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Leveraging Multistability and Ambiguity in Wearable Technology Design: A Postphenomenological and Design Perspective

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Abstract

In contemporary western societies, wearable technologies and systems for self-tracking are becoming increasingly popular and represent a rapidly growing and interdisciplinary field of research and practice. While much research is dedicated to improving these devices to better serve individuals' goals from a utilitarian perspective, there is also a growing body of knowledge investigating their impact on people's self-perception and self-image, beyond efficiency and usability. This paper proposes to further the current understanding of how data representation designs from wearable technologies shape individuals' experiences and behaviors by combining design research with postphenomenological inquiry. To achieve this, I use the method of variational cross-examination to compare data representations from a traditional commercial wearable tracker with a speculative research-through-design biosensing smart shirt. The paper offers two main contributions. Firstly, it brings wearable self-tracking devices as a productive field of inquiry closer to fashion-related studies. It shows how design research plays a crucial role in the ongoing debate on the impact of wearables on individuals and societal levels. Secondly, it proposes an approach to bridge theory and practice, revealing the mutually beneficial and dialogic relationship between postphenomenology and design. Specifically, it expands the postphenomenological concept of multistability from a tool to analyze interactive fashion design artefacts to a productive and generative design resource to develop intentionally ambiguous and open-ended designs.

Keywords: Wearable Technologies; Design; Ambiguity; Postphenomenology; Multistability.

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Wearable Technologies for Self-tracking as a Productive Field of Inquiry

Wearable technologies are attracting considerable research interest due to their exponential diffusion and pervasiveness in everyday practices. In particular, wearable technologies for self-tracking, such as smartwatches and activity trackers, enable individuals to seamlessly track and gain data on their physiological (e.g., heart rate, temperature, blood oxygen), behavioural (e.g., steps, exercise, and sleep), emotional and mental states (e.g., stress and focus) to make actionable decisions on their lifestyle and conduct.[1] Self-tracking may be performed through body-worn or hand-held devices, such as wristbands, headbands, smart rings, and smart clothes equipped with sensors and processing algorithms, translating streams of data from the body onto visualizations and insights.

The current design paradigm leading the wearable technology market is strongly rooted in a quantified, data-driven culture of performance and efficiency.[2] User interfaces reflect this perspective by offering the wearer prescriptive insights and nudges to push users to change their behaviour towards better, healthier, more productive lifestyles.[3] Commercial devices — like Apple Watch, FitBit, Garmin, and Samsung — represent data mostly through numbers, graphs, scores, and recommendations,[4] making previously intangible aspects of one's life and body visible, measurable, monitorable, and optimizable by nature.[5]

Much research is carried out within the Human-Computer Interaction field and is dedicated to improving these devices to better serve individuals' wellness and fitness-related purposes from a utilitarian perspective.[6] These studies aim to identify barriers and solutions, mainly leveraging behavioral change theories and techniques,[7] as well as technology use and acceptance frameworks, offering design guidelines to better support the user experience.[8] In the last decades, a growing body of knowledge is increasingly addressing the impact of wearable technologies on self-perception and self-image, beyond efficiency and usability,[9] proposing wider reflections on the intrinsic ironies, ambiguities, tensions, and polarised forces crossing the phenomenon of self-tracking mediated by technology.[10] These scholarly

1. Deborah Lupton, "Self-tracking cultures: towards a sociology of personal informatics," in *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: The Future of Design* (December 2014): 77–86.

2. Deborah Lupton, "The diverse domains of quantified selves: self-tracking modes and dataveillance," *Economy and Society*, Vol. 45.1 (2016): 101–122; Denise A. Baker, "Four ironies of self-quantification: wearable technologies and the quantified self," *Science and Engineering Ethics*, Vol. 26.3 (2020): 1477–1498; Amon Rapp and Maurizio Tirassa, "Know Thyself: A theory of the self for Personal Informatics," *Human-Computer Interaction*, Vol. 32.5–6 (2017): 335–380; Amon Rapp, "Wearable technologies as extensions: a postphenomenological framework and its design implications," *Human-Computer Interaction*, Vol. 38.2 (2023): 79–117.

3. Katherine Hepworth, "A panopticon on my wrist: the biopower of big data visualization for wearables," *Design and Culture*, Vol. 11.3 (2019): 323–344; Amon Rapp, Maurizio Tirassa, and Lia Tirabeni, "Rethinking Technologies for Behavior Change: A View from the Inside of Human Change," *ACM Transactions on Computer-Human Interaction (TOCHI)*, Vol. 26.4 (2019): 1–30.

4. Majedah Alrehiely, Parisa Eslambolchilar, and Rita Borgo, "A taxonomy for visualisations of personal physical activity data on self-tracking devices and their applications," in *Proceedings of the 32nd International BCS Human Computer Interaction Conference* (July 2018): 1–15.

5. Amon Rapp and Lia Tirabeni, "Personal Informatics for Sport: Meaning, Body, and Social Relations in Amateur and Elite Athletes," *ACM Transactions on Computer-Human Interaction (TOCHI)*, Vol. 25.3, Article 16 (June 2018): 30; Amon Rapp and Lia Tirabeni, "Self-tracking while Doing Sport: Comfort, Motivation, Attention and Lifestyle of Athletes Using Personal Informatics Tools," *International Journal of Human-Computer Studies*, Vol. 140, 102434 (2020): 1–14.

6. Daniel A. Epstein et al., "Mapping and taking stock of the personal informatics literature," in *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, Vol. 4.4 (2020): 1–38.

7. Rapp and Tirassa, *Know Thyself*, 335–380.

8. Matthias Bode and Dorthe Brogård Kristensen, "From techno-utopianism to personal panopticon and beyond: a call for a revised self-tracking research agenda," in *The Routledge Handbook of Digital Consumption*, edited by R. Llamas, R. Belk (London: Routledge, 2022), 269–283.

9. Cf. Hepworth, *A panopticon on my wrist*, 323–344; cf. Rapp, *Wearable technologies as extensions*, 79–117.

10. Denise A. Baker, "Four ironies of self-quantification: wearable technologies and the quantified self," *Science and engineering ethics*, Vol. 26.3 (2020): 1477–1498; Chiara Di Lodovico, "Exploring the Tensions of Wearable Technologies and Self-

contributions acknowledge that "technological perfection is a myth, and bugs and glitches are not the exception (which then can be eliminated) but should be seen as the normal and necessary reality when it comes to self-tracking."[11]

One of the most productive theoretical apparatuses assuming this perspective is postphenomenology, a philosophy of technology strand that focuses on how technological artefacts "mediate" (i.e., affect) people's experience. Rather than considering technologies as objects the designer has full control over or mere neutral tools and instruments for human empowerment, postphenomenology offers an analytical productive framework to investigate the mediating power of technology in shaping individuals' perceptions and actions, beyond the designer's deliberate intention.[12]

This paper proposes to further the current understanding of how data representation designs characterizing bio-sensing wearable technologies shape individuals' experiences and behaviors by combining design research with postphenomenological inquiry. To this aim, I use the method of variational cross-examination[13] to compare a traditional commercial wearable tracker with a speculative research-through-design bio-sensing smart shirt.[14] The present study aims to demonstrate the potential of leveraging ambiguity as a valuable and effective resource in the design of wearable data representations, in contrast to the conventional prescriptive approach commonly adopted by commercial devices.

The rationale behind this contribution is twofold. Firstly, this contribution aims to draw scholarly attention to wearable self-tracking devices as a productive field of inquiry for fashion and design research. While research on wearables is abundant in other disciplinary fields, there is a dearth of contributions from fashion-related studies.[15] In addition, Nobile et al. have pointed out[16] the absence of a coherent body of knowledge exploring the everyday impact of wearables on consumers' lives and their relationship with societal issues within digital fashion literature.

Secondly, as wearable technologies and self-tracking research domains are highly interdisciplinary and multifaceted, scholars from fashion and design-related fields may expand their reflections by incorporating analytical and theoretical frameworks from technology studies, like Human-Computer Interaction (HCI) research and philosophy of technology.[17] Integrating these theoretical lenses can help to reveal the complex relations between fashion artefacts and individuals, and to recognize how the technologi-

Tracking Data Representations through Design," in *Proceedings of HCI International 23 — Human-Computer Interaction. HCI in Digital Fashion Communication: Thematic Area, 25th International Conference on Human-Computer Interaction, HCII 2023, Copenhagen, Denmark, July 23-28, 2023* (Cham: Springer, 2023).

11. Bode and Kristensen, *From techno-utopianism to personal panopticon and beyond*, 269–283.

12. Don Ihde, *Postphenomenology: Essays in the postmodern context* (Evanston: Northwestern University Press, 1995); Don Ihde, "The designer fallacy and technological imagination," in *Philosophy and Design. From Engineering to Architecture*, ed. P. E. Vermaas, P. Kroes, A. Light, S. A. Moore (New York: Palgrave Macmillan, 2008), 121–131; Don Ihde, *Postphenomenology and technoscience: The Peking university lectures* (New York: SUNY Press, 2009); Peter-Paul Verbeek, *What things do: Philosophical reflections on technology, agency, and design* (University Park, Pennsylvania: Penn State Press, 2005); Robert Rosenberger and Peter-Paul Verbeek, "A field guide to postphenomenology," in *Postphenomenological investigations: Essays on human-technology relations*, ed. R. Rosenberger and P.P. Verbeek (Lanham, MD: Lexington Books, 2015), 9–41.

13. Robert Rosenberger, "Multistability and the agency of mundane artifacts: From speed bumps to subway benches," *Human Studies*, Vol. 37 (2014): 369–392; Robert Rosenberger, "On variational cross-examination: A method for postphenomenological multistability," *AI & Society* (2020): 1–14.

14. Noura Howell, et al., "Tensions of data-driven reflection: A case study of real-time emotional biosensing," in *Proceedings of the SIGCHI conference on Human Factors in Computing Systems (CHI '18)* (April 2018): 1–13.

15. Young-A. Lee and Sumin Helen Koo, "Introduction to special collection on 3D printing and wearable technology in fashion," *Fashion and Textiles*, Vol. 5.1 (2018): 1–4.

16. Tekila Harley Nobile et al., "A review of digital fashion research: before and beyond communication and marketing," *International Journal of Fashion Design, Technology and Education*, Vol. 14.3 (2021): 293–301.

17. Daniel Fallman, "The new good: exploring the potential of philosophy of technology to contribute to human-computer interaction," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)* (July 2011): 1051–1060; Kristina Höök and Jonas Löwgren, "Characterizing interaction design by its ideals: A discipline in transition," *She Ji: The Journal of Design, Economics, and Innovation*, Vol. 7.1 (2021): 24–40.

cal material agency and the sociocultural dimension influence the human.[18] This paper situates itself within a stream of research that spans from Human-Computer Interaction (HCI) to postphenomenology and fashion studies acknowledging the need for such integration.

The paper is structured as follows. The first section provides a brief overview of the key pillars and vocabulary of postphenomenology. The second section explains the method of multistability variational cross-examination. In the third section, I illustrate the results of the comparative analysis of a traditional commercial wearable tracker with a speculative research-through-design bio-sensing smart shirt. The final section includes a summary of insights, final reflections on the interplay between multistability and ambiguity in fashion and design research, and implications for future studies.

Postphenomenology, Human-Technology-World Relations and Multistability

> Everyone designs who devises courses of action aimed at changing existing situations into preferred ones.[19]

One of the most frequently cited definitions of "design" is taken from Herbert Simon's *The Science of Artificial*, first published in 1969. Simon's view on design describes it as a process that involves a rational set of procedures that aims to solve well-defined problems by decomposing complex systems and searching for alternative solutions[20]. This definition implies a prescriptive account, in which the designer is responsible for determining what is considered a preferred situation and for devising activities to move towards it. However, in recent years, the emergence of new hybrid physical/digital systems, a more intricate socio-technical fabric, and the rise of autonomous and ubiquitous technologies are increasingly challenging this straightforward view and designer's role.[21] In this highly layered and complex reality, the challenges involve not only identifying well-defined problems, but also designing artefacts and systems that effectively solve these issues, without creating future problems.[22] This is particularly true in the field of wearable technologies for self-tracking. In this context, assuming postphenomenology as a lens to widen our understanding of design is relevant because it challenges a traditional view of design as a prescriptive and deterministic process, where the designer has complete control over the artefacts and systems they create.[23]

Postphenomenology is a philosophy of technology strand introduced by the American philosopher Don Ihde[24] and extended by Peter-Paul Verbeek and Robert Rosenberger.[25] It combines insights from classical phenomenology, American pragmatism, and Science and Technology Studies. Postphenomenological inquiries

> investigate technology in terms of the relations between human beings and technological artefacts, focusing on the various ways in which technologies help to shape relations be-

18. Anneke Smelik, "New materialism: A theoretical framework for fashion in the age of technological innovation," *International Journal of Fashion Studies*, Vol. 5.1 (2018): 33–54; Lianne Toussaint, *Wearing technology: When fashion and technology entwine*, PhD dissertation, Radboud University, 2018; Pauline van Dongen, *A designer's material-aesthetics reflections on fashion and technology* (Arnhem: ArtEZ Press, 2019); Barile, Nello, and Satomi Sugiyama, "Wearing Data: from McLuhan's 'Extended Skin' to the Integration Between Wearable Technologies and a New Algorithmic Sensibility," *Fashion Theory*, Vol. 24.2 (2020): 211–227.

19. Herbert Simon, *The Sciences of the Artificial. Third Edition* (Cambridge, Massachusetts: The MIT Press; 1996), 111.

20. Xinya You and David Hands, "A reflection upon Herbert Simon's vision of design in the sciences of the artificial," *The Design Journal*, Vol. 22.1 (2019): 1345–1356.

21. Cf. Höök and Löwgren, *Characterizing interaction design*, 24–40.

22. Nynke Tromp, "Let's resist the temptation to solve problems," *Interactions*, Vol. 21.4 (2014): 20–21.

23. Don Ihde,"The designer fallacy and technological imagination," in *Philosophy and Design. From Engineering to Architecture*, eds. P. E. Vermaas, P. Kroes, A. Light, S. A. Moore (New York: Palgrave Macmillan, 2008), 121–131.

24. Cf. Ihde, *Postphenomenology*; cf. Ihde, *Postphenomenologyand technoscience*.

25. Cf. Rosenberger and Verbeek, *A field guide to postphenomenology*, 9–41; cf. Verbeek, *What things do*.

> tween human beings and the world. They do not approach technologies as merely functional and instrumental objects, but as mediators of human experiences and practices [...] combin[ing] philosophical analysis with empirical investigation.[26]

Postphenomenology is built upon several pillars and key concepts. These include the technological mediation theory, structures of human-technology relations, micro-perception and macro-perceptions, and multistability.

Technological Mediation

In his volume *What Things Do. Philosophical Reflections on Technology, Agency, and Design*, Verbeek[27] introduces the theory of technological mediation, a framework to analyse the mediating power of technologies in human-world relations (Fig. 1). The framework of technological mediation comprises two dimensions: experiential and existential.

In the experiential dimension, the emphasis is on how technologies shape the way the world appears and becomes meaningful to humans, in other words their influence on humans' experience and interpretation of reality. In this case, technologies enact a transformation in human-world relations, amplifying some perceptions while reducing others.

In the existential dimension, the focus is on the way technologies affect humans' actions and involvement in the world, that is, how humans behave and act in their reality. This technological mediation is referred as a translation, where certain practices and actions may be invited, while others could be inhibited.

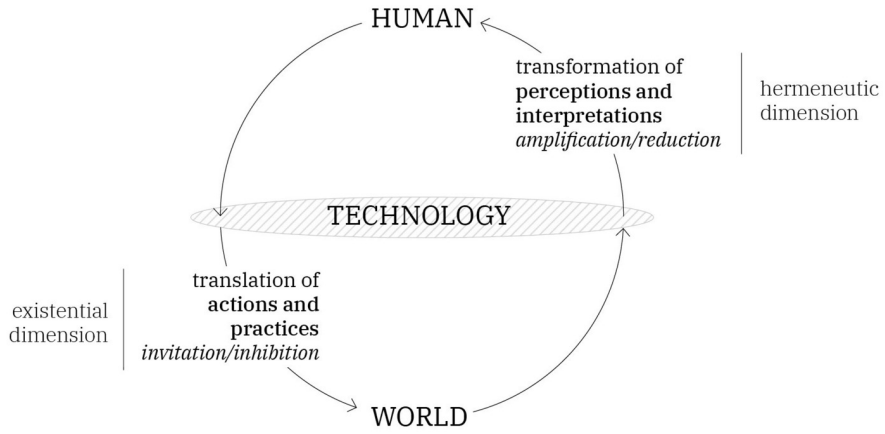

Figure 1: "Technological mediation" based on Verbeek (2005), Van Dongen (2019) and Hauser et al. (2018). Scheme created by the author.

Another cornerstone of postphenomenological investigations is the analysis of human-technology-world structures as a point of departure for philosophical inquiry.[28] Ihde[29] distinguishes four ways in which humans engage with technological artefacts and, by proxy, with the world: embodiment relations, hermeneutic relations, alterity relations, and background relations (Fig. 2).

26. Rosenberger and Verbeek, *A field guide to postphenomenology*, 9.
27. Cf. Verbeek, *What things do*.
28. Cf. Rosenberger and Verbeek, *A field guide to postphenomenology*, 9–41.
29. Cf. Ihde, *Postphenomenology and technoscience*.

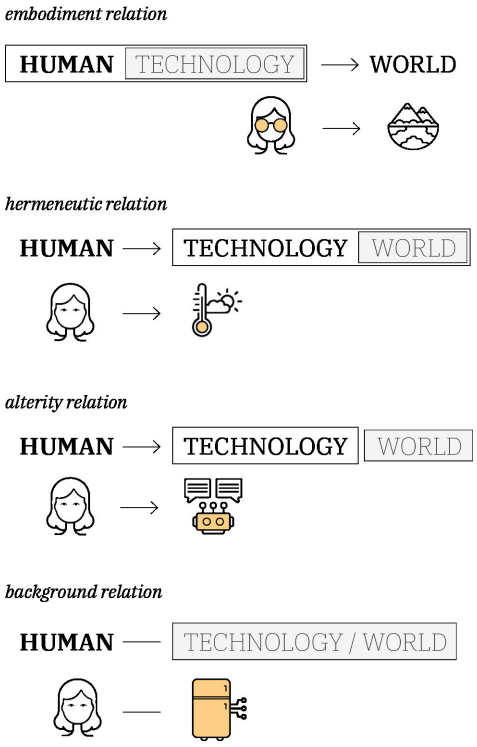

Figure 2: "Human-technology-world" structures based on Idhe (1990, 1995, 2009) and Verbeek (2005). Picture created by the author.

- The embodiment relation occurs when technologies are incorporated and conceived as natural extensions of the human body, modifying the abilities to perceive and act. The reality is experienced through the technology, which gradually becomes transparent and invisible to the user's awareness, as a "quasi-self". The most frequent example used to explain this relation is considering how the reality is experienced through eyeglasses.
- The hermeneutic relation pertains to relations that entail observing, listening to, or otherwise directly reading the output of a device. In this case, technology "represents" the world since it grants access to reality by offering a representation of it, which necessitates interpretation and understanding. The thermometer, for example, offers a representational account of an otherwise intangible aspect like temperature.
- The alterity relation is at the opposite end of the spectrum with respect to the embodiment relation. It entails the engagement with technologies behaving as "quasi-other," in a manner similar to human-to-human interaction. In this relation, technology is conceived as something different from both the human and the world, as a self-standing entity towards which the focus may be directed. Chatbots are examples of technologies where the alterity relations are more clearly visible.
- In the background relation, technologies operate outside of the user's awareness impacting their experience even in the absence of direct interaction. In this case, the technology is present and absent at the same time, merging with the environment and becoming visible for necessity or when it stops working. A few examples may be drawn from the relation we have with home appliances, like the fridge and heating systems.

It is important to note that the human-technology relations described above should not be seen as exclusive dimensions present only in the encounter with specific technologies. Instead, these relations can manifest in various situations involving the same technology, as explained in the next section.

Micro-perceptions and Macro-perceptions

Ihde's examination of human-technology relations is further extended considering not only individuals' bodily perceptual, visceral, embodied and experiential dimensions (micro-perceptions or "body one"), but also the historical, socio-cultural, and anthropological accounts of experience (macro-perceptions or "body two").[30] Van Den Eede describes "body two" as "our social and cultural body, the body that we are invited to push to shape according to cultural fashion, expectations, rules, and norms."[31]

Multistability

Multistability means that technologies are not univocal things but are ambiguous by nature, and that the interaction between technologies and individuals is not intrinsic or deterministic.[32] Multistability refers to the capacity of technology to "be used in different ways for different purposes and [acquire] different meanings in different contexts" across time.[33] By pairing multistability with human-technology structures it is possible to acknowledge "the polymorphic relationships between humans and technologies, or human-technology entanglements."[34] It is crucial to note that multistability does not suggest that any technology is suitable for every purpose or can have significance in any way, as the material quality of the device constrains the possible relationships that can occur.[35] Typically, a technology has a dominant usage or dominant material tailoring, which is the primary purpose for which it was created and produced. However, multiple unexpected variations could emerge from the interplay of the designer's intent (inscription or delegation), the materiality of the technology, individuals' appropriation, human-technology entanglements, and the temporal and sociocultural contextual dimensions in which the technology is used and integrated.[36]

A Postphenomenological Research Method: Multistability and Variational Cross-examination

The concept of multistability was initially devised to challenge deterministic views of technology and criticize designers' false belief of having complete control over how their solutions are used by individuals. This idea has undergone numerous expansions and revisions since its inception.[37]

30. Don Ihde, *Technology and the lifeworld: From garden to earth* (Bloomington: Indiana University Press, 1990); Don Ihde, *Bodies in Technology* (Minneapolis: University of Minnesota Press, 2002).

31. Yoni Van Den Eede, "Tracing the tracker: A postphenomenological inquiry into self-tracking technologies," in *Postphenomenological investigations: Essays on human-technology relations*, eds. R. Rosenberger and P.P. Verbeek (Lanham, MD: Lexington Books, 2015), 147.

32. Cf. Ihde, *Postphenomenology and technoscience*; cf. Rosenberger, *Multistability and the agency*, 369–392.

33. Robert Rosenberger, "Why it takes both postphenomenology and STS to account for technological mediation. The Case of LOVE Park," in *Postphenomenological methodologies: New ways in mediating techno-human relationships*, eds J. Aagaard, J. K. Berg Friis, J. Sorenson, O. Tafdrup and C. Hasse (Lanham, MD: Lexington Books, 2018), 175.

34. Kyle Powys Whyte, "What is multistability? A theory of the keystone concept of postphenomenological research," in *Technoscience and postphenomenology: The Manhattan papers*, eds. Jan Kyrre Berg O. Friis and Robert P. Crease (Lanham: Lexington Books, 2015), 69.

35. Robert Rosenberger, "Why it takes both postphenomenology and STS to account for technological mediation. The Case of LOVE Park," in *Postphenomenological methodologies: New ways in mediating techno-human relationships*, eds. J. Aagaard, J. K. Berg Friis, J. Sorenson, O. Tafdrup and C. Hasse (Lanham, MD: Lexington Books, 2018), 171–198.

36. Cf. Verbeek, *What things do*; cf. Whyte, *What is multistability?*, 69–81; cf. Rosenberger, *Multistability and the agency*; Robert Rosenberger, "On variational cross-examination: A method for postphenomenological multistability," *AI & Society* (2020): 1–14; Bas De Boer, "Explaining multistability: postphenomenology and affordances of technologies," *AI & Society* (2021): 1–11.

37. Rosenberger, *Multistability and the agency of mundane artifacts*, 369–392; Rosenberger, *On variational cross-examination*, 1–4; De Boer,*Explaining multistability*, 1–11; cf. Whyte, *What is multistability?*, 69–81.

One of the most significant contributions is Rosenberger's variational cross-examination methodology.[38] The method aims to describe technological mediations of artefacts by contrasting mainstream with alternative stabilities of the same technology to uncover and gain insights into the dominant paradigm design assumptions of a technology domain. The method foresees a two-step approach. The first step is to conduct a brainstorming session to identify both dominant and alternative stabilities of a specific technology. This process is referred to as "variational analysis" according to Ihde.[39] In the second step, the identified stabilities are compared using three multistability features: role within a program, the technology's concrete material tailoring, and the users' habits and comportments.

Taking up on Rosenberger's methodology, Jensen and Aagard[40] revisited and analyzed two HCI projects revealing novel insights on technologies roles, embodiment and material tailoring, and pointing to multistability as one of the most significant postphenomenological concepts for design. Other design researchers have come to recognize the importance of utilising the concept of multistability and postphenomenological research in research-through-design inquiries.[41] In particular, multistability as an analytical lens has proven to be particularly useful in studying how people interact with ambiguous, unfinished, and unfamiliar objects uncovering open-ended and insightful interactions that go beyond utility and usability.

The current paper methodology is inspired by variational cross-examination and research-through-design inquiries devising the deployment of ambiguous interactive systems. In this context, the term "role within a program" refers to the intended function or purpose of the technology as envisioned by the designer. It encompasses the *designer's intentions and inscriptions* related to the desired human-artifact interaction. The concept of technology's "concrete material tailoring" pertains to the physical and digital aspects of the technology, including its appearance and features. In this contribution, the traditional focus on "users' habits and comportments" is directed towards the analysis of human-technology relations. This shift allows for a deeper examination of how humans interact with technology, taking into account the complex dynamics and interplay between human beings and technological artifacts.

The cases selected for the comparative analysis are:

- A wearable for self-tracking technology representing the dominant stability in the field in terms of quantified-based and prescriptive data representations: the wrist-worn commercial smartwatch Fitbit Sense 2 by Fitbit, a wearable technology company producing fitness and activity wristband trackers for lifestyle and sport (Fibit, nd) (Fig. 3).
- A biosensing wearable device and speculative technology probe offering an alternative way to present data leveraging ambiguous and imprecise display, the bio-sensing shirt Ripple designed and deployed by Howell et al.[42] in an empirical investigation (Fig. 4).

38. Rosenberger, *Multistability and the agency of mundane artifacts*, 369–392; Rosenberger, *On variational cross-examination*, 1–14.

39. Don Ihde, *Husserl's missing technologies* (New York: Fordham University Press, 2016).

40. Mads Møller Jensen and Jesper Agaard, "A postphenomenological method for HCI research," in *Proceedings of OzCHI'18 30th Australian Conference on Computer-Human Interaction* (December 2018): 242–251.

41. Sabrina Hauser, *Design-oriented HCI through Postphenomenology*, PhD dissertation, Simon Fraser University, 2018; Sabrina Hauser et al., "An annotated portfolio on doing postphenomenology through research products," in *Proceedings of the DIS'18 ACM Designing Interactive Systems Conference* (June 2018): 459–471; Cf. van Dongen, *A designer's material-aesthetics reflections*.

42. Cf. Howell et al., *Tensions of data-driven reflection*, 1–13.

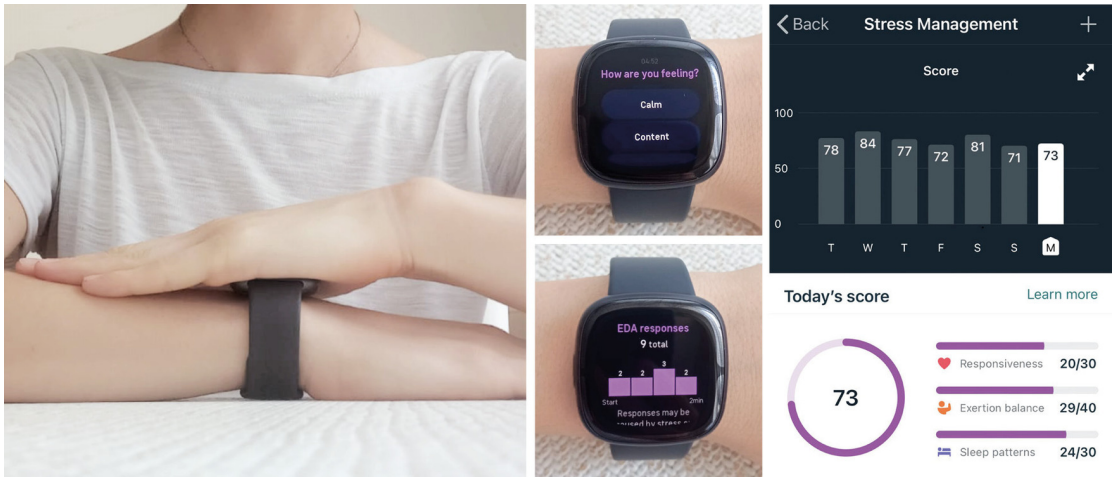

Figure 3: Fitbit Sense 2. EDA Scan and Stress Management dashboard. Pictures created by the author.

Figure 4: Ripple shirt. Users testing the system and thermochromic pinstripes displays. Courtesy of Noura Howell. Retrieved from https://nourahowell.com/projects/ripple.html.

Both devices leverage sensors measuring microfluctuations and changes in skin's sweat levels of the body, also known as skin conductance, galvanic skin response, or electrodermal activity. Fluctuations in this data may be associated with mental, physical, or affective arousal and excitement. However, it's important to note that these values are not indicative of whether the wearer's experiences are positive or negative, nor can they determine the cause of the arousal.[43]

In the following part of the section, the features of both devices, data representation modalities, and human-technology relations at play are presented and contrasted to discover how the materiality of the data representation may affect the user's interpretation of the same sensory data. Information on the functionalities and user experiences of the Fitbit device is sourced from the Fitbit website (Fitbit, nd) as well as customer reviews of Fitbit Sense 2, including reviews by So,[44] Song,[45] and Lee.[46] On the other hand, information on Ripple shirt is based on data retrieved from Howell et al.[47]

Designer's Intentions and Inscriptions

Fitbit Sense 2 is a wearable device equipped with a continuous electrodermal activity (cEDA) sensor, among other electronics. The device claims to identify stress levels by analyzing bodily vital signals, such as EDA, heart rate, heart rate variability, and skin temperature. Thanks to the sensor, computational power, and ad hoc visualizations, Fitbit Sense 2 encourages users to "track, understand, and manage stress" (Fitbit, nd) by monitoring and comprehending various bodily physical indications and patterns across time. The device's EDA-based number of body responses and recommendations provide straightforward and prescriptive guidance to monitor and improve stress for the wearer's well-being.

Conversely, the purpose of Ripple's design researchers

> rather than presenting data and inferences as already interpreted facts, ... designed an ambiguous biosensory data display to explore alternative design spaces and foster critical questioning of the data by users ... [and] to open opportunities for participants to explain their relationship to data through their situated interpretation.[48]

To this aim, the researchers deliberately designed the device's readout to be questionable and reduced the system's authority by leveraging ambiguity as a resource[49] on multiple levels. They specifically chose to represent skin conductance, as it is an inherently ambiguous phenomenon with various possible meanings associated with it. During the study, participants were informed about how the system worked, the potential imprecision of the readout due to the sensor and basic algorithmic processing (as opposed to complex computing), the influence of environmental temperature changes on the display, and the fact that individuals' skin electrodermal activity could result in different responsiveness to the device.

43. Jennifer Healey, "Physiological Sensing of Emotion," in *The Oxford handbook of affective computing*, eds. R. Calvo, S. D'Mello, J. Gratch and A. Kappas (Oxford: Oxford University Press, 2014), 204–216.

44. Adrienne So, "Review: Fitbit Sense This tracker measures stress — Sort of," *WIRED*, October 2022, https://www.wired.com/review/fitbit-sense-watch/.

45. Victoria Song, "Fitbit Sense 2 review: it doesn't make much sense," *The Verge*. 8 October, 2022, accessed March 2, 2023, https://www.theverge.com/23392564/fitbit-sense-2-review-google-fitness-tracker.

46. Alex Lee, "Fitbit Sense 2 review: I'm really stressed, apparently, and this smartwatch wants me to think about it," *Independent*, October, 2022, accessed March 2, 2023, https://www.independent.co.uk/extras/indybest/gadgets-tech/fitbit-sense-2-review-b2191752.html.

47. Cf. Howell et al., *Tensions of data-driven reflection*, 1–13.

48. Howell et al., *Tensions of data-driven reflection*, 1.

49. William W. Gaver et al., "Ambiguity as a Resource for Design," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York: ACM Press, 2003), 233–240; Phoebe Sengers and Bill Gaver, "Staying open to interpretation: engaging multiple meanings in design and evaluation," in *Proceedings of the 6th conference on Designing Interactive systems (DIS '06)* (2006): 99–108.

Concrete Tailoring

In order for the Fitbit Sense 2 cEDA tracker to work, the device should be worn on the wrist enabling the sensor to be in touch with the skin. Users can track continuously and on demand Electrodermal Activity (EDA) values. When the device detects stress signals, users receive real-time "buzz" stress alerts accompanied by stress-releasing recommendations, such as mindfulness sessions or breathing exercises. Additionally, users can manually log their daily moods and emotions from a predefined set of choices. The device offers the possibility to see session-related, daily and weekly stressful moments from body responses through histograms and numerical values. The device indicates that fewer EDA responses corresponds to more calmer states. Finally, each morning the system presents the user a stress score from 1 to 100 triangulating the EDA data, with physical activity exertion, and sleep patterns. According to the resulting score, Fitbit recommends calibrating daily activities accordingly "High score? Tackle your to-dos. Low score? Take a rest" (Fitbit, nd).

Unlike Fitbit, the Ripple shirt takes a different approach to displaying data. Instead of using a screen to provide quantitative and informative insights, the shirt itself serves as the medium for data visualization. The shirt incorporates thermochromic slow color variations occuring gradually over time. The shirt translates data detected from a skin conductance sensor embedded in the garment and modifies its pattern's color based on the wearer's arousal spikes. The shirt features three thermochromic threads sewn onto the left shoulder, which adjust their color in response to the wearer's arousal levels, as detected by the skin conductance sensor. When the wearer is not experiencing any significant arousal, the thermochromic threads blend with the base color of the garment and appear as a dark grey. However, when the wearer's arousal increases suddenly, causing a rise in skin conductance, the pinstripes become active. They change color from dark grey to white, gradually returning to the base color one by one over approximately ten minutes.

Human-Technology Relations, Habits and Behaviors

The analysis of human-technology relations in light of the designers' intentions and the material tailoring offer a great tool to explore the technological mediation at play. The following analysis is based on the revised version of human-technology relations curated by Kristensen and Prigge,[50] specifically tailored for the encounter of individuals with their own self-tracking data and devices. This analysis aims to unveil the mutual shaping relations between wearers and wearable technology, beyond usability and utility.

- In the *hermeneutic relation* by tracking bodily signals, technologies like Fitbit and Ripple shirt offer a representation of the self, providing feedback and visualizations that make intangible aspects of oneself tangible and visible in ways that would otherwise not be possible. Through this process, a "data self" is constructed, taking on various forms for the users to enact reflective accounts and ways of knowing the self.[51] Van Den Eede[52] explains that users of self-tracking technologies experience an objectified representation of themselves that is not an accurate mirror, but rather a "data double" that requires interpretation. This "data double" is a dynamic reconfiguration of data streams[53] that shapes the reality individuals have access to. In the cases of Ripple and Fitbit, the hermeneutic relations unfolded in different ways. As for the Fitbit Sense 2, the device amplified in the wearers' awareness the presence of the phenomenon tracked, opening up to data-driven reflection: the device readout primarily prompted considerations with respect to

50. Dorthe Brogård Kristensen and Carolin Prigge, "Human/Technology Associations in Self-Tracking Practices," in *Self-Tracking*, ed. B. Ajana (Cham: Palgrave, 2018), 43–59.

51. Cf. Kristensen and Prigge.

52. Cf. Van Den Eede, *Tracing the tracker*, 143–158.

53. Minna Ruckenstein, "Visualized and interacted life: Personal analytics and engagements with data doubles," *Societies*, Vol. 4.1 (2014): 68–84; Kevin D. Haggerty and Richard V. Ericson, "The surveillant assemblage," *The British Journal of Sociology*, Vol. 51.4 (2000): 605–622.

stressful moments detected by the wearable.[54] On the other hand, Ripple — not providing an already defined interpretation of the data — invited the wearers to formulate a broader range of interpretations, fostering more open-ended emotional meaning making processes, and stimulated discussions based on the display changes.[55]

However, what reality is made present through the materiality of the data? Fitbit presents stress as a quantified account through the number of body responses and scores, framing arousal parameters as directly connected with stress intended as a measurable, monitorable, and understandable entity. The system notifies users with buzzes and alerts when stress signs are recognized, providing recommendations on how to achieve calmer states and lower their body responses, Fitbit proceeds to normalize their bodies towards certain values of "optimal stress".

Conversely, Ripple detects and visualizes a color change only during arousal spikes, creating an ambiguous display that prompts a wider range of uncodified interpretations and experiences, triggering reflections on individuals' feelings, interpersonal relationships, and the potential of emotional displays. Study participants looked for patterns between color changes and their feelings, associating display changes with i.e., moments of excitement or enjoyment, unexpected events, rewarding situations, creative flow, and physical exertion. Interestingly, participants considered the display as representing the "presence" or "absence" of feelings and as a measure of emotion.[56] As noted by Howell et al.:

> By calling attention to, and perhaps even rewarding, certain kinds of emotion with a visible display change, Ripple implicitly lumped all other emotions together as not worth displaying. Participants mapped nonresponse to lack of emotion, which impacted their sense of self for better or worse.[57]

These examples demonstrate that different physicality of the same vital sign (i.e., skin conductance/electrodermal activity) data may prompt users to interpret their bodies and life events differently. The way the data are materially presented in the devices may affect users' interpretation and let them associate skin conductance arousals as signs of stress to discipline (Fitbit) or as an emotional moment that calls for reflection (Ripple).

- In the *embodiment relation*, the user could be defined as a "new experiencing entity of being at one with or merging with the technology."[58] In both Fitbit and Ripple examples, feedback and data representations have been iteratively linked with and incorporated into feelings and aspects of the body, transforming how individuals perceived themselves and experienced their own bodies. Van den Eede says that self-trackers "perceive in an embodied manner an however objectified version of [their] embodiment."[59] In this scenario, the dialogic and mutual influencing relation between bodily perceptions and data representations goes two ways. In one stance, perceiving the correspondence between the representation and the subjective feelings may strengthen the merging with technologies as being another sensory apparatus of the body. On another stance, incorporating the feelings from the device representation into bodily perceptions may alter one's subjective experience to feel one with the technology. Fitbit frames the technological-mediated wearer as an entity able to read stress levels from her/his body, bringing stress in the upfront of people's awareness. However, by quantifying the number of body responses and alerting users of their stressful moments through buzzes and recommendations, some Fitbit users noted that the smartwatch may amplify people's perception of stress and drive them to feel more stressed than

54. Cf. So, *Review*; cf. Song, *Fitbit Sense 2 review*.

55. Cf. Howell et al., *Tensions of data-driven reflection*, 1–13.

56. Howell et al., 8.

57. Howell et al., 7.

58. Cf. Kristensen and Prigge, *Human/Technology Associations in Self-Tracking Practices*, 48.

59. Cf. Van Den Eede, *Tracing the tracker*, 151.

they actually are, embodying the system readout.[60] A similar situation happened during interactions with Ripple. All participants connected the shirt readout with their feelings amplifying their awareness and emotional presence, while some of them incorporated the display changes into their bodily awareness experiencing being a "more emotional" or "less emotional" person.[61] In sum, while both the devices allowed the users to incorporate the data they collected and displayed, the prescriptive nature of Fitbit led individuals to experience "pre-defined" (by the device) sensations (i.e., stress); instead, Ripple's users experienced a greater emotional presence intertwining the data prompted by the device with their inner emotional sensations.

- In the *alterity mode*, the subject progressively "becomes aware of how the technology might also amplify, restrict, reduce or even contradict the subjective experience of the self."[62] In this situation, the focus turns to otherness than the self. There are multiple ways in which this relation may occur. A misalignment between the device readout and the user's expectations, may bring attention to the tracking device making it more present to the users' awareness as an object of reflection. Some Fitbit consumer's review[63] note accuracy issues in terms of wrong alerts time and stress score detection, unappropriated and context-unrelated tips, and expressed the difficulty to make data actionable.

  > The Sense didn't have any useful tips except telling me to breathe, which was ironic given that our air quality was so bad. Even on days when my head was about to explode, my Stress Management score stayed over 90. Today, a normal day, my Stress Management score is 74 because I had a hard workout yesterday. The score seems only marginally related to stress or my ability to manage it.[64]

  While this was not an intended outcome of the Fitbit designers, the impossibility of engaging in hermeneutic or embodiment relations with the device and data did still prompt users' reflections on the phenomenon tracked (i.e., stress).

  > I didn't always respond to alerts as intended, but overall, it is good to take a step back and acknowledge how you feel in a high-stress moment.[65]

  Conversely, the device contestability was one of the intended outcomes of Ripple shirt to be conveyed through multifaceted ambiguity, imprecision, and slow subtle display changes. Despite this, all the participants seemed to have invested in the data display of an unexpected authority, instead of engaging in critical questioning. When the device presented an unexpected spike, some participants just observed they were unable to find a link between the display changes and their feelings. The researchers realized that this may have been due to the materiality of Ripple's ambiguous display which "could never be clearly wrong" as it "did not provide an explicit interpretation linking data to emotion, an interpretation which might have been accepted or dismissed as participants chose."[66]

In summary, the materiality of wearable technologies for self-tracking may amplify and reduce human's perceptions and experiences, both in terms of sensor capabilities and data representations. They amplify the phenomena that the sensors are able to track and — at the same time — tend to conceal and reduce the relevance of untracked aspects that contribute to a more holistic understanding of lived experiences. In addition, the materiality of the data makes visible and amplifies only specific aspects of the tracked phenomenon, hiding and disregarding other variables and values that not represented in the data display.

60. Cf. Lee, *Fitbit Sense 2 review*.
61. Cf. Howell et al., *Tensions of data-driven reflection*, 1–13.
62. Cf. Kristensen and Prigge, "Human/Technology Associations in Self-Tracking Practices," 51.
63. Cf. So, *Review*; cf. Song, *Fitbit Sense 2 review*; cf. Lee, *Fitbit Sense 2 review*.
64. So, *Review*.
65. Cf. Song, *Fitbit Sense 2 review*.
66. Cf. Howell et al., *Tensions of data-driven reflection*, 9.

The materiality of wearables plays a crucial role in shaping, inviting, and inhibiting certain behaviors and actions throughout the process of tracking. Wearing the device itself is a prerequisite for tracking to take place. This act of wearing sensors and accessing data representations of the self not only impacts how individuals understand their bodies and make corresponding choices but also influences the very concept of what it means to be "healthy," "stressed," or "emotional,"[67] often disciplining their bodies to said ideals.

Overall, these findings underscore the importance for designers to consider not only the usability and practicality of wearable technologies but also the potential impact of their materiality on individuals' lived experiences and subjective well-being.

The Interplay Between Multistability and Ambiguity, and the Implications for Designers

This paper investigates the postphenomenological concept of multistability in the field of wearable technology for self-tracking. It provides a productive lens to explore the mediating power of technology design in the way individuals perceive themselves and act in their world. Multistability is used as an analytical concept to analyze the different stabilities emerging from a prescriptive traditional commercial activity tracker and an ambiguous research-through-design biosensing shirt through variational cross-examination.

As a generative concept, multistability has been paired with ambiguity in design, reframed as a design resource to further explore the power of material tailoring in mediating users' experience and behaviors when designers do a step back in imbuing technologies with preferred meanings.

The evidence from the analysis points towards a twofold reflection. Firstly, the deliberate use of ambiguity in the design of wearable data representations may allow for a more intimate and personal relationship between users and their data, as well as their sense-making processes. By refraining from rigidly codifying the meaning of data, designers provide users with the freedom to form their own interpretations. This approach has the potential of empowering users to develop a deeper connection with their data, resulting in a more meaningful and rewarding interaction with wearable technologies.

Secondly, this approach presents an opportunity for designers to reflect on the socio-cultural and material dimensions of technology and their influence on users' experiences with their data, beyond their deliberate ambitions. Comparing the designers' intentions with the concrete materiality and human-technology relations helps to uncover unintended consequences and acknowledge the intrinsic multistability of the devices.

Finally, by embracing ambiguity as a design resource, fashion and design researchers can develop a more nuanced understanding of the complex interplay between technology, materiality, and socio-cultural context, and use this knowledge to inform more thoughtful research in the field. Further research is needed to craft data into different wearable forms through fashion and design empirical investigations and explore the power of material tailoring in mediating users' experiences, comparing different ways to wear and experience personal data.

67. Cf. De Boer, *Explaining multistability*, 1–11; Cf. Van Den Eede, *Tracing the tracker*, 143–158; Elise Li Zheng, "Interpreting fitness: self-tracking with fitness apps through a postphenomenology lens," *AI & Society* (2021): 1–12.

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