Tangible Interactions with Physicalizations of Personal Experience Data

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Abstract: Individuals record large amounts of data about their daily lives, from locations to steps to heart rate. Services allow individuals to review and share this data. We explore physical representations—physicalizations—of data recorded by individuals during personally meaningful trail running activities. Physical interactions may change the way in which individuals recall and share their experiences. We present the results of two interview studies involving physicalizations of trail running data for advanced amateur runners. Our results appear to indicate that physicalization of personal experience data supports reflection and sharing, among other themes, and that physical interaction with the object plays a central role in driving these responses.

1 INTRODUCTION

Mobile devices and wearable technology enable the gathering of a vast amount of personal data, including data regarding physical activity. Many individuals take advantage of this in order to record GPS data for activities such as running and cycling. Platforms such as Strava[1] enable individuals to record, review, and share data from their activities, and to encourage one another.

Given the physical nature of such activities, researchers have explored creating physical representations—physicalizing—these activities. This includes 3D printed abstract representations of activities as in *Activity Sculptures* (Stusak et al., 2014) from Stusak et al. as well as Khot's *Sweat Atoms* (Khot, 2013). Khot has also explored other representations of physical activity such as with sports drinks in *TastyBeats* (Khot et al., 2015) and with chocolate as in *EdiPulse* (Khot et al., 2017). Such work physically commemorates and further encourages the types of daily physical activity that promote health and wellness.

Besides seeking to stay active and healthy, individuals often use daily physical activity to train for more significant and meaningful events such as races or larger outdoor adventures. This type of physical activity is unique in that it is planned for in advance, takes more time and effort, and is more challenging and rewarding than a typical daily training session. Such activities are often significant, personally meaningful experiences. Physicalization of data gathered from these types of activities has not been explored.

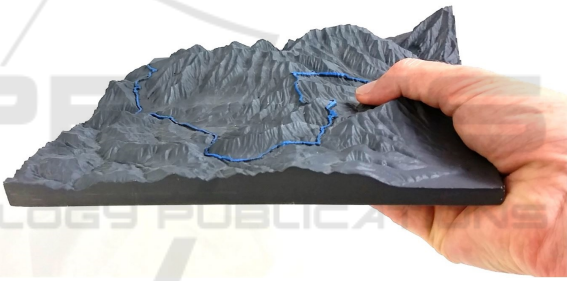

Figure 1: A tangible representation, or physicalization of a person's trail running route through mountainous terrain.

The most common method of visualizing this GPS data is a line on a map viewed on a PC, tablet, or smartphone. This method of reviewing GPS data may not adequately convey the physical terrain in which the adventure occurred, an essential—perhaps even defining—facet of such activities. Existing methods of visualization, such as shaded relief maps with topographic lines require interpretation to understand the actual terrain context. 3D printed models (as shown in Figure 1), on the other hand, allow the viewer to quickly see and understand the terrain context. This may lead more readily to reflection and promote sharing of experiences.

Our work explores physical representations which

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commemorate such experiences. Understanding the experience of interacting with physical representations of such personally meaningful events may help us better understand the potential and limitations of tangible interaction with personal data in general.

As an initial foray into this area, we have conducted interview studies involving physicalization of GPS data gathered by trail runners. Trail running is a sport in which people run on unimproved trails in an outdoor or wilderness setting. GPS data from trail running is a natural fit for exploring physicalization of data from exceptional personal experiences because the topography of the route traversed provides meaningful context for the GPS data, and such experiences are often undertaken as significant and exceptional personal experiences.

In an exploratory semi-structured interview study, we presented 10 "advanced amateur" (Knaving et al., 2015) trail runners with physicalizations of their runs and conducted interviews to understand their reaction to and interactions with these physicalizations. In a second interview study with 10 more advanced amateur participants, we sought to understand the phenomenon of sharing stories, which we encountered frequently in the initial study, and to see whether more stories were told with physicalizations than with paper maps.

Qualitative analysis of data from these studies revealed strong themes around remembrance and sharing, as well as other themes, all of which appeared largely to be driven by physical interactions with the physicalizations. In the second study, participants also told more stories with physicalizations than with paper maps. Physical interactions as provided by physicalizations may lead to increased reflection and more ready sharing of personally meaningful experiences.

2 RELATED WORK

2.1 Data Physicalization

A physicalization is "a physical artifact whose geometry or material properties encode data." (Jansen et al., 2015) An important body of existing work in Data Physicalization explores physicalization as a means for communicating data to a person.

Research involving physicalization in general includes exploration of the efficacy of physicalizations (Jansen et al., 2013) (Stusak et al., 2016) and work which investigates how well people remember data communicated using a physicalization (Stusak et al., 2015). Taher explores interacting with data through an actuated table which allows for physical interactions with a 3D bar chart (Taher et al., 2015) (Taher et al., 2017).

Jansen presents an overview of the field of Data Physicalization, outlining important concepts, related areas, and providing direction for future work (Jansen et al., 2015). More recently, Dragicevic et al. give a broad overview of the area of Data Physicalization (Dragicevic et al., 2019), including recent work, particular applications, and enabling technologies, among others.

2.2 Physicalization of Personal Data

Previous research on physicalization of personal data has focused on abstract physicalizations derived from heart rate or other activity data (Khot, 2013) (Khot et al., 2014) (Stusak et al., 2014). A body of work by Khot is largely focused on the physicalization of data gathered during exercise and/or regular daily activity. Mediums explored include plastic (Khot, 2013) (Khot et al., 2014), liquid (Khot et al., 2015), and chocolate (Khot et al., 2017). Much of this work explores the emotional and social aspects of individuals' interactions with these physicalizations and the way in which they support and encourage activity. We likewise begin by choosing to focus largely on emotional and social aspects of physicalizations of personal experience data.

Swaminathan presents MakerVis (Swaminathan et al., 2014), a tool which aids in the design and construction of physicalizations.Thudt explores personal reflection through the creation of hand-made physicalizations (Thudt et al., 2018).

Khot's work on Fantibles (Khot et al., 2016) is similar to ours in that the physicalizations produced include a component which is centered around the user—in this case, representing the user's excitement and social media activity during a cricket match—as well as a component which gives context to the user's data, with spokes which each represent a portion of the match and the number of wickets and during that portion.

This work, like ours, has focused on the emotional response produced by physicalizations of data which is personal in nature. However, the data itself is different in our work, centering around one-time significant personal experiences. In contrast, the work of Khot and Stusak largely explores the effect of physicalizing data from regular, day-to-day activity.

2.3 Terrain Models

Physical models of terrain, often called Terrain Models (Institute of Cartography, 2018b) or Raised-relief maps (Wikipedia, 2018), have existed in different forms for centuries (Institute of Cartography, 2018a). Their applications include education, urban planning, museums and visitors centers, and military use, among others (Institute of Cartography, 2010a).

Such models have been constructed using a variety of methods, largely driven by current technology at any given time. These include plaster models, pantograph, vacuum forming, CNC routing, and others (Institute of Cartography, 2010b). Advances in rapid prototyping and in particular 3D printing have made relief models for personal use more feasible. Caldwell gives a review of related technologies and their possibilities dating to 2001 (Caldwell, 2001), while Rase gives a similar overview of rapid prototyping techniques and their applications in creating solid terrain models (Rase, 2011) from 2011.

Online tutorials also exist for generating .stl files to print one's own terrain model. Companies are beginning to emerge in this space as well.

Our work builds on the history and current advances in terrain modeling and rapid prototyping, seeking to understand their application to personal experience data from an HCI standpoint.

3 METHODS

We conducted two studies, both of which were interview studies. In the first study, we sought to gain an initial understanding of individuals' interactions with and reactions to physicalizations of personal experience data from trail running. The second study was intended to build on the first, in particular by exploring the unexpected phenomenon of storytelling encountered in the first study.

Participants for both studies were recruited from within local trail running groups as well as online social media groups dedicated to trail running. Participants' backgrounds and experience varied, but all fell into the "advanced amateur" category identified by Knaving et al. in that they "run regularly and participate in races" (Knaving et al., 2015).

3.1 Study A: Exploratory

In the exploratory study we created physicalizations of trail running data and conducted interviews with 10 runners. 4 participants were female and 6 were male. Participant trail running experience ranged from a single race (on trail, with numerous prior road races) to having run many many trail races of different distances and difficulty.

We instructed participants to select a run or race that was personally significant or meaningful and for which they had GPS data, and to send us a GPX file from that run. From the GPX files submitted, we created and gave the physicalizations to the participants, and conducted two interviews with each participant.

Of the files selected by participants, 5 were from races, 4 included or were specifically focused on mountain summit attempts, and one was from a run that the participant had been on with their spouse while on vacation. Participants indicated that they selected the runs they did because they felt a connection to the terrain in which the run took place or to the particular path or course they ran, or because they felt the terrain would produce an interesting physicalization.

The first interview was given when the participant received their physicalization and was intended to assess their initial reactions. The second was given 7 to 10 days later and was intended to assess their response to the physicalization after a brief period of time. A secondary goal was to determine whether any of the initial response was due to the novelty effect since most participants were interacting with this type of physicalization for the first time.

The content of the initial interview focused on the participants' initial thoughts and feelings, how they felt the physicalization compared to familiar methods of visualization, and what they intended to do with the physicalization.

The second interview was intended to explore participants' impressions after interacting with the physicalization over a period of time. Participants were asked what they had done with the physicalization since receiving it. Other questions probed what impact, if any, the physicalization had over time on: participants' understanding of the actual terrain depicted, their remembrance of the event in question, the sharing of the experience with others, and their running in general.

3.2 Study B: Follow-up

In the initial study, participants told many stories in interviews, and made frequent mention of connecting to their own memories sharing them with others. We hypothesized that the physical nature of the physicalizations might have something to do with their ability to enable participants to remember.

In order to test this hypothesis we designed a study in which we sought to compare individuals' interac-

tions with physical maps with their interactions with physicalizations. The study had two main purposes. First, to determine whether or not participants tell more stories when interacting with physicalizations of their running data compared to interacting with a printed paper map showing the same data. Second, to compare participants' reactions to physicalizations and 2D printed maps as guided by the themes identified in the first study. We selected paper maps in order to compare two physical conditions as opposed to comparing a physical with an on-screen 2D or 3D condition.

Participants were recruited in the same manner as the first study and were given the same instructions, however, in this study only one interview was conducted. The interview was conducted in two parts: one focusing on the physicalization and the other on a paper topographic map the participant was given which was of roughly the same area as the physicalization and included the route. See example in Figure 3.

During each interview we counted how many stories the participant told for each representation of the data. At the end of the interview we told participants that we were counting stories told.

Questions for each portion of the interview were identical to the first study, with the exception of the physicalization portion also including a question asking the users how the physicalization compared to viewing a topographic map. The choice to use identical questions for both representations of the data avoids introducing biases based on the content of the questions. Half of the participants were shown and asked about the paper map first and the other half saw the physicalization first.

Questions were designed to generally probe participants' feelings about each medium, for example how they felt the medium portrayed and related to their experience and whether it had any effect on their remembrance of the experience or the physical terrain in which they ran. Questions were written to explore participants' response to each without specifically prompting for stories or memories, and follow-up questions were worded to avoid specifically asking for stories or memories. In addition to counting stories, we also made notes about the participants' reactions to each data representation.

Maps were generated using GPS Visualizer using data from Google Maps and printed on a color laser printer.

4 RESULTS

Our analysis of data followed a thematic analysis approach based on the constant comparative method and was performed by both authors. Initially we read through all interview notes twice to become familiar with the data. From these readings, we began developing a set of descriptive (rather than in vivo) codes to describe the data. Initial work was inductive, adopting an open coding approach. Following the constant comparative method, codes were continually compared to one another and to the data in order to arrive at a clear and useful set of codes which described the data.

We then performed an axial coding phase in order to arrive at broader themes which could help to paint an overall picture of the data. Following the constant comparative method, codes and themes were iteratively compared in order to refine them. We arrived at a set of codes and themes which seemed to accurately describe the phenomenon of individuals interacting with physicalizations of personal trail running data. Themes are described below.

4.1 Physical Interactions

Participants exhibited a number of different ways of interacting with the physicalizations, including:

- Holding the physicalization in their hands
- Tracing the route
- Tracing other contours of the terrain
- Rotating the physicalization to view from different angles
- Peering more closely at the terrain and/or route
- Holding the physicalization at a low viewing angle in order to simulate a ground-level view as one would see mountains in person
- Placing the physicalization on a flat surface and looking at it from different angles
- Attempting to match the physicalization with the actual mountains depicted (location permitting)

Such interactions often persisted throughout the interviews, either being relatively constant with the participant holding the physicalizationand referring to it, or occurring periodically throughout as the participant set it down and picked it back up at different points in the interview.

Participants also indicated that physical interactions were common among others with whom they shared the physicalizations. P1 said, "People seem to love to touch it."

Physical interactions with objects is a rather obvious result in a study involving physicalization. However, it is important to relate the manner of these interactions. We also note that such interactions frequently seemed to both spark and be an integral part of each of the other themes we relate below.

In all of the discussion about sharing the physicalizations and the runs and terrain depicted, physical interaction played a central role. Participants indicated that they used the physicalization as a prop in order to illustrate their discussions about their experiences with others, and that those with whom they shared also interacted with the physicalizations. Noticing the physicalization on a coworker's desk could also be said to be a form of physical interaction at a distance.

4.2 Memory

Participants made frequent mention of remembrance and memories during interviews. P6 stated, "It brings back a lot of memories." P9 said, "It gives a stronger sense of memory than anything else." In the second interview, P2 indicated that her interactions with the physicalization had allowed her to reflect more fondly on both the run depicted and the area in which she ran, which is near her home and in which she indicated she had done many other runs. P3, whose physicalization depicted a race she had run roughly two years prior to the study, appreciated the memories that viewing the physicalization brought back.

Mentions of remembrance typically took place as participants were interacting with the physicalizations. Quite often this would take the form of the participant touching the path or a part of the terrain and then telling a brief story related to that portion of the course or topology. Such sharing is discussed more below.

4.3 Sharing

The most frequent manner in which memories were manifested in our studies was participants sharing brief stories about their runs or other experiences in the terrain depicted. Some such recollections were very brief, such as P9 and P6, who pointed out places where they had become sick during their runs. Others were somewhat more extended in duration, and reflected on happenings, thoughts, and feelings regarding the run. Such sharing of stories was frequently augmented by physical interactions with the physicalizations, pointing to locations, tracing portions of the route, or holding out the physicalization to show a particular view.

This theme of sharing extended beyond what occurred in the interviews as well. One of the primary things that all participants indicated they wanted to do, and that they had done, with physicalizations was sharing them with family, friends, and coworkers.

Some of this sharing took the form of sharing the physicalization itself, which is unsurprising given the relatively new nature of 3D printing for participants and their loved ones. P10 indicated that the people he had talked to were interested in how the physicalization was made. This aspect of the sharing theme would seem to indicate that novelty definitely played a part in the experience for both participants and others with whom they shared the physicalizations. It seems unlikely that this could be entirely avoided given most individuals' relative inexperience with 3D printing.

Other sharing involved sharing of the experience or about the terrain depicted. P8 indicated that he was able to use the physicalization to help his wife more fully understand the run and terrain in which it took place, which she had found difficult in previous attempts using online maps and/or physical topographic maps.

Participants indicated sharing was both initiated by themselves as well as by others.

When sharing with family members, the reported level of interest and engagement varied. P8 indicated his son, with whom he had hiked a portion of the trail depicted, was very interested in the physicalization and used it to share his experience with friends, which also made his daughter jealous of her brother. In contrast, P5 indicated that his children "thought it was cool," but showed little actual interest. P10 also indicated that his spouse was less than interested in the physicalization apart from the first time he introduced it to her.

In similar fashion to P8's experience with his son, P2 said that her husband—who had been with her during the run depicted—was very interested in the physicalization. In particular, she indicated that they had spent time going over the terrain and the course as shown, and that it had helped him to remember portions of the run he had forgotten, mentioning that he tended to remember less than she did about runs. She described this interaction as "bonding over plastic."

Sharing was also initiated by people other than the participants. This seemed to take place most often in the workplace. Participants P1, P5, P6, and P9 indicated that they had taken their physicalizations to display at their workplace. These participants described interactions in which a coworker would notice the physicalization and ask about it. This led to participants sharing about their experiences and/or what

they had learned about the process of creating the physicalization, depending on whether the participant themselves and/or the coworker were more interested in the experiential or the technical aspects. P9 indicated that one coworker took a particular interest in the rugged nature of the mountains depicted, having come from a region lacking such terrain.

Other sharing took the form of displaying the physicalization. All participants who did not take their physicalization to work made mention of displaying it somewhere in their home, usually in a place of prominence, and specifically for some in the same location where they display medals and other race memorabilia. P6 and P7, who are husband and wife, indicated different intentions for displaying. P6 said he wished to display his "not to brag" but as a memento, while his spouse said she definitely wanted to "show off [her] accomplishment."

4.4 Understanding Geography and Topology

Participants said that the physicalizations aided in their understanding of the geography or topology of the area depicted. P4 said that the physicalization aided her in understanding and placing landmarks she had seen while on her run, and that when she and her husband reviewed the physicalization together it aided them in understanding one portion of the route which they had found confusing during the run.

P1 said that the physicalization made understanding the topology easier than topographic maps to which he was accustomed: "It makes more sense for my type of brain." P6 indicated that he was also able to better understand, and pointed out two portions of the race course depicted in his physicalization which were quite close geographically but separated by a mountain ridge, a fact he had not taken note of previously.

P10 compared the physicalization to viewing the same run on Strava and appreciated the contextual "bird's eye view" provided by the physicalization while noting that it did not provide the ability to zoom in for more detail as would an online topographic map. P3 also felt that seeing a physical, 3D depiction aided in contextual understanding when compared to 2D visualizations.

Participants who were more familiar with the terrain depicted, in particular P1, P2, P8, and P9, recognized and pointed out familiar geological landmarks such as peaks, ridges, and bowls. P1 said his coworker, an avid mountain biker, did the same when he noticed the physicalization and stopped to talk about it. Interestingly, some of the same participants also indicated they felt the physicalization helped them to better understand details and overall context for the areas depicted.

4.5 Route Discovery and Planning

Participants also described the physicalization functioning as a tool for seeking out and/or planning runs on new routes. P1 indicated that the physicalization was a useful tool for augmenting his planning and better understanding what to expect when contemplating a new route.

In the second interview, P8 indicated that his interactions with the physicalization had changed over time. Initially he focused on the path itself and on the novelty of having a tiny version of the mountain that he could hold in his hand. He said that by the time of the second interview, he had begun to use the physicalization to carefully examine features of the mountain and routes which he was interested in attempting and to share them with others. He described this type of interaction as "exploring."

Also in the second interview, P9 used the physicalization to show and describe a route that he had begun planning in the time since the first interview. He indicated that looking at the physicalization had inspired him to begin planning this route. Several months later, he reported having taken a trip with friends to run this route.

4.6 Aesthetic Appreciation

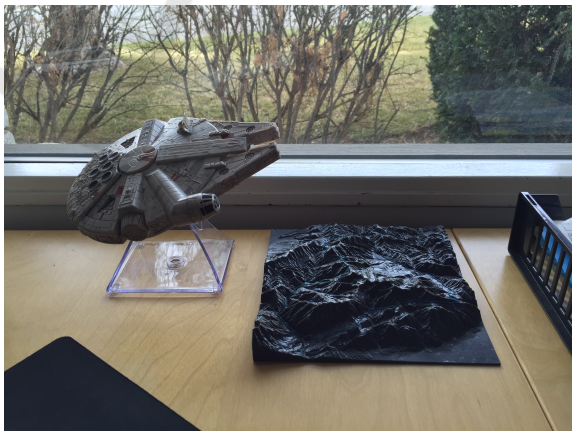

Figure 2: P1 sent this picture of the physicalization on his work desk next to his Millennium Falcon model.

Participants exhibited an appreciation for the aesthetics of the physicalizations. P1 and P4 said that it was like a piece of art. P1 sent a picture of the physicalization on his desk at work, next to his model of the Millennium Falcon from Star Wars (see Figure 2. P9 said, "I want to make a keychain out of it."

As mentioned before, each of the participants indicated that they displayed their physicalization, either at home or at work. Some in particular said they wanted to display it with other running memorabilia, possibly indicating as mentioned by P6 and P7 above, that the display of the physicalization is at least in part connected with wishing to share one's accomplishment. It also seems likely that this desire stems in part from the novelty of 3D printed mountains, as well as from appreciation of their aesthetic qualities.

4.7 Study 2: Map vs Physicalization

Overall, there were 41 stories told with the physicalizations and 12 with the maps. This gives a mean of 4.1 per participant with a standard deviation of 3.07 with physicalizations, and a mean of 1.2 with a standard deviation of 1.62 with maps, an interesting set of raw numbers but an inconclusive result statistically speaking.

General responses to the map ranged from positive: "I know it well" (P4-2) to ambivalent: "Uhh...I mean, it seems detailed..." (P6-2), to downright negative: "It's a piece of paper" (P3-2). Three participants mentioned that they themselves owned better maps that they were fond of but that this particular map wasn't of much interest to them.

One participant (P2-2) told more stories with the paper map than the physicalization. This participant stated he had a particular affinity for the topographic map of the race, saying that he had spent much time reviewing it both prior to his running the race as well as in the approximately two years since as he planned to return and finish the race, having had to drop out before.

One participant (P5-2) mentioned being colorblind and pointed out that the physicalization is easier to read than topographic maps which can depend on color cues.

5 DISCUSSION

5.1 Novelty

Novelty is an important consideration in our work given the relatively new experience it is for many people to interact with 3D printed objects. One way to gauge this is to consider how much of the discussion in interviews centered around the physicalization itself, the creation of it, and other aspects focusing on the physical object rather than on the experience it is meant to commemorate.

In interviews, all participats spent time discussing their excitement or wonder at the novelty of the physicalization. Participants in the first study also frequently mentioned others having been curious or interested in the creation of the physicalization during the time between interviews.

Overall, however, this represented a small portion of the interview time–perhaps 5%. One participant in the firs study, however, P10, spent most of the second interview expressing his excitement over the physicalization and its potential as something that others might also be interested in.

5.2 Embedded Data

GPS data collected from trail running fits into a category of data identified by Willett (Willett et al., 2017) which is "associated with specific locations, people, and objects." Willett explores the notion that such data is well-suited to embedded representations, in which data is displayed in the context of its *physical referent*—"the physical spaces, objects, and entities to which the data refers." More directly, the tangible representations used in our studies are what Willett terms a *facsimile*, and due to their high level of accuracy in depicting the topography of the area depicted, they "can be considered a physical referent in and of [themselves]" into which an individual's GPS track can be embedded.

Among the benefits and drawbacks of situated and embedded representations of data presented by Willett, one in particular relates to a result from our studies. Willett notes that embedded physicalizations may support collaboration in unique ways: "In particular, physical marks could provide concrete, persistent instantiations of data that support shared pointing, manipulation, and reasoning among collaborators." Such behaviors were indicated by our participants, particularly in the experiences of P2 with her husband, and P6 with both his wife and coworkers.

Further work may seek to explore the phenomenon of shared interaction with physical representations of personal data or of topographical and other geographical data, in particular as it relates to situations such as planning of trips and routes, search and rescue, and other collaborative activities.

5.3 Limitations

Interviews were not recorded. Each interview was conducted by a single interviewer who took notes while conducting the interview, and made further notes immediately or as soon as possible afterwards.

Figure 3: An example of a physicalization and corresponding map as used in the second qualitative study. The image on the right shows the physicalization from a low viewing angle.

This likely led to some data loss, however the data gathered still led to interesting and valuable insights.

5.4 Future Work

Looking at the physicalizations we produced, an obvious area for future work is to increase their data density. It may be helpful to find out how dense the physicalization can be with data before it begins to lose some of its ability to convey such data effectively, and at what point it becomes less of a piece of art or memento and more of an informative display. The addition of labels at different densities may be a way to begin to understand this, and it would be informative to see how adding labels changes the experience for individuals.

Another area for exploration is technical aspects of the physicalizations themselves. We have begun exploring lighting the path, either from within the physicalization or with light transmitted as from underneath the physicalization (Willis et al., 2012) (Baudisch et al., 2010) (Pereira et al., 2014). This could be used to display data such as pace or heart rate. We have also considered generating physicalizations which are simply a very large bundle of light pipes. This would allow for even greater flexibility, creating opportunities for data to be overlaid onto the physicalization surface and changed or updated in real time or on demand.

Finally, further exploration is warranted surrounding collaborative aspects of working with such physical representations. Such work might explore application in areas such as route planning or search and rescue. We look forward to this and other work which builds upon and explores new avenues uncovered in this work.

6 CONCLUSION

We have explored physicalizations of personal activity data recorded during personally meaningful trail running experiences. Through two interview studies, we have found that interactions with these physicalizations leads to reflection on one's experience, sharing, and further consideration of the topography and geography of the areas depicted, including planning of new routes. Furthermore, these responses seem largely to be driven by participants' physical interactions with the physicalizations. This work gives support to the ability of physicalizations to allow individuals to understand and connect with data. We look forward to further work by ourselves and others in exploring physicalizations, particularly personal physicalizations as enabled by the growing democratization of 3D printing technology.

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