thinking when I saw him that I wouldn't want it to go off right then. But it did. And then I got really excited thinking that it picked up the emotional substrate of that encounter: I was exposed emotionally before saying anything. It [Freaky] participated in the encounter. But it wasn't clear what it was [picking up on]. Probably excitement*" [67, p. 614]. Another participant, Max, found that Freaky prompted them to reflect on why he was having a strong emotional reaction, with the system contributing to his making sense of and reconciling previous experiences [67, p.614]. Further, according to participant C, Freaky "*act[ed] as a surface on which to project our needs, fears, aspirations, rewards. It almost feels like therapy: you work with mind objects, but in an embodied kind of way… Isn't that like transference? Is there a word for transference to machines?*" [67, p. 615]. In these reflections, we see a process of oscillation as Uma switches between her own perspective and the alternative perspective of the technology. This process of somatic sense-making – invited by Freaky – fosters reflection on the participants' personal experiences, opening space to consider aesthetic pursuits, i.e., alternative or more enriched ways of living .

*Suspended Circles.* We also see resonances with mechanical sympathy in *Suspended Circles* [5]. Through soma design and Dalcroze eurhythmics, Bang and Fdili Alaoui developed an embodied musical instrument that invites musicians to experience music as movement [5]. We find this work evocative as, though the authors' personal experiences of Dalcroze eurhythmics drove the design process, the instrument still left space for other practitioners to pursue their own aesthetic interests with the instrument. Further, the authors discovered a mutual relationality that emerged between the participants and the system where the instrument played a collaborative role in choreographing the movements of the participants, as a partner more than a tool, "*the participants were often moving around the instrument, in the circular space delimited around it, and building exercises that took advantage of that circularity. The instrument stood insular, in the middle, with the participants moving around it in a way that suggested it being another separate body, as expressed through the 'otherness' or mysteriousness brought up by the participants*" [5, p.9]. With other participants, they observed "*the instrument moulding the musicians' bodies, and that in turn the musicians moulded the instrument to their creative ideas*" [5]. Here, we see mechanical sympathy reflected in the emergence of creative, aesthetic pursuits in the relationships between dancer and instrument wherein individual meaning-making was fostered.

*Metaphone.* Finally, we see mechanical sympathy reflected in the distinct aesthetics of *Metaphone*. Metaphone, by Šimbelis and colleagues, is an interactive art piece that employs an actuating arm to draw mandalas using biodata input [106]. Drawing on perspectives from mechanical art – in which bodies and forces aggregate so that no meaningful differentiation can be made between human and machine agency – Metaphone actively explores a machine's aesthetic potential as a co-creator or actor rather than a tool [106]. "*I remember becoming involved in the way the red colour spread out and how I started to become conscious of how my actions might be affecting the way the pattern was progressing. Oddly enough I was not actively thinking of how I could control the painting when I did things. I was more spontaneously interacting with the movement of the instrument and then later transforming the sound*" [106, p.7]. Here, we again see machine-agency foregrounded explicitly in the positioning of Metaphone as a co-creator rather than a tool, and how this, in turn, led to mutually-shaped aesthetic outcomes characteristic of mechanical sympathy.

In these examples, we see similarities in the blurring of boundaries between human and machine – through art, dance, and other creative expressions. Therein, we also see the emergence of new possibilities for appreciative relationships with machines. We consider our focus on the aesthetics of such interactions as entangled with questions of what futures our technologies should support; that technologies can bring about ways of living that hold not only aesthetic but also ethical value [37]. Though not part of this enquiry, we see connections to approaches that seek to problematize and unpack our current conceptions of agency, embodiment, and material practices, and whether our research and practices support our desired technological futures [39, 123]. These represent potentially fruitful avenues of future enquiry to connect our design concept of mechanical sympathy to deeper, relational understandings of ethics in human–technology relations (i.e., alternative ways in which we can be in the world with technologies). Further, we see synergies with explorations within HRI and evolutionary robotics (e.g., [1]), where there is an interest in different ways robots can be trained or even learn to move on their own. We speculate that mechanical sympathy as a design concept could support a generative design approach in these spaces [60, 63].

## 7 SUMMARY AND CONCLUSION

We have articulated the qualities of mechanical sympathy using the case of the research product *How to Train your Drone*. We have unpacked each quality, detailing how each was intentionally or unintentionally designed for, how each was encountered in the system, and how each can extend soma design practice. Further, we have grounded the concept in similar and tangential works. To reiterate our contribution, we offer the following summary (as well as Figure 8). We do not claim this is an exhaustive list of every possible quality of mechanical sympathy, rather these are the qualities most apparent from our design case.

*Mechanical Sympathy.* is a process that leads to a cumulative appreciation of a machine; a synergy with, or bodily understanding that someone can develop of, a machine that mutually shapes how the two can act together. It can be a useful and generative design concept when designing for deep somaesthetic relationships with machines.

*Three Qualities of Mechanical Sympathy.*

(1) **Machine-Agency:** a machine's capacity to mutually shape the person engaging with them. This invites one to:
   (a) Cultivate a somatic sensitization and responsivity towards the capabilities and limitations of a machine, allowing for the deconstruction and reconfiguration of the different possibilities for interaction – which can be stimulated by purposefully accentuating a machine's capabilities and limitations.
   (b) Appreciate gradual changes to the machine, allowing for an evolving, temporal, and singular relationship – which can be encouraged by explicitly enabling someone to shape a machine.
   (c) Appreciate the differences between machines, allowing for an enhanced appreciation of the unique qualities of a machine relationship – which can be invited by supporting such differences to manifest and be explored.
(2) **Oscillations:** perception-action sequences that characterise the process of coming to somatically appreciate a machine - which can be supported by encouraging movement and action as the primary sense-making modality.
(3) **Aesthetic Pursuits:** the relationship with the machine evolves into one that is aesthetically rich and experientially meaningful. We have observed that such relationships emerge when space is left for a machine to play a role as an active socio-digital material.

*Five Extensions of Soma Design to Human–Machine Relationships:*

(1) conceptualising, engaging with and designing for appreciative relationships with machines.
(2) considering the temporal, somatic relationship between a person and a machine.
(3) considering individual machines as distinctive and idiosyncratic socio-digital design materials.
(4) complementing a somatic approach to learning about machines, alongside mechanical or technical learning.
(5) cultivating meaningful somaesthetic relationships with machines.


**Figure 8: Towards bridging somatic understanding and technical learning about machines: An overview of mechanical sympathy, framed as an extension of the soma design program towards human-machine interaction.**

Ståhl and colleagues have shown how long-term engagement with rigorously crafted somaesthetic design can offer transformative or "world-making" experiences [113]. We envision mechanical sympathy as a similarly transformative design concept, supporting these transformative reflections by providing the "scaffolding" to move from reflection on meaningfulness and value towards meliorative improvement [96, 107], or, in other words, supporting our co-creators to actively practice and cultivate these new uncovered values. This is, we argue, of great import in our current technological landscape, where we are increasingly entangled with machines, as well as other forms of technology. Mechanical sympathy can serve to, not only better articulate our experiences with technologies, but probe the shift towards a more relational understanding of ourselves and our technologies [123]. By attending to how humans and machines are interconnected and transformative, it is possible for designers to rethink our practice and how we design for meaningful human–machine relationships.

## ACKNOWLEDGMENTS

We would like to thank Justin, Nora, and Tom for participating in the study and congratulate Nora and Justin on their recent marriage! We also acknowledge those who helped in the technical implementation of the system including: Tim Fist, Nick Huppert, Kristoffer Richardsson, Tobias Antonsson, Sam Nolan, Michael Smith, Ben Koder, Robert Jarvis, and Stuart Lee. We also thank Catherine Fist who collected some additional interview data and Ian Peake who offered his lab space to develop this project during the pandemic. Finally we would like to thank Joseph's supervision team; Floyd Mueller and Leah Heiss for their invaluable input and feedback.
This research was conducted across; RMIT University, Melbourne, Australia; KTH Royal Institute of Technology, Stockholm, Sweden; and Stockholm University, Stockholm, Sweden.
This research is supported by; The Digital Futures Drone Arena, a Digital Futures Demonstrator Project at the Department of Computer and Systems Sciences at Stockholm University and The Connected Intelligence Unit at Research Institutes of Sweden (RISE); The Swedish foundation for Strategic Research (SSF) project CHI19-0034 Hardware for Energy Efficient Bodynets; and the Wallenberg AI, Autonomous Systems and Software Program – Humanity and Society (WASP-HS) through a Marianne and Marcus Wallenberg Foundation project MMW 2019.0228; This work was partially supported by the Wallenberg Al, Autonomous Systems and Software Program (WASP) funded by the Knut and Alice Wallenberg Foundation; The Australian Government Research Training Program (type RSS).
The title font in figure 8 is dronefly.

## REFERENCES

[1] 2023. *GECCO '23 Companion: Proceedings of the Companion Conference on Genetic and Evolutionary Computation* (Lisbon, Portugal). Association for Computing Machinery, New York, NY, USA.

[2] Naoko Abe. 2022. Beyond anthropomorphising robot motion and towards robot-specific motion: consideration of the potential of artist—dancers in research on robotic motion. *Artificial Life and Robotics* 27, 4 (01 Nov 2022), 777–785. https://doi.org/10.1007/s10015-022-00808-0

[3] Parastoo Abtahi, David Y Zhao, Jane L E, and James A Landay. 2017. Drone near me: Exploring touch-based human-drone interaction. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (2017), 1–8.

[4] Stephanie Arevalo Arboleda, Max Pascher, Annalies Baumeister, Barbara Klein, and Jens Gerken. 2021. Reflecting upon Participatory Design in Human-Robot Collaboration for People with Motor Disabilities: Challenges and Lessons Learned from Three Multiyear Projects. In *Proceedings of the 14th PErvasive Technologies Related to Assistive Environments Conference (PETRA '21)*. Association for Computing Machinery, New York, NY, USA, 147–155. https://doi.org/10.1145/3453892.3458044

[5] Tove Grimstad Bang and Sarah Fdili Alaoui. 2023. Suspended Circles: Soma Designing a Musical Instrument. In *Proceedings of the 2023 CHI Conference on*

*Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 687, 15 pages. https://doi.org/10.1145/3544548.3581488

[6] Karen Barad. 2007. Meeting the universe halfway. In *Meeting the universe halfway*. duke university Press.

[7] Jeffrey Bardzell and Shaowen Bardzell. 2016. *Humanistic HCI*. Vol. 23. Association for Computing Machinery, New York, NY, USA. 20–29 pages. https://doi.org/10.1145/2888576

[8] Mehmet Aydin Baytas, Damla Çay, Yuchong Zhang, Mohammad Obaid, Asim Evren Yantaç, and Morten Fjeld. 2019. The Design of Social Drones: A Review of Studies on Autonomous Flyers in Inhabited Environments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300480

[9] Genevieve Bell, Mark Blythe, and Phoebe Sengers. 2005. Making by making strange: Defamiliarization and the design of domestic technologies. *ACM Transactions on Computer-Human Interaction (TOCHI)* 12, 2 (2005), 149–173.

[10] Cynthia L. Bennett and Daniela K. Rosner. 2019. The Promise of Empathy: Design, Disability, and Knowing the "Other". In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300528

[11] Jane Bennett. 2010. *Vibrant matter: A political ecology of things*. Duke University Press.

[12] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa arXiv:https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp063oa

[13] Jessica R Cauchard, Jane L E, Kevin Y Zhai, and James A Landay. 2015. Drone & me: an exploration into natural human-drone interaction. In *Proceedings of the 2015 ACM international joint conference on pervasive and ubiquitous computing*. 361–365.

[14] S. Chetty and P. Lakshmi. 1991. Computer Aided Evaluation of Aircraft Handling Qualities. *IFAC Proceedings Volumes* 24, 4 (July 1991), 435–440. https://doi.org/10.1016/S1474-6670(17)54311-6

[15] Meia Chita-Tegmark, Theresa Law, Nicholas Rabb, and Matthias Scheutz. 2021. Can you trust your trust measure?. In *Proceedings of the 2021 ACM/IEEE international conference on human-robot interaction*. 92–100.

[16] Bohkyung Chun and Heather Knight. 2020. The robot makers: An ethnography of anthropomorphism at a robotics company. *ACM Transactions on Human-Robot Interaction (THRI)* 9, 3 (2020), 1–36.

[17] Karen Anne Cochrane, Kristina Mah, Anna Ståhl, Claudia Núñez-Pacheco, Madeline Balaam, Naseem Ahmadpour, and Lian Loke. 2022. Body Maps: A Generative Tool for Soma-based Design. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3490149.3502262

[18] G. E. Cooper and R. P. Harper. 1969. The use of pilot rating in the evaluation of aircraft handling qualities. (April 1969). https://ntrs.nasa.gov/citations/19690013177

[19] Emily S. Cross and Richard Ramsey. 2021. Mind Meets Machine: Towards a Cognitive Science of Human–Machine Interactions. *Trends in Cognitive Sciences* 25, 3 (March 2021), 200–212. https://doi.org/10.1016/j.tics.2020.11.009

[20] Ian de Vere, Gavin Melles, and Ajay Kapoor. 2010. Product design engineering – a global education trend in multidisciplinary training for creative product design. *European Journal of Engineering Education* 35, 1 (2010), 33–43. https://doi.org/10.1080/03043790903312154 arXiv:https://doi.org/10.1080/03043790903312154

[21] Joseph La Delfa. 2024. crazyflie-clients-python. https://github.com/cafeciaojoe/crazyflie-clients-python/tree/HTTYD_crazyflie_pull

[22] Joseph La Delfa. 2024. crazyflie-firmware. https://github.com/cafeciaojoe/crazyflie-firmware/tree/User_Study_Hand_Pads

[23] Andrew Denton. 2003. *Enough Rope with Andrew Denton - Interview with Peter Brock*. Australian Broadcasting Corporation. https://www.youtube.com/watch?v=AfSucm8neTc Accessed: September 7, 2023.

[24] J. Dewey. 2005. *Art as Experience*. Penguin Publishing Group. https://books.google.se/books?id=aAbqAGo5MwwC

[25] Stuart E Dreyfus and Hubert L Dreyfus. 1980. A five-stage model of the mental activities involved in directed skill acquisition.

[26] Sara Eriksson, Kristina Höök, Richard Shusterman, Dag Svanes, Carl Unander-Scharin, and Åsa Unander-Scharin. 2020. *Ethics in Movement: Shaping and Being Shaped in Human-Drone Interaction*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376678

[27] Sara Eriksson, Åsa Unander-Scharin, Vincent Trichon, Carl Unander-Scharin, Hedvig Kjellström, and Kristina Höök. 2019. Dancing with drones: Crafting novel artistic expressions through intercorporeality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–12.

[28] Daniel Fallman and Erik Stolterman. 2010. Establishing criteria of rigour and relevance in interaction design research. *Digital Creativity* 21, 4 (2010), 265–272.

[29] Mosh'e Feldenkrais. 1972. *Awareness through movement: health exercises for personal growth* (1st ed. ed.). Harper & Row, New York.

[30] Julia Fink, Valérie Bauwens, Frédéric Kaplan, and Pierre Dillenbourg. 2013. Living with a vacuum cleaning robot: A 6-month ethnographic study. *International Journal of Social Robotics* 5 (2013), 389–408.

[31] Jodi Forlizzi. 2007. How robotic products become social products: an ethnographic study of cleaning in the home. In *Proceedings of the ACM/IEEE international conference on Human-robot interaction*. 129–136.

[32] Christopher Frauenberger. 2019. Entanglement HCI The Next Wave? *ACM Trans. Comput.-Hum. Interact.* 27, 1, Article 2 (nov 2019), 27 pages. https://doi.org/10.1145/3364998

[33] Mafalda Gamboa. 2022. Living with Drones, Robots, and Young Children: Informing Research through Design with Autoethnography. In *Nordic Human-Computer Interaction Conference*. 1–14.

[34] Mafalda Gamboa, Mehmet Aydın Baytaş, Sjoerd Hendriks, and Sara Ljungblad. 2023. Wisp: Drones as Companions for Breathing. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction*. 1–16.

[35] Mafalda Gamboa, Sara Ljungblad, Wafa Johal, Omar Mubin, and Mohammad Obaid. 2023. Championing Design Knowledge in Human-Drone Interaction Research. In *Proceedings of the 11th International Conference on Human-Agent Interaction*. 365–368.

[36] Mafalda Gamboa, Mohammad Obaid, and Sara Ljungblad. 2021. Ritual Drones: Designing and Studying Critical Flying Companions. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 562–564.

[37] Rachael Garrett, Kristina Popova, Claudia Núñez-Pacheco, Thórhildur Ásgeirsdóttir, Airi Lampinen, and Kristina Höök. 2023. Felt Ethics: Cultivating Ethical Sensibility in Design Practice. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–15.

[38] William W Gaver, Jacob Beaver, and Steve Benford. 2003. Ambiguity as a resource for design. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 233–240.

[39] Petra Gemeinboeck and Rob Saunders. 2023. Dancing with the Nonhuman: A Feminist, Embodied, Material Inquiry into the Making of Human-Robot Relationships. In *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, Stockholm Sweden, 51–59. https://doi.org/10.1145/3568294.3580036

[40] Robert P. Harper and George E. Cooper. 1986. Handling qualities and pilot evaluation. *Journal of Guidance, Control, and Dynamics* 9, 5 (Sept. 1986), 515–529. https://doi.org/10.2514/3.20142

[41] Sabrina Hauser, Doenja Oogjes, Ron Wakkary, and Peter-Paul Verbeek. 2018. An annotated portfolio on doing postphenomenology through research products. In *Proceedings of the 2018 designing interactive systems conference*. 459–471.

[42] Sabrina Hauser, Ron Wakkary, William Odom, Peter-Paul Verbeek, Audrey Desjardins, Henry Lin, Matthew Dalton, Markus Schilling, and Gijs De Boer. 2018. Deployments of the table-non-table: A Reflection on the Relation Between Theory and Things in the Practice of Design Research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.

[43] V. Herdel, A. Kuzminykh, Y. Parmet, and J. R. Cauchard. 2022. Anthropomorphism and Affective Perception: Dimensions, Measurements, and Interdependencies in Aerial Robotics. *IEEE Transactions on Affective Computing* 01 (jan 2022), 1–12. https://doi.org/10.1109/TAFFC.2024.3349858

[44] Viviane Herdel, Lee J. Yamin, and Jessica R. Cauchard. 2022. Above and Beyond: A Scoping Review of Domains and Applications for Human-Drone Interaction. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–22. https://doi.org/10.1145/3491102.3501881

[45] Mads Hobye and Jonas Löwgren. 2011. Touching a Stranger: Designing for Engaging Experience in Embodied Interaction. *International Journal of Design; Vol 5, No 3 (2011)* (2011 2011). http://www.ijdesign.org/index.php/IJDesign/article/view/976

[46] Nicola J Hodges and A Mark Williams. 2012. Skill acquisition in sport: Research, theory and practice. (2012).

[47] Erik Holinagel. 1999. Modelling the controller of a process. *Transactions of the Institute of Measurement and Control* 21, 4-5 (Oct. 1999), 163–170. https://doi.org/10.1177/014233129902100404

[48] Erik Hollnagel. 2011. The Diminishing Relevance of Human-Machine Interaction. In *The Handbook of Human-Machine Interaction*. CRC Press.

[49] Erik Hollnagel and David D. Woods. 2005. *Joint Cognitive Systems: Foundations of Cognitive Systems Engineering* (0 ed.). CRC Press. https://doi.org/10.1201/9781420038194

[50] Kristina Höök. 2010. Transferring Qualities from Horseback Riding to Design. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries* (Reykjavik, Iceland) *(NordiCHI '10)*. Association for Computing Machinery, New York, NY, USA, 226–235. https://doi.org/10.1145/1868914.1868943

[51] Kristina Höök. 2018. *Designing with the body: somaesthetic interaction design*. MIT Press, Cambridge, Massachusetts. https://mitpress.mit.edu/9780262038560/designing-with-the-body/

[52] Kristina Höök, Steve Benford, Paul Tennent, Vasiliki Tsaknaki, Miquel Alfaras, Juan Martinez Avila, Christine Li, Joseph Marshall, Claudia Daudén Roquet, Pedro Sanches, et al. 2021. Unpacking Non-Dualistic Design: The Soma Design Case. *ACM Transactions on Computer-Human Interaction (TOCHI)* 28, 6 (2021), 1–36.

[53] Kristina Höök, Martin P Jonsson, Anna Ståhl, and Johanna Mercurio. 2016. Somaesthetic appreciation design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 3131–3142.

[54] Kristina Höök and Jonas Löwgren. 2012. Strong concepts: Intermediate-level knowledge in interaction design research. *ACM Transactions on Computer-Human Interaction (TOCHI)* 19, 3 (2012), 1–18.

[55] Richard J. Jagacinski and John Flach. 2003. *Control theory for humans: quantitative approaches to modeling performance*. L. Erlbaum Associates, Mahwah, N.J.

[56] Annkatrin Jung, Miquel Alfaras, Pavel Karpashevich, William Primett, and Kristina Höök. 2021. Exploring Awareness of Breathing through Deep Touch Pressure. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–15.

[57] Malte F Jung. 2017. Affective grounding in human-robot interaction. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. 263–273.

[58] Pavel Karpashevich, Pedro Sanches, Rachael Garrett, Yoav Luft, Kelsey Cotton, Vasiliki Tsaknaki, and Kristina Höök. 2022. Touching our breathing through shape-change: Monster, organic other, or twisted mirror. *ACM Transactions on Computer-Human Interaction (TOCHI)* 29, 3 (2022), 1–40.

[59] George Khut. 2006. Development and evaluation of participant-centred biofeedback artworks. *Unpublished doctoral exegesis, University of Western Sydney* (2006).

[60] Joseph La Delfa. 2023. *Cultivating Mechanical Sympathy: Making meaning with ambiguous machines*. Ph. D. Dissertation. KTH Royal Institute of Technology.

[61] Joseph La Delfa, Mehmet Aydin Baytaş, Emma Luke, Ben Koder, and Florian 'Floyd' Mueller. 2020. *Designing Drone Chi: Unpacking the Thinking and Making of Somaesthetic Human-Drone Interaction*. Association for Computing Machinery, New York, NY, USA, 575–586. https://doi.org/10.1145/3357236.3395589

[62] Joseph La Delfa, Mehmet Aydin Baytas, Rakesh Patibanda, Hazel Ngari, Rohit Ashok Khot, and Florian 'Floyd' Mueller. 2020. *Drone Chi: Somaesthetic Human-Drone Interaction*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376786

[63] Joseph La Delfa, Rachael Garrett, Airi Lampinen, and Kristina Höök. 2024. How to Train Your Drone - Exploring the umwelt as a design metaphor for human-drone interaction. In *Proceedings of the 2024 Conference on Designing Interactive Systems*. 1–14. https://doi.org/10.1145/3643834.3660737

[64] Joseph La Delfa, Robert Jarvis, Rohit Ashok Khot, and Florian 'Floyd' Mueller. 2018. Tai Chi In The Clouds: Using Micro UAV's To Support Tai Chi Practice. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts* (Melbourne, VIC, Australia) *(CHI PLAY '18 Extended Abstracts)*. Association for Computing Machinery, New York, NY, USA, 513–519. https://doi.org/10.1145/3270316.3271511

[65] Przemyslaw A Lasota, Terrence Fong, Julie A Shah, et al. 2017. A survey of methods for safe human-robot interaction. *Foundations and Trends® in Robotics* 5, 4 (2017), 261–349.

[66] Theresa Law and Matthias Scheutz. 2021. Trust: Recent concepts and evaluations in human-robot interaction. *Trust in human-robot interaction* (2021), 27–57.

[67] Lucian Leahu and Phoebe Sengers. 2014. Freaky: performing hybrid human-machine emotion. In *Proceedings of the 2014 conference on Designing interactive systems*. 607–616.

[68] Min Kyung Lee, Jodi Forlizzi, Paul E Rybski, Frederick Crabbe, Wayne Chung, Josh Finkle, Eric Glaser, and Sara Kiesler. 2009. The snackbot: documenting the design of a robot for long-term human-robot interaction. In *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*. 7–14.

[69] Lian Loke and Toni Robertson. 2013. Moving and making strange: An embodied approach to movement-based interaction design. *ACM Transactions on Computer-Human Interaction (TOCHI)* 20, 1 (2013), 1–25.

[70] Jonas Löwgren. 2013. Annotated Portfolios and Other Forms of Intermediate-Level Knowledge. *Interactions* 20, 1 (jan 2013), 30–34. https://doi.org/10.1145/2405716.2405725

[71] Yoav Luft, Pavel Karpashevich, and Kristina Höök. 2023. Boards Hit Back: Reflecting on Martial Arts Practices Through Soma Design. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 683, 18 pages. https://doi.org/10.1145/3544548.3580722

[72] A.M. Mackey, R.L. Wakkary, S.A.G. Wensveen, O. Tomico Plasencia, and B.J. Hengeveld. 2017. Day-to-day speculation: designing and wearing dynamic fabric. In *RTD2017 : proceedings of the 3rd Biennial Research through Design Conference,22-24 March 2017, Edinburgh, UK*. 439–454. RTD2017, 3rd Biannial Conference on Research through Design, 22-24 March 2017, Edinburgh, UK, RTD2017 ; Conference date: 22-03-2017 Through 24-03-2017.

[73] Elena Márquez Segura, Laia Turmo Vidal, Asreen Rostami, and Annika Waern. 2016. Embodied sketching. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 6014–6027.

[74] Lynn McAlpine. 2016. Why might you use narrative methodology? A story about narrative. *Eesti Haridusteaduste Ajakiri. Estonian Journal of Education* 4, 1 (2016), 32–57.

[75] John McCarthy and Peter Wright. 2004. *Technology as experience*. MIT Press, Cambridge, Massachusetts.

[76] D.T. McRuer and H.R. Jex. 1967. A Review of Quasi-Linear Pilot Models. *IEEE Transactions on Human Factors in Electronics* HFE-8, 3 (Sept. 1967), 231–249. https://doi.org/10.1109/THFE.1967.234304

[77] Maurice Merleau-Ponty. 1965. Phenomenology of perception. *Translated by Colin Smith. New* (1965).

[78] Elena Márquez Segura, Laia Turmo Vidal, and Asreen Rostami. 2016. Bodystorming for movement-based interaction design. *Human Technology* 12, 2 (Nov. 2016), 193–251. https://doi.org/10.17011/ht/urn.201611174655

[79] Aishath Nasheeda, Haslinda Binti Abdullah, Steven Eric Krauss, and Nobaya Binti Ahmed. 2019. Transforming transcripts into stories: A multimethod approach to narrative analysis. *International Journal of Qualitative Methods* 18 (2019), 1609406919856797.

[80] A. Newey. 2017. *How to Build a Car*. HarperCollins Publishers Limited. https://books.google.se/books?id=Sm3NAQAACAAJ

[81] Claudia Nunez-Pacheco and Lian Loke. 2014. Crafting the body-tool: a body-centred perspective on wearable technology. In *Proceedings of the 2014 conference on Designing interactive systems*. 553–566.

[82] William Odom, Ron Wakkary, Youn-kyung Lim, Audrey Desjardins, Bart Hengeveld, and Richard Banks. 2016. From Research Prototype to Research Product. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 2549–2561. https://doi.org/10.1145/2858036.2858447

[83] Linda Onnasch and Eileen Roesler. 2021. A Taxonomy to Structure and Analyze Human–Robot Interaction. *International Journal of Social Robotics* 13, 4 (July 2021), 833–849. https://doi.org/10.1007/s12369-020-00666-5

[84] Lachlan Palmer. 2021. What Is Mechanical Sympathy And Why Should Every New Driver Learn About It? https://www.kashy.com.au/post/what-is-mechanical-sympathy-and-why-should-every-new-driver-learn-about-it

[85] Marianne Graves Petersen, Ole Sejer Iversen, Peter Gall Krogh, and Martin Ludvigsen. 2004. Aesthetic interaction: a pragmatist's aesthetics of interactive systems. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*. 269–276.

[86] William T. Powers. 1973. *Behavior: the control of perception*. Aldine Pub. Co, Chicago.

[87] Susanne Ravn. 2022. Embodied Learning in Physical Activity: Developing Skills and Attunement to Interaction. *Frontiers in Sports and Active Living* 4 (2022). https://www.frontiersin.org/articles/10.3389/fspor.2022.795733

[88] Johan Redström. 2017. *Making design theory*. MIT Press, Cambridge, Massachusetts.

[89] David Rokeby. 1995. Very Nervous System (VNS).

[90] David Rokeby. 1998. The construction of experience: Interface as content. *Digital Illusion: Entertaining the future with high technology* 27 (1998), 47.

[91] Robert Rosenberger and Peter-Paul Verbeek. 2015. A field guide to postphenomenology. *Postphenomenological investigations: Essays on human-technology relations* (2015), 9–41.

[92] Stuart Russell and Peter Norvig. 2009. *Artificial Intelligence: A Modern Approach* (3rd ed.). Prentice Hall Press, USA.

[93] Eleanor Sandry. 2015. Re-evaluating the Form and Communication of Social Robots - The Benefits of Collaborating with Machinelike Robots. *Int. J. Soc. Robotics* 7, 3 (2015), 335–346. https://doi.org/10.1007/s12369-014-0278-3

[94] Thecla Schiphorst. 2011. Self-Evidence: Applying Somatic Connoisseurship to Experience Design. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI EA '11)*. Association for Computing Machinery, New York, NY, USA, 145–160. https://doi.org/10.1145/1979742.1979640

[95] Donald A Schön. 1987. *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*. Jossey-Bass.

[96] Donald A Schön. 2017. *The reflective practitioner: How professionals think in action*. Routledge.

[97] M. Sheets-Johnstone. 2011. *The Primacy of Movement: Expanded second edition*. John Benjamins Publishing Company. https://books.google.se/books?id=xZa85IJZH1IC

[98] T.B. Sheridan. 2002. Some musings on four ways humans couple: implications for systems design. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 32, 1 (Jan. 2002), 5–10. https://doi.org/10.1109/3468.995525

[99] Thomas B. Sheridan. 1992. *Telerobotics, automation, and human supervisory control*. MIT Press, Cambridge, Mass.

[100] Thomas B. Sheridan. 2017. *Modeling human-system interaction: philosophical and methodological considerations, with examples.* John Wiley & Sons, Hoboken, New Jersey.

[101] Thomas B. Sheridan and William R. Ferrell. 1974. *Man-machine systems; Information, control, and decision models of human performance.* The MIT Press, Cambridge, MA, US.

[102] Richard Shusterman. 2000. *Pragmatist aesthetics: Living beauty, rethinking art.* Rowman & Littlefield Publishers.

[103] Richard Shusterman. 2008. *Body consciousness: A philosophy of mindfulness and somaesthetics.* Cambridge University Press.

[104] Richard Shusterman. 2012. *Thinking through the body: Essays in somaesthetics.* Cambridge University Press.

[105] Richard Shusterman. 2018. *Introduction: Aesthetic Experience and Somaesthetics.* Brill, Leiden, The Netherlands, 1 – 13. https://doi.org/10.1163/9789004361928_002

[106] Vygandas Šimbelis, Anders Lundström, Kristina Höök, Jordi Solsona, and Vincent Lewandowski. 2014. Metaphone: machine aesthetics meets interaction design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* 1–10.

[107] Petr Slovák, Christopher Frauenberger, and Geraldine Fitzpatrick. 2017. Reflective practicum: A framework of sensitising concepts to design for transformative reflection. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems.* 2696–2707.

[108] Kyle Smith. 2022. Welcome to Mechanical Sympathy. https://www.hagerty.com/media/opinion/mechanical-sympathy/welcome-to-mechanical-sympathy/

[109] Marie Louise Juul Søndergaard, Ozgun Kilic Afsar, Marianela Ciolfi Felice, Nadia Campo Woytuk, and Madeline Balaam. 2020. Designing with Intimate Materials and Movements: Making" Menarche Bits". In *Proceedings of the 2020 ACM Designing Interactive Systems Conference.* 587–600.

[110] Mousa Sondoqah, Fehmi Ben Abdesslem, Kristina Popova, Moira McGregor, Joseph La Delfa, Rachael Garrett, Airi Lampinen, Luca Mottola, and Kristina Höök. 2024. Shaping and Being Shaped by Drones: Programming in Perception-Action Loops. In *Proceedings of the 2024 Conference on Designing Interactive Systems.* 1–29. https://doi.org/10.1145/3643834.3661636

[111] Anna Ståhl, Madeline Balaam, Marianela Ciolfi Felice, and Irene Kaklopoulou. 2022. An Annotated Soma Design Process of the Pelvic Chair. In *Designing Interactive Systems Conference.* 1921–1933.

[112] Jackie Stewart and Peter Manso. 1972. *Faster!* Farrar, Straus and Giroux, London.

[113] Anna Ståhl, Madeline Balaam, Rob Comber, Pedro Sanches, and Kristina Höök. 2022. Making New Worlds – Transformative Becomings with Soma Design. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22).* Association for Computing Machinery, New York, NY, USA, Article 176, 17 pages. https://doi.org/10.1145/3491102.3502018

[114] Anna Ståhl, Martin Jonsson, Johanna Mercurio, Anna Karlsson, Kristina Höök, and Eva-Carin Banka Johnson. 2016. The Soma Mat and Breathing Light. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI EA '16).* Association for Computing Machinery, New York, NY, USA, 305–308. https://doi.org/10.1145/2851581.2889464

[115] Anna Ståhl, Vasiliki Tsaknaki, and Madeline Balaam. 2021. Validity and Rigour in Soma Design-Sketching with the Soma. *ACM Trans. Comput.-Hum. Interact.* 28, 6, Article 38 (dec 2021), 36 pages. https://doi.org/10.1145/3470132

[116] L.A. Suchman. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication.* Cambridge University Press.

[117] Dante Tezza and Marvin Andujar. 2019. The state-of-the-art of human–drone interaction: A survey. *IEEE Access* 7 (2019), 167438–167454.

[118] Vasiliki Tsaknaki. 2021. The Breathing Wings: An Autobiographical Soma Design Exploration of Touch Qualities through Shape-Change Materials. In *Designing Interactive Systems Conference 2021.* 1266–1279.

[119] Vasiliki Tsaknaki, Madeline Balaam, Anna Ståhl, Pedro Sanches, Charles Windlin, Pavel Karpashevich, and Kristina Höök. 2019. Teaching soma design. In *Proceedings of the 2019 on Designing Interactive Systems Conference.* 1237–1249.

[120] Vasiliki Tsaknaki, Kelsey Cotton, Pavel Karpashevich, and Pedro Sanches. 2021. "Feeling the Sensor Feeling you": A Soma Design Exploration on Sensing Non-habitual Breathing. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* 1–16.

[121] P.P. Verbeek. 2010. *What Things Do: Philosophical Reflections on Technology, Agency, and Design.* Pennsylvania State University Press. https://books.google.se/books?id=vURh8gy8nPAC

[122] Peter-Paul Verbeek. 2008. Cyborg intentionality: Rethinking the phenomenology of human–technology relations. *Phenomenology and the Cognitive Sciences* 7, 3 (2008), 387–395.

[123] Ron L. Wakkary. 2021. *Things we could design: For more than human-centered worlds* (1st ed.). MIT Press.

[124] Ron Wakkary, Doenja Oogjes, Sabrina Hauser, Henry Lin, Cheng Cao, Leo Ma, and Tijs Duel. 2017. Morse things: A design inquiry into the gap between things and us. In *Proceedings of the 2017 conference on designing interactive systems.* 503–514.

[125] Ron Wakkary, Doenja Oogjes, Henry W. J. Lin, and Sabrina Hauser. 2018. Philosophers Living with the Tilting Bowl. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18).* Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173668

[126] Danielle Wilde, Anna Vallgårda, and Oscar Tomico. 2017. Embodied Design Ideation Methods: Analysing the Power of Estrangement. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17).* Association for Computing Machinery, New York, NY, USA, 5158–5170. https://doi.org/10.1145/3025453.3025873

[127] Charles Windlin. 2020. Designing with the Body: Addressing emotion regulation and expression. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference.* 557–562.

[128] Charles Windlin, Anna Ståhl, Pedro Sanches, Vasiliki Tsaknaki, Pavel Karpashevich, Madeline Balaam, and Kristina Höök. 2019. Soma Bits-mediating technology to orchestrate bodily experiences. In *RTD 2019-Research through Design Conference 2019, the Science Centre, Delft, on 19th to 22nd March 2019.* https://doi.org/10.6084/m9.figshare.7855799.v2

[129] Katie Winkle, Donald McMillan, Maria Arnelid, Katherine Harrison, Madeline Balaam, Ericka Johnson, and Iolanda Leite. 2023. Feminist Human-Robot Interaction: Disentangling Power, Principles and Practice for Better, More Ethical HRI. In *Proceedings of the 2023 ACM/IEEE International Conference on Human-Robot Interaction.* ACM, Stockholm Sweden, 72–82. https://doi.org/10.1145/3568162.3576973

[130] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through Design as a Method for Interaction Design Research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07).* Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704