LOOP

Exploring Physicalization of Activity Tracking Data

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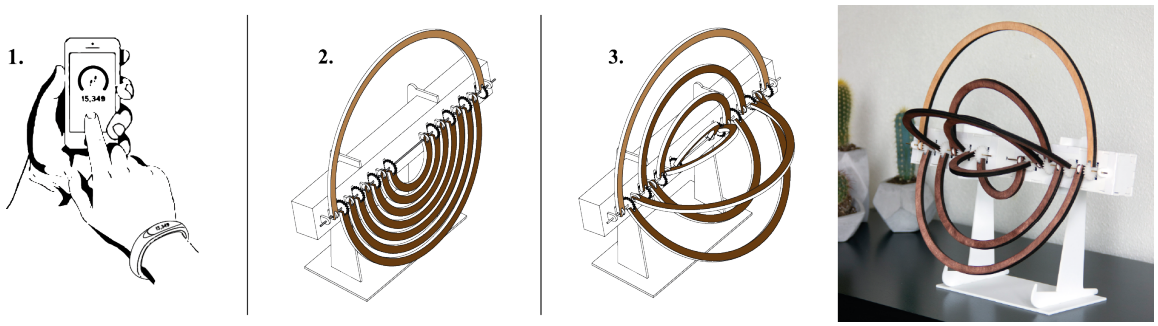

Figure 1: The traditional activity tracking system (1) providing step data to *LOOP* (2) and over time showing the number of steps made on each day of the week (3).

ABSTRACT

Wearables, mobile devices and Internet-of-Things (IoT) sensors are enabling us to monitor our environment, understand our social connections, and track our personal health. However, most of these systems communicate data through information visualizations that are often 'hidden' inside devices, such as mobile phones and tablets, requiring users to undertake explicit actions to reveal them. Novel interfaces and devices embedded in people's everyday life have the potential to help users visualize, use, and appropriate their collected personal data. To this end, we designed the physical artifact *LOOP*, which provides an abstract visualization of the user's activity data by changing its shape. In this paper, we elaborate on the design and present a one-week field study in which *LOOP* was deployed in the homes of five end-users. We found that the physical presence of *LOOP* facilitated reflection and the layered visualization supported various personal tracking.

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CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Empirical studies in HCI.

KEYWORDS

Physical Visualization, Ambient Information Systems, Shape-Changing Interfaces, Self-Tracking

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1 INTRODUCTION

Activity tracking has become increasingly popular due to the introduction of commercially available wearable trackers such as FitBit [6], Miband [24], and Jawbone [15]. Such devices track, among other things, one's number of steps taken, distance traveled, heart rate, sleep pattern and calories burned. Most existing activity tracking platforms use Graphical User Interfaces (GUIs) to communicate the data to the user, typically using numbers and graphs. Retrieving their activity data helps users reflect on their activity level and can eventually support them in understanding and adjusting their behavior.

However, these data representations are often 'hidden' inside personal devices such as smartphones and tablets, and users need to undertake explicit actions to reveal them [11]. Li et al. [22] found that users of activity trackers often do not take the time to go through their data. As a result, they lack a holistic view of their activity data, which prevents users from appropriating it to reflect on their behavior [22]. Hence, related work [10, 12, 31] suggests the use of ambient information as a strategy to reduce the attention needed to use the system and foster engagement. Therefore, we suggest that an ambient approach to data physicalization can help activity data to become a seamless part of everyday life.

We propose to unobtrusively integrate the tracked activity data in the user's physical environment through ambient physical interfaces. Exposing people to their data more often may be advantageous because it allows them to reflect more regularly about the meaning of the data. Specifically, we focus on how a data physicalization of personal activity data helps people understand their own activity patterns. Physicalizations are "physical artifacts whose geometry or material properties encode data" [14]. Research has shown that physicalizations enable people to understand and engage with their data through its tangible properties [14]. While examples of physicalizations of activity tracking data are known [18, 20, 34], these works use static data representations, and therefore do not enable users to reflect on their real-time activity data.

Building further on this concept, we explore the dynamic physicalization of personal data. We designed *LOOP* (Figure 1), a system which unobtrusively presents real-time activity tracking data to inform people as part of their everyday routines when glancing at it. We use *LOOP* as a tool to investigate whether a physical artifact that changes its shape according to the activity data of the owner is an effective alternative for reflection to the kinds of graphs, steps and percentage completion bars common to most commercial activity trackers. The rationale is that a dynamic physical abstraction of the data can encourage a different way of reflecting and engaging with the data, specifically to the user's needs.

In this paper, we describe the design of *LOOP* and report on an exploratory field study in which five people used it in their home environment for up to seven days. Our study revealed that *LOOP* facilitated reflection on activity data by providing a physical overview of the week. Additionally, it supported the different goals people can have with activity tracking by allowing for comparison between rings of choice.

2 RELATED WORK

Li et al. [22] found that barriers such as the lack of a holistic view and context can prevent users from appropriating and interpreting their data during reflection. Regular viewing of their data allows for immediate short-term reflection on current performance, as well as a more elaborate long-term reflection on occurring trends [22]. Additionally, they found that users often do not have the time to go through all their data. Moreover, users can have different goals when starting to track [29] and changing information needs over time [4, 22]. Lastly, it is important to facilitate users in making meaningful transitions between the qualitative goals they have (e.g. becoming more active or losing weight) and the quantitative goals supported by activity tracking systems (e.g. a daily goal of 8000 steps) [27]. Hence, the standard configuration of numbers and graphs on the screens of most activity tracking tools are not always appropriate to the user's needs. Therefore, there is a need for technologies that appropriate the visualization of personal data to the user's needs and make it readily available.

Others have explored the digital visualization of activity data. For example, Ubifit [2], Fish'n'Steps [23] and Spark [5] showed that visualizing activity data on a smartphone screen can motivate and engage users with their data. However, such solutions may not result in users being more frequently confronted with their data in everyday life as it requires deliberate interaction with a smartphone.

Ambient information systems [25] visualize abstract information for it to be perceived both in the periphery and center of attention. They often display information that is important, but not essential for the user's personal life. Examples of related work are the ambient displays Glanceable Feedback [9], Breakaway [13] and Twinkly Lights and Clouds [28]. The benefit of these types of systems over digital representations is the ability for coincidental encounters of the user with their data, providing new opportunities for reflection and integration in their everyday life.

Similarly to ambient systems, physicalizations demonstrate benefits over conventional visualizations; they make data tangible and allow for exploration and interaction [14]. Physicalizations can be anywhere and are always "on" allowing individuals to interact with their data in new ways [14]. A number of physical metaphors have been proposed to encourage physical activity. Example works introduce 3D printed artifacts as tools for reflection, such as SweatAtoms [18] and Activity Sculptures [34], or provide feedback on the activity tracker itself with patina-like engravings, such as Patina Engraver [20]. Lee et al.'s work suggests that the visualization of tracking data might become more personalized and useful by allowing the user to choose the data shown [20] and interpret it in a way that makes sense within their personal lifestyle, e.g. visualizing the data per day or week. Additionally, prior work illustrates the possible values in the (social) comparison of personal data [18, 34], and highlights how delayed [18, 20, 34] or slow-motion feedback [38] can support reflection and reminiscence with the data. Lastly, the abstract nature of a physical representation of data can leverage reflection as personal knowledge is required to read it, without overexposing themselves to others [34]. Other example works in this area are EdiPulse [16] and TastyBeats [17]. They examined how palatable representations can support the experience people have with their activity data. They found that the visual aspect of a tangible data representation positively affected the user, even if it visualized negative feedback [16], and could inspire them to deliberately vary their performance to see how it would reflect in the incentive [17]. Additionally, Thudt et al. [36] illustrated how a constructed physical artifact can enable the presence of the data in everyday life, coincidentally sparking reflection. However, these approaches use static representations, that only partially exploit the potential of physicalizations [14] and might not be sustainable over time.

Different from static physicalizations, shape-changing interfaces [26] are dynamic objects which display real-time data. One aim of shape-changing interfaces is to use physical qualities to enhance people's interaction with digital information [26], which shows common ground with physicalizations. Examples of work in which

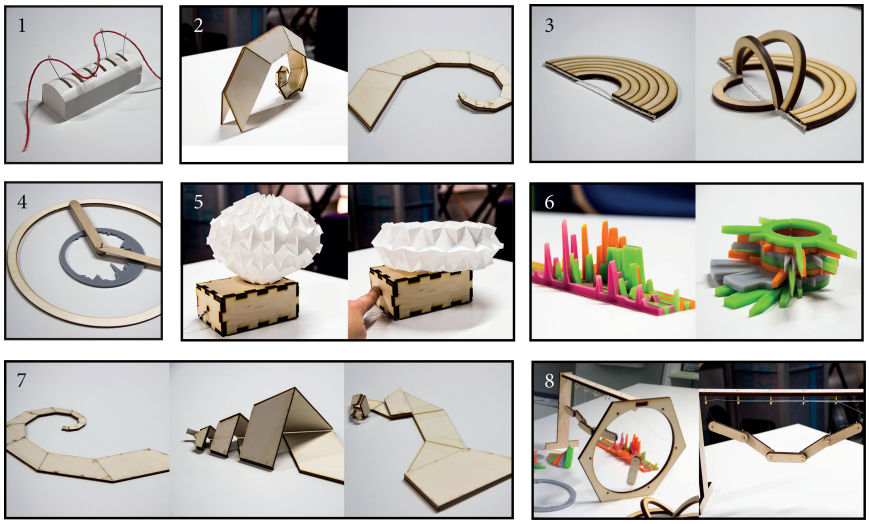


Figure 2: The prototypes used in the design critique sessions.

shape-changing properties are intertwined with physicalizations are Relief [21], inFORM [7], EMERGE [35] and CairnFORM [3]. The introduction of shape change in data physicalizations allows for dynamic, real-time, and always available physical data representations.

To integrate the accumulative data more fully into someone's everyday life, we propose an alternative approach for data representation, by means of a real-time dynamic physicalization. The rationale is that a physical abstraction of the data can encourage a different way of reflecting and engaging with the data by regular confrontation [12, 31]. Further, the dynamic nature of a real-time physicalization opens up opportunities to support changing user needs and enables (delayed) feedback over time in a sustainable fashion.

3 DESIGNING FOR PERSONAL TRACKING

In this section, we discuss the design process, final concept, and implementation of *LOOP*. We designed *LOOP* [32], as a new physical ambient artifact that enables people to visualize and reflect on personal activity tracking data (Figure 1). The aim of designing an abstract and dynamic visualization of real-time data was to (i) provide people with a way of both exploring and reflecting on their activity data over time and (ii) appropriating it to their own interests. We were interested in providing a physical representation that could present different states of data in a novel spatio-temporal way – to engender different forms of reflection.

3.1 Design process

The design of *LOOP* was informed by a user-centered design process in which we interviewed 11 end-users of activity trackers and organized two design critique sessions with six end-users.

3.1.1 Interviews. We conducted initial interviews to extract (i) the current values activity tracking provides to the individual and (ii) possible opportunities for a physicalization that could be further explored. Specifically, the interviews revealed the challenges of interpreting the raw data coming from mobile applications of activity trackers. The sense-making of the raw data was different per participant, though overall it seemed that no clear appropriation was made. The ability to compare numbers, which on itself made no sense, allowed the participants to make sense of the data as a whole. When the interviewees were questioned whether they saw value in the physical representation of their data the majority responded positively. However, they were not able to give a clear embodiment of what this physical representation should be. The concept of physical data visualization seemed to be too hard to grasp from imagination solely.

3.1.2 Creation of generative tools. To further facilitate ideation on the possible opportunities of the physicalization of activity data, we designed a collection of eight prototypes (Figure 2) to be used as generative tools [30]. The creation of the prototypes was a semi-structured process and the shape explorations were directed by analyzing existing research prototypes (e.g. SweatAtoms [18]) or commercial products (e.g. Fitbit application [6]), and reviewing the design possibilities in shape-changing interfaces [26]. These guidelines [26] gave information on the different possibilities in the type of shape change, type of transformations and type of interactions one could have with a shape-changing artifact.

The final characteristics of the prototypes are shown in Table 1 the first row illustrates with what kind of shape change [26] the comparison of data is made, and the second row illustrates what association the visual representation of the prototype is likely to create. Lastly, prototypes 4 and 6 allow for sharing of data within the artifact whereas the others would include multiple similar artifacts to allow for sharing of data.

3.1.3 Design critique sessions. We conducted two design critique sessions with three participants each. At the start of the sessions, we interviewed the participants collectively on their prior knowledge on activity tracking to let them get used to each other and the topic. Subsequently, we provided each participant with a prototype and

Table 1: The characteristics of the prototypes.

#	Type of change	Association
1	Orientation	Graph
2	Volume	Organic
3	Spatiality	Organic
4	Orientation	Time
5	Volume	Organic
6	Texture	Graph
7	Form	Organic
8	Orientation	Graph

asked them to imagine as if it was a digital device in their home showing data from their activity tracker. Specifically, we asked them to answer the following questions in relation to the prototype: (i) What information would it show you and how? (ii) Where would it be in your house? (iii) When would you use it? Every 5 minutes we encouraged the participants to discuss their ideas together and repeated this whole process twice. The distribution order of the objects was randomized across sessions.

3.2 Design principles

Together the interviews and design critique sessions resulted in a better understanding of the current use of the technology and allowed for the introduction of the concept of physical data visualization to reveal opportunities to improve on this use. From these activities we extracted the following design principles:

3.2.1 Aesthetics. Placing a physical data visualization in someone's home means it will become part of their environment which they must look at every day. Participants were averse to scientific-looking objects as these may not blend into the home environment. Further, it is important to keep in mind the aesthetics when creating the mapping of the visualization and make sure it is aesthetically pleasing, regardless of the performance of the owner.

3.2.2 Abstraction. To leverage reflection, the metaphor used to represent the data should be abstract by nature. With the use of movement, different layers of information can be provided. The abstraction serves two different functions: (i) it allows the owner to shift from the focus of attention to the periphery and (ii) it informs but provides privacy when others observe it. Suggested associations for the visualization were natural forms and behaviors such as growth, and not too much quantification but something that looks visually appealing. Lastly, the abstraction should be meaningful to the dataset it represents, as one participant explained for prototype 7: letting it fold from small to large would suit the metaphor of the first little bit of sleep not doing you much good, but the longer you sleep the more exponential the result.

3.2.3 Comparison and correlation. The design critique sessions confirmed that the ability for comparison of data is very important, which was not satisfied very well by anything the participants used. Participants noted that current activity data is not very useful in isolation, but historical data could be used to create meaningful comparisons. Furthermore, the importance of correlation became clear. For example, with step data, one must set a fixed step goal which requires memorization, and representing this step goal in the physical data visualization would enable both relative and absolute estimations.

4 *LOOP*

From the design process, we concluded that the visualization of *LOOP* should balance informative and aesthetic properties for it to be meaningful to the owner while blending in the home environment. Additionally, a combination of both absolute and relative cues will allow the user to observe the detailed visualization in their focused attention but also to obtain a synopsis of their performance in their periphery.

LOOP [32] visualizes the step data collected from an activity tracker by eight wooden moving rings (Figure 1). The rings are intended to make it easy to see contrasts between days, while also showing data at various levels. Whereas the ring data visualization is quite common in digital interfaces (like on the Apple Watch Activity [37] or Fitbit [6] apps), using rings in a physical artifact has not been explored.

Seven rings have a dark brown color and each represents one weekday, orientated from Monday (smallest ring) to Sunday (largest ring). The outermost ring is colored light brown and represents the goal a user has set (the number of steps they wish to walk each day). The start position of *LOOP* consists of the seven day-rings positioned downwards (with a value of 0) and the step goal ring positioned upwards (with the value of the step goal set by the user). When users are active, the ring representing the current weekday moves upward and positions itself relative to the step goal ring (see Figure 3 for examples). In case the user takes more steps than the goal, *LOOP* will rescale according to the highest number of steps that week (Figure 4).

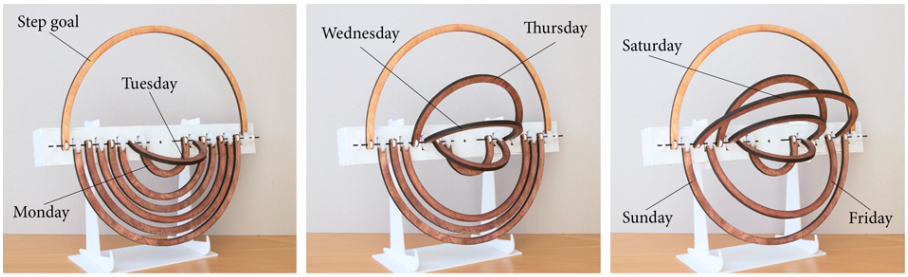
4.1 Design considerations

In this section, we elaborate on the design considerations for the final realization of *LOOP* and contextualize the design decisions embodied in the final prototype.

4.1.1 Material and form. The design of *LOOP* is strongly inspired by prototype 3 of the design critique sessions (Figure 2). The participants perceived the repositioning of the rings as abstract, but also associated it with growth. Additionally, while the movement of the rings was linear, due to its circular properties it allowed different aesthetics to appear. The final size of *LOOP* was based on the average size of a wall clock. The materials used are wood and white acrylic, with the aim to make the appearance match current interior styles.

4.1.2 Dataset. LOOP uses step data as the input for the visualization. This dataset was chosen as it was on average the most used by all the participating end-users. Additionally, the step dataset provides not only a comparison between current and historical data, but also involves a step goal. Therefore, the step goal can function as a clue for absolute values to allow for both relative and absolute comparison.

4.1.3 Data mapping. To establish the visualization of *LOOP* we explored what mapping of the step data would provide an aesthetically pleasing artifact, though would also convey enough information.

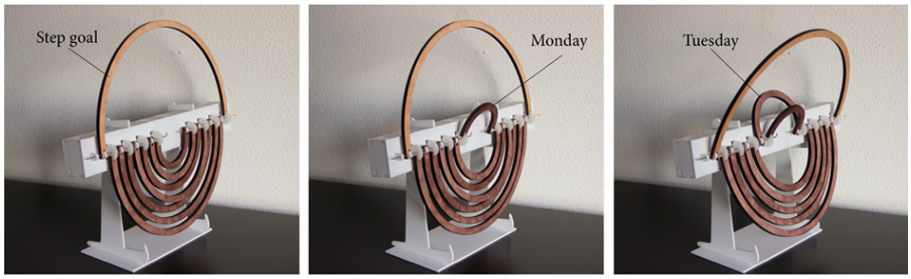


Step goal: 10.000 steps
Monday: 0 steps
Tuesday: 4000 steps

Wednesday: 5500 steps
Thursday: 9000 steps

Friday: 2000 steps
Saturday: 7000 steps
Sunday: 1000 steps

Figure 3: The change of *LOOP* throughout the week.



Step goal: 10.000 steps

Monday: 9.000 steps

Tuesday: 12.000 steps

Figure 4: The rescaling of *LOOP* if the step goal is reached.

Example data showed that using a fixed range would create either too small or too large changes in data, which would not result in an aesthetical rearrangement of the rings. Therefore, we opted for a relative mapping that would scale itself according to the range of steps of the particular user. Additionally, we introduced the step goal ring to allow the physicalization to provide both relative and absolute cues. As users are generally familiar with their step goal number, showing data relative to this goal, allows them to obtain an indication of absolute values from the visualization via the step goal ring.

A time span of seven days was chosen as this provides an overview of historical data that is in line with the commonly used Fitbit [6] application, which updates after every week. Additionally, the presence of seven rings representing seven weekdays allows for an understanding of activity data relative to the performance on other days. The day rings are fixed, as this allows the user to immediately associate each ring with a particular day from the past week. We decided to map the progress of days from the inside to the outside of the artifact, as the past days are represented by smaller entities and the result becomes more prominent as the week progresses. Related to that, a horizontal orientation with the rings moving from down to up was perceived as more natural and neutral by the participants. Lastly, the step goal ring was placed on the outside of the artifact, as a goal is something the participants would set for the future and therefore it was more logical to put it close to the outer rings, which are the days in the future.

4.1.4 Interaction. *LOOP* facilitates interaction with the activity data in an indirect way. The input of the system is implicit [26], based on the user's actions with the activity tracker. The shape change will be the output and can be perceived by the user. This allows the user to reflect upon their data when encountering *LOOP* in their home and if desired act upon it. In this way, the user can make decisions without the necessity to open up a mobile app, lowering the threshold to engage with their data at a time they choose. As no numbers or graphs are provided by the system, the user is forced to 'read' their data in a different way than they are used to. We were interested in whether physical interaction promotes reflection about what they have done over several days. By providing slow-motion feedback [38], *LOOP* emphasizes the importance of a spatio-temporal dimension, giving the users time to notice what is happening, and if desired, act upon their data.

4.2 Implementation

To enable a user evaluation of the concept of *LOOP* we developed two working prototypes. Each prototype has a maximum size of approximately 30x30x30cm due to the spatial movement of the rings. The entire model was laser cut, the rings from plywood and the electronics casing and stand of frosted white acrylic (Figure 5).

Figure 5: Final prototype of *LOOP*.

Table 2: Demographics of the participants.

#	Age	Gender	Motivation	Activity Tracker	Living	Days used
1	24	Female	Become more active	Fitbit Flex	Family	7
2	28	Female	Lose weight	Fitbit Charge HR	Independent	7
3	21	Male	Curiosity for technology	Fitbit Charge HR	Family	7
4	18	Female	Become more active	Fitbit Flex	Independent (with 3 flatmates)	4
5	25	Female	Curiosity for technology	Fitbit Charge 2	Partner	7

To move the rings the prototype contains a Wi-Fi-enabled microcontroller powering eight servo motors. The personal activity data of the participants is connected to *LOOP* via the Fitbit developer website [6]. A light in its center informs the user of the state of the system, indicating whether it is connected to Wi-Fi or retrieving data. Currently, *LOOP* is compatible with Fitbit activity trackers and updates once per hour.

5 FIELD STUDY

To evaluate how *LOOP* affects the frequency at which people are confronted with their activity tracking data, and their ability to appropriate these data in everyday life, we conducted an exploratory one-week field study in which *LOOP* was deployed with five participants.

5.1 Participants

Five people using a Fitbit activity tracker [6] were recruited by convenience sampling via social media. All of them were students (4 identified as female) with an average age of 23 years. On average, participants used their Fitbit for 13 months and paid attention to both their Fitbit and the Fitbit application on a daily basis. The participants gave different motivations for starting to track (Table 2 column 4). P1 and P4 owned a Fitbit Flex, which is a tracker only showing up to five dots to indicate the percentage reached of the step goal. The other three participants owned a Fitbit with a display on the tracker itself, providing the actual number of steps made. For more background information of each participant see Table 2

5.2 Procedure

During the first visit to the participants' homes, we introduced each of them to the study and let them sign an informed consent. We collected the demographics and conducted an interview on the participant's current experience with self-tracking. Following, each participant was introduced to *LOOP* and 3 exercises (Figure 6) were done to make them familiar with the system.

With the participants' permission, we set up a connection between their Fitbit and *LOOP* and they received *LOOP* to be placed in their homes. Four of the participants used the system for 7 days, whereas one participant used it for 4 days (due to practicalities). During these days we asked the participants to answer diary questions and send a picture of the current position of *LOOP* 2 to 3 times a day. The request for entries was done via a medium of their preference, either via e-mail, WhatsApp or Facebook Messenger. We asked participants whether the visualization was as expected, if a change of shape was noticed and understood, how they would describe their performance compared to other days, how often they looked, talked or thought about the system and how it made them feel while observing it. After 2 or 3 days, we contacted each

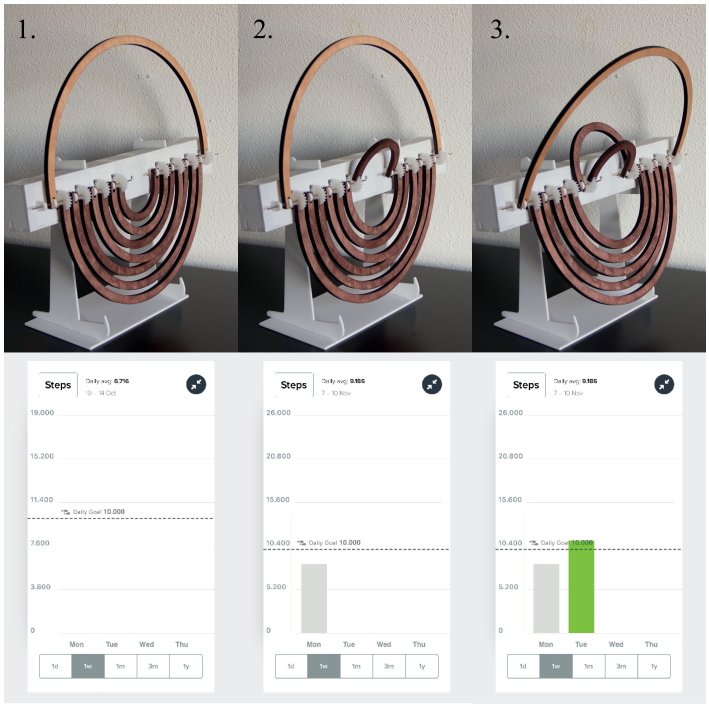


Figure 6: We asked the participants to explain similarities between the visualization of the Fitbit app and *LOOP* for 3 different situations: (1) the position of the goal ring, (2) the progress on Monday and (3) when the step goal is exceeded.

participant again to ensure the system was technically working. After the study period, we visited the participants to conduct a semi-structured interview on their overall experience with *LOOP*.

5.3 Data collection & analysis

During the study, we collected qualitative data via (i) intermediate diary entries and (ii) pre- and post-interviews. All interviews were audio-recorded with participants' consent. Recordings were transcribed and analyzed using inductive thematic analysis [1] to identify emerging common themes in the data. We outline the resulting themes below.

5.4 Results

Overall, participants interacted with *LOOP* multiple times a day and the visualization was understood and appropriated to physical activity. Participants found *LOOP* aesthetically pleasing and an unobtrusive addition to their home decor. Three participants set up *LOOP* in their living room and two participants placed it in their bedroom. On average the participants were at home in the morning and evening during weekdays, and in the weekend either at home or elsewhere the entire day. Participants usually noticed *LOOP* at similar moments as they did with their tracker and app: in the morning and the evening. When looking at engagement over time (through daily entries), three participants consistently observed *LOOP* throughout the study period, whereas P2 and P3 only paid attention to it occasionally. We will discuss the results in the following themes: assessment of performance, first impressions of *LOOP*, understanding the visualization, synchronization and visualization reset, moment of engagement, motivation and visibility for others, historical data, placement, physicality, and the end result.

5.4.1 Assessment of performance. During the pre-interview, when we asked how the participants would assess their performance of the previous week, four instantly reached for the application. They replied with sums of their steps, kilometers and calories burned. Additionally, P4 gave a short explanation of why the data was as is: "In my opinion my performance was really substandard [. . .] I just did a lot of work for school". The last participant had been ill the previous week; therefore, she already knew her performance was bad and felt no need to check. Of all participants, two assigned a neutral to positive value judgment to their performance, whereas three assessed their performance as negative.

5.4.2 First impressions of LOOP. At first sight, participants reacted upon *LOOP* with phrases such as 'striking' or 'simplistic' and would associate it with for example a decorative artifact or a kind of clock. They had different ideas of what *LOOP* could visualize, for example (i) a different ring would rise every so many steps, (ii) the largest ring would symbolize overall activity with the smaller rings the individual datasets or (iii) the percentage of completion with regards your step goal.

5.4.3 Understanding the visualization. LOOP's data mapping was understood by all participants. They were able to make sense of the visualization by comparing the positions of the rings with each other. Three of the participants were positive about the abstraction of *LOOP*, "I don't always need numbers to see the stats, because it's

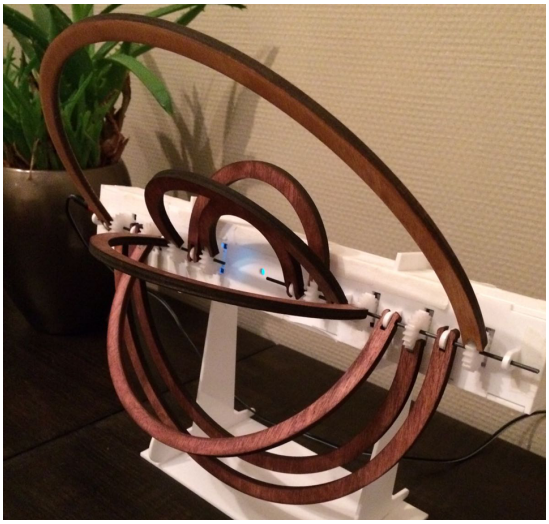


Figure 7: *LOOP* of P1, showing she went above her goal early in the week and below it on Thursday and Friday.

all relative anyway" (P2); whereas two others were neutral about it. In case *LOOP* rescaled throughout the deployment because the step goal was reached (Figure 7), the participants were still able to indicate what each ring meant: "I think I performed reasonably on some days of this week, though I also have been barely active on other days. Besides knowing that I moved less, I can also see it back on the app and the goal ring on the device" (P1).

When asked what first caught their eye when observing *LOOP* participants gave different answers. P4 and P5 compared the ring of the current day with the ring of yesterday to see their progress across days: "I looked at what I walked the previous day and would challenge myself to excel that" (P4). Two other participants first looked at the highest ring (P2) or the goal ring (P1) after which they compared it with their progress of the current day: "First I would look at the highest ring, because that would remind me of my victory. The ring of the day would usually be the second" (P2). P3 used *LOOP* to compare his daily numbers of steps to the step goal ring to estimate the highest value: "It is a combination of guesswork and logical thinking".

Regarding the readability of LOOP over time and from different perspectives P2 stated the following: "After a couple of days the shape kind of changed, which is a good thing. But then it got a bit confusing with the rings. [. . .] For instance, when viewing from the side all the rings get tangled in each other, perspective wise." She also found the exponential increase in the size of the rings a bit confusing, as she would usually associate size with growth. She suggested that changing the orientation of LOOP by placing it on a table surface might result in clearer differences in height of the rings. Lastly, P5 explained that she would observe LOOP from above to compare the several rings with each other (Figure 8).

5.4.4 Synchronization and visualization reset. Four participants reported that they would notice immediately when the visualization of *LOOP* was not showing the correct data. This happened when, for instance, the application did not sync throughout the day as the participants sometimes had no connection to Wi-Fi or Bluetooth. Three participants explained that in case they saw an unexpected visualization when coming home, they sometimes would deliberately sync their app to see if *LOOP* was correct. P5 stated the following: "I would prefer that if I sync [the app], it [LOOP] will sync as well, instead of doing something every hour. Otherwise, I would miss it every time it moves." (P5). On other occasions, when participants did not actively try to sync their app, they did not mind the delay of *LOOP* as long as it eventually visualized the result correctly.

After seven weekdays *LOOP* would reset on Sunday night. None of the participants found this problematic, though three participants found it a pity, especially when the results were good: "If I walked very well in the previous week, I would find it too bad to not be able to look back on it" (P1). P5 suggested letting the reset of the rings be up to the user: "I just really would like to press the reset myself as I was not home on Sunday, so I missed the result". When it was questioned whether or not the Monday of the new week missed reference material P3 remarked: "As you have the goal ring which provides clear reference material for how much you walked [. . .] those previous days don't matter as you are already in a new week."

5.4.5 Moment of engagement. In general, when observing *LOOP*, P4 and P5 would use the app or activity tracker simultaneously to check if the visualization of *LOOP* matches the data. P1 and P3 would occasionally use the app, for example to sync the data or look up additional information such as calories burned. P1 did not feel the need to use the app while observing *LOOP*.

During the study, the participants paid attention to *LOOP* at similar moments as they did with their tracker and app, in the morning and the evening. Four participants indicated to find it interesting to observe *LOOP* when coming or leaving home as well. P4 states: "I liked looking at it most when I came home to see what I had walked. When I am at home I don't care as much, as I won't walk and therefore the thing won't move." Being at home resulted for some in less attention: "When I am at home it does not really matter because I do not walk, so the thing will hardly move" (P5); and for some in more attention; "In the evening [. . .] I would walk around, for instance while cooking, and then see it and sometimes even observe if it does anything" (P2).

When looking at engagement over time, three participants consistently observed *LOOP*. Whereas the slightest change of the artifact excited them in the beginning, they got used to it later and looked at it more strategically. P2 stopped looking consciously at it halfway the study and P3 did not feel the necessity to observe the artifact: "Because I already keep an eye on my wrist". P2 and P3 would mainly observe *LOOP* when filling in the diary and taking the picture.

5.4.6 Motivation and visibility for others. Participants made comments in relation to the physicality of *LOOP* when talking about motivation. For example, it would make P2 aware of her inactivity: "I see the difference between my goal and actual achievement, makes me feel very lazy". P1 liked that she could visually keep track of her progress as *LOOP* made the data more tangible.

P4 felt motivated by *LOOP* to be more active: "It would be stupid if at the end of the day your ring is hanging limp at the bottom. [. . .] It is present enough to be motivating to take some extra steps".

Figure 8: Diary picture made by P5, illustrating how she observed the system from above.

P3 and P5 were motivated by a more indirect motive: "For me, it felt like shaping a little art object with your data. If I had kept it for longer, I would've tried to make for example a beautiful wave, just to mess a little around" (P3). In the case *LOOP* was kept for a longer period, they would have liked to experiment further how their activity could manipulate the appearance of it.

A family member of P1 would occasionally remark the repositioning of *LOOP* and question the meaning of the current position of the rings. Two participants, who had a partner also owning a Fitbit, mentioned in the post-interview that they would like to have a *LOOP* for them too, to be able to do side by side comparisons and compete with each other. Additionally, P4 explained the social influence of *LOOP* showing her data: "Other people can also see whether or not you have walked. Because it is so visual, I am more inclined to do my best".

5.4.7 Historical data. The historical data provided a reminder of previous days and promoted reflection, "This was the day that I went to work and there was a lot of walking within work. It also kind of gave me a reminder of what I did that day as I would think: why did I walk more or why didn't I walk more?" (P2). It also provided a motivation for the next day, "You can actually see that as I continued using it, I really pushed myself: come on, aim for the 10.000!" (P4). Lastly, four of the participants made statements about the accessibility of historical data, for example P5: "In the app you cannot immediately see the entire overview of the week, then you have to go through the pages. This shows immediately how you did from moment to moment."

5.4.8 Placement. *LOOP* was setup two times in the bedroom and three times in the living room. From the post-interviews it became clear that, although the initial placement was with their agreement, all participants had an alternative placement in mind for them to be able to see *LOOP* more often. For example, P1 would like *LOOP* to be in the kitchen as in the mornings she would not always come in the living room. P3 would change the placement of *LOOP* from the desk to the bedside in his bedroom: "Purely because it will be the first and last thing what I see". P5 would possibly place *LOOP* in the hallway instead of the living room. She felt that although *LOOP* fitted in the layout of the living room, in the hallway it would be the first thing she sees when coming and leaving home.

5.4.9 Physicality. The appearance and material of *LOOP* were assessed as beautiful and comforting and blended easily in the home environment: "It gives me a nice feeling and it is pleasant to have in my home; I'm certainly going to miss it later" (P5). The physical properties of *LOOP* were perceived as practical and less obtrusive then for example notifications of the application: "I liked the fact that you have something visible and not necessarily have to get your phone, you can just walk by it while being busy at home" (P1). The light in the center of *LOOP* was perceived as peaceful by P5, she mentioned: "I really like the light, it gives me a sense of calm as it shows me the system is operative".

Four participants were excited about seeing *LOOP* actually move and would have liked to see it more often: "On Friday, I heard it, that's why I turned around and was like: oh, it moves!" (P2). This also illustrates that the sound the movement of *LOOP* made triggered the participants to observe and reflect upon *LOOP's* behavior.

5.4.10 End result. At the end of the study period, *LOOP* looked different per individual. All the participants aimed for approximately the same step goal, though different visualizations were created. Again, the participants were asked to give an assessment of their performance so far. The performance assessments from left to right are: zero position, neutral, negative, neutral, positive, positive (Figure 9).

6 DISCUSSION

In this paper, we explored how a physical representation of activity data can encourage a different way of reflection and integration in everyday life by allowing for coincidental encounters of the user with their data. Our field study demonstrated how *LOOP* was used by five participants in a domestic context. All participants found *LOOP* a pleasant system to have, providing an informative but

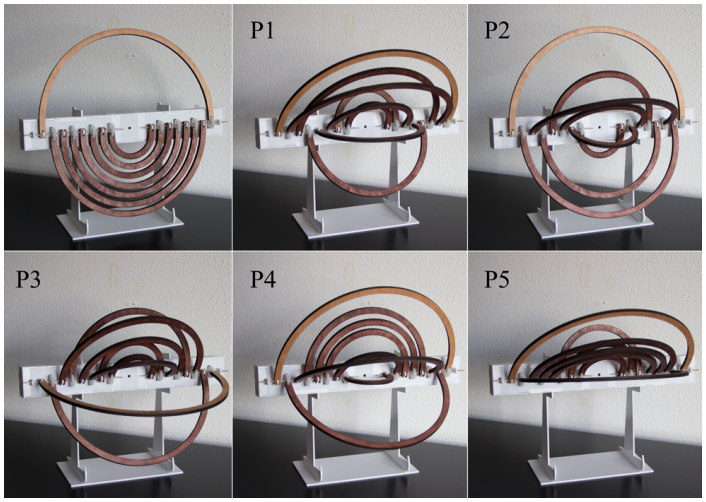


Figure 9: The results of *LOOP* after one week.

aesthetic presence in their home. *LOOP* allowed for continuous but unobtrusive exposure to personal activity data and could be used to both facilitate and manipulate the moment and occasion at which participants interacted with their data dependent on the context it is placed in. Participants had different strategies for reading the visualization of *LOOP*, comparing different rings to their own liking. By physically depicting current progress in relation to step goal and previous days, *LOOP* motivated participants to move in both direct and indirect ways. *LOOP* made historical data more accessible and prompted participants to link the repositioning of its rings to their activities during the week. However, some elements of *LOOP*'s visualization did create some confusion, such as the size differences of the rings and their reconfiguration over time, causing it not to be informative from all perspectives. Lastly, participants would have liked to have more control over the synchronization and reset of the system for it to better fit their routines.

6.1 Physicality

During the deployment, participants observed *LOOP* at similar moments as they would do with their traditional system, either in conjunction or as a replacement. However, our results show that a physical system also created new moments of engagement with data [36], in particular when coming or leaving home. We consider this is something specific to activity tracking as leaving or coming home influences the activity of the person which shows in the physicalization. This engagement on these particular moments would not necessarily occur when using a digital application, which has to be opened and synced before retrieving their data and cannot be observed immediately.

The dynamic nature of *LOOP* allowed for real-time data in contrast to static physicalizations [18, 20, 34]. However, participants seemed to desire some sense of control over the moment the shape change happened, instead of preferring a real-time display. The moment of shape change could be strategically used to engage the user with their data more. A solution the participants gave themselves was that in case they sync the application, the physicalization should sync as well, so they could immediately observe the shape change.

Next to that participants found *LOOP* less obtrusive compared to their mobile device. They indicated that they could observe or ignore the system whenever they wanted and that it is not as disturbing as notifications or reminders from an application. Even though *LOOP* had an unavoidable physical presence, participants had the feeling they had the choice to look at it whenever they want.

To generalize, the physicality of a shape-changing display such as *LOOP* allows for continuous but unobtrusive exposure to information and could be used to both facilitate and manipulate the moment and occasion at which people interact with their data dependent on the context it is placed in.

6.2 Reflection

The study showed that the layers of information *LOOP* offered, with both relative and absolute data, can be valuable for two reasons: the compatibility with different types of users and the ability to reflect on past physical activity.

Prior work discussed how the physicalization design for activity tracking should consider the *purpose* in relation to the user's needs [22]. Our results show that the same physical visualization supported the participants in different ways. The participants that started tracking because of intrinsic motivations - e.g. become more active or lose weight - used *LOOP* to keep track of their progress, whereas the participants curious for the technology were more extrinsically motivated by the shape-change of the system.

These different interactions with the physicalizations seem to have been facilitated by the possibility to compare different data to each other. For example, some participants compared the ring of the current day and the previous day to see if they improved, while others observed the highest ring to be reminded of their victory. Research on the motives for activity tracking shows that users have different goals when starting to track [29], and after a period of time they sometimes switch to different information needs [4, 22].

In the case a physicalization offers different layers of information, as *LOOP* does, it allows multiple interaction possibilities which are beneficial for the different motives and information needs users of activity trackers can have. Additionally, the interplay of relative and absolute cues from the system could allow people to extract different levels of detail from the physicalization according to their desires, which can facilitate people to transition between their qualitative user goals and the quantitative goals supported by their activity trackers [27].

These findings resonate with related work that showed that a physical reward can indirectly motivate users [17]. However, in contrast to static physical rewards, observing the real-time repositioning of the rings of *LOOP* was also a motivation in itself for the participants. Therefore, future work could examine how the dynamic nature of physicalizations - the type of transformation and shape change [26] - could influence intrinsic and extrinsic user motivations over time and could develop different kinds of relations with data that go beyond typical motivations.

The participants enjoyed being able to see the results of an entire week in the visualization of *LOOP*. While such overviews are also available in mobile applications, you usually have to slide through multiple pages to see them. *LOOP* enabled users to immediately place their performance of the current day in perspective of other days. Therefore, we believe that the physical comparison provided of current and historical data is a good facilitator for reflection and understanding of activity data in new ways.

6.3 Visualization mapping

The mapping of *LOOP* created some occasional confusion among the participants. Khot et al. [19] discuss the importance of *data mapping* between the activity data and the artifact, and in related work the increase of physical activity is often mapped to increase in size of the artifact [18, 34]. In contrast, the visualization of *LOOP* visualized increase of physical activity by an upward motion and the increase in size of rings indicated days of the week, which was not always perceived as intuitive. Additionally, the readability of *LOOP* changed over time as occlusion of the rings occurred. Participants reported on different strategies to read the visualization and observed *LOOP* from different perspectives, making the physicalization prone to incorrect interpretations as shown by prior work [33]. Future work could investigate how different orientations of the entire system (e.g. on a wall or table surface as suggested by participants) could lead to different interpretations.

In contrast to work on ambiguity as a resource for design [8], we designed *LOOP* to be abstract but not ambiguous, and aimed for a clear interpretation of the system cues. As the current representation of activity data is often in numeric formats, we wanted to complement this with a more abstract representation, balancing aesthetic and informative properties. However, it could be interesting to explore further how enhancing the ambiguity of information [8] can be used in favor of the user interaction with activity data. As discussed by Gaver et al. [8], using imprecise data representations could be an opportunity to draw more attention to the inherent inaccuracy of activity data and create a space for personal reflection and provoke independent assessment of performance.

Our results show how abstract comparison of certain variables of a dataset was beneficial for activity tracking data. However, more research is needed to see if abstract comparisons could also be suitable for understandability and reflection on other (personal) data. In the current study *LOOP* operated with a fixed configuration of visualizing the step data per day over the course of a week. However, due to the abstract nature of *LOOP* it could function as a platform system to visualize any time-based data. Therefore, it could visualize activity data in different ways - e.g. the increasing size of the rings indicating increments in steps, or each ring representing one dataset related to activity tracking, as suggested by participants. Future work could explore how *LOOP* could visualize different time-based data (e.g. activity data, personal finances or calorie count), in different configurations (e.g. per day, week or month; for different related datasets; or for multiple users), and how it could allow the user to reconfigure the visualization to fit their goals and changing information needs over time.

6.4 Limitations

Although the study of *LOOP* demonstrates promising findings on how a real-time dynamic representation of data can open up new opportunities, our findings are narrow in certain ways. Our study is of an explorative nature, therefore the focus was on providing an in-depth discussion of the qualitative findings. Nonetheless, a noteworthy limitation of our study is, while it was "in the wild", the sample size was small and the study featured only up to seven days of using the system. This prevents us from drawing any conclusions about long-term behavior from the present findings. Future research is required to reveal how a physicalization could become part of people's interaction with their personal data even after the novelty effect has gone.

7 CONCLUSION

In this paper, we took the specific context of activity tracking as an example to investigate how a physical artifact could support reflection on personal activity data in everyday life. We designed and evaluated *LOOP*, a physical artifact that changes its shape according to the activity data of the owner and provides an abstract visualization. Our study showed how *LOOP* to be valuable for its specific context of use as the physicalization elicited reflection on activity data and supported the different goals users of activity trackers can have with this technology.

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