Soulbloom: towards physicalisation of personal data for well-being and communication

BENJAMIN L. SEARLE

Soulbloom is a tangible interface that promotes self-awareness and mental health by mirroring one's physical and mental state through symbolic interactions. The device supports personal and social use as a non-verbal expression medium to communicate affective state. Using physiological, reflective, and contextual data, the system utilises artificial intelligence to infer users' state, which is then expressed through the morphology of the device based on crossmodal correspondences that adapt to users' personal 'language'. *SoulBloom* imagines a future where AI and robotics can be perceived as empathetic extensions of oneself, furthering our understanding of human-technology relationships and how they are formed.

CCS Concepts: • **Hardware → Emerging interfaces**; • **Human-centered computing → Visualization design and evaluation methods**; **Ubiquitous and mobile computing design and evaluation methods**.

Additional Key Words and Phrases: mental well-being, physical health, emotional state recognition, human-robot interaction, social robotics

1 INTRODUCTION

Mental health is a critical issue affecting millions worldwide, often leading to serious ramifications for physical and social well-being. Untreated mental health issues may contribute to poor physical health outcomes, reduced quality of life, and an increased risk of suicide or self-harm. [34] However, waiting lists, high costs, and remnant stigmas have rendered treatment and support inaccessible to many.

Increasing demand and amplified conversation around well-being have convinced industries and academic institutions to find solutions through technology. Commercial wearables have long been available to promote physical well-being practices, and digital solutions for self-reflective practices, such as habit trackers and journalling apps and practices, have also become commonplace.

Unfortunately, many existing designs for solutions to mental health and physical well-being issues tend to focus on a single aspect of well-being, further fragmenting the process of self-care or making it inaccessible. [13] This results in a lack of consideration for the interplay between physical and mental health, which is critical to ensuring that the whole person can achieve wellness.

Soulbloom proposes a tangible interface that integrates data collection, processing, and physicalisation to promote both mental and physical health through self-awareness and self-reflective practices. The device is a tangible interface that relies on various visual crossmodal correspondences to reflect on the users physical and mental state - supporting interactive capabilities that allow for both passive and active possibilities for engagement.

This paper discusses previous work on physiological and emotional state recognition, personal informatics, and human-robot interaction. The design of *Soulbloom* is described in detail, after which interaction scenarios and evaluation plans are presented. Lastly, benefits and limitations surrounding its implementation are considered. human-robot relationship

2 RELATED WORK

This section discusses related work in emotional state recognition using physiological data, and developments in personal informatics and tangible interfaces. Crossmodal correspondences between visual perception and emotions are

discussed, including robotics and the arts in relation to physicalisation of personal data and how they are interpreted by individuals.

2.1 Physiological data for emotional state detection

HCI literature has dealt with the inference of emotional state across several modalities. Can et al. used accelerometer, heart, and skin conductance data from commercially available smartwatches to infer when users were stressed [6]. In their further work [8], they gather evidence for other works that have achieved significant results in broader mood detection, or following models of emotional state such as Russell's circumplex model of affect across the dimensions of valence and arousal [30]. Egger's review of emotion detection through physiological data discusses less-explored modalities being deployed successfully, such as voice recognition, facial expressions, and respiration. [12] From this work, new opportunities emerge for environmentally integrated data collection devices that may be less obtrusive than traditional wearables. Notably, Searle attempted to *anticipate* emotion regulation behaviour, such as nail-biting, allowing users to become aware of their physiological state *before* it peaked so as to explore in situ interactions beyond in-retro. [32]

2.2 Personal informatics

Personal informatics (PI) is a class of practices and technologies about gathering relevant personal information across various experiences and activities to create self-awareness and support reflection. [1] Of recent PI literature, 74% of all artefacts created are digital [13]; however Thudt uncovered preferences for non-digital forms of self-tracking, due to more frequent familiarity with the materials and forms they take. [37] Furthermore, when it comes to artefacts for the reflection stage of Li's model of personal informatics [21], digital mediums for data visualisation often lean on complex mathematical notation, sacrificing accessibility. [2] In their work, Abtahi [2] also discusses emerging trends of "casual" data representations that take on more artistic and metaphorical forms. They suggest the primary purpose of such experimental forms of data representation is to invite new types of engagement and interactions between the data and the user.

Lee and Hong [20] invited participants to create tangible artefacts of their experiences, and found that such flexible modalities supported "expressive therapy, self-soothing, and emotion self-regulation". Building upon previous work on the relations between form and emotion[23], they suggest that such output could be extended to incorporate intelligent systems to track patterns. Wannamaker's work on I/O bits [38] offers insight into in situ instead of automated data collection. They also conclude that PI technologies would benefit from integrating of various facets of data collection across documentary, reflective, and physiological signals.

Further good design practices for tangible PI technologies are discussed by Lee [20], and Coskun [11], such as the requirement for personal systems to be developed, flexibility in interaction and customisation [15], and the benefits of socially interactive features. Pantzar warns of the 'objectivity' of PI technologies and their effects on self-perceived state, mentioning the conflict between how they were and how they felt (describing the "numbers" and their perception respectively). [27]

2.3 Crossmodal correspondences in art and social robotics

Crossmodal correspondences or congruences are non-arbitrary links between various perceptive and affective modalities. [3, 28] Numerous such links have been described that link emotional states to the perception of light, colour, shape, angle, and texture [9, 17, 22, 24, 26] More recently, in art, we have seen robotics deployed with animation associated

Fig. 1. "Can't help myself" by Sun Yuan and Peng Yu represents a robot with the Sisyphean task of cleaning up a perpetual mess.

with emotional states [35] and to illicit emotions through engaging interactions and life-like metaphors.[4] Perhaps most famously, Sun Yuan and Peng Yu's Can't Help Myself (see Figure 1) deploys an industrial robot completing the Sisyphean task of cleaning up a mess.[35] Viewers have associated it with the experience of trauma: *"this is what trauma feels like. you can sweep it away but it's always there no matter what you do"*, and suggest it elicits the feeling of agony through its actions and 'dances'. [16]

Numerous studies have shown that people have created intimate relationships with robotics perceived as 'living', such as with their Roombas [36], or well-being focused robotic agents [5, 10, 19]. These works suggest that people willingly form emotional connections and relationships with technology perceived as organic or 'living'.

3 SOULBLOOM

3.1 Technical Overview

Soulbloom is a tangible interface that mirrors the user's physical and mental state through symbolic language and congruence. The device achieves this by employing an open-protocol information architecture to combine diverse data sources and multi-modal emotional state inference, finally expressing physical and emotional state through metaphorical languages and congruence across various manipulable characteristics. The device supports both individual and social use to help reflective mental health practices and as a non-verbal communication medium of well-being.

3.1.1 Data collection & processing. To achieve reliable and versatile inference of both physical and mental state, the system requires a diverse set of data to work. Currently, few self-tracking technologies exist that pull from a suitably multimodal set of data. To address this, *Soulbloom* assumes an open standard of personal informatics data so that it can

	Physiological Data	Experiential Data	Contextual data
Data types	• Heart • Motion & postural data • Facial expressions • Respiratory patterns	• Reported notes • Reflections • Goals	• Events • People • News • Location
Data sources	• Wearable sensors • Environmental sensors • Webcam • Microphone	• Journals • Habit trackers	• Calendar • Email • Location

Fig. 2. Utilised data types for physical and emotional state inference.

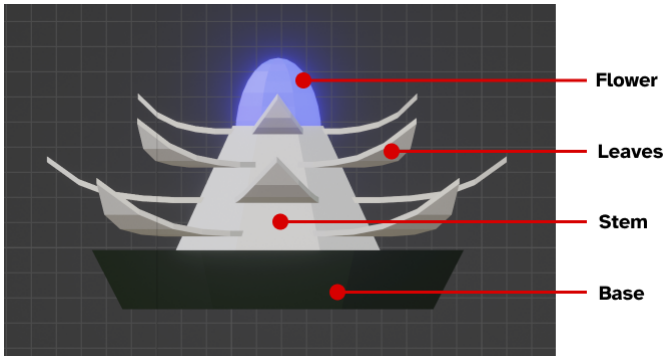

Fig. 3. "Anatomy' of *Soulbloom* with component names.

pull from wearables, situated sensors, and ubiquitous input devices such as webcams and microphones (see Figure 2) - chosen for their significance to physical well-being and emotional state inference [7, 12]. Data related to the user's 'lived experiences' are collected from documentary and reflective informatics tools, such as digital journalling apps and habit trackers, which provide invaluable insight into the user's individual experiences. [27] To provide the system with contextual awareness, spatiotemporal data would also be pooled to track correlations. The user's calendar, email, and location information could be integrated to satisfy this requirement.

Inferring emotional state from the data types mentioned above is achieved through a combination of Machine Learning (ML) and Natural Language Processing (NLP) algorithms for non-textual and textual data, respectively. [8, 12, 25] Inferred mental states and physiological markers are then expressed through the device's morphological modalities. (See §3.1.2)

3.1.2 The device and data physicalisation. The device consists of four main parts (see Figure 3). The flower is composed of a light surrounded by a hard, translucent casing that is touch and pressure sensitive. The leaves are built with robotic arms encased in touch-sensitive soft silicon shells. [39] The stem is a simple plastic casing with a rotary motor attaching it to the base, enabling it to move in one degree of freedom. Lastly, the base contains the control unit, networking components, and power supply. To create dimensions of expression that may be used to represent various aspects of state, the device uses the universal and culture-agnostic language of plantlife:

- **Leaf shape** (see Figure 4.B): The 'leaves' can morph between a round or sharp shape. Such properties are congruent with valence and arousal [30] when associated with emotional states. [22, 24, 26]

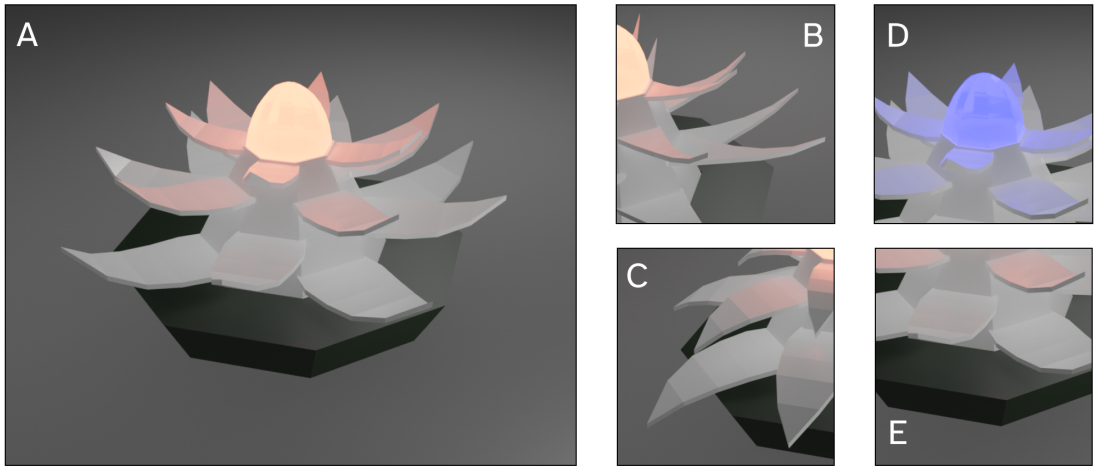

Fig. 4. Prototype renders of *Soulbloom*, a versatile tangible device that mimics the user's physical and emotional state through metaphors and congruence.

- **Leaf angle** (see Figure 4.C): The angle of leaves can be lowered or raised individually or together. Direction and angularity are congruent with arousal. [9, 31]
- **Flower light** (see Figure 4.D): The light capable of displaying the full RGB colour spectrum, adjustable brightness, and lighting patterns (such as flickering, breathing, or pulsing). Colour and brightness are congruent with complex emotional states, as well as valence and arousal. [22, 24]
- **Stem movement** (see Figure 4.E): The stem rotates in an oscillatory motion with variable speed, smoothness, and regularity. Motion behaviour is congruent with longitudinal emotional state. [23]

It is important to note that the meaning of each characteristic is demonstrative and invites the user to consider alternative interpretations for each, such as sociocultural and botanical. [33] The intentional ambiguity of meaning is informed by the need for personalisation and customisation of data interactions when it comes to forming individual practices. [15, 20, 29]

3.2 Interactions

3.3 Personal scenarios

Soulbloom is primarily designed for personal use. It may be situated on the user's desk, allowing their internal state to be reflected to them throughout their working day. For example, during a meeting, the stem may oscillate quickly and irregularly to reflect the user's speech and breathing behaviour, which may result from nervousness. Furthermore, in the afternoon, the flowers may lower and the leaves morph to sharp representing fatigue and the associated state of apathy.

Interactively, the user may use the leaves' touch-sensitive surfaces to change their individual shapes or angles to represent personally meaningful reflections or goals. These interactions contribute to forming the user's relationship

with the device through the creation of a shared expressive language. For example, users may express their desired or experienced state in situ by morphing the device, noted in symbolic meaning for a particular leaf or flower colour.

3.4 Social scenarios

Whilst the primary focus of *Soulbloom* is for personal use, literature suggests that socialisation of the device's interaction capabilities may be beneficial for all participating parties regarding motivation, accountability, and connection. [29] For example, the device may be used between romantic partners as a communication aid for their emotional and physical state that can help understand how they are, or between non-verbal autism spectrum disorder (ASD) patients and their carers, who may have divergent associations regarding expression and crossmodal correspondences. [18] Devices may be synchronised, shared, or linked with others to turn them into communication tools for affective and physical states. Engaging with the device offers a non-verbal symbolic communication medium, such as sending symbolic messages of "rounding one's leaf" from one device to another as a wish of good luck for a stressful situation a partner may be experiencing.

4 PLANS FOR EVALUATION

The evaluation of *Soulbloom* would focus on the how the user perceives the holistic mirroring of their physical and user, and whether it has any perceived effect on their well-being and self-awareness. To inform future work, the formation of the human-robot relationship would be investigated.

We would conduct longitudinal diary studies (2-4 weeks) involving a diverse set of users from technical and non-technical backgrounds. Participants would be given the device and supporting apparatus (such as wearables, sensors, and software) to take home. Throughout the study, participants would follow reflective journalling practices to be used as input for the device and as reference for the investigators. After the study, microphenomenological interviews would be conducted to better understand the experience of interactions between the user and the device. [14] The main topics of interest would include: (1) perceived effect on mental and physical well-being and self-awareness; (2) formation of connection to the device; (3) openness to the use of such technology.

Data processed by the device and interactions would be recorded for analysis to help develop hypotheses for how the relationship is formed. Engagement time and type would be primary quantitative markers of the project's success.

Additional studies exploring the social interactions through synchronised or linked devices would also be recommended.

5 CONTRIBUTIONS, BENEFITS, AND LIMITATIONS

The main contribution of *Soulbloom* regards the user-device interaction feedback loop, which integrates complex personal data physicalisation with user expression and perception through intuitive and universal correspondences. The device extends the literature with its holistic approach to include both physical and mental well-being to promote health and self-improvement.

Soulbloom has the following benefits: (1) users' situational and longitudinal mental state can be reflected in the device thanks to its diverse data architecture; (2) users can improve their awareness of their emotions and experiences through the recognition of recurring patterns in the device's morphology; (3) users can define and implement their own 'language' of experience and mental state; (4) users can communicate their mental state non-verbally with themselves or with others through universal or personal metaphors.

Soulbloom has the following limitations: (1) technical feasibility of open-protocol for PI data; (2) user willingness to gather and create necessary data; (3) user willingness to participate and engage with mental well-being practices; (4) social perception and privacy concerns.

6 ETHICAL CONSIDERATIONS

The biggest issue with the use of *Soulbloom* regards the accuracy and consequent user interpretation of its mirroring. Misaligned expectations or results may have detrimental effects on one's self-perception or self-awareness if the device is imbued with some sense of authority due to its data. [29] Users must be well-informed about the device's specifications to ensure healthy practices and relationships are formed around it.

Soulbloom relies on continuous data collection across numerous modalities to work as intended, which raises concerns around data privacy and its usage. User consent will be required, and they will be assured about proper data management practices, such as encryption and anonymisation.

7 CONCLUSION

This paper proposes *Soulbloom*, a tangible interface that mirror the user's physical and mental state through symbolic and congruent modalities. The feasible accuracy for inferring mental state and physiological markers combined with our novel interactions enables users to engage with their lived experiences combining both objective data and their subjective perceptions expressed in their own 'symbolic language'. Finally, the paper discusses an evaluation plan for the system, along with contributions, benefits, and limitations associated with its implementation.

Social trends signal an increasing desire for self-improvement and well-being; thus, it is crucial to explore how technology can not only support but extend our understanding and awareness of self and others. We believe that designing for the personal informatics paradigm contributes to creating a more empathetic and sustainable future.

REFERENCES

[1] 2023. Personal informatics. https://www.personalinformatics.org/

[2] Parastoo Abtahi, Victoria Ding, Anna C. Yang, Tommy Bruzzese, Alyssa B. Romanos, Elizabeth L. Murnane, Sean Follmer, and James A. Landay. 2020. Understanding Physical Practices and the Role of Technology in Manual Self-Tracking. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 4 (Dec. 2020), 115:1–115:24. https://doi.org/10.1145/3432236

[3] Elisheva Ben-Artzi and Lawrence E Marks. 1995. Visual-auditory interaction in speeded classification: Role of stimulus difference. *Perception & Psychophysics* 57, 8 (1995), 1151–1162.

[4] Leticia S. S. Bialoskorski, Joyce H. D. M. Westerink, and Egon L. van den Broek. 2009. Mood Swings: design and evaluation of affective interactive art. *New Review of Hypermedia and Multimedia* 15, 2 (Aug. 2009), 173–191. https://doi.org/10.1080/13614560903131898 Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/13614560903131898.

[5] Indu P Bodala, Nikhil Churamani, and Hatice Gunes. 2021. Teleoperated robot coaching for mindfulness training: A longitudinal study. In *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)*. IEEE, 939–944.

[6] Yekta Said Can, Bert Arnrich, and Cem Ersoy. 2019. Stress detection in daily life scenarios using smart phones and wearable sensors: A survey. *Journal of biomedical informatics* 92 (2019), 103139.

[7] Yekta Said CAN and Cem ERSOYSenior Member. 2022. Smart Affect Monitoring with Wearables in the Wild: An Unobtrusive Mood-Aware Emotion Recognition System. *IEEE Transactions on Affective Computing* (2022), 1–12. https://doi.org/10.1109/TAFFC.2022.3232483 Conference Name: IEEE Transactions on Affective Computing.

[8] Yekta Said CAN and Cem ERSOYSenior Member. 2022. Smart Affect Monitoring with Wearables in the Wild: An Unobtrusive Mood-Aware Emotion Recognition System. *IEEE Transactions on Affective Computing* (2022).

[9] Nuoya Chen, Jinfeng (Jenny) Jiao, Xiucheng Fan, and Shaobo (Kevin) Li. 2021. The shape of loneliness: The relationship between loneliness and consumer preference for angular versus circular shapes. *Journal of Business Research* 136 (Nov. 2021), 612–629. https://doi.org/10.1016/j.jbusres.2021.07.046

[10] Andreia P Costa, Louise Charpiot, Francisco Rodríguez Lera, Pouyan Ziafati, Aida Nazarikhorram, Leendert Van Der Torre, and Georges Steffgen. 2018. More attention and less repetitive and stereotyped behaviors using a robot with children with autism. In *2018 27th IEEE International*

Symposium on Robot and Human Interactive Communication (RO-MAN). IEEE, 534–539.

[11] Aykut Coşkun and Armağan Karahanoğlu. 2022. Data Sensemaking in Self-Tracking: Towards a New Generation of Self-Tracking Tools. *International Journal of Human–Computer Interaction* 0, 0 (May 2022), 1–22. https://doi.org/10.1080/10447318.2022.2075637 Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/10447318.2022.2075637.

[12] Maria Egger, Matthias Ley, and Sten Hanke. 2019. Emotion recognition from physiological signal analysis: A review. *Electronic Notes in Theoretical Computer Science* 343 (2019), 35–55.

[13] Daniel A. Epstein, Clara Caldeira, Mayara Costa Figueiredo, Xi Lu, Lucas M. Silva, Lucretia Williams, Jong Ho Lee, Qingyang Li, Simran Ahuja, Qiuer Chen, Payam Dowlatyari, Craig Hilby, Sazeda Sultana, Elizabeth V. Eikey, and Yunan Chen. 2020. Mapping and Taking Stock of the Personal Informatics Literature. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 4 (Dec. 2020), 126:1–126:38. https://doi.org/10.1145/3432231

[14] María Isabel Gaete Celis. 2019. Micro-phenomenology and traditional qualitative research methods. *Constructivist Foundations* 14, 2 (2019), 146–149.

[15] Rúben Gouveia and Daniel A Epstein. 2023. This Watchface Fits with my Tattoos: Investigating Customisation Needs and Preferences in Personal Tracking. (2023).

[16] Alex Greenberger. 2022. 'me watching Y'all cry over a robot scooping Red Paint': Sun Yuan and Peng Yu installation becomes bizarre viral hit on social media. https://www.artnews.com/art-news/news/sun-yuan-peng-yu-cant-help-myself-twitter-tiktok-1234615686/

[17] Souta Hidaka, Wataru Teramoto, and Yoichi Sugita. 2015. Spatiotemporal Processing in Crossmodal Interactions for Perception of the External World: A Review. *Frontiers in Integrative Neuroscience* 9 (2015). https://www.frontiersin.org/articles/10.3389/fnint.2015.00062

[18] Souta Hidaka and Ayako Yaguchi. 2018. An investigation of the relationships between autistic traits and crossmodal correspondences in typically developing adults. *Multisensory Research* 31, 8 (2018), 729–751.

[19] Hee Sun Kang, Kiyoko Makimoto, Rie Konno, and In Soon Koh. 2020. Review of outcome measures in PARO robot intervention studies for dementia care. *Geriatric Nursing* 41, 3 (2020), 207–214.

[20] Kwangyoung Lee and Hwajung Hong. 2017. Designing for Self-Tracking of Emotion and Experience with Tangible Modality. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. Association for Computing Machinery, New York, NY, USA, 465–475. https://doi.org/10.1145/3064663.3064697

[21] Ian Li, Anind Dey, and Jodi Forlizzi. 2010. A stage-based model of personal informatics systems. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 557–566.

[22] Anan Lin, Meike Scheller, Feng Feng, Michael J Proulx, and Oussama Metatla. 2021. Feeling Colours: Crossmodal Correspondences Between Tangible 3D Objects, Colours and Emotions. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–12. https://doi.org/10.1145/3411764.3445373

[23] Edward Melcer and Katherine Isbister. 2016. Motion, emotion, and form: exploring affective dimensions of shape. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 1430–1437.

[24] Oussama Metatla, Emanuela Maggioni, Clare Cullen, and Marianna Obrist. 2019. "Like Popcorn": Crossmodal Correspondences Between Scents, 3D Shapes and Emotions in Children. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. ACM, Glasgow Scotland Uk, 1–13. https://doi.org/10.1145/3290605.3300689

[25] Pansy Nandwani and Rupali Verma. 2021. A review on sentiment analysis and emotion detection from text. *Social Network Analysis and Mining* 11, 1 (2021), 81.

[26] Letizia Palumbo, Nicole Ruta, and Marco Bertamini. 2015. Comparing Angular and Curved Shapes in Terms of Implicit Associations and Approach/Avoidance Responses. *PLOS ONE* 10, 10 (Oct. 2015), e0140043. https://doi.org/10.1371/journal.pone.0140043 Publisher: Public Library of Science.

[27] Mika Pantzar and Minna Ruckenstein. 2017. Living the metrics: Self-tracking and situated objectivity. *DIGITAL HEALTH* 3 (Jan. 2017), 2055207617712590. https://doi.org/10.1177/2055207617712590 Publisher: SAGE Publications Ltd.

[28] Geoffrey R Patching and Philip T Quinlan. 2002. Garner and congruence effects in the speeded classification of bimodal signals. *Journal of Experimental Psychology: Human Perception and Performance* 28, 4 (2002), 755.

[29] Kyrill Potapov and Paul Marshall. 2020. LifeMosaic: co-design of a personal informatics tool for youth. In *Proceedings of the Interaction Design and Children Conference (IDC '20)*. Association for Computing Machinery, New York, NY, USA, 519–531. https://doi.org/10.1145/3392063.3394429

[30] James A Russell. 1980. A circumplex model of affect. *Journal of personality and social psychology* 39, 6 (1980), 1161.

[31] Alejandro Salgado-Montejo, Carlos Velasco, Juan Sebastián Olier, Jorge Alvarado, and Charles Spence. 2014. Love for logos: Evaluating the congruency between brand symbols and typefaces and their relation to emotional words. *Journal of Brand Management* 21, 7 (Nov. 2014), 635–649. https://doi.org/10.1057/bm.2014.29

[32] Benjamin Lucas Searle, Dimitris Spathis, Marios Constantinides, Daniele Quercia, and Cecilia Mascolo. 2021. Anticipatory Detection of Compulsive Body-Focused Repetitive Behaviors with Wearables. In *Proceedings of the 23rd International Conference on Mobile Human-Computer Interaction* (Toulouse amp; Virtual, France) *(MobileHCI '21)*. Association for Computing Machinery, New York, NY, USA, Article 17, 15 pages. https://doi.org/10.1145/3447526.3472061

[33] Beverly Seaton. 2012. *The language of flowers: A history*. University of Virginia Press.

[34] Amy E Sickel, Jason D Seacat, and Nina A Nabors. 2014. Mental health stigma update: A review of consequences. *Advances in Mental Health* 12, 3 (2014), 202–215.

[35] Yuan Sun and Yu Peng. 2016. Can't help myself. https://www.guggenheim.org/artwork/34812

[36] Ja-Young Sung, Lan Guo, Rebecca E Grinter, and Henrik I Christensen. 2007. "My Roomba is Rambo": intimate home appliances. In *UbiComp 2007: Ubiquitous Computing: 9th International Conference, UbiComp 2007, Innsbruck, Austria, September 16-19, 2007. Proceedings 9*. Springer, 145–162.

[37] Alice Thudt, Uta Hinrichs, Samuel Huron, and Sheelagh Carpendale. 2018. Self-reflection and personal physicalization construction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.

[38] Kendra A. Wannamaker, Sandeep Zechariah George Kollannur, Marian Dörk, and Wesley Willett. 2021. I/O Bits: User-Driven, Situated, and Dedicated Self-Tracking. In *Designing Interactive Systems Conference 2021 (DIS '21)*. Association for Computing Machinery, New York, NY, USA, 523–537. https://doi.org/10.1145/3461778.3462138

[39] Mengjia Zhu, Shantonu Biswas, Stejara Iulia Dinulescu, Nikolas Kastor, Elliot Wright Hawkes, and Yon Visell. 2022. Soft, wearable robotics and haptics: Technologies, trends, and emerging applications. *Proc. IEEE* 110, 2 (2022), 246–272.