Journal of Ambient Intelligence and Humanized Computing
https://doi.org/10.1007/s12652-024-04762-6

ORIGINAL RESEARCH

TIDAL: exploring the potential of data physicalization-based interactive environment on runners' motivation

Mengyan Guo[1] · Jun Hu[1] · Steven Vos[1,2]

Received: 12 June 2023 / Accepted: 24 January 2024

Abstract
Representing fitness-related data physically can better help people gain awareness and reflect on their physical activity behavior. However, there has been limited research conducted on the impact of physicalizing personal data in a public context, particularly regarding its effect on motivations for physical activity. Augmenting the physical environment with interactive technology holds great promise in facilitating outdoor physical activity. To explore the design space of data physicalization-based interactive environments, we created TIDAL, a design concept that provides physical rewards in the form of tiles on the road to acknowledge runners' goal achievements. We created a video prototype as a probe to gather insights through semi-structured interviews with six recreational runners to evaluate TIDAL. The co-constructing stories method, a participatory design technique, was employed during these interviews to facilitate qualitative evaluation. The results of our study showed that TIDAL has the potential to increase runners' motivation. We reported the key insights derived from participants' feedback and co-constructed stories and discussed the broader implications of our work.

Keywords Interactive environment · Physical activity · Data physicalization · Urban design

1 Introduction

Physical inactivity has become a global pandemic threatening public health. It is the fourth leading cause responsible for more than 5 million theoretically preventable deaths annually (Kohl et al. 2012). This serious public health challenge can be effectively prevented by increasing regular physical activity (PA) to help manage non-communicable diseases and improve health (World Health Organization 2022). With the advantages of health-related benefits and a low threshold, recreational running is becoming popular worldwide to develop a healthy lifestyle among various physical activities. However, among recreational runners, there is a high drop-out rate due to injuries and motivation loss. This paper focuses on motivating outdoor recreational running, which has considerable benefits for physical and mental health than indoor (Bowler et al. 2010; Thompson Coon et al. 2011).

A variety of data monitoring-based technologies (e.g., wearable devices, products, and applications) have been developed in line with the popularity of running, which generates a vast amount of data and has prompted the research area of Personal Informatics (Murnane et al. 2018). The common strategy of visualizing data in Personal Informatics community follows a heavily quantitative approach (Murnane et al. 2020) (e.g., numbers and graphs). This approach appears to be less effective and has a negative influence on motivation and self-integrity (Cohen and Sherman 2014). Moreover, it can foster a negative mindset making physical activity feel more like a struggle than desirable (Crum and Langer 2007). It is challenging but essential to find the motivation to turn intentions into sustainable behavior change (Menheere et al. 2020).

Data physicalization appears promising among the attempts to transmit running data tacking in alternative formats. With the tangible nature, data physicalization expands the design space for presenting exercise data, offering possibilities to convey meaning beyond the data and creat a more engaging experience, which in turn encourages deep exploration, interaction, reflection, and anticipation of healthy

✉ Mengyan Guo
m.guo@tue.nl

1 Department of Industrial Design, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands

2 School of Sport Studies, Fontys University of Applied Sciences, Eindhoven, The Netherlands

activity (Menheere et al. 2021). However, previous works in the community of data physicalization focused on presenting individuals' running data in relatively private scenarios, such as artefacts or interactive systems used in the home (Menheere et al. 2021) or office (Botros et al. 2016). Attributing to the significantly perceived social interaction, showing PA data digitally through public display has been indicated to motivate PA and trigger communication (Altmeyer et al. 2018). However, presenting PA data tangibly in a more public, environmental context remains largely unexplored and unexploited, partly due to the technical challenges and the relative lack of information on its value.

Reducing physical inactivity is a complex societal issue requiring multidisciplinary expertise and interdisciplinary collaboration (World Health Organization and International Labour Organization 2021). In the realm urban design, outdoor exercise is classified as an optional activity, which is highly dependent on the physical characteristics of the urban environment and will occur to a greater extent if the physical characteristics of public urban spaces are inviting. Specifically, the roles of urban facilities, artificial landscapes, and social interactions in enhancing physical activities are remarkable (Smith et al. 2017). Physical environments have indirect effects on physical activity through motivation and self-efficacy (Haughton McNeill et al. 2006). The urban environment has the potential to strongly contribute to physical activity through its design, especially with the possibilities of evolving and increasingly integrated technology continuously adding new opportunities (Stibe and Larson 2016). Currently, most interactive environments engaging PA are based on instant interaction due to the people's movement at the same moment. The feedback effect is temporary and will disappear with the end of the exercise. What if we physically present people's PA data in terms of elements in the public space, such as facilities, landscapes, and installations? The environment will change with their running, which is continuous, slow, and visible to runners and co-located people. Yet, stimulating physical activities outdoors in this way is rather complex but worth exploring. It involves individual, social, and environmental factors that are strongly interconnected and continuously reshape each other (Bandura 1986).

Traditionally, fitness apps often reward users with digital medals for accomplishing new challenges, typically based on the mobile phone screen. We envision a transformation in that the urban environment acts as an interactive display. We argue that there is an opportunity to explore new ways of motivating PA by data physicalization that should go beyond private usage scenarios to public. For instance, when a runner conquers a new milestone, instead of a digital badge on their screen, an actual tile on the path they run would serve as a physical medal. It not only celebrates the runner's success but also creates a tangible and public recognition of their accomplishment, turning the city's pathways into an interactive canvas. To explore the potential impact and design space of the data physicalization-based environment on outdoor running, we created TIDAL (as in "TIle" and "meDAL"), a design concept of a running social service provided by an interactive system that encodes running data and the completion of running goals into tiles on the road as physical rewards in the public space (for details, please refer to Sect. 3). Using a video prototype of TIDAL as a probe, we *conducted* semi-structured interviews based on co-constructing stories (Buskermolen and Terken 2012), a participatory design technique to collect deep and specific feedback for early, formative concept evaluations. In this paper, we report runners' in-depth feedback and their stories based on our design concept and the implications derived from the results.

The contribution of this paper is threefold: first, we offered a novel lens into integrating personal data into public urban space to motivate PA from a multidisciplinary perspective of HCI and the urban environment. Next, we designed TIDAL, a video prototype of a future smart city augmented with new technology and services, and explore its potential effect on runners' motivation. Then, through the co-construction stories, and interviews, we explored the design space of the interactive environment based on data physicalization. Based on our results, we discussed the motivation effect and concern of TIDAL and how an interactive environment like TIDAL could be better designed to motivate the public. Our research could inform physical activity intervention, data physicalization, and urban design research fields and how the different fields can benefit from each other's work.

The rest of this article is structured as follows. In Sect. 2, we review the related theory and works that inspire our work. In Sect. 3, we detailly introduce the concept of TIDAL and the video prototype. In Sect. 4, we report the methods used for qualitative concept evaluation. In Sect. 5, we report the results of the evaluation and co-design. In Sect. 6, we will discuss the findings, future work, and limitations of this study. Section 7 concludes the paper.

2 Related work

2.1 Persuasive technology and persuasive city

Persuasive technology (PT) is designed to motivate beneficial activity, which is increasingly used and effective at promoting PA. According to the Fogg Behavior Model (FBM) (Fogg 2009), sufficient motivation, sufficient ability, and an effective trigger are three principal factors that result in a target behavior commonly used for persuasive technology design. For example, Go & Grow (Botros et al. 2016), UbiFit (Consolvo et al. 2009), and Fish'n'Step (Lin et al.

2006) provided feedback for achieving milestones or completing goals with a living plant, digital flowers, and digital fish to increase vitality. These cases are also designed to stimulate long-term behavioral change by creating a strong emotional bond (through feelings such as pride, guilt, and a sense of responsibility) through caring for pets or plants and by building social influences through the participation of close people.

Previous work has examined how technology can support health behavior monitoring in social contexts. For instance, popular fitness-tracking applications like Strava and Runkeeper were developed with social affordances such as allowing data sharing, creating social support through comments and Kudos on others' performance, and social competitiveness by showing the performance of others in the nearby running location. Further, Altmeyer et al. (2018) extended the gamified fitness application from personal mobile to a public display. Their result proved that making step data visible to outsiders by public display increased step counts, encouraged socialization, and provided additional motivation for PA. In line with Orji and Moffatt (2018) and Aldenaini et al. (2020) reported that platforms employed by persuasive technology frequently emerged as mobile, handheld devices, games, websites, and social networks. Only a few examples integrate into the physical environment in terms of ambient or public displays or interactive workstations. However, the environment can powerfully influence individuals' desire and ability to pursue behavior change (Parker 2014). Stibe and Larson (2016) have proposed persuasive cities that embed persuasive features with conceptually new urban designs to improve wellbeing across societies. They argued that socially influencing systems supported by a technologically enabled built environment might have a more sustainable impact on behavior change. Their work pointed out a promising ecosystem of the future city to increase PA from the theoretical level, but there is a lack of specific design practice and research. Thus, we contribute to exploring the design space of the persuasive city by extending digital presentation from public display to physical space. We proposed a novel approach to motivating PA by rewarding the people's efforts of PA with environmental change on their running route.

2.2 Data physicalization

Data physicalization has become an emerging research area in the last decade (Sauvé et al. 2022), defined as "a physical artefact whose geometry or material properties encode data (Jansen et al. 2015)." It represents meaningful data through physical shapes or materiality that encourage people to explore, understand, self-reflecting, and share its meaning. Data physicalization has been applied in the context of physical activity as a novel feedback form, which offers continuous access to user's data allowing for reflection and integration in their everyday life (Sauvé et al. 2020). For instance, researchers transformed PA data into 3D printed artefacts (Stusak et al. 2014) (Khot et al. 2014) or chocolate (Khot et al. 2017) as a physical reward of which the shape corresponds to the PA data. These studies reported that physical artefacts were considered rewards for participants' invested physical efforts that contributed to increased PA and reflection of PA.

Beyond static physicalization, Loop was a dynamic physicalization based on a shape-changing interface, visualizing the step data by eight wooden moving rings to integrate weekday accumulated data more fully into users' daily life sustainably (Sauvé et al. 2020). Based on Loop, Laina, a shape-change art piece, adopted an aesthetics perspective to spark positive feelings towards running through a slow feedback mechanism, which maps the running route and metrics into position and length of pins (Menheere et al. 2021). Loop and Laina provide an interesting perspective that the tangible artefact incorporated in the physical environment and users' daily routines as an ambient display, presenting accumulated data, could trigger more moments to remind oneself of previous runs and stimulate reflection. They serve as permanent companions remaindering of one's exercising endeavor.

While prior work on the physicalization of exercising data has shown its unique value in representing data materially to motivate physical activity, it also presents limitations and unexplored design possibilities. First, most existing research has focused on individuals and indoor or portable usage scenarios, lacking exploration in a public and social context. Rogers et al. (2010) reported that compared to the most informative PA data visualization on large screens tended to be ignored by people, the abstract interactive installations attracted more "eyeballs," "talk," and "curiosity". Data physicalization is inherently susceptible to their surrounding audience and context with the physical and tangible nature (Sauvé et al. 2022). This offers the foundation for our approach that data physicalization could be used to physicalize the accumulated personal PA data in public spaces to increase engagement. Furthermore, ccording to López García & Hornecker's typology (2021), most PA data physicalization design cases focus on small and medium sizes, which could be held in hands or used as furniture. We contribute to the data physicalization field by providing design concepts of the 'assembly' scale of physicalization in the public context. The "assembly" scale refers to the physicalization comprised of individual pieces and can, as a result, change their size based on the number of pieces used (Dumičić et al. 2022) Specifically, we map runners' efforts onto the tiles on the path, which progressively elongate, creating a long-term and dynamic interactive surface with increased engagement.

2.3 Interactive environments for physical activity

The urban environment has a significant impact on improving public health. In the domain of urban design, researchers found that four dimensions of environmental quality influenced physical activity in public space: (1) physical, (2) functional, (3) visual, and (4) social quality (Fathi et al. 2020). Due to human perception, the role of urban visions and artificial landscapes, such as the quality of walls, urban facades, skylines, and natural visions and landscapes, in enhancing physical activities was remarkable (Fathi et al. 2020). Based on the persuasive power of the environment, researchers in HCI investigated the impact of interactive environments embedding intelligent technology in the public space to facilitate physical activity among the public through inclusive interactivity (van Renswouw et al. 2022). It provides a unique perspective to solving the complex public health issue by combining potentials of both fields. They have been investigated in different contexts through various forms, such as the interactive floor (Graf et al. 2019), public stairs (Tan and Chow 2017), the playground (Soler-Adillon et al. 2009), and the installation (Grønbæk et al. 2012). Distinctively from digital interventions, environmental interventions are embedded in public spaces where people are more likely to be immersed in them with intuitive actions. Prior projects have shown that playful interaction in public spaces can increase users' physical activity, engage passersby, and create cooperation and social connectedness since they are more accessible to various user groups thanks to the inclusive nature of the public environment (Grønbæk et al. 2012; van Renswouw et al. 2022). This echoes Sauvé et al.'s (2022) work in the data visualization community, which is a dynamic between users and spectators as two types of audience, in which spectators could be attracted by the interaction and become implicit users. Therefore, we believe an interactive environment, such as an interactive road, could be an effective carrier for presenting PA data to motivate runners.

Related examples utilizing tiles as an interaction medium to encourage outdoor exercise can be categorized into the static medium and the dynamic medium. KWIEK is an example of a social exercise route utilizing static tiles with specially developed symbols to guide people to exercise with nearby infrastructure (Fig. 1 left). Sensation (van Renswouw et al. 2021) is a sonification running track consisting of dynamic tiles providing audio feedback to the runner (Fig. 1 right). Based on this, (van Renswouw et al. 2021) developed a 1.8 km path consisting of LED and displays in a public park to support runners or walkers to set personal goals and track performance to gain intrinsic motivation. Their results demonstrated that Human Environment interactions (HEI) have great potential to encourage PA and a healthy lifestyle. However, current interactive environments rely on direct and

Fig. 1 Examples of static and dynamic tiles

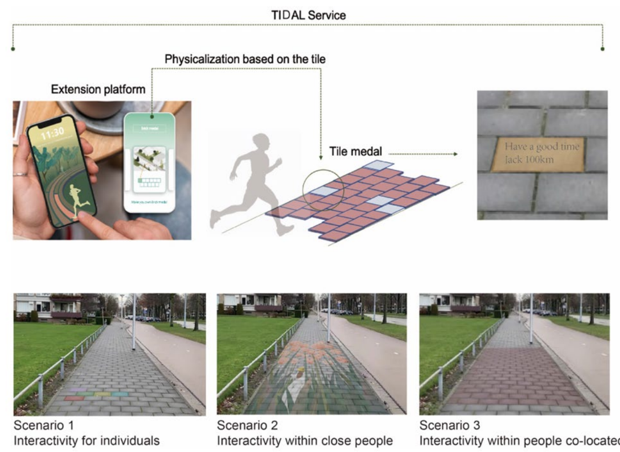

Fig. 2 TIDAL service system and three scenarios

temporary bodily movement to engage people, which will disappear once physical activity is completed. Few studies have explored the impact of persistent environmental interactions on long-term behavioral changes, especially in outdoor physical activity. Building upon the existing research and theories, we aim to leverage the advantages of data physicalization and the interactive environment. Our work distinguishes it self by utilizing road tiles as a physical medium to publicly present individuals' data.

3 TIDAL

3.1 The concept of TIDAL

We have developed the concept of TIDAL, a service system that combines persuasive theories, data physicalization, and interactive environments to motivate individuals with their data. The concept was inspired by a motivating strategy commonly used in running software applications: motivating people to complete challenges of different difficulty through digital badges. In our concept, we used the tiles on the road to represent the digital badges. The extended application (Fig. 2) provides a platform to help runners set and track their running goals quantitatively. Runners can also use it to choose their tile medal's location and physicalization forms after they achieve phased goals. The runner's goal achievement and the running data will be present on tiles of the road they choose in a physicalization form, which makes the regular running road into a slow feedback-based interactive tangle interface. The tile medal looks like the regular tiles on the ground, of which the color, pattern, and text can be added or changed, as shown in Fig. 2. Once individuals reach their running goal, they will get a tile medal embedded in the road accessible to every passerby. More running goals they reach, the more tiles they get. For example, people can change the color of a part of the road to green or make a heart pattern with the tile medals they get.

Moreover, based on this initial concept of encouraging people to move with physical medals in the running environment, we further envisioned three scenarios of different interactivities to explore people's responses to the physicalization of individuals and groups. Scenario 1 is the interactivity of individual data physicalization that allows runners to individually change the tile's color, pattern, and material or show a sentence or personal data on the tile. Scenarios 2 and 3 are both interactivities involving social cooperation, allowing people to join groups with others to make changes together. The social cooperation of scenario 2 is between acquaintances, such as friends, family, and partners. While scenario 3 is the cooperation between geographically close people, such as people who run around the same area.

3.2 Video prototype of TIDAL

In this study, we aim to explore the design concept and use this concept as a probe eliciting inspirational responses within runners to figure out the direction for future development in the early design stages rather than test a prototype with high refinement regarding functionality and data access. Thus, we chose to make a video prototype, a useful prototyping tool for exploring design ideas of which the validity and usefulness have been confirmed (Zwinderman et al. 2013). Compared to the physical prototype, as a powerful medium, the video prototype could eliminate all technology and implement limitations for communicating the functionality, spirit, and personality of a new application, computer, or system (Tognazzini 1994).

Following this tool, a video prototype of TIDAL was made. This video depicts a runner's experience running outdoors with TIDAL. The storyboard of this video prototype is shown in Fig. 4 Video B. In the beginning, the runner used TIDAL to record his running. After achieving the running goal, he used the TIDAL online platform to choose the location to place his tile medal. Serval days later, when he ran there again, he saw his tile medal was on the road. To stimulate more imagination of participants to co-construct new stories, in our video prototype, we did not report any specific technology used for implementation.

4 Method

Previous research has highlighted the importance of contextualized and grounded feedback from end-users (Özçelik Buskermolen et al. 2012). To explore runner's attitudes, in-depth feedback, and expectation of this design concept for further development, we conducted semi-structured interviews adopting Buskermolen and Terken's (2012) co-constructing stories method, a participatory design technique eliciting deep and specific feedback for early, formative concept evaluations (as shown in Fig. 3). This technique consisting of sensitization and elaboration phases can help designers in obtaining a deep understanding of users and their current and anticipated use contexts through storytelling. It has been applied in architectural design (Broffman 2015), smart homes (Eggen et al. 2017), and future technologically augmented cityscapes (Kukka et al. 2014) to elicit deep and specific feedback on future concepts or technology in the early design phase.

4.1 Participants

Given the exploratory nature of the research, our study first focused on runners' perspective as data providers to discover and generate insights that could guide and shape further investigations. We recruited 6 recreational runners between the ages of 26–48, which is adequate for the interviews conducted following the think-aloud method (Nielsen 1994). They are employees working in the same university but in different departments, with an average of 32 years old. All participants voluntarily participated in the experiment following the study protocol approved by our university's ethics review board. Before the interviews, participants completed questionnaires about their demographic and current running routines (see Table 1). Four participants (P1, P2, P4, P6)

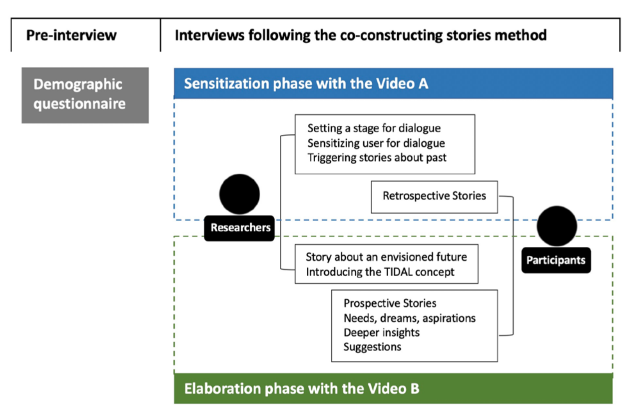

Fig. 3 Research method based on the co-constructing stories (Buskermolen and Terken (2012))

Table 1 Participants information

PID	Sex/age	Running frequency	Average distance
P1	M/33	2–3 times a week	6–8 km
P2	M/27	Twice a week	6–8 km
P3	F/26	Once a week	2–3 km
P4	F/48	4–5 times a week	8–10 km
P5	F/26	2–3 times a month	3–5 km
P6	M/32	Twice a week	6–8 km

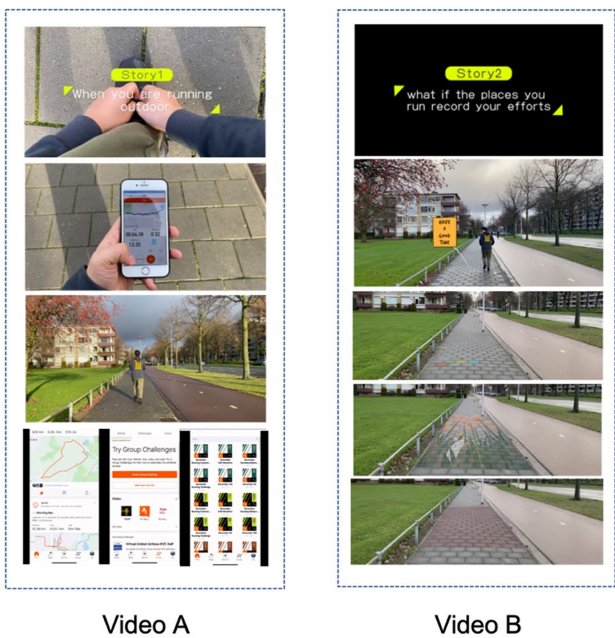

Fig. 4 Storyboard of the videos

have more than 3 years of running experience. P3 and P5 just started running recently, but P5 went climbing weekly. All participants received a 5 Euro voucher after interviews for their time.

4.2 Procedure

Following the co-constructing stories method, our interviews were divided into two parts (as shown in Fig. 3). During the first part, in line with the sensitization phase, participants were shown Video A (left Fig. 4) basic fictional story describing a fictional story of an outdoor running journey with Strava to introduce the context and set the stage for dialogue between researchers and participants. After video A, participants were asked experience-related questions to evoke relevant outdoor running experiences. To maximally probe participants' experiences and align with the video prototype, we told the story of the first part for sensitization in the form of videos performed by the same actor in the same location.

The second was consistent with the elaboration phase. The second part started with video B (right Fig. 4), the video prototype (detailed description in Sect. 3.2), and a fictional story introducing the TIDAL design concept in an envisioned context. Then participants were asked what they liked and disliked in the story to elicit positive and negative feedback about the concept. We provided three pictures with different patterns on the street, as shown in Fig. 2, and explained them to the participants orally. We asked participants to choose the interactivity they would like to participate in and explain why.

In the second part, participants received markers and papers printed with the same street scene as in the video prototype. Then they were asked to envision how the design concept would be more motivated if the runner in the video were themselves for open-ended feedback. Meanwhile, they were encouraged to think aloud while sketching their envisioning to supplement the basic story about the concept with contents representing anticipated future experiences, based on their needs, past outdoor running experiences, and aspirations.

4.3 Data collection and analysis

The interviews were audio-recorded and lasted between 30 and60 min. All interviews were manually transcribed and anonymized. Runners' vision sketches in the third part based on the concept shown by the video prototype Fig. 4 were also collected for analysis. Beyond participants' reactions to TIDAL, we were also interested in their stories based on the context we built. Therefore, we analyzed the sketches parallel to the interviews and examined the similarities and differences between the participants' sketches. We coded transcriptions of interviews and their sketches related to a part of the phenomenon and clustered these into different themes. Then we made illustrations according to the participants' sketches and co-constructed stories to provide a clear picture of runners' expectations and co-create outcomes of the motivational environment in the outdoor running context.

5 Results

Here we report on results from the sensitization and elaboration phases of co-constructing stories.

5.1 Sensitization phase

5.1.1 Outdoor running experience, environment, motivation

Five Participants agreed that their running experience was generally consistent with video A. P2 disagreed since he took the telephone with him while running to listen to music, not to monitor data. P4 mentioned that besides running alone, as shown in the video, she also ran with her running group. Participants tended to run in nature with flat roads, such as parks and countryside, for the running environment. They liked immersing themselves in the outdoor scenery without being interrupted or stopped. The physical and mental benefiting of running, such as keeping healthy, reducing stress, and losing weight, were frequently mentioned by all participants. Additionally, performance improvement also motivated three participants (P1, P4, P6). Rewarding also affected P1's motivation, and social connection played an essential role in P4's motivation. As P1 stated, collecting different level challenge badges in his sports watch and improving running parameters were his main motivating factors: "I want to get all the badges, although some are impossible for me, like running 500 km per month. I like seeing my progress over the years, running more or a little bit faster this year than last year."

Contrary to P1, P4 was not motivated by the badges but usually ran twice a week with her running group, which was composed of a coach and people who live nearby: "The running group motivated me a lot when you run with other people you need to keep up with them, you need to get faster. That is also a social connection that you have … also looking at Strava and what others did today, then I feel like I need to do something by myself. That helps a lot."

5.1.2 Running technology and data

Five participants used sports watches or running applications, quantitatively monitoring running data to know well about their performance. However, there was one participant, P2, with no experience of recording running data by technology, who usually estimated running distance by time, the total amount of laps around the park, or songs listened to during running: "I never monitored data because I don't care about the speed and accurate distance or share the data with others. Running is personal for me. I will run when I want to. But I keep running twice a week." Among other participants tracking data, there were two ways to share data. One was that recorded data was automatically shared on the running platform. Another was that it was manually shared on social media to record the special moment as a milestone, like starting to run again, breaking personal records, etc.

5.2 Elaboration phase

5.2.1 Positive anticipations on motivation

Theme 1 Stronger incentive All participants indicated that they would be motivated by the physical feedback of TIDAL, which was considered exciting and original, and expressed the willingness to get their tile medal by participating in outdoor running. Compared with the digital medal, the physical medal became a stronger incentive giving participants stronger achievement and stimulating reflection. P1 mentioned that "the physical medal on the road motivated me more than the virtual medal in his sports watch with longer impact, and it is always there reminding me like a milestone…it's like the physical holiday card is always better than e-cards for me." Consistent with P2, P3 stated that TIDAL was meaningful and attractive with a double sense of accomplishment: "Being rewarded with a tile medal after reaching a staged goal would bring me a sense of accomplishment. It also reminds me of a Jigsaw puzzle (P3). I look forward to completing my puzzle picture by running more and putting more tiles together." Meanwhile, P5 reported that along with the sense of achievement was the sense of belonging and ownership that connected participants with the road they usually run.

Theme 2 Comparison and competition The physicalization on the tiles in public was visible to all, bringing out two types of comparisons: among runners and within runners' own tile medals. Comparisons between runners create an implicit competitive environment indicated more by experienced runners (P1 and P6). As P1 stated, "If I see someone's speed on their tile faster than mine, I want to try to improve myself as much as possible can." Conversely, three participants (P2, P3, P5) reported that they don't like to compare with others, so the competition caused by presenting PA data publicly might be less motivating for them. But they showed more tendency to compare their medals. As P2 reported that "I hope that every time I can receive a better tile medal than last time so that I will have continued motivation."

Theme 3 Trigger interaction TIDAL was frequently reported to contribute to triggering interactions. All Participants stated that the tile medal on the road would attract them to interact with the environment, expecting to see how many medal tiles would eventually appear on the road and the content of the tile medal. Seeing their awards during running could generate positive emotions for behavioral change. P5 thought this system may be useful: "If I saw a road with many tile medals, I would assume it was a nice road for running and try to start from here." Furthermore, we observed that the system has a great potential to trigger social interaction, which can motivate behavior change effectively. P4 and P6 expressed wanting to complete a group goal and be rewarded with their running group and friends. In addition, TIDAL would result in indirect interaction and connection between runners and passersby. As P1 and P3 considered, "The tiles as a part of the running environment are accessible to all, breaking the communication limitation and connecting users from different running platforms." On the one hand, the interaction could occur among runners based in the same location. Besides the social competition and social cooperation between runners, P6 provided a different cause of interaction motivating himself: “If someone expressed something on his tile that I don’t agree with, like he supported a player I dislike, I would definitely run to get a tile to express my opinion.” On the other hand, the interaction could happen indirectly between runners and passersby. Because once the tile medal was installed on the road, it would also be visible to passersby. As P4 stated: “I would like to participate in this event with my running group using the tile medals to display our running team logo and information. We were happy with the achievement, and perhaps people nearby would be attracted to join us when they access it.” P2 and P5 imagined the future scene: “If many people engaged in it, this road might become an amazing landscape which will attract people’s visit.”

5.2.2 Concerns about implementation

Theme 4 Feasibility Although the system is attractive, five participants (P1, P2, P3, P5, P6) were concerned about whether this would be allowed and implemented without prejudice to others since changing the tile on the public road was under the management of the relevant city departments involving multiple stakeholders and requiring sponsorship. P1 suggested that making road changes is not easy, but doing this in a park might be easier than on the downtown street. However, P6 had the opposite view: “I like to run in nature, so it is not a good idea for me to pave with bricks on the dirt road, which reduces the feeling of being in nature.” Three participants (P1, P3, P5) additionally worried about people’s engagement in real situations, which was closely related to the final effect of data physicalization: “If few people are participating, there will be few tile medals on the ground that is not easy to be noticed. If plenty of people actively participate, a long road with enough area needs to be planned in advance.” P2 asked about the charges and safety: “Do I need to pay? I will try if it is free, and the road is always flat for a walk or running.”

Theme 5 Aesthetics Participants’ concerns about aesthetic issues mainly focused on the tile medal itself and the impact of the landscape composed of plenty of medal tiles on the city's appearance. Three participants would like to run for beautiful, novel patterns on their tile medals (P2, P5, P6). Considering the appearance of tile medals, P5 and P6 consistently suggested that graffiti artists can be involved in creating artwork as rewards for running goals and stated that “I would be proud of my tile medal customized with the graffiti displayed in the public space and even share this via social media.” Last but not least, the overall in-process and final appearances were the crucial aspects four participants (P1, P2, P3, P5) were concerned about: “People got their tile medals at different times with the patterns determined by themselves then the final look might be messy.” The public space is open to all citizens, so the physicalization in the public space should be aesthetically pleasing and orderly managed.

5.2.3 Feedback on PA data physicalization

Theme 6 Data Presentation and Privacy All Participants had an interest in running for their tile medal. We found that people with rich running experience are more inclined to display relevant information, such as sports data. P1 stated he wanted to show his fastest running speed, accumulated mileage, and location he had run on the tile medal. P4 would show her name and general running information like time, distance, and the running team logo. Except for P1 and P4, the other four participants did not clearly express the specific content to be presented on the tiles but preferred tiles with color or pattern. They reported that the information they would show on the tile depended on their mood and situation when they got the tile medal. The participants (P2, P3, P5, P6) reported that the information they would show on the tile depended on their mood and situation when they got the tile medal. As P6 state, "It depends on how difficult I get this tile medal. If it is easy, I will present something related to my interest. If difficult, I would like to engrave my name on it.” P2 stated he preferred visualizing pretty patterns: “I prefer the tile with a pretty pattern. And If other runners put their names on the tiles, It will be fine for me to show my name there.” Interestingly, P5 mentioned she would prefer to show her cultural background: “Because I chatted with a friend about cultural differences before this interview, I may show something related to my country's culture on the tiles. (P5).”

5.2.4 Interactivities of individual and group data physicalization

Beyond the design concept of TIDAL, we also explored perceptions of individual and group data physicalization. Specifically, we asked participants to choose the interactivity they would like to participate in and explain why. Three participants (P2, P3, P5) prefer the interactivity that physicalizes individual data and stated that accomplishing shared goals would become unmanageable when others were involved: “If someone in my group wants to give up, can I still get the tile medal there? Meanwhile, I don’t want to hinder others if I struggle to complete my running. So for me, it would be better to have the chance to physicalize my data.” Two participants chose Interactivity 2 as their favorite, and they stated that it is fun and exciting to do something with friends and running partners. They were more likely to get the tile medal with close friends than strangers. Because working with a large group of strangers means that there are more uncontrollable factors. Only P1 hesitated between interactivity 2 and 3 but finally chose 3. He explained: “I think it's interesting to collaborate with friends, but it seems more socially valuable to me to collaborate with all the people running in this area to complete a larger work."

5.2.5 Co-constructed stories and sketches from runners

Here we reported the results from participants' co-constructed stories and sketches. Figure 5 shows the original participants' sketches of their stories and illustration made by researchers. Three participants sketched two concepts, and three others sketched one concept as a supplementation to the basic story, for a total of nine co-constructed stories. Three co-constructed stories were created using the tiles as a carrier (P2, P4, P5). Three participants proposed integrating the data physicalization with the existing facilities and buildings (P1, P4, P3). Four stories attempted to add installations in the empty lawn or sidewalk shown in the provided street view (P1, P3, P4, P6).

Considering that people's vision focused on eye level, P1 first proposed adding a screen on the building near the street to show the cumulative number of runners running through the area. In addition, he suggested that the lawn area could be enriched with more trees, which could be associated with people's running data. He mentioned a game he played to explain his second co-constructed story: "If I achieve my running goal, there will be one more tree in this location with my name like the game like the game Ant Forest, and my name can be written on this tree. I will be more active." P1 proposed using an artificial tree's growth on the roadside lawn as a metaphor for running. The number of branches represented the number of people running on the road, and the length of the branches represented distance. P1 thought it would be even better if time were involved. He envisioned this tree would bloom and became deciduous with the changing seasons.

P2 further developed the tile concept of using shades of color or complexity of the pattern on the tile to present different running levels. If a person got dark red bricks, it

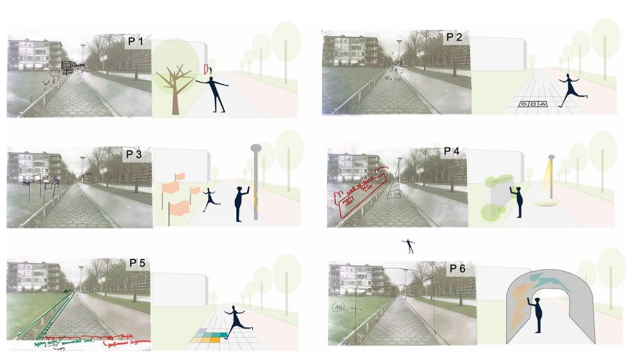

Fig. 5 Participants' original sketching stories and illustrations based on their sketch

means they ran a long distance every time. The lighter the color of the bricks, the shorter the distance it referred to. He used different shapes in the sketch to represent different levels of delicate patterns: "I want the pattern on the tile I get to be increasingly beautiful; for example, the first time I run, I get a triangle. The second time, I get a circling row. The third time I get a square, and in the future, I might get a famous painting or a custom pattern on my tile. If every time I get the same pattern, I get bored and lose interest."

Puzzles inspired P3's co-constructed story. She suggested using the street light poles on the roadsides as a carrier to display the tile medals people got. In her sketch, the tile medals were scaled into small arc-shaped squares which could be attached to the light pole with the magnetic. When more people are running nearby, the medals they get could surround the pole as decoration. Moreover, P3 designed flags on the lawn to represent the running performance of different groups or individuals. The flags would display running parameters and inspiring sentences and get higher as the goal is completed. She was concerned that "Where we live is often windy, which might be dangerous to the passersby if these flags are scraped down."

P4 proposed installing projectors on the street lights to dynamically display the runners' data on the road, using the ground as the primary carrier. She stated: "I would like to run to have our running team logo here with my group; it will be great teamwork." She also sketched an extendable wall frame in the Lawn area to display the physical medal, which could be extended as the number of runners on the road increased. And she emphasized that there would be greenery around the wall frame for decoration.

P5's story iterated on the TIDAL concept. She stated: "As a novice, I want to know which road is better for running. So if the road were decorated with appearance-colored tiles medals, I would know that this road is a good place to run since many people have gotten their medals here." She wanted to place her tile medals in a row with one color but in different shades: "Different shades represent different running challenges so that I can see my improvement directly. Rows of tiles in different colors represent the number of runners. Then the more people run here, the longer the road becomes."

P6 often ran in the park, and he suggested to installed displays on the street or park entrances to show the digital tile medal. In his sketch, the shape of the display was like a tunnel. He imagined: "It would be better if artists were involved in making digital graffiti paintings. Runners' data generate this digital painting and can be displayed on the screen." He was asked about the difference between his concept and the digital medal shown in video A. He stated: "In my concept, although the medal was digital, it was represented artistically and displayed in the physical space through a physical display. For example, when I achieve my goal, I can text my interest, such as the dog on the platform, and then it will automatically create a grafting painting-related dag and display it in the public space. I would go there and take a picture with my artwork and then post it to my social media."

6 Discussion

In this section, we discuss our results and the implications of our work for the design of data physicalization to increase physical activity in the public context and future work.

6.1 Impact of TIDAL on motivation

Encouragingly, all participants reported they would run to get their tile medal, which confirms that TIDAL has a positive impact on runners' motivation. Previous research on running data physicalization (Khot et al. 2014) suggested that the material artifacts could contribute to an increase in physical activity and reflection, which was considered a testimony to participants' invested physical efforts. Our findings support this argument, as all participants reported that running for a physical tile medal is more attractive than the digital medal shown in video A. We observed that participants would participate because novelty, appropriate challenge difficulty, and diverse rewards were the motivations that could attract participants to maintain continuous behavior change. For those who with less running experience (P3, P5), TIDAL may motivate them to run more and regularly through appropriate challenge settings and rewards: "I don't like the conditions to be too challenging to get the reward, and if I get the same brick every time, I want the challenge to be the same. But if it's a better reward, I'm willing to put in more effort." TIDAL provided extra motivation related to the social aspect to P1, P4, and P6, who were more experienced since they frequently mentioned social cooperation and social interaction when they talked about the impact on motivation.

In our preliminary observations, participants would be more proud of their reward physicalization in a public context rather than worried about privacy issues and negative social pressures, partially inconsistent with Lim et al. (2010). Indeed, it may be because our study was conducted in the lab rather than an in-the-wild study, so the privacy issues didn't apparently expose. However, we also speculate this is probably due to the slow feedback and indirect interaction weakening negative social pressure and reinforcing positive encouragement and rewards, which is more pleasant. In addition, TIDAL edged PA data with additional value, contributing to the environment, which is reflected in runners' feedback regarding belonging to the place they run, responsibility, and concern for the cityscape as a citizen: "When more people participate, an urban public art will be formed." These positive factors may have contributed to the results that runners focused more on motivational effects than social pressure and privacy concerns.

6.2 Alternative technology for implementation

All Participants reported that they were willing to get their tile medal placed on the ground, indicating that the concept was worth implementing. However, replacing tiles on the ground is challenging and requires the support of labor, finance, and city administration. What people liked about the TILDAL was the material reward they could get after exercise. The reward for their PA effort can be displayed in and contribute to the physical environment. From the participants' feedback and co-constructed stories on TIDAL, we found that tiles are not the only carrier for PA data physicalization. Only two stories refine the TIDAL concept, and seven of nine co-constructed stories proposed using other existing facilities or adding installation in the street view to present data physicalization. And we found all the participants' sketch echoes the broad definition of situated visualization, which are related to and displayed in its environment (Bressa et al. 2021). For example, P6 argued that using the display in the physical space to dynamically show the digital artwork generated by running data also could be a solution. He stated: "Compared to the digital reward on the telephone, presenting the reward in the public space will have a greater impact on me, even if it's on a digital display at the park entrance. More people will see mine, and I will see others."

Besides physicalization and display, immersive technology AR have been frequently used to show situated (Bressa et al. 2021). AR has the ability to superimpose the virtual medal on the ground, which can easily realize the concept of TIDAL without construction on the ground. However, runners need extra effort to bring and look through their mobile or wearable devices to experience the AR effect. In addition, it is more accessible to the runners who have already experienced it, not direct open to all co-located people. Thus, we believe it is worth exploring the implementation of TIDAL in more physical ways, which is always "on" for the public.

In addition to static ways (manually replacing the tiles and pasting stickers), living environment-friendly methods using natural materials provide a new perspective for implementation. Tanaka et al. designed a dynamic grass color scale display technique based on a grass length for a green landscape-friendly animation display (Tanaka et al. 2022). This technique can meet the runners' expectations: presenting data in a public space should preserve and improve the urban landscape. For instance, P6 stated that he did not want the tile medal installed in the park's forest path, which would destroy the natural feeling. P1 and P4 related the data presentation to the artifact and real plants. As a result, we see further opportunities and consider it an interesting design space for designers to explore further by realizing the data physicalization with the interactive urban landscape.

6.3 Diverse interactive activities for individual and social runners.

Competition, social comparison, and cooperation are the three most commonly used persuasive strategies (Almutari and Orji 2019). In our case, cooperation is directly provided in Interactivity 2, 3. Competition and comparison arise indirectly in three interactivities through publicly displaying data. Through interviews, we learned about the running routines of different types of runners and their feedback on the three interaction scenarios provided by the TIDAL service. We found that the social pressure reported by participants is not because of presenting the data in public but a possible result of social collaboration in Scenarios 2 and 3. Participants worried that it would prevent the group from achieving goals if they or someone else couldn't finish the task in time. The social pressure stemming from social collaboration plays both positive and negative roles in runners' motivation. Based on that, we suggest that the design could use this to create diverse, engaging interaction scenarios for individual and social runners' needs to provide them with different ways of participating and reduce the negative effects of a single choice.

6.4 Future work

Our result highlights the importance of the aesthetics of the data physicalization on tile medals which is one of the drivers motivating running. Specifically, participants expect the patterns on their tile medals to be visually pleasing and in harmony with the environment. And in their co-creation stories, we observed that rather than seeing TIDAL as a physical data presentation in public space, participants associated it more with the urban landscape driven by running data, which fits with the definition of socially engaging art. It refers to the art medium that focuses on engagement through human interaction and social discourse.

In research regarding future cities, Kukka et al. projected an increased sophistication in the sociable uses of urban spaces and technologies, where people blend their online and offline worlds into a single-lived reality (Kukka et al. 2014). They believed that public services could be more engaging ad efficient through urban technology and embodied interaction. It is in line with the proven benefits of inclusivity of embedding technology into the physical environment to ensure access to all, as identified by Van Renswouw et al. Researchers in the persuasive technology and personal informatics communities have recommended designers consider designing a cross-platform application to increase their reach and accessibility (Aldenaini et al. 2020) and look beyond support for publishing data to social networks (Rooksby et al. 2014). Hybrid digital-physical services with the multidisciplinary collaborations of design of the product, service, interaction, and environment create new possibilities for solving complex social issues such as physical inactivity. Our work extends quantitative data visualization on the interface of mobile and wearable devices to the tangible city surface, providing a more qualitative perspective. Our approach to transferring PA data into the tile medals is rather qualitative compared to the statistical chart or graphic used in many running tracking applications. The "medals" are not only a result of the achievement of accumulated quantitative data; they are also rendered with qualitative recognitions, appraisals, and encouragement. Also, we provide a new perspective on the future city public space and design direction of cross-platform applications.

Based on our findings, there is a future direction for our work. We believe socially engaging urban art based on data physicalization could be a promising medium. Everybody can contribute to an art piece in the urban space by being physically active. Motivating people with socially engaging art and the city environment as a slow-feedback interface for new infrastructure and services might play a vital role as a design opportunity in promoting physical activity and enhancing the vitality of society. Thus designers are suggested to develop data physicalization-based interactive environment with high aesthetic value and make it effective and sustainable attractiveness for both runners and passersby.

6.5 Limitation

Our study entails several limitations. First, we conducted semi-structured interviews following the co-constructing stories technique with a video prototype to gain insight from runners' perspectives in a lab setting. This approach is helpful with valuable information extraction for future design and development. However, it is important to acknowledge that the validity of the research heavily relies on the skills of the researchers due to the dialogue-based nature of the co-constructed stories method. Additionally, instead of developing a physical prototype, we used a video prototype as a probe to qualitatively assess the potential impact of TIDAL. The absence of field study limits our ability to assess how TIDAL effectively motivates individuals and whether is may lead to boredom over time which is a common concern with exercise interventions. Furthermore, we have not thoroughly investigated the privacy implications that may arise from the long-term use of TIDAL, specifically when presenting data in outdoor public space.

Our research initially focused on the perspective of runners during the exploration stage, considering they are the direct providers of data and the owners of data physicalization. However, TIDAL is a service accessible to the public. Therefore understanding perspectives of passersby who serve as the audience for runners' data physicalization, is necessary and valuable. It remains unclear whether TIDAL would engage the passersby in a real-life setting. As a result, our future research plans include conducting an in-the-wild study using a prototype developed with the insight gained from this preliminary study to examine its effects on motivation for physical activity for both runners and passersby.

7 Conclusion

In this paper, we introduced TIDAL, a concept integrating data physicalization with the physical environment to motivate runners. Following the co-constructing stories method, we conducted semi-structured interviews with video prototypes to explore whether and how our proposed intervention could motivate outdoor runners. The encouraging results from qualitative study indicate that TIDAL has the potential to motivate outdoor running through physicalized rewards and enhance social impact through public exposure by integrating personal data with the public environment. Drawing from the insights gathered during the elaboration phase of co-constructing stories, we discussed the future opportunities for incorporating a data physicalization-based interactive environment to complement existing running technologies, and design considerations for further implementation. This research contributes to the expansion of data physicalization design into a more public and environmental context. Moreover, it provides a novel lens for urban design on promote physical activity.

Acknowledgements The first author is partially supported by the China Scholarship Council (no. 202006790053).

Data availability The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy or ethical restriction but are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

References

Aldenaini N, Alqahtani F, Orji R, Sampalli S (2020) Trends in persuasive technologies for physical activity and sedentary behavior: a systematic review. Front Artif Intell 3:7. https://doi.org/10.3389/frai.2020.00007

Almutari N, Orji R (2019) How effective are social influence strategies in persuasive apps for promoting physical activity? A systematic review. In: Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization. ACM, Larnaca Cyprus, pp 167–172

Altmeyer M, Lessel P, Sander T, Krüger A (2018) Extending a gamified mobile app with a public display to encourage walking. In: Proceedings of the 22nd international academic mindtrek conference. ACM, Tampere Finland, pp 20–29

Bandura A (1986) Social foundations of thought and action: a social cognitive theory. Prentice-Hall, Hoboken

Botros F, Perin C, Aseniero BA, Carpendale S (2016) Go and grow: mapping personal data to a living plant. In: Proceedings of the international working conference on advanced visual interfaces. ACM, Bari, pp 112–119

Bowler DE, Buyung-Ali LM, Knight TM, Pullin AS (2010) A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 10:456. https://doi.org/10.1186/1471-2458-10-456

Bressa N, Korsgaard H, Tabard A et al (2021) What's the situation with situated visualization? A survey and perspectives on situatedness. IEEE Trans vis Comput Graph 28:107–117

Broffman A (2015) The building story: architecture and inclusive design in remote aboriginal Australian Communities. Des J 18:107–134. https://doi.org/10.2752/175630615X14135446523341

Buskermolen DO, Terken J (2012) Co-constructing stories: a participatory design technique to elicit in-depth user feedback and suggestions about design concepts. In: Proceedings of the 12th participatory design conference on exploratory papers workshop descriptions industry cases—volume 2—PDC '12. ACM Press, Roskilde, pp 33

Cohen GL, Sherman DK (2014) The psychology of change: self-affirmation and social psychological intervention. Annu Rev Psychol 65:333–371. https://doi.org/10.1146/annurev-psych-010213-115137

Consolvo S, Klasnja P, McDonald DW, Landay JA (2009) Goal-setting considerations for persuasive technologies that encourage physical activity. In: Proceedings of the 4th international conference on persuasive technology—persuasive'09. ACM Press, Claremont, pp 1

Crum AJ, Langer EJ (2007) Mind-set matters: exercise and the placebo effect. Psychol Sci 18:165–171. https://doi.org/10.1111/j.1467-9280.2007.01867.x

Dumičić Ž, Thoring K, Klöckner HW, Joost G (2022) Design elements in data physicalization: a systematic literature review. In: Lockton D, Lenzi S, Hekkert P, Oak A, Sádaba J, Lloyd P (eds) DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.660

Eggen B, van den Hoven E, Terken J (2017) Human-centered design and smart homes: how to study and design for the home experience? In: van Hoof J, Demiris G, Wouters EJM (eds) Handbook of smart homes, health care and well-being. Springer International Publishing, Cham, pp 83–92

Fathi S, Sajadzadeh H, Mohammadi Sheshkal F et al (2020) The role of urban morphology design on enhancing physical activity and public health. IJERPH 17:2359. https://doi.org/10.3390/ijerph17072359

Fogg B (2009) A behavior model for persuasive design. In: Proceedings of the 4th international conference on persuasive technology—persuasive'09. ACM Press, Claremont, pp 1

Graf R, Benawri P, Whitesall AE et al (2019) iGYM: an interactive floor projection system for inclusive exergame environments. In: Proceedings of the annual symposium on computer-human interaction in play. ACM, Barcelona, pp 31–43

Grønbæk K, Kortbek KJ, Møller C et al (2012) Designing playful interactive installations for urban environments—the swingscape experience. In: Nijholt A, Romão T, Reidsma D (eds) Advances in computer entertainment. Springer, Berlin, pp 230–245

Haughton McNeill L, Wyrwich KW, Brownson RC et al (2006) Individual, social environmental, and physical environmental influences on physical activity among black and white adults: a structural equation analysis. Ann Behav Med 31:36–44. https://doi.org/10.1207/s15324796abm3101_7

Jansen Y, Dragicevic P, Isenberg P et al (2015) Opportunities and challenges for data physicalization. In: Proceedings of the 33rd annual ACM conference on human factors in computing systems. ACM, Seoul Republic of Korea, pp 3227–3236

Khot RA, Hjorth L, Mueller F "Floyd" (2014) Understanding physical activity through 3D printed material artifacts. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, Toronto, pp 3835–3844

Khot RA, Aggarwal D, Pennings R et al (2017) *EdiPulse*: investigating a playful approach to self-monitoring through 3D printed chocolate treats. In: Proceedings of the 2017 CHI conference on human factors in computing systems. ACM, Denver, pp 6593–6607

Kohl HW, Craig CL, Lambert EV et al (2012) The pandemic of physical inactivity: global action for public health. Lancet 380:294–305. https://doi.org/10.1016/S0140-6736(12)60898-8

Kukka H, Luusua A, Ylipulli J et al (2014) From cyberpunk to calm urban computing: exploring the role of technology in the future cityscape. Technol Forecast Soc Change 84:29–42. https://doi.org/10.1016/j.techfore.2013.07.015

Lim BY, Shick A, Harrison C, Hudson SE (2010) Pediluma: motivating physical activity through contextual information and social influence. In: Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction. ACM, Funchal, pp 173–180

Lin JJ, Mamykina L, Lindtner S et al (2006) Fish'n'Steps: encouraging physical activity with an interactive computer game. In: Dourish P, Friday A (eds) UbiComp 2006: ubiquitous computing. Springer, Berlin, pp 261–278

López García I, Hornecker E (2021) Scaling data physicalization—how does size influence experience? In: Proceedings of the fifteenth international conference on tangible, embedded, and embodied interaction. ACM, Salzburg, pp 1–14

Menheere D, Lallemand C, van der Spek E et al (2020) The Runner's journey: identifying design opportunities for running motivation technology. In: Proceedings of the 11th Nordic conference on human–computer interaction: shaping experiences, shaping society. ACM, Tallinn, pp 1–14

Menheere D, van Hartingsveldt E, Birkebæk M et al (2021) Laina: dynamic data physicalization for slow exercising feedback. In: Designing interactive systems conference 2021. ACM, Virtual Event, pp 1015–1030

Murnane EL, Walker TG, Tench B et al (2018) Personal informatics in interpersonal contexts: towards the design of technology that supports the social ecologies of long-term mental health management. Proc ACM Hum Comput Interact 2:1–27. https://doi.org/10.1145/3274396

Murnane EL, Jiang X, Kong A, et al (2020) Designing ambient narrative-based interfaces to reflect and motivate physical activity. In: Proceedings of the 2020 CHI conference on human factors in computing systems. ACM, Honolulu, pp 1–14

Nielsen J (1994) Estimating the number of subjects needed for a thinking aloud test. Int J Hum Comput Stud 41:385–397. https://doi.org/10.1006/ijhc.1994.1065

Orji R, Moffatt K (2018) Persuasive technology for health and wellness: state-of-the-art and emerging trends. Health Inform J 24:66–91. https://doi.org/10.1177/1460458216650979

Özçelik Buskermolen D, Terken J, Eggen B (2012) Informing user experience design about users: insights from practice. In: CHI '12 extended abstracts on human factors in computing systems. ACM, Austin, pp 1757–1762

Parker AG (2014) Reflection-through-performance: personal implications of documenting health behaviors for the collective. Pers Ubiquit Comput 18:1737–1752. https://doi.org/10.1007/s00779-014-0780-5

van Renswouw L, Neerhof J, Vos S et al (2021) Sensation: sonifying the urban running experience. In: Extended abstracts of the 2021 CHI conference on human factors in computing systems. ACM, Yokohama, pp 1–5

van Renswouw L, van Hamersveld Y, Huibers H, Vos S, Lallemand C (2022) Fontana: triggering physical activity and social connectedness through an interactive water installation. In: CHI 2022 - extended abstracts of the 2022 chi conference on human factors in computing systems article 462 association for computing machinery, Inc. https://doi.org/10.1145/3491101.3519765

Rogers Y, Hazlewood WR, Marshall P et al (2010) Ambient influence: can twinkly lights lure and abstract representations trigger behavioral change? In: Proceedings of the 12th ACM international conference on Ubiquitous computing. ACM, Copenhagen, pp 261–270

Rooksby J, Rost M, Morrison A, Chalmers M (2014) Personal tracking as lived informatics. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, Toronto, pp 1163–1172

Sauvé K, Bakker S, Marquardt N, Houben S (2020) LOOP: exploring physicalization of activity tracking data. In: Proceedings of the 11th Nordic conference on human–computer interaction: shaping experiences, shaping society. Association for Computing Machinery, New York, pp 1–12

Sauvé K, Sturdee M, Houben S (2022) Physecology: a conceptual framework to describe data physicalizations in their real-world context. ACM Trans Comput Hum Interact 29:1–33. https://doi.org/10.1145/3505590

Smith M, Hosking J, Woodward A et al (2017) Systematic literature review of built environment effects on physical activity and active transport—an update and new findings on health equity. Int J Behav Nutr Phys Act 14:158. https://doi.org/10.1186/s12966-017-0613-9

Soler-Adillon J, Ferrer J, Parés N (2009) A novel approach to interactive playgrounds: the interactive slide project. In: Proceedings of the 8th international conference on interaction design and children. ACM, Como, pp 131–139

Stibe A, Larson K (2016) Persuasive cities for sustainable wellbeing: quantified communities. In: Younas M, Awan I, Kryvinska N et al (eds) Mobile web and intelligent information systems. Springer International Publishing, Cham, pp 271–282

Stusak S, Tabard A, Sauka F et al (2014) Activity sculptures: exploring the impact of physical visualizations on running activity. IEEE Trans vis Comput Graph 20:2201–2210. https://doi.org/10.1109/TVCG.2014.2352953

Tan L, Chow KKN (2017) Piano staircase: exploring movement-based meaning making in interacting with ambient media. In: Bernhaupt R, Dalvi G, Joshi A et al (eds) Human–computer interaction—INTERACT 2017. Springer International Publishing, Cham, pp 282–291

Tanaka K, Kato Y, Mikawa M, Fujisawa M (2022) Dynamic grass color scale display technique based on grass length for green landscape-friendly animation display. Sci Rep. https://doi.org/10.1038/s41598-022-27183-x

Thompson Coon J, Boddy K, Stein K et al (2011) Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. Environ Sci Technol 45:1761–1772. https://doi.org/10.1021/es102947t

Tognazzini B (1994) The "Starfire" video prototype project: a case history. In: Proceedings of the SIGCHI conference on Human factors in computing systems celebrating interdependence—CHI '94. ACM Press, Boston, pp 99–105

World Health Organization (2022) Global status report on physical activity 2022: executive summary. World Health Organization, Geneva

World Health Organization, International Labour Organization (2021) Healthy and safe telework: technical brief. World Health Organization, Geneva

Zwinderman M, Leenheer R, Shirzad A et al (2013) Using video prototypes for evaluating design concepts with users: a comparison to usability testing. In: Kotzé P, Marsden G, Lindgaard G et al (eds) Human–computer interaction—INTERACT 2013. Springer, Berlin, pp 774–781