

Activity Sculptures: Exploring the Impact of Physical Visualizations on Running Activity

Simon Stusak, Aurélien Tabard, Franziska Sauka, Rohit Ashok Khot, Andreas Butz

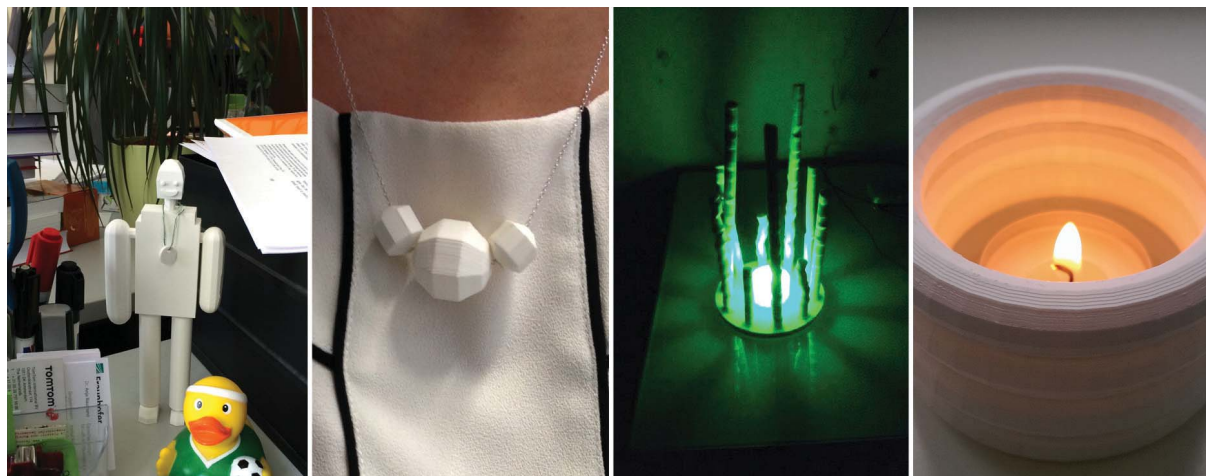


Fig. 1. Four Activity Sculptures of running activity: a figure, a necklace, a lamp and a jar. The sculptures are extensible by additional pieces, and each individual piece represents a specific run.

Abstract—Data sculptures are a promising type of visualizations in which data is given a physical form. In the past, they have mostly been used for artistic, communicative or educational purposes, and designers of data sculptures argue that in such situations, physical visualizations can be more enriching than pixel-based visualizations. We present the design of *Activity Sculptures*: data sculptures of running activity. In a three-week field study we investigated the impact of the sculptures on 14 participants' running activity, the personal and social behaviors generated by the sculptures, as well as participants' experiences when receiving these individual physical tokens generated from the specific data of their runs. The physical rewards generated curiosity and personal experimentation but also social dynamics such as discussion on runs or envy/competition. We argue that such passive (or calm) visualizations can complement nudging and other mechanisms of persuasion with a more playful and reflective look at ones' activity.

Index Terms—Physical Visualizations, Activity Sculptures, Physical Activity, Data Sculptures, Behavioral Change

1 INTRODUCTION

Physical visualizations use specifically shaped objects to give abstract data a concrete physical form. Vande Moere argues that the tangible nature of physical objects conveys messages beyond the data itself, encourages people to reflect on its meaning, and provides a more enjoyable and engaging experience [41]. These promising properties of physical visualizations have been explored in various settings, including art installations, scientific experiments and education [36].

This research focused mostly on the representation of generic data.

- Simon Stusak is with University of Munich (LMU).
E-mail: simon.stusak@ifi.lmu.de.
- Aurélien Tabard is with Université de Lyon & CNRS.
Université Lyon 1, LIRIS, UMR5205, F-69622, France
E-mail: aurelien.tabard@univ-lyon1.fr.
- Franziska Sauka is with University of Munich (LMU).
E-mail: sauka@cip.ifi.lmu.de.
- Rohit Ashok Khot is with Exertion Games Lab, RMIT University.
E-mail: rohit@exertiongameslab.org.
- Andreas Butz is with University of Munich (LMU).
E-mail: andreas.butz@ifi.lmu.de.

Manuscript received 31 Mar. 2014; accepted 1 Aug. 2014. Date of publication 11 Aug. 2014; date of current version 9 Nov. 2014.

For information on obtaining reprints of this article, please send e-mail to: tvcg@computer.org.

Digital Object Identifier 10.1109/TVCG.2014.2352953

We are interested in investigating the impact of physical visualizations of personal data. Indeed Khot et al. recently showed that physicality of personal data visualizations [20] can provide additional benefits such as strengthening emotional connections. These preliminary results are promising but did not focus on the long term impact (both positive and negative) of physical visualizations. The question of long term impact is particularly relevant given the nature of physical visualizations as long lasting and “always on” objects. In this paper, we present a three-week field study, in which we investigated how physical visualizations of personal running activity changed participants' running behaviors.

Sport is a domain in which physical tokens such as medals or cups are already widely used as material rewards. In similar spirit, we designed *Activity Sculptures*, a family of physical visualizations with the purpose of fostering comparison, reflection and communication about running activity. In our work, the data from every run is processed to create a unique piece, which becomes part of a larger sculpture (see figure 1). This fabrication process is based on a web pipeline we developed for fetching and transforming participants' running data in order to produce the physical visualization parts.

We evaluated the concept of Activity Sculptures with 14 participants in a three-week field study. We were particularly interested in comparing the different types of sculptures and their respective impact on participants. Moreover, since existing research in technology-supported behavioral change shows that feedback and (digital) visualizations of past activity can increase current physical activity, we aimed at detecting whether the same effects would come into play with physical visualizations, or which other dynamics would emerge.

2 RELATED WORK

Over the past decade, technological solutions have been proposed to foster change in people's behavior, from decreasing energy consumption to increasing physical activity. Such solutions are motivated by the social challenges our societies are facing from widespread medical conditions, to environmental change. While focusing on physical activity we ground our work in the research on behavioral change, but also consider criticisms to this approach.

2.1 From Lifelogging to Quantified Self

Artists and scientists have used tools such as notebooks to track and reflect on their activity before computers were ever available. As personal informatics gained importance at the end of 1990's, a number of self-tracking projects emerged. The MyLifeBits project is a prominent example of these experiments [13]: Gordon Bell and his colleagues from Microsoft Research recorded and organized large amounts of his personal data. Starting with computer based data [11], lifelogging prototypes incorporated an increasing number of sensor data [3], in order to augment personal memory. One of the conclusions of these experiments was that capture and reflection on personal activity could have the most impact on areas of health and well-being [21]. This led to the recent emergence of the Quantified Self movement [38], an "*international collaboration of users and makers of self-tracking tools*"¹. The movement aims at making sense of personal data from spending habits, to stress or physical activity, often with the underlying goal of self-improvement.

2.2 Motivating Physical Activity

Tracking and motivational applications often ground their design on behavioral psychology [7, 12], with the hypothesis that immediate contextual feedback can promote behavioral change [22]. While recent sensing technology² has made activity tracking and contextual feedback much easier, the main challenges to behavioral change remain human ones, i.e. helping people reach their goals and maintain the changes over time [2]. Behavioral and social theories offer a wealth of strategies to support change. These include the promotion of gradual changes in individuals' behavior (e.g., with the transtheoretical model [14]) or mechanisms for sustaining the changes over time. Through a thorough review of the literature, Consolvo et al. identified the following strategies [7]:

1. *use abstraction*, rather than raw sensor data to foster reflection;
2. *be controllable*, by letting people set their own goals [24];
3. *show trends*, for users to relate past efforts to the goals they set;
4. *be positive*, positive reinforcement encourages change [8]; negative feedback or punishment are not effective motivators [23];
5. *be comprehensive*, by not limiting feedback and rewards to what can be sensed, but account for other positive behaviors that were not captured by the system [6];
6. *be aesthetic*, by displaying information in a comfortable and attractive manner; this can increase enjoyment and engagement [10];
7. *be unobtrusive*, by collecting data without interrupting users and presenting it when needed;
8. *be public*, allow sharing [26] as well as social influences through family participation [25].

In the design we present next, we used these strategies as guidelines, as they provide powerful motivators and can impact behavior even without people noticing. E.g., the field study of twinkly lights [29] showed that ambient information could transform the way people behave without them being aware of it, in this case, taking stairs rather than the elevator.

Nonetheless, many other factors besides psychological elements contribute to lifestyle improvements. For instance Munson showed

¹<http://quantifiedself.com/about/>

²From mobile apps (RunKeeper, Nike+ Running, Endomondo, Runtastic), to wearables devices (e.g. Jawbone, Misfit Shine, Fitbit, Nike+ fuelband, Withings Pulse)

that digital rewards do not motivate inherently [26] which raises questions about how such rewards should be designed. More importantly behavioral change systems often coincide with norms and visions of ideal behaviors embedded into their design [30]. Rather than nudging or persuading users into a specific behavior, more positive strategies might aim at changing attitudes (rather than behaviors), fostering mindfulness and leaving room for stories [28], or moving beyond the individual [5, 9]. As suggested by Yetim [40] seeing persuasion as a communicative act can enable designers to promote discussion "on the intent of persuasion and the strategies chosen to achieve the desired attitude and/or behavior change", thereby avoiding an overly rational model of human behavior criticized by many [5, 28]. In this article, we investigate how physical visualizations can foster reflection and communication on physical activity, but also a playful rather than utilitarian relationship to physical activity.

2.3 Casual Infovis

Visualizations for reflection and playfulness depart from traditional information visualization which has historically investigated analytical tasks conducted by experts. Such visualizations often differ from desktop-centric applications to provide a more personal or shared experience, through mobile applications³, ambient visualizations conveying lightweight information in the background [32], social ones [39], informative art [37], or even on wearables [1]. Pousman et al. framed this as *Casual Infovis* or "the use of computer mediated tools to depict personally meaningful information in visual ways that support everyday users in both everyday work and non-work situations" [27]. Our project investigates a specific type of casual visualization in which pixels are replaced by physical objects.

2.4 Physical Visualizations

Compared to traditional digital visualizations, which map data to pixels or ink, physical visualization map data onto a physical form [18]. Jansen et al. [17] extended the information visualization pipeline model with an interaction model for beyond-desktop visualizations to describe the process from raw data to a visualization to the rendering in the physical world. When designing a physical visualization, three aspects have to be considered, i.e. the *design goals*, the *aesthetic features* and the *assembly / manufacturing features* [34].

While physical visualizations can serve analytical purposes [33], we are more interested in making data exploration an intriguing and memorable experience. Vande Moere argues that data sculptures have the potential to encourage people to reflect on the meaning of the data and thereby change their behavior [35].

One example for this kind of data sculptures is *Breakaway* by Jafari-naimi et al. [16], which reflects the form of the human body through its shape and movement. It communicates in a non-obtrusive manner how long a user has been sitting on a chair. The data is gathered through sensors placed on the chair. Khot et al. [19] designed a system called *SweatAtoms*, which transforms the physical activity data based on heart rate into five different 3D printed material artifacts. The evaluation of the system in six households for two weeks revealed that participants' relationship to physical activity can be affected by physical representations.

This paper complements/differs from their approach in the following ways: 1) Broader study: We conduct a study with more participants (14 vs. 7) and for a longer duration. 2) Different data: We focus on running activity, not everyday physical activity. We visualize a larger number of variables (running time, distance, speed, duration, elevation gain) rather relying solely on heart rate data. This allow us to study how participants interpret these data mappings. 3) Different design strategies: We also explore alternate designs in which physical objects add to each other, leading to bigger objects. As a result, users can easily see and compare their progress through these artefacts as a continuum of their physical activity. 4) Focus on social dynamics: We also investigate the affect of physical visualization on social dynamics by deliberately choosing study participants who know each other.

³<http://mobilev.is/>



Fig. 2. Sketches of eight early concepts that were used in the brainstorming session and for the online questionnaire.

We aim to understand whether such physical representations can foster communication, competition, envy among participants which could further aid in the motivation for physical activity. 5) Off-site printing: We investigate how the production and reception of physical visualization impacts participants. In our case, participants directly receive artifacts (like rewards) rather than printing themselves.

Finally, several commercial services offer the creation of physical artifacts based on the data of the user. Loci⁴ for example is a series of 3D printed sculptures of one's flight paths. The web service Meshu.io⁵ generates jewelry based on the travel data of the users. The data can be entered manually or users can allow the service access to their social media data. After selecting the material and the fabrication technique the object is remotely fabricated and mailed to the user.

3 DESIGNING ACTIVITY SCULPTURES

This section describes the design and the fabrication process of the Activity Sculptures. Based on our literature review, a brainstorming session and an online survey we explored various concepts (see figure 2), which we then refined into four types of sculptures. We developed a fabrication process leveraging web technologies to fetch running data, and generated 3D models which could then be printed.

3.1 Design Process

Our first step was to define the space within which we would design Activity Sculptures. We organized a Brainstorming Webs [15] session with five colleagues (graduate students) to discuss ideas what such Activity Sculptures could look like and to specify which characteristics they should meet. Their ideas were later refined through a review of the literature presented above. We also presented our initial directions to the wider public through an online survey (47 participants).

3.1.1 Initial Design Directions

Based on the brainstorming session, previous discussions and the literature, we identified a set of design principles, categorized in three main design directions:

- **Reflection:** sculptures should support self-reflection more than comparison; should display intermediate goals and stages; ought to reflect met and unmet goals; should always stay within sight.
- **Motivation:** sculptures should constantly support motivation and feedback; should display good and bad performances.
- **Form:** should only look aesthetically pleasing if good performances were achieved; should serve some kind of practical purpose; should be modifiable and variable.

We explored these directions through eight concepts (see figure 2) including a lamp, a jar, a picture frame, a modular sculpture and an engraved sculpture. Apart from these abstract concepts we also included classical visualizations such as bar charts or stacked line graphs.

3.1.2 Online survey

To assess our initial directions, we conducted an online survey. We collected answers from 47 participants (57% were female and 43% male) between 23 and 50 years old.

The majority of respondents (35) stated that they would like to have sculptures of physical activity. For 75% of the respondents the visibility of their own data was more important than the possibility to compare their performances with other runners. To see all activities including "bad" performances was favored by 70% (21% were not interested in viewing "bad" performances).

Respondents considered the motivational potential of physical representations positively, with 34% (16) perceiving a very good opportunity and nearly half (23) thinking that it could motivate them a little. The majority (32) considered the motivational aspects of physical visualizations of running activity positive.

However, motivation should not be considered the only purpose of the sculptures, while 23 respondents considered an increase in motivation as important, 14 preferred sculptures supporting self-reflection, 9 artwork pieces, and 20 participants preferred a mixture of all three purposes. These preferences were reflected in the types of sculpture the respondents preferred: aesthetic and extensible sculptures. The lamp was rated best, followed by the jar, the picture frame, the sculpture with engraving and the modular sculpture. The more conventional visualizations, i.e. stacked line graphs and bar charts were ranked lowest.

Participants stated that they would prefer longer periods of time between receiving sculptures: 19 participants preferred to receive sculptures when reaching pre-established goals and 11 chose the option of receiving one sculpture per month. Only a few (5) participants wanted a sculpture for every run.

Overall, the survey outlined interesting directions: appreciation for the concept of Activity Sculptures, interest in the motivational potential of the sculptures but also in the reflective and aesthetic aspects of the sculptures. This is particularly evident when looking at the ranking of the sculptures. The slow pace at which participants expected to receive sculptures reveals the importance of excitement and contemplation over instant feedback and quantitative comparison.

3.2 Design Decisions

Based on this initial feedback, we decided to focus on sculptures of an abstract nature and which support self-reflection. We aimed at creating aesthetically pleasing sculptures that would not seek constant attention. Comprehensibility and direct readability of the exact data at the first glance was secondary since participants used the sculptures

⁴<http://vimeo.com/64390930>

⁵<http://meshu.io/>

for a longer time. We decided to make the sculptures modular, rewarding each running session with a piece of the sculpture. The pieces add up to make a whole, as a means to promote regular physical activities. While the feedback from our survey indicated a slower update rate, we decided on producing one piece after every run to reach the evaluation of the concepts after about one month.

Of all concepts explored, we retained three which fit best our design directions: lamp, jar, figure. We further added a necklace sculpture (see fig. 2). The introduction of this concept seemed interesting for investigating the potential of self-expression. As a sculpture that predominantly appealed to women it also served as a fitting contrast to the robot-shaped figure sculpture (which was preferred by men in our survey). Both the necklace and the figure tended to be decorative pieces whereas the jar and the lamp had a practical purpose.

All sculptures had in common that the size of the single parts increased with better performances. The performance also influenced their *form*, going from an angular and sharp appearance to appearing smoother and in our opinion more aesthetically pleasing. For every sculpture the *average speed*, *duration* and *distance* was used as the underlying data, because they were the most popular in the online questionnaire. The lamp also included *elevation gain* and the figure *calorie consumption*. This was decided in order to investigate whether additional variables can have an impact, e.g. on motivational aspects. As all sculptures represent running data they can be used for *self-reflection* and may catch one's attention (depending on where the participants placed them). The figure and lamp clearly showed met and unmet goals. Missing pieces could be noticed easily, increasing *motivation*. With each run represented by a piece, feedback is provided after every run.

3.2.1 Jar

The jar (see figure 3 left) is composed of an undefined number of round layers, each representing one run. The layers can be stacked on top of each other, as the center-to-center diameter is fixed. The duration of a run is visualized by the diameter of one layer, average speed and distance influence the shape of a layer. The number of width segments is a factor of the speed and the number of height segments of the distance covered.

3.2.2 Necklace

The necklace (see figure 3 right) is composed of an undefined number of beads, each representing one run. The beads can be added to a chain, and the size of a bead indicates the duration of a run. The shape of a bead depends on the average running speed affecting the number of width segments and the distance covered visible in the number of height segments.

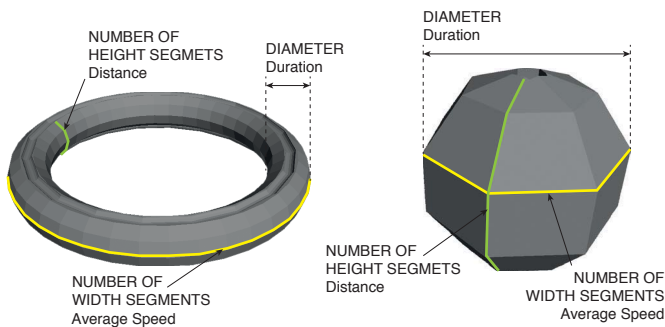


Fig. 3. Digital 3D models of a layer of the jar sculpture (left) and a bead of the necklace sculpture (right).

3.2.3 Lamp

The lamp (see figure 4 left) is composed of ten pillars, each representing one run. Each pillar can be plugged into a dedicated hole at the

lamp's base. The difference in altitude associated with a run is represented by the two-dimensional progression of a pillar. A run with no altitude differences results in a straight pillar, while a jagged pillar represents large differences. To receive 3D printable models based on large data variances, the elevation gain data is normalized. The average speed of a run can be perceived in a pillar's thickness, the distance affects the number of width segments and the duration is mapped to the number of height segments.

3.2.4 Figure

The figure (see figure 4 right) is composed of eight body parts, each representing a run. The body parts can be plugged into the unfinished figure. The height of a body part depends on the run's duration, its scope on the covered distance and the calories burned and average speed affect its shape (number of width and height segments).

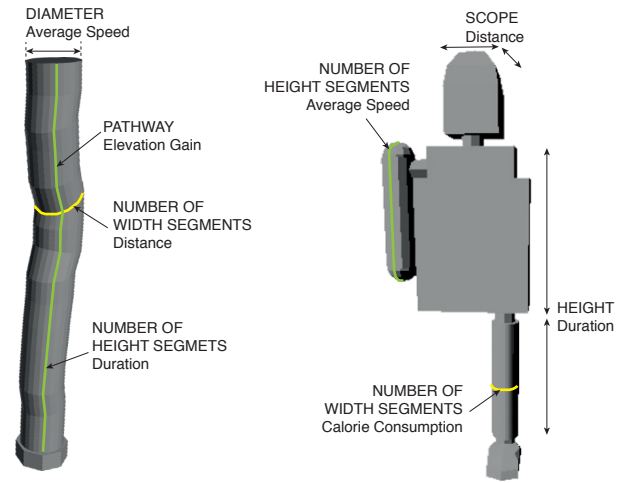


Fig. 4. Digital 3D models of a pillar of the lamp sculpture (left) and several parts of the figure sculpture (right).

3.2.5 Extensibility of the Sculptures

All the sculptures consisted of parts which can be assembled, enabling the extension of the sculptures. We anticipated that producing regular feedback (a piece per run) would uphold users' interest, as well as maintain motivation through regular rewards and reflection through the opportunity for comparing runs. We further discuss participants' reactions to the sculptures in the results section. In the case of the figure and the lamp, we expected the desire to "*complete*" the sculpture to encourage regular running activity. The figure consisted altogether of eight body parts and the lamp had ten holes at the base which had to be filled. In contrast, receiving a single piece of the necklace or the jar can provide sufficient satisfaction.

3.3 Fabrication Process

Figure 5 offers an overview of the process we used to produce the sculptures. The running data was tracked with a mobile tracking application and saved in the cloud (fig. 5-1). The data was then gathered either through website export and mail (fig. 5-2a) or API calls (fig. 5-2b). Based on the captured data, we generated a digital version of the sculptures as 3D STL files. We then used an Ultimaker Original⁶ to 3D print the sculptures (fig. 5-3). Each piece of the Activity Sculptures was either handed out in person (fig. 5-4a) or by letter (fig. 5-4b).

3.3.1 Data

We extracted running data from four popular mobile running applications (Endomondo, Runkeeper, Nike+ Running and Runtastic). We used as parameters to the sculptures: 1. the duration of a run, 2.

⁶<https://www.ultimaker.com/>

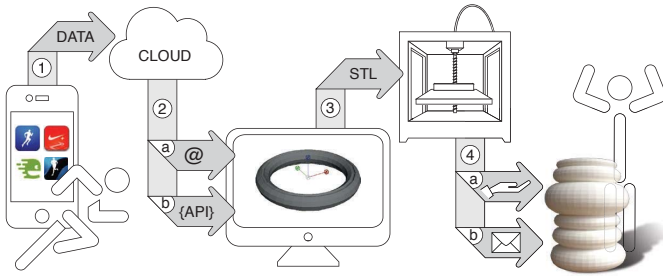


Fig. 5. The fabrication pipeline of the Activity Sculptures.

the distance covered, 3. the average speed 4. the amount of calories burned and 5. the elevation gain of a running session. These data types were recorded by each of the running apps. We collected the data of each run as TCX, GPX or CSV files. Depending on the participants' preferences these were either sent directly by the participants, or accessed from their user accounts via website export or API calls.

3.3.2 Digital 3D Models

Based on the extracted activity data, we produced the 3D models. We first implemented the generation of the 3D objects, which were then converted to obtain printable 3D objects. We used Three.js⁷, a JavaScript library for WebGL - 3D in the browser - for developing the digital 3D models of the Activity Sculptures. In addition, we used Csg.js⁸ another JavaScript library for WebGL for the construction. The Constructive Solid Geometry (CSG) library uses boolean operations (i.e. add, subtract, union and intersect) to build complex objects by assembling simple objects. We used ThreeCSG.js⁹ as a bridge between Three.js and Csg.js since the two libraries use different formats for geometry. In order to display the sculptures, we created scenes for each sculpture, including the physical activity data and the 3D geometries. We used HTML templates which could be loaded in a Web browser and exported the 3D models as STL (STereoLithography) files, a format suitable for 3D printing.

3.3.3 3D printing

We used Cura¹⁰ to transform the 3D models (STL files) into G-Code, the machine code understood by the Ultimaker. Cura enabled us to control printing options and increase the quality of printing results. To keep the printing process as easy and fast as possible the only material used was white polylactic acid (PLA).

4 FIELD STUDY

For a better understanding of the impact of physical visualizations of running activity, we conducted a three-week field study. The main objective of our study was to observe the influence of physical visualizations on participants' behavior. We were especially interested in the way visualizations would trigger reflection and discussions. We also aimed at understanding participants' general perception of physical visualizations of running data.

4.1 Participants

We recruited 14 participants¹¹ to take part in the field study (8 females and 6 males, aged between 24 and 62) by announcing the study in a Facebook group of our university and using a newsletter with subscribers who are interested in study participation. The participants

⁷<http://threejs.org/>

⁸<http://evanw.github.io/csg.js/>

⁹<https://github.com/chandlerprall/ThreeCSG>

¹⁰<https://github.com/daid/Cura>

¹¹We recruited 16 individuals but one participant did not have time to go for a run and another had technical issues, therefore the data of these two participants was not taken into account.

represented a range of occupations including controller, designer, business consultant, assessor, students, and research assistants from our university (see table 1).

Existing running habits: Our participants had various levels of running experience. Six participants had not gone running at all before the study, whereas the remaining participants ran between one and three times a week.

Existing use of tracking applications: Nine participants had already used a tracking application (see also table 2). Four participants were even part of a running team, meaning they worked together in the same building and saw each other several times a day. They already shared their running data in the same mobile tracking app (*Endomondo*). The five students attended the same university and knew each other by sight. Five participants had never used a mobile tracking app before the study, either due to the inconvenience of carrying a smartphone along or the perceived lack of additional value.

Table 1. Demographic details of the participants.

ID	Gender	Age	Occupation	Running routine	Running Team
1	male	25	student	once a week, 30-40 min	no
2	male	30	research assistant	3 times a week, 10-20 km	yes
3	male	31	student	1-2 times a week, 5-10 km	no
4	female	29	research assistant	twice a week, 5-10 km	yes
5	female	28	research assistant	non-runner	no
6	male	27	controller	once a week, 5 km	no
7	female	24	student	non-runner	no
8	female	24	student	once in two weeks	no
9	female	24	student	non-runner	no
10	male	29	research assistant	3 times a week, 10 km	yes
11	female	62	assessor	non-runner	no
12	female	30	designer	twice a week, 5 km	no
13	female	30	research assistant	non-runner	yes
14	male	32	business consultant	2-4 runs a week, 7-8 km	no

4.2 Setup

To be part of the study, participants used one of the following tracking applications: *Endomondo*, *Runtastic*, *Nike+ Running* or *Runkeeper* to track their data. These were the most used tracking applications at the moment of the study. The participants who did not use a tracking app before were asked to choose one of these four applications. Furthermore participants chose the way in which their running data was accessed. Options included sending the data per e-mail or providing account data for the duration of the study.

4.3 Procedure

We conducted a three-week long field study in November 2013 in the local area of Munich in Germany, with 14 participants. The study leader conducted semi-structured personal interviews at the beginning and at the end of the study. The interviews were complemented with pen-and-paper questionnaires. Furthermore, we met with the participants throughout the study to hand-over the physical items. Participants received no compensation, but could keep their Activity Sculptures.

4.3.1 Preliminary Interviews

In the preliminary interviews participants signed a consent form and were asked about their current physical activity routines and goals, important types of running data and their experience with physical visualizations.

We then introduced the four physical visualizations by presenting images of each visualization printed out on paper. First, we showed only the visualizations without a legend, after that we presented variations with explanations about the data mapping. We decided not to present any 3D printed visualizations, to better observe participants' reactions when receiving their first piece. After this introduction we asked the participants to share their first impressions of each visualization. Participants were also asked to rate aspects such as the potential of motivation or self-reflection on 5-point Likert scales. Finally, each individual chose the type of Activity Sculptures they would get throughout the study.

4.3.2 Field Study

During the three weeks of the study the participants went running, and collected their running data with one of the tracking applications mentioned above. The digital 3D sculpture pieces were generated according to the runs of the participants and then 3D printed. We tried to keep the period between submitting the data and receiving the physical visualization as short as possible (between one and three days). We observed reactions and statements of the participants when the handover of the physical visualizations occurred in person and asked them to express their first impressions of the sculpture.

4.3.3 Closing interviews

In the final interviews, we asked each participant to recall their experiences in the last weeks and gathered feedback on the physical visualizations. The interview focused on the visualizations, the social aspects that came along with them and the participants' running behavior. Additionally the interviewees had to rate the same aspects on 5-point Likert scales as in the preliminary interview as well as new questions focusing on their impressions on the chosen sculpture.

4.3.4 Data Collected

We gathered data via semi-structured interviews, questionnaires as well as running logs. The interviews were audio recorded and transcribed by two researchers. We followed a qualitative coding approach to identify both overall themes and more specific findings linked to single participants.

5 RESULTS

This section describes our key findings from the field study. We start with an overview of participants and the results of the questionnaires, and continue our focus on the qualitative analysis of the semi-structured interviews.

5.1 Participants Overview

Table 2 offers an overview of the study setup for every participant. Five participants used *Endomondo* to track their data, four participants chose *Runtastic*, three used *Nike+ Running* and two tracked their runs with *Runkeeper*.

The most often mentioned reasons to go running were fitness (6), relaxation (4), fun (2), balance (2) and group motivation (2). The most important types of running data for the participants were speed (6), distance (5), duration (4), progress (4) and route (2). Eight participants did not have any experience with physical visualizations, six had already seen various examples.

The lamp was chosen by four participants, the jar by four as well, the necklace by three, and the figure by three. Participants ran between one and nine times over the three weeks of the study, for a total of 71 runs across participants. Twelve participants preferred a personal delivery of the sculpture pieces, the remaining two chose a delivery by letter.

5.2 Questionnaires

During the preliminary and closing interviews, participants filled 5-point Likert scale questionnaires (ranging from 1: very good; to 5: very poor). Participants appreciated the general idea of visualizing running data through physical visualizations (*median=1*, in preliminary and closing interview respectively). Before the study only four

Table 2. Overview of the study setup for every participant.

ID	Tracking App (*no app use before study)	Visualization	Delivery	# runs / received pieces
1	RunKeeper*	lamp	personal	6
2	Endomondo	figure	personal	9
3	RunKeeper	jar	personal	6
4	Endomondo	jar	personal	8
5	Endomondo*	necklace	personal	3
6	Nike+ Running	lamp	per letter	4
7	Runtastic*	lamp	personal	5
8	Nike+ Running	figure	personal	5
9	Runtastic	necklace	personal	4
10	Endomondo	jar	personal	6
11	Runtastic*	figure	personal	7
12	Nike+ Running	jar	per letter	4
13	Endomondo	necklace	personal	1
14	Runtastic*	lamp	personal	3

participants were impartial, whereas all other participants rated the idea as good (2 participants) or very good (8 participants). In the closing interviews all participants rated the idea as either good (6 participants) or very good (8 participants). The motivational potential was also rated as good (*median=2*, in preliminary and closing interview respectively).

After the study, participants rated the suitability of the sculptures for comparison with others and for self-expression (before *median=2*, after *median=4*) less positively than before. However, it should be noted that only participants who were impartial before the study decreased their ratings. While participants that were convinced of the potential for comparison with others and self-expression before the study did not change their opinion. The necklace stood out, as the only sculpture whose ratings increased in these two questions. Finally, the ratings for self-reflection increased for all sculptures after the study (before *median=2*, after *median=1*).

The questionnaire used in the closing interview included further questions regarding the participants' impressions on their chosen sculptures. The scale ranged from 1 (very good) to 5 (very poor). Participants rated the aesthetics, practical benefit, information content and the quality of the sculptures overall as good (for all questions *median=2*). It is worth mentioning that the necklace sculpture received the best ratings overall, apart from practical benefit, in which the lamp and the jar scored better.

5.3 Interviews

We interviewed participants throughout the study. In our preliminary interviews we focused on the first impressions of each sculpture type, e.g. what participants appreciated and disliked about the visualizations, and their motivation in picking a specific type. Throughout the study, the study leader also collected feedback from the twelve participants who received their sculpture pieces personally. Finally the concluding interviews included open-ended questions about the physical visualizations and their influence on participants' behavior. Below, the results from the interviews are presented.

5.3.1 Initial Choice of Activity Sculpture

Participants picked the type of visualization they preferred. They balanced considerations about aesthetics, practicality and design, envisioning how the sculptures would *scale*, look and stand after multiple runs.

Aesthetics The aesthetical aspects played an important role in the choice of sculpture. One participant (*P5*) liked the necklace sculpture because it was enjoyable jewelry she could wear. Two participants also

mentioned that the necklace would be an attractive piece of jewelry with only one bead on it as well as many.

Aesthetics were strongly linked to the concerns participants expressed regarding the ability of certain sculptures to scale and their appearance after several runs. Most participants expected the jar and the necklace to scale well, independent of the number of runs completed. Four participants did not like the robot-like shape of the figure sculpture and worried that it would look unaesthetic or unproportional when assembled. One participant (*P11*) had difficulties imagining the single pieces of the jar fitting together if large differences between the runs occurred.

Abstract representation Six participants explicitly liked the *abstract* manner in which the running data was visualized. The figure sculpture represented the least abstract visualization to them and as such they preferred the other visualization options.

Interpreting the data The ability to “read” or interpret the sculpture was also an important factor to some of the participants. Two participants appreciated the visibility of progress enabled by the lamp sculpture. One participant (*P6*) liked the lamp “*because it is clear when pieces are missing*”. Similar to the lamp, two participants valued the same property in the figure sculpture. Overall, the additional variables such as the *elevation gain* used in the lamp, had little influence on the initial choice.

Practical purpose The *practicality* or usefulness of the sculpture was favored by some participants. They appreciated the jar for its visibility and storage ability. The practical purpose of the lamp was also noted positively. On the other hand the perceived lack of usefulness and later use of the figure sculpture led five participants to pick other sculptures.

Playfulness Two participants who chose the figure sculpture stated that “*it is funny and exciting to imagine what will come out in the end, and what it would look like*”. All participants who chose the figure highlighted it as the most interesting option.

5.3.2 Perception of the Activity Sculpture

Our preliminary interviews and surveys indicated that participants were not interested in getting a data oriented representation of their activity, which led us to propose more abstract Activity Sculptures.

Interpreting the Data The abstract nature of the sculpture meant that participants had at times difficulties understanding the way in which their run was mapped to the shape they received. However, these difficulties diminished as participants received more sculpture parts with different shapes. For instance, *participant 14* noted that the first piece was not expressive but once in association with the second piece, the difference between the two runs was noticeable. In contrast, *participant 4* who had almost identical runs, had difficulties in perceiving any differences between the sculpture parts. Participants who chose the necklace stated that they appreciated the distinct visibility of increased running performance and the fact that it was kept rather simple.

Expectations and Aesthetics After participants registered for the study and took part in the initial interviews, expectations started to form as well as anticipation for the objects they would receive. Many participants were concerned about the appearance of the pieces once put together (i.e. the jar). In addition there was concern about the reliability of the data (particularly the elevation gain). However scalability concerns were not expressed in later interviews and participants seemed to appreciate how the pieces fitted together.

As they received their first pieces, the reactions of participants fell into two broad categories, i.e. positive surprise about the aesthetics, and disappointment related to a discrepancy between their expectations and the pieces they received.

The necklace beads were appreciated by participants who had selected them. *Participant 6* found her first bead smaller than she had expected however she regarded it as “pretty” and wore the necklace around her neck immediately. *Participant 12*, who had chosen the jar found his pieces beautiful and enjoyed their usefulness even when the

jar consisted of merely two pieces, as he immediately used it to hold a pencil.

Positively surprised by the sculpture, *participant 10* noted that he did not expect the pieces to look as nice as they did, but much more clunky. He also remarked that for others the figure may not appear as nice, which was secondary to him, as he would know what effort he put into receiving the sculpture. According to this participant, watching the sculpture grow created an emotional attachment, which increased the significance of the sculpture to him personally.

Overall, all participants but two were happy with their choice and would have chosen the same sculpture again. *Participant 8* would have chosen the necklace over the figure since she found that the necklace scaled better. *Participant 10* would have selected the lamp instead of the jar because this sculpture type also visualizes differences in altitude.

Surprises arose as participants received their piece and started to compare them to their other pieces or the pieces of others. *Participant 2* expressed minor disappointment about his first piece as he saw other participants receiving their first jar pieces which were much larger than the small foot of his figure, although he had run for a long time.

Another participant (*P5*) was disappointed when she received a piece after a short route, which she had run at a relatively high speed by her standards. She found that the sculpture piece only expressed the short distance she ran compared to her other runs, but that it did not represent the speed of this run.

Personalization The tangibility of the pieces enabled participants to personalize the sculptures to their liking. Given the minimalist form of the sculptures, participants were able to appropriate them through various means.

One participant (*P1*) had the idea to write the number of the runs at the bottom of each piece of the lamp figure to allow him to track the order. Another one (*P6*) spelled out a strategy on how to arrange the beads of her necklace by putting the biggest piece in the middle and the others around it. She also had thought about painting the single pieces in different shades of blue according to the date of the run so that she can always track the order despite rearranging them on the necklace. *Participant 2* thought of personalizing his figure sculpture by dressing it in a shirt with a name or a number and finally he attached a small medal to his figure.

The sculptures were actually embedded in everyday life by several participants (see also figure 1). For instance, jars were used as a storage box for a USB stick, adhesive tape and pencils while another participant used it as a tea candle holder. The necklace was worn by all participants and the lamp and figure sculpture were placed at various locations such as an office desk or a nightstand.

Perception by Other People The visibility and uniqueness of the Activity Sculptures meant that they often caught the attention of people surrounding the participants. *Participant 6* mentioned that she normally did not like to share her running data, e.g. by posting a run on Facebook, however she liked to show her necklace as she preferred it as a way of self-expression. According to the participant, this coincides with the rather subtle data representation and the fact that she could see peoples’ reactions immediately.

The abstract nature of our objects also meant that participants could choose to explain its significance whenever they liked. *Participant 1* stated that one of his visitors liked the idea of having a physical object which cannot be identified as being related to physical activity. *Participant 11* enjoyed the necklace because it could be worn openly around the neck and is thus easily noticed by others. She further experienced the necklace as a nice conversation starter.

5.3.3 Impact on the Running Activity

The interviews revealed some anecdotal evidence of the Activity Sculptures’ motivational potential and influence on running routines.

Motivation The “always on” aspect of the Activity Sculptures was an important motivational factor, as they were visible at any time the participants were in their vicinity. The most extreme case being the necklace which is worn at all times. *Participant 13* who was part of

the running team referred to her only piece as the “pearl of shame”, since it indicated that she only ran once.

Comparison of pieces also increased the motivation of some participants, either by comparing them to a previous run, or comparing them to others’ runs. For instance, *participant 11* accidentally saw a larger piece than her own which motivated her to achieve larger pieces as well. *Participant 4* however was disappointed when receiving his second piece, as it was clearly thinner than the first piece. This raised his motivation to a longer subsequent run in order to receive a wider ring for his jar.

Assembling complete figures, i.e. receiving all pieces also proved to be a motivational factor, especially for the sculptures with a defined number of pieces (figure and lamp). Three participants mentioned that the lamp influenced their running behavior such that it provided an incentive to fill all the hollows.

Changing Running Habits An interesting impact the Activity Sculptures had was on the change of participants’ running habits. Curiosity, playfulness and aesthetics began influencing the way participants ran as they tried to control the shape of the pieces they would receive. One participant (*P9*) even mentioned having a piece in mind during every run.

One necklace user (*P5*), who had mentioned in the preliminary interviews that she normally did not run when it rains, actually ran in the rain, due to her *excitement* about receiving her first sculpture piece.

The participants receiving the lamp, felt motivated to *experiment* with speed and altitude. One participant (*P6*) for example intentionally ran uphill and another (*P7*) ran the same route twice in a different manner, in order to see how this would be reflected in the sculpture.

Participant 5 was also surprised at how small and angular her first piece was. This motivated her to modify her running accordingly in order to achieve a *nicer and rounder bead*. In contrast, *participant 11* tried to achieve an unproportional figure sculpture to test the limits of the system.

5.3.4 The Reward Experience

The participants also raised questions related to their expectation and the actual reception of the pieces as rewards.

Time of Delivery The *timing of the reward* was also a source of discussion. As mentioned in the design discussion, we initially envisioned a slower reward mechanism. Participants seemed to consider that having a delay between the run and the reward was beneficial. *Participant 9* felt that receiving a piece the day after the run was the best choice, because receiving it directly after running did not leave any chance to speculate on the run and what the piece would look like. Along the same lines, *participant 14* preferred receiving the pieces with a delay, arguing that directly after a run one already felt the reward of having finished it, whereas receiving the piece a few days later could act as an additional reward for the run.

Excitement Participants described the ways in which they *anticipated* the pieces they would get and *surprise* appeared to be an important part of the rewarding experience. For example, *participant 11* wanted to go running immediately after she received her first piece since she wondered what she would receive next. *Participant 8* skipped her yoga classes several times during the study weeks since she knew that she would not get a visualization for this kind of activity. She mentioned that it would have been nice to get rewarded with sculpture parts for this activity too.

Participants who picked the figure sculpture were always looking forward to receiving the next part of their figure. The mystery of which body part would be presented to them next was especially appreciated. *Participant 10* even noted that she would have found it more interesting if she had not known in advance what her sculpture would look like until she had put the pieces together.

Conversation Finally, the rewards provoked exchanges and discussions. *Participant 5* mentioned that when she received a new piece she wanted to go to her colleague to show it to him and find out if he also received a new piece. Apparently, her colleague had the same idea and so both met in the corridor holding their new pieces. All

participants pointed out the ability of the sculptures to encourage discussion. They often served as a conversation starter. The participants who were part of the running group mentioned that they often talked about not only the sculptures but the entire study during lunch.

6 DISCUSSION

The design and study of the Activity Sculptures raised questions regarding the interpretation of the data, its mapping, the role of comparison and experimentation in supporting reflection, sense-making and engagement with the data. It also raised technical questions related to scalability and sustainability. We believe that the physical nature of such visualizations stresses design questions which are relevant for casual information visualization, and maybe even information visualization in general.

6.1 Sculptures as Personal Visualizations

Materializing personal data encouraged the interpretation and reflection on participants’ activity. Participants improved their reading of the visualizations over the course of the study. Through experimentation, they developed a finer understanding of how their runs influenced the sculptures. For instance, the mapping of the elevation gain and the impact of different runs on the sculpture parts were explored in a creative and playful way by the participants.

The fact that the visualizations required personal knowledge to be interpreted seemed to have fostered reflection on the pieces and the corresponding runs. It led participants to engage with the objects, by observing them, testing their limits or comparing them. It also meant that participants could display them freely without feeling as if they were over-exposing themselves: it neither felt as bragging about one’s performance, nor did it feel as displaying something one would have preferred to keep to oneself. This could be argued in any type of casual visualizations which can be shared with others (via social networks or other means).

6.2 Challenges of Static Representations

One of the main benefits of digital media is its dynamic properties: most infovis work supports updates in visualizations as new data comes in, and lets users manipulate the view to match their interest. Physical visualizations are different in that they are extremely static and hard to update once they have been produced. This is the reason for our choice of an extensible model which enabled us to augment the sculpture as new data was being produced. However the variables and the mappings were set from the beginning and did not change.

It could be interesting to give participants more freedom of choice, e.g. letting them choose and change the variables and mappings or specify concrete goals. It is even conceivable to let the user create their own sculptures, for example with the help of an online customizer.

6.3 Scalability

Running data often underlies strong variances, which makes scalability challenging, especially because Activity Sculptures evolve over a long period of time (as they aim at fostering regular physical activity). Finding a data mapping that accommodates people’s different running patterns can be difficult. It needs to display both minor and large changes in the data, while supporting comparison and, not the least, resulting in an object that is suitable for 3D printing. Scalability can be considered along various dimensions.

1. Across people: The sculpture needs to accommodate both a runner training for a marathon and someone running short distances at high speeds. The sculpture should still be readable in both cases (one should be able to notice the variations), and support comparability.

2. Over time: The sculpture should still stand on its own and be meaningful after a high number of runs. The necklace and the jar are theoretically scalable but would become less attractive or less functional at a certain point. The lamp and the figure are not scalable because of their fixed amount of possible parts. A solution could be choosing one type of sculpture for a specified goal and once this is accomplished another can be chosen. This could be combined nicely

with well-known gamification principles, e.g. unlocking new sculpture types after attaining specific achievements.

6.4 Reflection and Self-Expression

By making the runs visible and tangible, Activity Sculptures appeared to foster reflection but self-expression only in specific conditions.

Activity Sculptures are a promising medium for fostering reflection on activity. Schön describes that reflective practices are composed of reflection-in-action and reflection-on-action [31]. Reflection-in-action is related to thinking ahead of the action, critically experiencing and adjusting to the activity as it unfolds. We observed this precise phenomenon as participants anticipated the sculptures before the runs, thought about them while running, and sometimes adjusted their running in order to get a specific shape. Reflection-on-action is much more related to the appraisal of the action after it has occurred, which was observed as participants compared their pieces and conversed these with others. Furthermore, Activity Sculptures allow are more abstract and enjoyable reflection on ones' physical activities than through detailed activity data composed of precise numbers and histories. In a sense, Activity Sculptures are complementary to the digital visualizations which are accessible through most mobile tracking applications.

The ratings for the jar for the comparison with others decreased markedly. This may be due to the fact that only two participants had contact to each other but were not interested in comparison, since they knew that they were running on different performance levels. Similarly none of the participants who chose the figure were bothered by the circumstance that it was hard to compare these sculptures with each other. Taking these findings into account we think that it is of minor importance that the comparison of the sculptures in a competitive way is supported.

The necklace was the only sculpture type which fulfilled participants' expectations regarding self-expression and the comparison with others. It is the only sculpture type which can be worn on the body and therefore easily be seen and shown to others. In our opinion it seems to be the most promising design direction for Activity Sculptures to be geared to accessory design and wearable visualizations.

6.5 Sustainability

Producing plastic objects for playful or motivational purposes raises issues of sustainability. We argue that this only emphasizes the issue of sustainability, more so than usual infovis projects. Indeed, mobile activity tracking, remote data storage and processing also consume great deals of energy as well as require the production of technological artefacts. Nonetheless we acknowledge, that Activity Sculptures increase the amount of products in the environment. To overcome this concern we might consider only offering *summary sculptures* that represent the data of an entire month. In addition or in complement, old sculptures could be recycled. Projects such as the *Filabot Reclaimer*¹² for example allow the recycling and reuse of 3D prints created with PLA. Another possibility is the usage of biodegradable PLA filament.

6.6 Impact on Motivation

We conducted this exploratory field study with 14 participants over the duration of three weeks. Longer studies with more participants are needed before drawing conclusions on the motivational potential of Activity Sculptures.

The manual handover process enabled us to gather feedback from participants and better our understanding of their relationship to the sculptures. However, this manual handover might have influenced the participants' experience, especially at initial handover. As the participants were in regular contact with the study leader multiple times they might have felt an obligation to comply and be a 'good subject' [4], e.g. to run several times during the study.

Finally, we limited our study to four types of Activity Sculptures, a very small sample of the design space. It would be interesting to

compare against more traditional physical visualizations such as bar charts or digital visualizations in a follow up study.

7 CONCLUSION AND FUTURE WORK

We presented the design and creation process of *Activity Sculptures*, a series of material representations of tracked running data. The system was evaluated in a three-week field study with 14 participants. The study revealed a great acceptance for the Activity Sculptures. Especially their ability to improve *motivation* and *self-reflection* convinced the participants. We further uncovered their potential for a more creative view at ones' activity (*playfulness*), as participants started to change their running routines in order to impact the form and aesthetics of the final sculpture pieces. The physical and "always on" nature further reinforced social interactions among participants. We found that *personalization* was important for our Activity Sculptures. The abstract and minimalist form of the sculptures was well received and encouraged participants to style and utilize them according to their own ideas. Furthermore individual preferences should be considered regarding the data mapping of the sculptures. These findings could be transferred to digital visualizations as well, e.g. by giving the opportunity to personalize the visualizations in a mobile tracking application.

The results collected through the online questionnaire revealed that participants preferred receiving the sculptures only for the achievement of pre-established goals or once per month. While our field study could not take these preferences into account due to the limited study time, this could be a valuable strategy for a longer term study. In order to investigate whether the sculptures actually have a motivational effect in the long term, (which is clearly the objective,) and to preclude the novelty effect as a predominant explanation of this success, further longitudinal studies with a larger sample are needed. Material costs and the time-consuming printing process play an important role for the practicality of physical visualizations of running data. Before realizing this concept for a long-term study or beyond a study, these aspects in particular need to be taken into account.

In this paper, only a small part of the design space of such Activity Sculptures was covered. One aspect to be investigated in future studies is the utilization of other materials. Plastic seemed an inferior material for visualizing running data, as running is associated with nature. Therefore, natural materials such as wood and other fabrication tools such as laser cutters could be used. Furthermore the concept of one sculpture for each person could be changed to one sculpture on which numerous people collaborate. Each person would then contribute to the common sculpture. This approach could be particularly interesting for members of a running team, a group of physically active colleagues or people who share an apartment and want to engage in more regular physical activity.

Another area of future investigation is the mapping of meaningful training patterns to beautiful sculpture shapes. The aesthetical mappings of longer distances and higher speeds to rounder shapes were purely experimental. For a purposeful product, these mappings would have to be determined together with experienced trainers, such that the different types of training (e.g. endurance, speed or interval) would each lead to meaning- and beautiful sculptures.

To broaden the scope of Activity Sculptures by reaching a larger audience, public events such as marathons could reward runners with such artifacts tailored to their performance instead of medals. An extension to other physical activities is conceivable as well. Examples are cycling, hiking or daily routines. Even the progress of completion of to-do lists could be physically visualized and thereby promote efficient and timely completion in a playful and unobtrusive way.

ACKNOWLEDGMENTS

We wish to thank Tessa-Virginia Hannemann for proof-reading and helpful comments, our colleagues for fruitful discussions, our participants for running and our reviewers for their constructive feedback.

¹²<http://www.filabot.com/>

REFERENCES

- [1] D. Agnelli, D. Buzzini, and T. Drori. Fashion victims. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*, pages 312–312. ACM, 2004.
- [2] L. Bacon, N. Keim, M. Van Loan, M. Derricote, B. Gale, A. Kazaks, and J. Stern. Evaluating a “non-diet” wellness intervention for improvement of metabolic fitness, psychological well-being and eating and activity behaviors. *International Journal of Obesity*, 2002.
- [3] C. G. Bell and J. Gemmell. *Total Recall: How the E-Memory Revolution Will Change Everything*. Dutton Adult, 2009.
- [4] B. Brown, S. Reeves, and S. Sherwood. Into the wild: Challenges and opportunities for field trial methods. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’11, pages 1657–1666. ACM, 2011.
- [5] H. Brynjarsdottir, M. Håkansson, J. Pierce, E. Baumer, C. DiSalvo, and P. Sengers. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’12, pages 947–956. ACM, 2012.
- [6] S. Consolvo, K. Everitt, I. Smith, and J. A. Landay. Design requirements for technologies that encourage physical activity. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*, CHI ’06, pages 457–466. ACM, 2006.
- [7] S. Consolvo, D. W. McDonald, and J. A. Landay. Theory-driven design strategies for technologies that support behavior change in everyday life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’09, pages 405–414. ACM, 2009.
- [8] S. Consolvo, D. W. McDonald, T. Toscos, M. Y. Chen, J. Froehlich, B. Harrison, P. Klasnja, A. LaMarca, L. LeGrand, R. Libby, et al. Activity sensing in the wild: a field trial of ubifit garden. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’08, pages 1797–1806. ACM, 2008.
- [9] P. Dourish. Hci and environmental sustainability: The politics of design and the design of politics. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, DIS ’10, pages 1–10. ACM, 2010.
- [10] C. Fan, J. Forlizzi, and A. K. Dey. A spark of activity: exploring informative art as visualization for physical activity. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, pages 81–84. ACM, 2012.
- [11] E. Freeman and D. Gelernter. Lifestreams: A storage model for personal data. *ACM SIGMOD Bulletin*, 25:80–86, 1996.
- [12] J. Froehlich, L. Findlater, and J. Landay. The design of eco-feedback technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’10, pages 1999–2008. ACM, 2010.
- [13] J. Gemmell, R. Lueder, and G. Bell. The mylifebits lifetime store. In *Proceedings of the 2003 ACM SIGMM Workshop on Experiential Telepresence*, ETP ’03, pages 80–83. ACM, 2003.
- [14] D. Grimley, J. O. Prochaska, W. F. Velicer, L. M. Blais, and C. C. DiClemente. The transtheoretical model of change. *Changing the self: Philosophies, techniques, and experiences*, pages 201–227, 1994.
- [15] D. Hyerle. *Visual tools for transforming information into knowledge*. Corwin Press, 2008.
- [16] N. Jafarainaimi, J. Forlizzi, A. Hurst, and J. Zimmerman. Breakaway: An ambient display designed to change human behavior. In *CHI ’05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA ’05, pages 1945–1948. ACM, 2005.
- [17] Y. Jansen and P. Dragicevic. An interaction model for visualizations beyond the desktop. *Visualization and Computer Graphics, IEEE Transactions on*, 19(12):2396–2405, 2013.
- [18] Y. Jansen, P. Dragicevic, and J.-D. Fekete. Evaluating the efficiency of physical visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’13, pages 2593–2602. ACM, 2013.
- [19] R. A. Khot, L. Hjorth, and F. F. Mueller. Understanding physical activity through 3d printed material artifacts. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’14. ACM, 2014.
- [20] R. A. Khot and F. F. Mueller. Sweat-atoms: Turning physical exercise into physical objects. In *CHI ’13 Extended Abstracts on Human Factors in Computing Systems*, CHI EA ’13, pages 3075–3078. ACM, 2013.
- [21] I. Li, A. Dey, and J. Forlizzi. A stage-based model of personal informatics systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’10, pages 557–566. ACM, 2010.
- [22] I. Li, A. K. Dey, and J. Forlizzi. Understanding my data, myself: Supporting self-reflection with ubicomp technologies. In *Proceedings of the 13th International Conference on Ubiquitous Computing*, UbiComp ’11, pages 405–414. ACM, 2011.
- [23] J. J. Lin, L. Mamykina, S. Lindtner, G. Delajoux, and H. B. Strub. Fish’n’s: Encouraging physical activity with an interactive computer game. In *UbiComp 2006: Ubiquitous Computing*, pages 261–278. Springer, 2006.
- [24] E. A. Locke and G. P. Latham. Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American psychologist*, 57(9):705, 2002.
- [25] N. McLean, S. Griffin, K. Toney, and W. Hardeman. Family involvement in weight control, weight maintenance and weight-loss interventions: a systematic review of randomised trials. *International journal of obesity*, 27(9):987–1005, 2003.
- [26] S. A. Munson and S. Consolvo. Exploring goal-setting, rewards, self-monitoring, and sharing to motivate physical activity. In *Pervasive Computing Technologies for Healthcare (PervasiveHealth)*, 2012 6th International Conference on, pages 25–32. IEEE, 2012.
- [27] Z. Pousman, J. T. Stasko, and M. Mateas. Casual information visualization: Depictions of data in everyday life. *IEEE Trans. Visualization and Computer Graphics (TVCG) (Proc. InfoVis)*, 7:2007, 2007.
- [28] S. Purpura, V. Schwanda, K. Williams, W. Stubler, and P. Sengers. Fit4life: the design of a persuasive technology promoting healthy behavior and ideal weight. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 423–432. ACM, 2011.
- [29] Y. Rogers, W. R. Hazlewood, P. Marshall, N. Dalton, and S. Hertrich. Ambient influence: Can twinkly lights lure and abstract representations trigger behavioral change? In *Proceedings of the 12th ACM International Conference on Ubiquitous Computing*, UbiComp ’10, pages 261–270. ACM, 2010.
- [30] Y. Rogers and G. Marsden. Does he take sugar?: Moving beyond the rhetoric of compassion. *interactions*, 20(4):48–57, July 2013.
- [31] D. A. Schön. *The Reflective Practitioner: How Professionals Think in Action*. Basic Books, June 1983.
- [32] T. Skog, S. Ljungblad, and L. E. Holmquist. Between aesthetics and utility: designing ambient information visualizations. In *IEEE Symposium on Information Visualization, INFOVIS 2003*, pages 233–240. IEEE, 2003.
- [33] S. Stusak, A. Tabard, and A. Butz. Can physical visualizations support analytical tasks? *Vis’ 2013 (poster)*, November 2013.
- [34] S. Swaminathan, C. Shi, Y. Jansen, P. Dragicevic, L. Oehlberg, and J.-D. Fekete. Supporting the design and fabrication of physical visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’14. ACM, 2014.
- [35] A. Vande Moere. Beyond the tyranny of the pixel: Exploring the physicality of information visualization. In *Information Visualisation, 2008. IV’08. 12th International Conference*, pages 469–474. IEEE, 2008.
- [36] A. Vande Moere and S. Patel. Analyzing the design approaches of physical data sculptures in a design education context. *Visual Information Communications International (VINCI’09)*, 2009.
- [37] F. B. Viégas and M. Wattenberg. Artistic data visualization: Beyond visual analytics. In *Online Communities and Social Computing*, pages 182–191. Springer, 2007.
- [38] G. Wolf. Know thyself: Tracking every facet of life, from sleep to mood to pain 24/7/365. *Wired*, 17(07):92–95, 2009.
- [39] R. Xiong and J. Donath. Peoplegarden: creating data portraits for users. In *Proceedings of the 12th annual ACM symposium on User interface software and technology*, pages 37–44. ACM, 1999.
- [40] F. Yetim. Critical perspective on persuasive technology reconsidered. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI ’13, pages 3327–3330. ACM, 2013.
- [41] J. Zhao and A. Vande Moere. Embodiment in data sculpture: a model of the physical visualization of information. In *Proceedings of the 3rd international conference on Digital Interactive Media in Entertainment and Arts*, pages 343–350. ACM, 2008.