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How to Design with Ambiguity: Insights from Self-tracking Wearables

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Abstract

Nearly 20 years ago, Gaver et al. introduced ambiguity as a design resource, proposing tactics to reflect everyday uncertainty into interactive systems. This approach is especially relevant for self-tracking wearables, which often obscure the inherent ambiguity of system design and tracked phenomena with seemingly clear, prescriptive data and insights. Although scholars recognize the importance of ambiguity, its practical application in the design process remains underexplored. To address this, we conducted a two-week workshop with 60 designers, examining the application of Gaver et al.'s tactics into 11 design concepts, and performed interviews with 16 participants. Our findings reveal eight relevant ambiguity tactics for self-tracking and offer insights into participants' experiences with designing using ambiguity. We discuss prescription and overlooked ambiguity as levers for the operationalization of ambiguity, the potential benefits and downsides of ambiguity tactics for users, future directions for HCI research and practice, and the study limitations.

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1 Introduction

Commercial self-tracking wearable technologies, such as fitness and activity trackers, enable individuals to detect, monitor, and record data on sleep, stress, physical activity, and biosignals, aiming to enhance health and well-being by making bodily data measurable and actionable [54, 93]. These systems primarily use screen-based interfaces, graphs, scores, and quantitative data to visualize personal information [1], presenting it as objective, scientific, and precise insights into an individual's behaviors, activities, and states [4, 37, 71, 94]. Despite documented benefits of engaging with such visualizations [14, 15, 83], a series of tensions may emerge from the interplay of sensors, algorithms, cultural norms, and users' embodied experiences [21, 93]. These tensions are partly due to the way data is represented, which can obscure the inherent ambiguity present in both the system design and the phenomena being tracked, [4, 6], conveying normative and prescriptive understandings of bodies and practices [53]. In response, recent literature has suggested that ambiguity could be strategically employed to offer alternatives to the rigid, quantified nature of current self-tracking devices [42, 58, 78, 94, 95].

Nearly 20 years ago, Gaver et al. [35] introduced *ambiguity as a design resource* to prompt designers to reflect on the inherent ambiguity of everyday life in interactive systems and *"engage users with issues without constraining how they respond"*. To help designers and practitioners understand and adopt ambiguity as a strategic resource, Gaver et al. [35] identified three types of ambiguity, along with corresponding design tactics, illustrated through examples drawn from arts and design projects. Since Gaver et al.'s framework was introduced, it has garnered significant attention within the HCI community. Numerous scholars have extended its theoretical and practical apparatus [3, 20, 34, 85] across various domains, including personal communication and storytelling [3, 7], activity tracking and behavioral design [8, 9, 18], and reflection support systems [5].

Notably, a growing body of literature has recognized ambiguity as a valuable design resource in the context of wearable technologies for self-tracking [22, 58, 78, 94]. Research highlights ambiguity can help designers acknowledge the complex meanings of biosignals (e.g., heart rate, brainwaves), reducing rigid data interpretations while addressing device limitations [41, 43, 50, 65]. At the same time, it can empower users to develop their own interpretations of intimate bodily phenomena, ultimately enhancing their autonomy in meaning-making [42, 51, 65, 78].

Despite growing interest in ambiguity, the majority of HCI empirical research that draws on this concept often fails to explicitly reference Gaver et al.'s ambiguity tactics in their system designs [38]. This tendency is also visible in bio-sensing and self-tracking research-through-design studies - with Howell et al. [42] as a notable exception. As a result, the practical application of these tactics in the design process remains underexplored, limiting their full generative potential. This gap is not necessarily problematic in itself, as the absence of these tactics in empirical investigations has not prevented scholars from exploring the practical implications of ambiguity. However, to establish ambiguity as a valuable design resource, it is crucial to investigate whether and how these tactics can function as an accessible form of *intermediate-level knowledge* [40, 89]: i.e., a generative form of knowledge specific enough to inform design practice but broad enough to be transferable to diverse contexts or projects. Such exploration would provide deeper

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insights into how these tactics might be integrated into the design process, as well as the opportunities they present in exemplar cases like self-tracking technologies.

To investigate the application and adaptation of Gaver et al.'s ambiguity tactics in the design process, we adopted design workshop as a research method, drawing upon previous works in HCI [48, 96, 97, 100]. Specifically, we conceptualized a design process incorporating original ambiguity tactics and we deployed it in a two-week design workshop on self-tracking wearables with 60 graduate-level designers. We followed a multi-stage data collection and analysis approach. First, we analyzed how participants applied the tactics across 11 design concepts and how these tactics informed their design choices, identifying new domain-specific ambiguity tactics. Next, we combined data from on-site observations, workshop materials, and semi-structured interviews with 16 participants to gain insights into the experience of designing with ambiguity as a design resource.

This paper makes the following main contributions:

(1) It introduces eight plug-and-play tactics and three higher-level categories tailored for the self-tracking domain. These tactics represent design-oriented, context-based adaptations of Gaver et al.'s original ambiguity tactics and are accompanied by illustrative examples.
(2) It proposes the acknowledgment of prescription and overlooked ambiguity in current wearable technologies design as key entry points for the adoption of ambiguity tactics, warning on the possible benefits and downsides of novel tactics for users.
(3) Finally, it demonstrates the value of ambiguity as a form of intermediate-level knowledge and *strong concept* [40], with ambiguity tactics serving as generative constructs bridging theoretical abstraction and concrete design instantiations.

2 Theoretical framework

Our work builds on three research areas: ambiguities and tensions in the self-tracking wearables domain, ambiguity as a design concept, and the application of ambiguity as a resource for the design of self-tracking, bio-sensing, and activity-tracking technologies.

2.1 Ambiguities and tensions in the self-tracking wearables domain

Nowadays, commercial wearable technologies like fitness and activity trackers (e.g. Fitbit, AppleWatch, Xiaomi MiBand) allow individuals to detect, monitor, and record sleep, stress, steps, physical activity, and bio-signals. These devices promise to support individuals improve their health, fitness, and well-being, making aspects of their body and life visible, measurable, and optimizable [54, 93]. The current approach to personal data visualization mainly entails screen-based interfaces, quantitative data, graphs, scores, and recommendations [1, 71], which aim to convey objective, scientific, trustworthy, and precise measures of the individual's behavioral patterns, activities, and states [4, 37, 94]. While several studies confirm the benefits individuals may find in engaging with such visualizations [14, 15, 83], there are a series of tensions that may arise from the interplay of sensors and algorithms, the way data are represented, the contextual socio-cultural norms and standards, and users' personal embodied and experiential perceptions [4, 21, 93].

A primary tension exists between data's perceived scientific objectivity and its actual partiality [4, 21]. Indeed, data are anything but neutral and unbiased [36]. On the one hand, sensors and algorithm-related accuracy issues and other technical limitations (e.g., device battery lifetime) may provide incomplete and erroneous data to the wearer [46, 56, 69]. On the other hand, data are socially constructed through decision-making processes in which stakeholders from different disciplinary domains and interests decide what constitutes a 'step' and what defines a *"good performance"* [53]. Ultimately, shaping what knowledge is accessible to the user and how [4].

A second tension arises from the reductionist process of translating complex, rich, and subjective phenomena, such as stress, mood, health, and sleep, into discrete, quantified, measurable entities that can then be optimized [94]. Although the advantages of this simplification are in accessibility and attainability of otherwise inaccessible information [62], the risk remains in disregarding other body signals not traceable through sensors and algorithms, considering the reductive summary more thorough than it actually is [4, 19, 93]. Moreover, despite the intended actionability, users may struggle with sense-making and meaning-making, leading to anxiety about whether their status is 'normal' or not. [39, 52].

The third tension regards what Van den Eede defines as a: *"fixed entity fallacy: the idea that phenomena can be reified as fixed entities with unambivalent qualities ('sugar' is 'bad'; 'exercise' is 'healthy')"* [93]. The fixed entity fallacy combined with the reductionist assessment may deliver quantified standards of what ideal 'wellness', 'fitness', and 'health' mean, pushing users to conform to predefined cultural stereotypes [93, 94] (i.e. 10.000 steps). In this scenario, overtrust in data and an excessive focus on quantification can lead people to trust numbers more than their subjective experience [76, 94]. Users may modify their behavior to comply with what the device can track, optimize data, and improve scores rather than tackling the underlying phenomena, and cheat for rewards [94]. For example, users may reduce calorie intake to be healthier while experiencing stress in reaching an ideal value [19]. In addition, they may struggle between *"well-being and not being well enough"* [4], feeling pressure to perform and guilt for weak performances, compared to the normative standards offered by the devices [53].

By and large, current devices tend to obscure the inherent ambiguity — i.e. the possibility for multiple interpretations — within system design and users' interactions with data and tracked phenomena, presenting an illusion of clarity, objectivity, and precision. In contrast, a growing body of research highlights ambiguity as a valuable resource for designing systems that enable individuals to develop personalized interpretations of their data, rather than adhering to normative, standardized frameworks.

2.2 Ambiguity as a design concept

Ambiguity refers to the capacity of signs, words, and systems to support multiple meanings simultaneously [82]. Its usage in HCI and design research varied consistently [88]. Some scholars investigated the role ambiguity plays in design processes and designers' conversations as both a source of creativity and innovation [47, 80], and misunderstandings [88]. Brun and Steinar Sætre [12] view it as an ever-present condition in design to mitigate or temporarily sustain. Ambiguity is also an integral component of projects that challenge the solution-oriented design paradigm [55]. Approaches like speculative and critical design, leverage ambiguity to provoke reflections and question the implications of emerging technologies, proposing imaginative, compelling, and assertive future-oriented artefacts seemingly embedded in everyday life [25, 29, 102]. Other researchers use ambiguity as an inspirational concept in research-through-design to create interactive systems that resist a single, specific, and clear interpretations [34, 81]. This approach has been applied e.g. in personal communication and storytelling [3, 7], activity tracking and behavioral design [8, 9, 18], and reflection support systems [5].

This body of work is largely influenced by Gaver, Beaver, and Benford [35], who proposed, nearly twenty years ago, that ambiguity could serve as a valuable resource for designers. They argued that incorporating the inherent ambiguity of everyday life into interactive systems could elicit a range of heterogeneous, sometimes contradictory, yet co-existing interpretations from users, extending beyond mere utility and efficiency [81]. In their seminal work, *Ambiguity as a Resource for Design*, they suggest that:

> *"it allows designers to engage users with issues without constraining their responses . [...] it allows the designer's point of view to be expressed while enabling users of different sociocultural backgrounds to find their own interpretations. [...] [it] can make a virtue out of technical limitations by providing the grounds for people's interpretations to supplement them."* [35]

Through the analysis of exemplars from speculative design and art-oriented projects, they identified three types of ambiguity and related tactics to support designers in enhancing ambiguity of information, creating ambiguity of context, and provoking ambiguity of relationship (see Table 2 for an overview).

Since then, several scholars have expanded on Gaver et al.'s framework. Boehner and Hancock [7] propose a set of design and evaluation guidelines to create spaces for the emergence of ambiguity in Personal Communication systems. Devendorf et al. [20] explore *'ambiguity of information'* in clothing-based displays, noting how ambiguity can arise from the relationship between the wearer, the artefact, and observers, a dimension Howell et al. [43] call *'ambiguity of observation'*. More recently, Sivertsen et al. [85] introduced *'ambiguity of process'* in artists' practices involving AI and Machine Learning, using the original tactics [35] to analyze the role of ambiguity in the artistic design process. However, Herbes [38] highlighted a literature gap regarding the lack of explicit adoption of existing ambiguity tactics in the design of interactive systems within HCI studies, limiting their generative potential toward design practice. This gap is not necessarily problematic in itself, as the absence of these tactics in empirical investigations has not prevented scholars from exploring the practical implications of ambiguity. However, to establish ambiguity as a valuable design resource, it is crucial to investigate whether and how these tactics can serve as an accessible form of *intermediate-level knowledge* [40]- broad enough to be transferable between different contexts or projects, but specific enough to inform particular instances of design practice.

Our research addresses this gap by examining the practical application of Gaver et al.'s ambiguity tactics in a domain-specific context — namely, the design of self-tracking wearables and data representations. By testing these tactics in a design workshop with graduate-level designers, we aim to provide preliminary insights into how they can be integrated into the design process, adapted to the self-tracking domain, and the value and challenges of designing with and for ambiguity.

2.3 Ambiguity in self-tracking, bio-sensing and activity tracking design

Since the seminal introduction of ambiguity as a design resource, there has been increasing interest within the HCI community regarding its potential application in self-tracking wearables. Several examples illustrate how ambiguity can be applied to this design space.

The *Eloquent Robe* [65] transforms heart rate data into *"abstract and aesthetic"* colorful projections on the wearer's body, deliberately avoiding prescribed interpretations to encourage self-observation and self-reflection. *Affective Health* [78] represents skin conductance data through an *"evocative"* spiral-like visualization on a mobile-app, allowing users to develop their own understanding of physiological patterns and associated tracking practices. The *Hint Shirt* [43] employs cloth-based thermochromic patterns that slowly react to arousal levels, creating opportunities for shared interpretation and collective meaning-making among wearers and observers.

From a designer's perspective, incorporating ambiguity into wearables offers several advantages. First, it allows designers to account for the open-ended and multifaceted meanings of biosignals (e.g. heart rate, brainwaves) and life phenomena (e.g. emotions, stress), reducing normative interpretations of data [41, 43, 50, 65, 72]. Indeed, ambiguous displays can serve as an alternative to the quantified, prescriptive, and diagnostic frameworks common in commercial self-tracking devices [23, 42, 58, 78, 94]. Second, ambiguity allows designers to reflect uncertainty in data representations, accommodating device imprecision and technical limitations through less precise visualizations [28, 72, 94]. Third, it enables designers to prompt people's reflection on the reliability of wearables and explore trust dynamics [42, 95]. From a user's perspective, ambiguity allows individuals to develop their own interpretations of bodily functions, emotions, and behaviors, fostering self-reflection and avoiding rigid, top-down data interpretations [31, 42, 65, 78]. This, in turn, can enhance their autonomy in making sense of their data [51, 65, 78]. Nevertheless, the enhanced cognitive effort necessary to interpret ambiguous data might lead to confusion and misunderstanding, or prevent meaningful interactions [50, 51].

Although current research substantiates growing interest and a suitable context for employing ambiguity, only a limited number of contributions [42, 78] provide detailed accounts of how ambiguity is explicitly integrated into design. Most studies refer to terms such as 'ambiguous' or 'abstract' to imply its incorporation into system features [18, 51, 65, 87]. Indeed, despite the majority of contributions cite *"ambiguity as a design resource"* [35], only a few explicitly account for the specific ambiguity tactics used in the development of their design [42, 70].

Finally, while these contributions offer valuable exemplars that illustrate how ambiguity was made more concrete, there remains a notable lack of studies putting ambiguity tactics to test in a domain-specific context. Such investigations are essential for empirically assessing and advancing forms of intermediate-level knowledge [40, 89] originally conceived to make abstract HCI concepts more accessible and actionable for designers. Given these premises, our work seeks to address this gap by advancing knowledge on how ambiguity can be applied in the design of self-tracking wearables; specifically, by identifying ambiguity tactics tailored to the self-tracking domain through the application and adaptation of the original ones [35] in the design process.

3 Methodology

This study aims to explore the practical application of Gaver et al.'s ambiguity tactics in a domain-specific context — namely, the design of self-tracking wearables. By testing these tactics with graduate-level designers, we aim to provide insights into how ambiguity can be integrated into the design process. To address this, we followed a multi-method qualitative approach adopting design workshop as a research method, similarly to previous works in HCI [96, 97].

(1) We developed and deployed a design process integrating Gaver's et al. ambiguity tactics in a workshop setting with 60 designers. The workshop addressed the concept of ambiguity as a design resource in the self-tracking wearables and data representation domain.
(2) We analyzed 11 resulting concepts/artefacts, how participants employed the original ambiguity tactics, and how these tactics informed their design choices. This process led to the identification of eight domain-specific ambiguity tactics.
(3) Finally, we combined data from (a) design process documentation, (b) audio/visual presentations, and (c) post-hoc semi-structured interviews with 16 participants to gain insights into the experience of designing with ambiguity as a design resource.

3.1 Design workshop

Previous work has effectively used design workshops as a way to engage participants in collaborative design processes, testing design concepts and frameworks, and generating insights that can inform both theory and practice [2, 48, 75, 100]. In the context of our study, we adopted design workshop as a particularly advantageous method for contributing to a practical understanding of ambiguity, as an abstract topic of HCI design research, guided by the following reasons.

- From a *process-oriented perspective*, a design workshop enables a close examination of the design process in practice. By observing how participants navigate the design brief, it is possible to iteratively identify approaches and strategies that may be difficult to detect otherwise [66].
- From an *artefact-oriented perspective*, the design workshop facilitates knowledge generation through its outcomes, including design concepts and artifacts created by participants, which can serve as concrete examples to inspire creative design cycles [48]. Additionally, developing an annotated portfolio of projects can further consolidate knowledge into a novel design space [10].
- From a *designer-oriented perspective*, previous studies show that observing process materials and interviewing workshop participants provide deeper insights into their experiences. Participants' reflections further reveal their approaches, challenges, and emerging opportunities in practice. [96, 97].

Finally, we opted for a design workshop as our study model within an educational setting because it offers a semi-controlled environment allowing participants to approach the design brief autonomously, while still fulfilling specific documentation requirements essential for our data collection [26, 75]. Furthermore, the extended duration of the workshop, spanning 12 full days, allowed for a thoughtful design process beyond mere brainstorming or prototyping exercises.

3.1.1 Participants. The workshop was conducted over a two-week period and involved 60 graduate-level designers enrolled in master's programs at Politecnico di Milano. Participants were recruited from two programs: 34 from "Design for the Fashion System" and 26 from "Digital and Interaction Design". The workshop, offered as an elective course, granted university credits, and no budget was allocated for the development of their designs. The activities were carried out in a hybrid format, with most participants collaborating in person and three teams working entirely remotely. Before the workshop, participants completed a survey that detailed their educational background and performed a self-assessment of various soft and hard skills. Soft skills included teamwork, presentation, public speaking, creativity, lateral thinking, scheduling, and project management. Hard skills included sketching, sewing and pattern-making, 3D modeling, User Interface (UI) design, coding, and programming. Participants were organized into 11 interdisciplinary teams to balance competencies and disciplinary expertise (see Table 1). Although participants had limited practical experience outside the academic environment, they can be positioned between the *"competent"* and *"proficient"* levels, as intended by Dorst and Reymen [24]. During their bachelor's studies in design, they developed essential problem-solving skills, competence in planning through trial and error, reflective learning, and abilities in problem-framing, ideation, development, and prototyping. These skills were evident in their performance during the workshop.

3.1.2 Design process and workshop structure. We asked participants to *"design an interactive artefact, interface and/or data representation system to support the interpretation, sense-making, and self-reflection of data collected through a wearable self-tracking device, leveraging ambiguity as a design resource"*. Building on the premises illustrated in *Section 2.1*, we developed a design process aimed at supporting the meaningful integration of ambiguity tactics within the self-tracking domain. Specifically, the workshop encompassed three main phases, as detailed below.

- **Workshop introduction.** As workshop organizers, we explained the workshop brief and schedule. We delivered introductory lectures on self-tracking wearable technologies, tensions emerging from the interplay of quantified data representations and subjective experience, ambiguity as a design

Table 1: Workshop participants teams distributions, educational backgrounds: Master Program and Bachelor Degree

Group	MA Program	BA Degree
G1	3 DFS, 3 DID	1 Political Science, 1 Environmental Design, 2 Fashion Design, 1 Graphic Design, 1 Product Design
G2	3 DFS, 2 DID	2 Fashion Design, 2 Digital Media and Advertising, 1 Product Design
G3	4 DFS, 2 DID	2 Fashion Design, 2 Product Design, 2 Engineering and Product Design
G4	3 DFS, 3 DID	3 Fashion Design, 2 Product Design, 1 Communication Design
G5	4 DFS, 2 DID	3 Fashion Design, 1 Product Design, 2 Digital Media and Game Design
G6	3 DFS, 2 DID	3 Fashion Design, 1 Graphic Design, 1 Interior Design
G7	2 DFS, 3 DID	2 Product Design, 1 Fashion Design (Knitwear), 1 Architecture, 1 Materials Engineering for Fashion
G8	3 DFS, 3 DID	2 Product Design, 1 Fashion Design, 3 Communication Design
G9	3 DFS, 2 DID	2 Fashion Design, 1 Management for Fashion, 1 Computer Science, 1 Product Design
G10	3 DFS, 2 DID	2 Fashion Design (Knitwear), 1 Product Design, 1 Digital Arts, 1 Architecture
G11	3 DFS, 2 DID	2 Fashion Design, 2 Architecture, 1 Interior Design

concept, and ambiguity tactics [35]. Subsequently, participants engaged in ice-breaking collective activities sharing their knowledge of wearable technologies for self-tracking and personal experiences. At the end of the kick-off, participants received information on the first teamwork task to be completed by the end of the first workshop week.

- **Tensions identification, ambiguity tactics selection, and design brief definition.** During the first week of the workshop, we asked each team to analyse one wearable self-tracking device and its data representation modalities. Participants could choose a wearable in one of two application domains: (1) fitness and sport or (2) mental and emotional well-being. The choice of these domains was driven by the extensive availability in the market of devices dedicated to well-being in terms of fitness and lifestyle [98], offering designers the opportunity to choose from a wide range of devices to analyze and a higher likelihood of being users themselves or reaching potential users for the initial research. Furthermore, these domains were selected because of the growing interest of the research community in personal informatics research [27], and the increasing interest of users in adopting such devices to improve their overall well-being, thus delimiting a productive design space to explore the application of ambiguity. To help participants understand the implications of dominant practices in wearable data representation, we prompted them to explore, analyze, and discuss tensions arising from user interactions with the self-tracking data representations of their chosen device. Specifically, we asked them to reflect on how such data representations might propose an 'objective truth' (e.g., by using numbers, graphics, recommendations, etc.) and to identify possible tensions related to their interplay with users' subjectivities in terms of ambivalences (e.g. performance vs wellbeing).
  Simultaneously, we asked designers to read the paper *Ambiguity as a resource for design* [35] and select one or more of the ambiguity tactics (see Table 2) to inform a possible mitigation or exaggeration of the identified tensions [67]. For *mitigation*, participants were prompted to use tactics to design 'market-oriented' systems, smoothing tensions through ambiguity. For *exaggeration*, the aim was to apply the tactics to highlight tensions and provoke critical reflection.
  This approach aligns with Gatehouse and Chatting's [32] invitation of using ambiguities and ambivalences in technology encounters and adopting modes of expression that retain *"some of the ambiguous or unresolved elements"* to render tensions visible through design, for future problem-solving and reflection. By the end of the first week, each team had to present their research, including the selected device, data representation, identified tensions, and chosen tactic(s), all compiled into a brief to guide the second week activities.
- **Concept development, design prototyping, and project presentation.** In the second week, we asked participants to engage with ambiguity through an iterative prototyping process, practically exploring how to translate ambiguity tactics into specific design choices. We encouraged participants to prototype through bodystorming techniques [79], experience prototyping [13], low-fidelity and mid-fidelity prototyping [49, 57]. We favored these techniques for several reasons. The provisional and transient nature of low-fidelity prototypes, while helping in materializing ideas for discussion, also keeps the creative process open [49, 57]. This openness allows for the exploration of multiple potential evolutions, thereby delving into the capacity of ambiguity to steer the progression of the design process. Bodystorming [79] and experience prototyping [13] involve immersive bodily engagement in brainstorming, acting, simulating, and the exploration of ideas through physical involvement. The combination of these approaches was specifically sought to support designing for self-tracking practices and intimate bodily data. To support their project progress, we also invited participants to share and test their concepts/prototypes with peers. Recognizing the hybrid nature of the workshop and the potential difficulties faced by remote teams in conducting thorough testing, we refrained from making peer testing mandatory.

We structured the workshop day-by-day on the collaborative online platform Miro [59] to support the design process and documentation [86]. We provided each group with a whiteboard for brainstorming, collecting references, and sharing ideas. We also asked teams to complete annotated *"progress cards"* [44], summarizing prototype images, storyboards, and upcoming tasks to track the

Table 2: Ambiguity types and tactics as proposed by Gaver et al. [35]

Ambiguity type	Ambiguity type description	Ambiguity tactics
Ambiguity of information	Ambiguity arises in the way that information is provided. It asks the reader to project personal expectations into an interpretation of incomplete information and impels people to question for themselves the truth of a situation.	Use imprecise representations to emphasize uncertainty.
		Over-interpret data to encourage speculation.
		Expose inconsistencies to create a space of interpretation.
		Cast doubt on sources to provoke independent assessment.
Ambiguity of context	Ambiguity arises when meanings shift across contexts. Blocking a system's interpretation within familiar discourse can help people expand, bridge, or reject common product meanings.	Implicate incompatible contexts to disrupt preconceptions.
		Add incongruous functions to breach existing genres.
		Block expected functionality to comment on familiar products.
Ambiguity of relationship	Ambiguity stems from an observer's personal connection to design artifacts, sparking self-examination, ambivalence, contradiction, or imaginative engagement.	Offer unaccustomed roles to encourage imagination.
		Point out things without explaining why.
		Introduce disturbing side effects to question responsibility.

project's progress and the application of ambiguity tactics. These materials enabled us to monitor how tactics evolved throughout the process. We required participants to update these cards daily during the second week. Finally, we provided a dedicated presentation space for mid- and final deliveries, with clear content guidelines.

We planned expert reviews and plenary presentations after one week, on day 10, and at the end of the workshop. During these sessions, instead of offering direct guidance, we asked questions to help clarify unclear aspects of the projects, encouraging participants to refine their approaches independently. At the end of week two, participants had to illustrate their final design concept, highlighting the project's value proposition, identified tensions, ambiguity tactics, data representation features, and experience context. Along with their visual and oral presentations, designers were also required to create a video showcasing key features of their data representation system or prototype experience. We recorded and transcribed all plenary presentations with participants' consent.

For evaluation, we focused on how well participants applied ambiguity principles in their design process rather than the utility or usability of their outcomes. The evaluation criteria included three main aspects: (1) the coherence and appropriateness of the design concept in addressing the identified tension, with particular emphasis on the effective use of ambiguity; (2) the participants' ability to articulate and reflect on how ambiguity tactics were integrated into their design process and how they influenced their decisions; and (3) the quality of the presentations, including how clearly participants explained their concepts, supported by materials like sketches, annotated pictures, videos, and prototypes, from identifying the tension to applying ambiguity tactics.

3.2 Ambiguity tactics translation analysis

Our process for deriving why and how ambiguity tactics were applied in the resulting design concepts followed a two-step approach.

(1) Firstly, to ensure consistency across materials, the first author created a textual-visual document for each project summarizing the project title, purpose, system components, data representation, context, identified tensions, and ambiguity tactics. This document was compiled from transcriptions of final presentations, visual documentation, and interviews. To further analyze the artefacts, she annotated project images, linking design tactics (e.g., *"use imprecise representations to emphasize uncertainty"* [35]), with interaction qualities (e.g., *"translating heart rate ranges and pressure data into animations and colors"* to specific artefact representations (e.g. a picture of a necklace display), providing a clearer connection between the tactics and their implementation in the device.

(2) Secondly, drawing on the aforementioned material, the first author conducted a cross-project analysis using thematic analysis and affinity mapping to cluster data. This involved, first, organizing material based on the original ambiguity tactics, clustering common reasons for adopting the tactics, and examining how these informed design choices in the different projects. The clustering process underwent multiple rounds of revision and discussion among the three authors, ensuring clarity and coherence in the final consolidation of domain-specific ambiguity tactics. These tactics were later clustered into higher-level categories encompassing different forms of reduction/augmentation of prescription.

In summary, this process integrates participants' interpretations of the original ambiguity tactics, their translation into project features, and the intended project goals as conveyed in team presentations. Notably, all the eleven teams, ultimately, referred to Gaver et al's ambiguity tactics in their final presentations - with three groups making an effort to come up with their own tactic phrasing. These insights led to the identification of eight novel self-tracking-specific tactics clustered in 3 categories, presented in *Section 5.*

3.3 Analysis of the design process

To gain additional insights into the process of designing with ambiguity tactics, we performed a triangulation of observations and post-hoc semi-structured interviews with 16 workshop participants, ensuring representation from each team. Interviews investigated participants' perceptions of ambiguity as a design resource, the role of self-tracking tensions, ambiguity tactics, low-fidelity prototypes, and their impact on the project's evolution. Additionally, we collected feedback on facilitating or hindering factors when designing with ambiguity. We provided participants with access to workshop materials and interview questions beforehand. During the interviews, a Miro board was used to present key moments from the design process, including screenshots of annotated templates and relevant information to aid memory recall. The first author transcribed and analyzed interviews using a deductive content analysis approach. Initially, pre-defined categories aligned with the interview questions were employed, a technique known as 'hypothesis coding' [77]. These categories guided the organization of participant quotes. She then identified recurring themes and patterns, discussed the data structure with the third author, and collaborately refined the categories into sub-themes. This process facilitated the identification of both commonalities and divergences in participans' perspectives, providing a nuanced understanding of their experiences.

4 Ambiguity tactics for data representation in self-tracking wearables

The workshop ended with eleven design concepts (for an overview, see Fig. 1 and Fig. 2) aimed at fostering multiple interpretations, sense-making, and self-reflection. These projects involved the design of self-tracking wearables and data representations deliberately incorporating ambiguity tactics. Six of the eleven teams opted for a *tension/s mitigation*; five groups for *tension/s exaggeration*. Most teams selected 'emotional and mental well-being' as their application field, while four teams focused on 'fitness and sport'. The declared goals of the projects included: *"foster self-awareness"*, *"encourage conversation"*, *"inspire play and discovery"*, and *"prompt reflection"*. In particular, the concept of reflection was delineated across three distinct levels: contemplation of data, contemplation of the tracked phenomenon (such as emotions), and contemplation of the individual's relationship with technologies. Some teams indicated several goals. Rather than providing an extensive description of each project, we propose to elicit their contribution through an annotated portfolio [10] of the emerging ambiguity tactics, which facilitates a descriptive yet generative and open-ended presentation of insights [48].

We introduce eight domain-specific ambiguity tactics for self-tracking wearables, contextually adapted from the original tactics proposed by Gaver et al. [35]. The tactics are organized into three primary categories: *Description*, *Omission*, and *Extrapolation*. Following a brief overview of the overarching category, each tactic is detailed, including its associated tensions, its relation to Gaver et al.'s original tactics [35], the concrete manifestations of the tactic across different projects, and the specific purposes it serves.

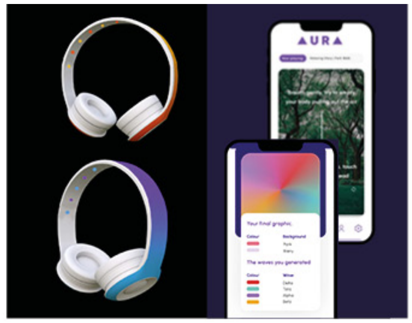
4.1 Description

Description involves translating biosignals and movements into 'direct' representations of sensor data, refraining from providing interpretations or meanings (e.g. missing data are visually described in form of gaps or holes). The tactics following the *Description* approach include *'Turn uncertain data into sensory aesthetic experiences'*, *'Lower the data resolution'*, and *'Highlight missing data'*.

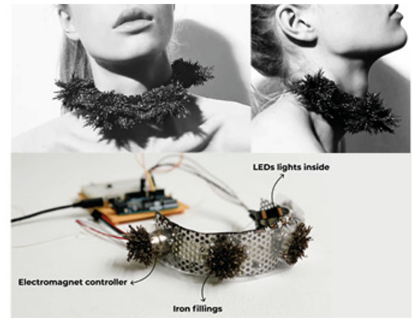
4.1.1 Turn uncertain data into sensory aesthetic experiences. This tactic challenges the prevailing design paradigm in self-tracking wearables, which traditionally emphasizes 'precision' in data representation. Drawing inspiration from the tactic *"Use imprecise representations to emphasize uncertainty"* [35], most teams shifted away from the conventional approach. This shift reflects a desire to convey the inherent multiplicity of interpretations surrounding bodily phenomena and the uncertainty involved in defining them according to rigid canons. Therefore, several teams translated sensor data into abstract, artistic, and aesthetic sensory experiences. This approach prioritizes experiential forms over exactitude, thereby emphasizing the inherent ambiguity and variability of the data. For instance, some projects utilize static and/or dynamic data physicalization to achieve this goal. The project *The Void* represents visitors' experiences at an emotionally intense exhibition through a personal knitted piece. This piece encodes data from a sensorized balaclava that records brainwaves and facial movements of each visitor. Facial movements are translated into various stitch textures, while brainwave frequencies are represented through color variations mapped according to amplitude. Similarly, *Uwave* concept features an interactive neckpiece that translates glucose data into abstract iron-magnetic peaks corresponding to real-time glucose levels detected by a sensorized patch. While, *Aura* incorporates data sonification, translating real-time brainwave data into auditory and visual stimuli. The headphones are equipped to produce sounds that vary in pitch and tone according to the user's brainwave activity, creating a dynamic, 'direct', amplified auditory experience of inner phenomena. While it is important to note that self-tracking devices already abstract biosignals and movements into numbers and graphs, these projects extend abstraction further, using tangible and unconventional representations to encourage alternative ways of engaging with data. This approach serves two purposes: prompting users to rethink the meaning of tracked activities through descriptive, artistic representations rather than prescriptive, scientific ones, and safeguarding users' privacy by requiring access to underlying codes and meanings for interpreting the data. Thus, protecting their information from other people's gaze.

4.1.2 Lower the data resolution. This tactic, again, counters the conventional emphasis on 'precision' in self-tracking wearables. In fact, it challenges the claim of accuracy pursued by wearables companies advocating for a less granular approach to data representation, inspired by the tactic *"Use imprecise representations to emphasize uncertainty"* [35]. In this case, rather than using exact numerical values, these projects lower data resolution by using input data as averages and ranges, and representing data via gradients and blurred representations. The focus shifts from exactitude to an overall impression, which highlights the inherent uncertainty and fluidity of the data. For instance, the project *SEE: Show Every Emotion* translates heart rate ranges and pressure data from a smartband into pulsating, colored animated waves displayed on a digital pendant necklace. Heart rate data is represented by a spectrum of colors ranging from pink to purple, while wristband pressure influences the animation with ephemeral green fluxes. Similarly, the

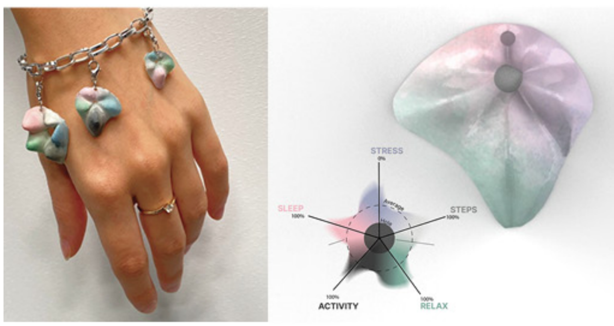
SEE. See Every Emotion is a necklace visualizing heart rate and finger pressure, detected by a screenless smartband, as coloured pulsating waves in a digital pendant display.



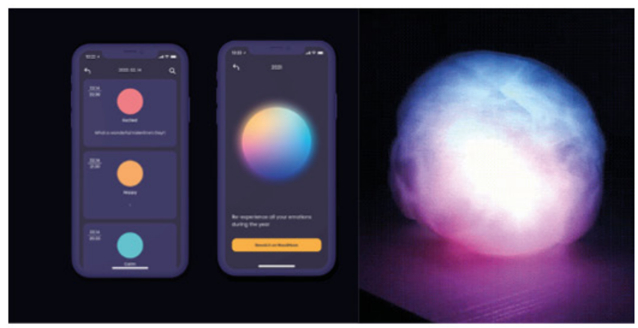
AURA headphones are equipped with ECG and EEG sensors measuring heart rate and brainwaves and translating each biosignal into an auditory and visual feedback on the device.



Uwave is a shape-changing neckpiece continuously displaying along the day the wearer's glucose levels, detected via a smart patch on the users' skin, through dynamic iron-magnetic peaks.



Wavy is a bracelet made of pendants as physicalisations of monthly activities avarage goals metrics (sleep, stress, steps, physical activity, and relax), detected by a wristband tracking biosignals and body movements, not providing access to underlying metrics.



MoonMood is a LED lamp - working only in the evening - displaying heart rate data, detected by a screenless wristband worn during the day, as emotional states through colourful dynamic lights presented in a randomized order.

Figure 1: Pictures and descriptions of SEE Show Ever Emotion (G1), AURA (G2), Uwave (G3), Wavy (G4), and MoonMood (G5)

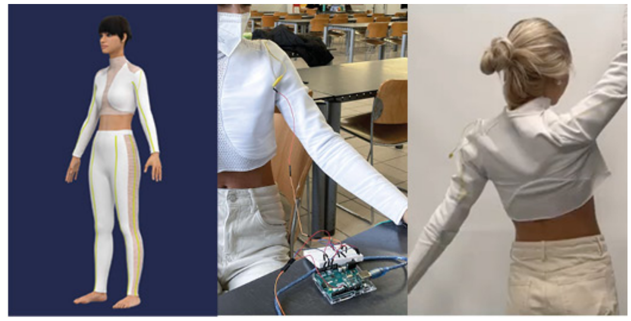
project *Wavy* transforms daily, exact quantified data and percentages into an average monthly summary of metrics, like sleep, steps, stress, physical activity, and relaxation. This data is represented through a bracelet of charms, with tridimensional volumes and color gradients indicating performance levels, with higher volumes indicating higher performance and different colors representing various activities. By using less precise forms of representation for typically quantified and performance-driven metrics — such as scores — these projects seek to diminish the authoritative weight of self-tracking systems prompting users to engage with their data in a contemplative rather than performative way.

4.1.3 Highlight missing data. This tactic arises from the critique of wearables' claims of accuracy, acknowledging that the device may be influenced by technical limitations, sensor inaccuracies, or the failure to detect data when not worn. This highlights a gap in the conventional approach to data representation in wearables, where missing data often goes unnoticed. To make this misalignment visible, participants adopted the tactic *"Expose inconsistencies to create a space of interpretation"* [35]. To reveal the inconsistency between wearables idealized accuracy and their real-world usage, *Wavy* materializes data absence. Each pendant displays a hole whose size grows with the duration the device remains unworn. This negative space acts as a physical representation of missing data, drawing attention to the partiality of the displayed information. Indeed, the project points to data gaps as important information for understanding and interpreting self-tracking data, inviting users to recognize their role in the overall narrative of their tracked experiences.

4.2 Omission

Omission involves deliberately concealing certain common system features from users. The tactics following this trajectory include *"Conceal instructions and input-output mapping"*, *"Use opaque data representations as social displays"*, *"Restrict data access"*.

Lyftpal is an interactive and gamified weightlifing training experience translating weight, speed and lifting power, sensed by an arm-band, into colourful paintings completing an empty visualizations without providing instructions to the wearer.

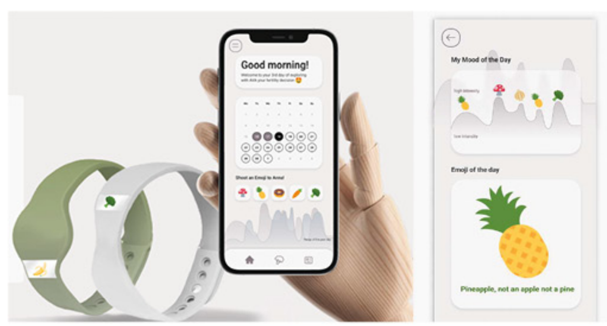


DanceSuit is a smart dancing suit equipped with e-textile sensors and real-time haptic actuators, translating in real-time body movements in randomized vibrations along the dancer's body.

The Bad Apple is a smartwatch sensing user's activities and obliging the wearer to perform a 'good' or a 'bad' action suggested by the system, pushing every following proposal to more extreme choices.

MatchMe. The Experience is an interactive installation claiming to support participants finding true love based on their arousal biosignals (heart rate and skin conductance), whose intensity manifested in a heart-like blinking sculpture.

The Void is an exhibition confronting participants wearing a sensorized balaclava with four extreme perfomances and translating their EEC and EMG data (emotional response) into incomprehensible knitted pieces, to be collectively deciphered.



EVA is a dual-device tracker for couples made of two wristbands traslating and sending partners' emotions, detected during the day, into fruit and vegetable emojis, whose meaning is unclear and needs to be jointly discovered.

Figure 2: Pictures and descriptions of Lyftpal (G6), DanceSuit (G7), The Bad Apple (G8), MatchMe (G9), The Void (G10), and EVA (G11)

4.2.1 Conceal instructions and input-output mapping. This tactic addresses the tension between the benefits of tracking life activities and the traditional quantified, performance-oriented approach, which can induce pressure, anxiety, and demotivation. To mitigate these issues, some projects embraced the tactic *"point out things without explaining why"* [35]. This approach entailed shifting the focus toward more playful, open-ended, and exploratory experiences by minimizing explicit guidance and concealing the direct relationship between input, output, and the system's functioning rules. For example, *Lyftpal* offers a gamified weightlifting experience where participants adjust their lifting speed, direction, and power to progressively transform complex black-and-white sketches into colorful paintings. Without specific instructions on how to achieve the transformation, users must intuitively connect their movements with the game's outcomes. In this context, through exploration users may also find unconventional ways to complete the game by *"cheat[ing] the system to gain rewards"* [94]. Another project, *DanceSuit*, converts arm and leg movements detected by stretch sensors into real-time, randomized vibrations that vary in position along the body, with no clear correlation between input and output. Similarly, *EVA*, a dual-device system for couples, uses wristbands to track physiological changes and displays random fruit and vegetable emojis on each partner's device. The system conceals both the data driving emoji selection and their meanings, revealing only that they signify strong emotions experienced by the partner during the day. By withholding crucial information required for a singular interpretation, this tactic invites users to explore and interpret how their actions and physiological responses interact with the device — and how the device, in turn, shapes their experiences. This open-ended approach aims to transform traditional self-tracking into a more dynamic, exploratory process, fostering deeper engagement with data through a reciprocal relationship between the body and the device's feedback.

4.2.2 Restrict data access. This tactic stems from self-tracking devices' real-time monitoring and unrestricted access to personal data, which can lead to both benefits and potential anxiety due to constant exposure to data. Some teams recognized this tension and sought to address it by omitting this typical functionality of wearables. Specifically, drawing from the tactic *"block expected functionality to comment on familiar products"* [35], these teams intentionally delayed or limited users' access to their self-tracked data, over real-time monitoring. For example, the project *MoonMood* features a color-changing light ball linked to a screenless wristband that detects emotions. Activating only in the evening when the wearer is nearby, the ball displays a flux of user-defined colors representing the emotions experienced throughout the day, acting as a personal diary of daily emotional journeys. At a different timescale, *Wavy* offers a pendant as a tangible summary of monthly activity data, encapsulating activity trends in a data sculpture. Instead of providing detailed, ongoing statistics, the device delivers the completed pendant at the end of the month. Overall, these projects revised traditional self-tracking wearables' role, transitioning from allowing rapid data consumption to slower fruition. The purpose is to encourage users to engage in self-assessment using the device as a litmus test rather than an oracle to evaluate and reflect on personal activities and experiences.

4.2.3 Use opaque data representations as social displays. This tactic addresses the tension between the seemingly straightforward interpretation of wearable data and the complex, nuanced nature of phenomena such as emotions, stress, and well-being. To highlight the possibility of multiple, even conflicting, interpretations, several teams incorporated a social dimension into the sense-making process, moving beyond the individualistic focus of traditional self-tracking. Most teams drew inspiration from the tactic *"Point out things without explaining why"* [35] to spark this multiplicity. By involving collective efforts in interpreting the data, they highlighted how meaning varies based on individual perspectives. This approach is evident in various projects, where personal representations of data are made visible and open to commentary by onlookers who, without access to the underlying codes and meanings, cannot interpret the data with precision. For example, in *The Void* visitors are presented with encrypted physicalizations of their emotions, publicly displayed in the exhibition hall, encouraging interaction and discussion with fellow attendees. The knitted artifact serves as a conversational catalyst, prompting visitors to collectively decipher its meaning through comparison, fostering dialogue and self-disclosure. In other projects like *SEE*, *Wavy*, and *Uwave*, which present data sculptures as fashion accessories, the aesthetic appeal and enigmatic nature of these data objects may spark curiosity, speculation, and conversations. Overall, the tactic *'Use opaque data representations as social displays'* shifts data interpretation to a collective, collaborative decoding process, pointing to the socially constructed yet deeply personal nature of the underlying phenomena.

4.3 Extrapolation

Extrapolation involves deliberately extending or exaggerating the interpretations made by wearables, pushing them beyond reasonable limits. This approach critiques and aims to reveals the implicit biases embedded in the underlying decisions and design of commercial activity trackers. Tactics under this category include *'Craft assertive systems'* and *'Over-estimate the system's capabilities'*.

4.3.1 Craft assertive systems. This tactic emerges from a critique of recommendation systems confidently asserting prescriptive propositions on what constitues a 'good' behaviour. Inspired by the tactics *"Cast doubt on sources to provoke independent assessment"* and *"Introduce disturbing side effects to question responsibility* [35], this tactic aims to cast doubts on the 'perfection allure' proposed by mainstream activity trackers, provoking thoughts on the *"fixed entity fallacy"* [93]. For example, *The Bad Apple* features an activity tracker confidently categorising 'good' and 'bad' actions and forcing the wearer to perform one of the two options in response to detected daily behaviours. As choices are made, the proposals progressively become more extreme, and the wristband tightens around the arm, symbolizing the inflexibility of blindly adhering to the device's recommendations. While *MatchMe: The Experience*, a matchmaking event, explores reductionist assessment and familiar associations by claiming to detect the connection between couples based solely on bodily biosignals. Pairs' arousal parameters, such as skin conductance and heart rate, are translated into light intensity variations on a hearth-like sculpture nearby. The sculpture's brightness reflects the sum of the participants' arousal levels, symbolizing love and connection. This metaphor reinforces the system's claim, making it difficult to separate the feedback from the interpretation of a matchmaking diagnosis. The opportunity of delegating decisions to technologies may appear desirable for many reasons, e.g. time optimisation and offloading comforts. Against the subtle and innocuous consequences of following the devices' nudges, this tactic aims to spark reflection on concrete situations in which the devices' voice may overcome the wearer's autonomy in making choices, from partners-in-love to daily actions.

4.3.2 Over-estimate the system's capabilities. This tactic highlights the exaggerated claims of wearables, which suggest they can detect and evaluate complex phenomena—often beyond the actual capabilities of their sensors and operating systems (e.g., assessing sleep quality based solely on physiological data). Drawing inspiration from the tactics *"Cast doubts on sources to provoke independent assessment"* and *"Over-interpret data to encourage speculation"*, some teams sought to make this implicit overestimation visible. They deliberately amplified the supposed capabilities of the systems, pushing the boundaries of what they claim to detect. For instance, in *MatchMe*, the system presents itself as a sophisticated device capable of diagnosing the romantic compatibility of a couple. However, it obscures the fact that this 'love diagnosis' is nothing more than a basic aggregation of physiological metrics, i.e. the sum of the pair's arousal data. Similarly, the project *EVA* tricks couples into believing that the device holds knowledge about their emotions. It displays random emojis, implied to represent the partners' feelings, though they are not directly linked to their actual emotional states. Instead, EVA encourages the couple to speculate about the device's outputs, creating an illusion that the system possesses a higher understanding of their feelings, the couple being left to decode. Overall, these projects highlight the gap between the overconfidence and overstated capabilities of wearable devices and their actual limitations. By doing so, they prompt individuals to reconsider the trust they place in such devices and to approach their interpretations with a healthy degree of skepticism.

5 Designing with ambiguity tactics

This section presents participants' accounts on designing with ambiguity tactics following the design process devised in the workshop.

5.1 Ambiguity tactics open-endedness

Almost unanimously, participants identified dealing with ambiguity as the primary challenge they encountered, largely due to the novelty of designing with ambiguity tactics. Additionally, the inherent ambiguity of the concept itself added a layer of complexity to the design challenge (P3a, P5, P6). As P6 remarked, *"Honestly, the first challenge was to understand and grasp what it means to design with ambiguity. Because each of us apparently had different understandings about it"*. Some participants highlighted such misalignment as a challenge, struggling to be *"on the same page"* (P3a) and *"speaking the same language"* (P11b). They noted difficulties in communication and reconciling diverse backgrounds, terminologies, and conceptual interpretations, especially when *"there was too much ambiguity among the group to reach consensus"* (P11b). While some participants saw this lack of alignment as a struggle, others viewed the open-ended nature of ambiguity tactics as an advantage. This openness allowed greater freedom of personal interpretation, giving participants more room to explore how these tactics could materialize in their projects (P4, P8, P9, P10a, P10b). As P10a noted,

> "it's funny because ambiguity tactics are themselves ambiguous in a way, in how you interpret them. [...] So, they didn't dictate a specific approach or solution, but rather, they facilitated thinking within a defined yet ambiguous space"

From participants' reflections, original ambiguity tactics [35] appear as broader guiding directions rather than rigid directives. In this context, the tactics were reported to function more at a strategic level, offering a flexible framework that encouraged open-ended exploration rather than limiting participants to specific solutions. While navigating this ambiguity may have brought participants into frustration, it concurrently empowered teams to explore the design space with greater freedom and creativity, allowing for more diverse interpretations to co-exist.

5.2 Familiarizing with ambiguity

Most participants found the tactics and accompanying examples illustrated in Gaver et al.'s [35] paper a particularly beneficial resource for familiarizing themselves with the concept of ambiguity (P1, P3a, P4, P5, P9, P10a, P10b). A few commented on the clarity and simplicity of the tactics' formulation as an advantage once the problem space was framed, even though their meaning and application were not straightforward (P8, P10a). Examples from the paper were deemed highly beneficial to ground the tactics' abstractness into tangible instances. Nevertheless, some participants found the paper difficult to understand, presenting overlapping and ambiguous tactics requiring several readings and many discussions to get aligned (P2, P7, P11a).

Ultimately, most teams reported that reflecting on ambiguity tactics related to the identified tensions and project design brief was the most effective way to make ambiguity an operational concept (P1, P4, P5, P6, P8, P9, P10b). As highlighted by P9, embracing and applying ambiguity necessitated progressive comprehension.

> "In our case, we had stages of understanding it. So, first, when it was introduced in the class, of course, like 'Nothing. . . Blank!'. And then, after reading the paper, it was a bit clearer. [. . .] and then after the first presentation, these words started making sense. We were understanding [ambiguity tactics] through experiments. They also changed many times. So, in the end, I think it was more or less everything clear. So, reading the paper and also coming up with our own examples of this." (P9)

The design process documentation analysis reflects this gradual understanding and integration of ambiguity in the projects. Several groups reported refining their initial ambiguity tactics as they saw how these tactics manifested in design decisions, ultimately choosing the most relevant translation. Overall, participants employed a combination of *"learning-by-sharing"* [90] and *"learning-by-doing"* [73] to develop their understanding of ambiguity.

5.3 Tensions highlight overlooked ambiguity in systems design

The tensions identified by the participants included trade-offs between continuous tracking and data overexposure, the interplay between performance pressure and well-being, the contrast between seemingly objective data and potential inaccuracies due to device limitations or missing data, and the metrification of complex, ambiguous phenomena like emotions. Teams who explicitly identified tensions stemming from the apparent lack of ambiguity in self-tracking devices defined transitioning to ambiguity tactics a *"quite straightforward"* (P8) process and *"a pretty easy flow"* (P10b). For instance, P10a stated

> "This identification and analysis of tension helped us to see the apparent lack of ambiguity that happens in the real-world products, the fact that the visualization is so structured and unambiguous, this is what really clicked in our heads."

Some participants used bodystorming with commercial trackers to identify tensions and their connection to ambiguity tactics (P4, P5, P8, P9), emphasizing the value of a first-person perspective in transitioning from tensions to tactics. This experiential approach is particularly visible in the *The Bad Apple* project. The team *"tried spending a day"* (P8) wearing an activity tracker, immersing themselves in the smartband's daily notifications, including prompts to stand up, walk, and engage in stress management exercises. The constant barrage of notifications led to feelings of overwhelm and annoyance. After this bodily engagement, the team decided to reveal the prescriptive nature of such devices, which impose standardized notions of healthy behavior. By exaggerating these prescriptions, the team employed *"Cast doubt on sources to provoke independent assessment"* and *"Introduce disturbing side effects to question responsibility"* tactics [35] to highlight the ambiguity in universal definitions of 'good' or 'bad' behaviour, encouraging deeper reflection on offloading and decision-making within the context of intimate technologies.

In contrast, teams that misinterpreted ambiguity as a usability issue struggled to effectively use the tactics. Three teams showed this misunderstanding in their first-week presentations. For example, the *DanceSuit* team analyzed a sensor-equipped music glove and a smart sock, identifying the glove's *"difficulty in conveying clear measurements"* as a tension. They proposed improving it by drawing on the sock's *"superior accuracy"* in tracking performance, which - however - directly conflicted with the workshop's goal of challenging such assumptions. In fact, the team struggled with ambiguity tactics, finding them unclear and difficult to apply, as P7 admitted:

> "During the workshop, our entire team was completely lost with ambiguity. [...] I would say that ambiguity tactics were unclear, to be honest. It was complicated to understand them in general and to understand how to work with them."

The varied experiences of teams in grappling with ambiguity tactics reveal key insights into what facilitated or hindered the translation process. A key factor was recognizing that wearable data representations often overlook the inherent ambiguity of bodily phenomena. Teams that understood this concept at an early stage were able to effectively adopt ambiguity tactics to address and reflect the complexities and uncertainties in data about human experiences. Conversely, teams that failed to grasp this foundational aspect struggled with ambiguity tactics, often misinterpreting ambiguity itself as an issue to be solved.

5.4 Ambiguity as an unnatural concept to pursue

Exploring ambiguity as a resource led participants to reflect on its role in the design process. A few recognized that ambiguity *"is part of the natural evolution of the project; as the project unfolds step by step, you don't know what the result will be"*, allowing multiple potential directions to co-exist (P2, P4, P9). Some noted that incorporating ambiguity in the workshop helped leverage diverse viewpoints effectively. As (P2) noted, *"It's a great starting point for us to understand that ambiguity exists in design, both in terms of issues and tactics, and even among individuals with different design backgrounds and experiences"*. However, many participants found it challenging to align the concept of ambiguity with their traditional views on the design process, which typically emphasize eliminating ambiguity rather than incorporating it into the final product. In contrast, the idea of intentionally designing for multiple interpretations — allowing the final product to be open-ended and subject to diverse user perspectives — was reported by participants as unfamiliar and challenging. P8's reflection well conveys a shared feeling among participants:

> "Ambiguity is a very challenging concept to deal with and incorporate within design [as] using ambiguity for design isn't even a natural thing, as ambiguity is usually sought to be removed. Applying it is difficult because it's not a natural concept that you are taught. They teach you the exact opposite." (P8)

In addition, many reported that translating very specific data (e.g. numbers) into ambiguous representations (P1, P2, P3a, P5) and finding a balance between ambiguity and clarity (P2, P3a, P5, P9, P10b) was difficult to achieve as it was *"hard dosing ambiguity to give real value to the user, without putting too much ambiguity and messing up everything"* (P5). Interestingly, the analysis of the groups' final presentations revealed a contradiction in how teams portrayed user experiences with their 'ambiguous' designs. In several cases, participants assumed a straightforward users' understanding and interpretation of data, overlooking the possibility of harmful or absent interpretations. They depicted the 'ideal' user's experience as a clear, prescriptive sequence of actions, closely aligned with the project's intended outcome. This trend was particularly evident in projects using design tools like personas, storyboards, and customer journey maps, framing the user experience in a linear narrative flow.

5.5 Ambiguity as creativity fuel

Unltimately, participants described ambiguity as an inspiring, different, and novel approach to designing "innovative" and "future-oriented technologies" (P1, P2, P3c, P10a, P11a), *"extra-ordinary and out-of-the-box"* (P6), *"surreal"* and *"unexpected"* (P10b), *"not obvious"* (P8) projects. Many participants referred to designing with ambiguity as a creativity fuel (P2, P3a, P10b), enabling them to open up alternative design opportunities (P5) when working within ambiguous and unclear problem spaces (P6, P10a).

6 Discussion

In this study, we aimed to develop practical insights on the adoption of ambiguity as a design resource for the self-tracking domain. To do so, we organized a two-week workshop and asked graduate-level designers to develop wearable data representations by leveraging ambiguity tactics [35] to address self-tracking tensions. We summarize here our main findings:

- Our work confirms that the tactics introduced by Gaver et al. over 20 years ago proved adaptable and strategic to the specific context of self-tracking, leading to the *identification of eight novel and distinct tactics* through the workshop. These new tactics represent context-specific adaptations of the original concepts. While not groundbreaking nor exhaustive, their value lies in offering accessible, plug-and-play, and practical resources encouraging designers to question prevailing paradigms and experimenting with alternative approaches to wearable data design.
- Our findings demonstrate the value of ambiguity as a form of intermediate-level knowledge. We further support positioning ambiguity as a *"strong concept"* [40] within HCI, as it exhibits horizontal transferability while maintaining empirical groundedness, with ambiguity tactics serving as generative constructs bridging theoretical abstraction and concrete design instantiations. Indeed, rather than applying original ambiguity tactics [35] as directive solutions, teams leveraged them as flexible strategies acquiring meanings in response to identified tensions in the design brief.
- The workshop methodology combined with the triangulation of process-, designer-, and artifact-oriented analysis proved effective in exploring ambiguity's *"generativity, scope and validity"* [40] making the practical translation of intermediate-level knowledge explicit and analyzable [96, 97]. This confirms its validity as a viable methodological paradigm for bridging conceptual and practical domains, putting to test abstract HCI concepts in empirical work [17].

In this section, we discuss (1) prescription and overlooked ambiguity as levers for the operationalization of ambiguity, (2) potential benefits and downsides of ambiguity tactics for users, and (3) future directions for HCI research and design practice.

6.1 Operationalizing ambiguity through the lens of prescription

Our study reveals insights on how ambiguity can be operationalized in self-tracking technology design by examining its relationship with prescription - defined as *"a plan or a suggestion for making something happen or for improving it [...] that is authoritatively put forward"* [45]. Contemporary self-tracking wearables typically employ prescriptive design approaches, presenting data through fixed, authoritative representations that assume objective meaning and direct user behavior. Prescription manifests in current self-tracking designs through multiple features: predetermined goal-setting frameworks (e.g., standardized step counts), normative data interpretations (e.g., "normal" heart rate ranges), directive feedback mechanisms (e.g., "move!" notifications), and behavior recommendations. Our participants identified these prescriptive elements as points where user agency is constrained and where the inherent uncertainties of physiological measurement, individual variation, and contextual factors are overlooked. This recognition of prescription's prevalence became a crucial first step in applying ambiguity tactics meaningfully. Specifically, our findings reveal that making ambiguity a concrete resource in self-tracking design may involve two mechanisms: identifying where prescription dominates current designs, and then strategically applying ambiguity tactics to either *reduce* prescription or *amplify* prescription.

For example, several design teams challenged the prescription of meaning and apparent precision in detecting complex phenomena by deliberately *"us[ing] imprecise representations to emphasize uncertainty"* [35]. By *'transforming uncertain data into sensory aesthetic experiences'* and *'lowering data resolution'*, they aimed at *reducing* the authoritative stance of the device and leaving an interpretive gap for the emergence of personal meanings to broaden user interpretation of their bio-data (e.g. glucose levels, heart rate, and brainwaves) and life phenomena (e.g. emotions). Other teams aimed to *minimize* prescriptive use patterns and directive behaviours by concealing traditional recommendations and instruction-based interactions. Drawing on the tactic *"point out things without explaining why"* [35], they developed approaches like *'concealing instructions and input-output mappings'* and *'using opaque data representations as social displays'*. By omitting explicit guidance they aimed to encourage more exploratory and collaborative user-driven engagement and experiences, with respect to traditional devices. Conversely, other teams deliberately *amplified* prescription to challenge the perceived objectivity in declaring what is better for users and provoke critical reflection on trust and agency in current self-tracking design paradigms. Using tactics such as *"over-interpreting data"*, *"casting doubt on sources"*, and *"introducing disturbing side effects"* [35], they created *'assertive systems'* while *'over-estimating the system's capabilities'* to expose limitations and biases inherent in wearable technologies' authoritative claims, inviting skeptisism.

It is important to note that our novel tactics position themselves as adaptations, rather than groundbreaking revisions, of Gaver's original tactics. However, they extend their work by demonstrating a dual nature: they both offer alternatives to and critique dominant paradigms in self-tracking (e.g., lowering data resolution versus precision, missing versus comprehensive data). These adaptations not only reveal the limitations of prescriptive approaches but also highlight the potential of ambiguity to uncover untapped relationships with self-tracking devices and bio-data.

In conclusion, prescription emerges as a key lever for nudging designers to explore the use of ambiguity as a resource within the self-tracking domain. This perspective can also extend beyond self-tracking to other sensor-based fields where ambiguity in data representation is hidden behind prescription and apparent authority.

6.2 Potential benefits and downsides of ambiguity-infused wearables

Traditional design education and practice emphasize minimizing ambiguity to create clear, unambiguous user interactions [35, 81]. This approach aligns with Norman's principles of affordances and signifiers, where design elements are crafted to suggest specific uses and ideally guide users toward intended interactions [64]. In our study, participants tasked with designing for ambiguity revealed an inherent contradiction in their approach. Despite their stated goal of creating open-ended designs, they still exhibited a prescriptive bias unconsciously reinforcing assumptions that users would interpret and appropriate their designs as intended - e.g. for self-reflection and meaning-making - and would naturally benefit from ambiguity. This prescriptive approach is particularly problematic when considered against existing research reporting the spectrum of responses ambiguity-infused wearables might support, ranging from benefits to detrimental effects [42, 51, 52]. These outcomes were largely overlooked in the workshop projects, exhibiting a form of *illusion of control* over user's interactions [33, 84].

Overall, our novel ambiguity tactics overlap with how ambiguity has been applied in previous empirical studies. This convergence suggests the potential validity of our revised tactics while also providing an opportunity to reflect on their potential benefits and downsides for users, informed by past research insights.

6.2.1 Potential benefits. There are several potential benefits for users to engage with wearables designed according to our proposed tactics. First, *Description* ambiguity tactics, such as *'turn uncertain data into sensory aesthetic experiences'* and *'lower the data resolution'* formats, show promise in fostering embodied engagement with data [43, 51, 63, 65, 87]. Such representations can encourage users to leverage embodied cognition and enhance self-awareness to bridge interpretive gaps left open by the designer [65, 72]. The lack of clear, standardized metrics in these representations may promote user autonomy in meaning-making, surfacing interpretations and behavior that might otherwise remain hidden [43, 65, 78]. Secondly, long-term engagement with ambiguous displays lacking clear interpretive frameworks and use guidance — e.g. incorporating tactics from *Omission* and *Description* categories — can support users' gradual adaptation to the data display, allowing them to situated meaningful insights through sustained interaction [58, 101]. Although this process may initially increase cognitive load, it can ultimately foster self-discovery and adapt to evolving needs as users become familiar with the device and develop personalized interpretation methods [78, 92]. Finally, combining the *Description* tactics with *'Opaque data representations as social displays'*, designers can foster playful engagement with data, enhance interpersonal awareness, and promote supportive social exchanges [42, 43, 51, 63]. In fact, by disrupting conventional social reference frames, ambiguity can reduce competitive comparisons and create more inclusive, collaborative decoding spaces [16, 61, 87, 91].

6.2.2 Potential downsides. Despite these potential benefits, several user downsides may arise when designing for ambiguity. One primary concern, as already anticipated, is the increased cognitive load required to make-sense and meaning out of ambiguous displays, which may lead to confusion or meaningless interactions, particularly during initial use [51, 92]. Users may struggle to interpret data designed according to *Description* tactics because their meaning is not given by default, potentially hindering interest and engagement [43, 65]. Second, the social dimension of ambiguity also presents risks. While *'Opaque representations'* can encourage collective meaning-making, they can also lead to misattribution or inappropriate projections of meaning based on personal biases [43, 51], leading to inaccurate conclusions about others' behaviors or intentions. This leads to consider privacy concerns when ambiguous data representations are shared in social contexts, requiring careful consideration for their implementation [50, 65]. Another significant challenge is the relationship between the system's authority and user's agency when adopting *Extrapolation* tactics. Research shows that even when wearables are designed to intentionally display imprecise data, users may uncritically accept these representations as authoritative, projecting personal vulnerabilities or attributing excessive trust to the systems [42, 95]. If not properly managed, ambiguity may inadvertently reinforce the perceived algorithmic authority of the system, undermining users' agency or critical assessment of the data reliability.

This overview highlights the central challenge of designing with and for ambiguity: balancing ambiguity and clarity [31, 65, 78]. As seen in both the design experiences of participants and in previous research, the process of *dosing* ambiguity involves navigating a wide spectrum of user responses. Designing for ambiguity, therefore, requires careful consideration of user agency, social implications, and temporal engagement with data.

6.3 Future directions for HCI research and practice

The application of ambiguity tactics opens several promising avenues for future research and design practice. Our analysis uncovers some key directions for investigation, along with methodological considerations for evaluating ambiguous systems.

- *Description* and *Omission*-related tactics show particular promise for developing technologies that support interpretative flexibility [60]. These tactics could be deployed in exploratory research examining how users relate to and interpret unconventional data representation modalities. Conversely, *Extrapolation* tactics present research opportunities to investigate individuals' responses to systems constraining user's agency [30] or coping strategies with deliberately wrong data [95]. Findings from such studies could then inform subsequent design processes to develop wearables tailored to emerging practices and meaningful interactions [78, 92].
- The inherent interpretive flexibility of ambiguity-based systems necessitates a fundamental reconceptualization of evaluation approaches [81]. The same representation might prove beneficial for some users while being harmful for others, as designing for ambiguity reduces the designer's control over how systems are interpreted and appropriated. Traditional metrics centered on utility and efficiency may prove insufficient for understanding how these systems mediate user experience and knowledge construction [99]. We propose that evaluation should instead focus on how technology may support interpretations and uses beyond the designer's

intent [81]. This aligns with concepts of technological 'multistability' [74] and 'Non-Intentional Design' (NID) [11].

6.4 Limitations

This study has three main limitations that should be considered when interpreting the findings.

(1) First, the research took place in an academic setting where design students participated for course credits, which may have influenced their behavior. Aware of being evaluated, participants may have prioritized adherence to the ambiguity tactics and the critical stance on wearables proposed by the workshop organizers [2]. This could have limited their willingness to challenge the brief or interpret ambiguity tactics more radically [68]. While the workshop yielded valuable insights, the outcomes should be viewed as partial examples of how ambiguity tactics can be applied and translated in wearables design.
(2) Second, the study was carried out in an artificial setting that does not reflect the complexities of designing wearables in professional industry contexts. Participants had only two weeks to work on their concepts, and none had prior experience in wearable technology design or working with ambiguity. Future research should adapt and replicate the study with industry professionals skilled in wearables design to further explore the applications and limitations of novel ambiguity tactics.
(3) Finally, the absence of user testing for the designs developed during the workshop limited the ability to assess the impact of ambiguity in practice. Therefore, it remains unclear whether the designs might achieve meaningful ambiguity or risk creating detrimental user experiences [42]. Future research should test projects based on our ambiguity tactics to evaluate their implications, as some may be better suited for research than commercial use. Real-world testing will be crucial for assessing their viability.

7 Conclusion

Previous work highlights the significant potential of ambiguity for designing self-tracking wearables [51, 65, 78]. However, despite the existence of established ambiguity tactics to make this concept actionable for designers [35], only a few studies has adopted these tactics [42, 70], thereby limiting the understanding of their generative value. To address this gap, we explored the application of Gaver et al.'s ambiguity tactics [35] in the context of self-tracking wearables and data representations. We developed a design process incorporating these tactics and implemented it in a two-week workshop involving 60 graduate-level design students, organized into 11 teams. Using a threefold lens — focusing on the design process, artefacts, and designers' perspectives — we investigated how ambiguity can be practically applied in this domain. This investigation was supported by observations, analysis of workshop documentation, and interviews with 16 participants. Our findings reaffirm the value of ambiguity as a generative form of intermediate-level knowledge, particularly as a strong concept within HCI [40]. In this paper, we formalize eight novel, domain-specific ambiguity tactics grouped into three categories — (1) Description, (2) Omission, and (3) Extrapolation — presenting them as flexible, plug-and-play resources to provide alternatives and challenge conventional approaches to self-tracking wearables design. We observed that participants navigated the challenges of ambiguity translation through coping strategies, using critique of prescriptive designs and apparent lack of ambiguity in data representations as entry points for ambiguity tactics implementation. Nevertheless, key challenges emerged in balancing openness with clarity and resisting prescriptive approaches to user experience, calling for thoughtful consideration of ambiguity-infused wearables' unintended implications in real-world scenarios. Finally, our study demonstrates that ambiguity possesses significant generative power for developing unconventional and out-of-the-box concepts. By adopting ambiguity in self-tracking devices, participants not only created alternative interaction possibilities to prevailing approaches [28, 78], but also uncovered hidden ambiguities within ostensibly 'objective' data-driven systems [32]. This dual function reveals ambiguity's potential in domains where data interpretation and technological accuracy are often unquestioned in representing complex phenomena.

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