SweatAtoms: Materializing Physical Activity

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ABSTRACT
Visualization plays an important role in motivating users towards physical activity. In this paper, we present a novel approach to represent physical activity in the form of material artifacts. We have designed a system called SweatAtoms that builds material artifacts using the measured heartbeat data during the physical activity. By crafting such material artifacts, our aim is to harness physical activity as a medium for self-expression and make the experience of participating in physical activity more engaging beyond screen-based feedback. This paper describes the implementation and design of the SweatAtoms system. We hope our work can inspire fellow interaction designers and researchers to consider the role of materiality while designing interactive technology to support physical activity.

Categories and Subject Descriptors
H.5.2. [**Information Interfaces and Presentation**]: User Interfaces – *Miscellaneous*.

General Terms
Design, Experimentation, Human Factors.

Keywords
3D printing, physical exercise, materiality.

1. INTRODUCTION
With the rapid advancements in sensing technologies, we are witnessing a growing interest in using technology to foster a healthy lifestyle [7, 32]. Supporting this trend, studies have pointed out that a lack of awareness about physical activity may lead to a sedentary lifestyle [56]. In response, there has been an increase in technology that aims to motivate people to engage in physical activity: for example, many personal informatics tools exists that sense and collect personally relevant information of individuals to provide them with opportunities for self-monitoring and reflection on their activities and behaviors [35, 36]. In particular, personal informatics tools measure bodily movements and bodily responses that occur during physical activity and communicate this information to the user. For example devices like heart rate monitors [51] inform users about their exercise intensity by measuring the changes in heartbeats during a physical activity session. There are also many systems that use this input to facilitate play experiences [8, 45]: for example, the Fish'n'Steps system [37] utilizes the virtual fish, whose growth depends on number of steps taken by the user while Berkovsky et al. [4] have looked at virtual game rewards in exchange of the physical activity. Studies have shown that regular use of these tools can increase physical activity among people [5, 39, 56].

However, we argue that as personal informatics tools are becoming increasingly pervasive in our daily lives, what we design for them does not need to be limited to making users aware of their activity and prompt for the next goal like so many existing applications do. We believe there is opportunity for complementary design strategies surrounding physical activity and its representation [62]. In particular, we ask: "Are there any alternate approaches to harnessing personal informatics tools to enrich the physical activity experience beyond virtual representations?"

In this paper, we advocate an innovative approach of representing physical activity data in the form of material artifacts. By material artifacts, we refer to physical objects that are constructed from digital designs using a digital fabrication process [44]. By incorporating the digital fabrication process for constructing material artifacts, the proposed research aims to explore a "*physical – digital – physical*" mode of interaction. In this interaction, physical energy is first invested in creating a digital output, which is later converted back into physical form, re-entering the physical world.

We have designed an application called SweatAtoms that constructs 3D printed objects using the heartbeat pattern of the individual engaged in physical activity. While the user is exercising, she wears a heart rate monitor around her chest, which records and sends changes in the heartbeats to the SweatAtoms application. The SweatAtoms application then builds an abstract 3D model using the received heartbeat patterns, which is subsequently printed using a 3D printer.

2. Related work
Li et al. [35] argued that visualization plays an important role in motivating users towards physical activity because it helps users to reflect upon their performance and to gain insights into their physical activity levels. However, the data measured through personal informatics tools is often very abstract in nature: in

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particular biofeedback data such as heart rate and breathing rate "has no natural counterpart that can be graphically reproduced" Vande Moere [58, 59] points out. This proposed research work therefore draws on the role of the designer in creating meaningful metaphors and mappings to communicate this data to the user.

Over the last decade, the field of Human Computer Interaction (HCI) has seen various attempts at creating novel information visualizations of physical activity data [2, 3, 11, 13, 17], which we will explore in more detail next.

2.1 Numbers and graphs

Most of the commercial personal informatics tools use numbers and graphs to show the recent and past activities of the users on screens [32]. The advantage with numbers is that they need only a small display space and they are easy to interpret when compared with other graphical models of visualization. However, interpreting them can become difficult with an increase in the tracked data. Graphs on the other hand are easier to glance at but it is difficult to identify the accurate information for specific intervals. As a solution, some commercial applications such as RunKeeper [52] have used a combined approach of numbers and graphs and made them interactive, where a user can hover over a particular point in the graph and find an exact value presented as number.

2.2 Virtual metaphors

In this type of visualization, the tracked data is represented in the form of a virtual metaphor such as a virtual fish [37] or flower [11]. Unlike charts or graphs virtual metaphors can be more engaging, motivating and easy to glance at. Moreover, it is hoped that users will develop an empathy with the virtual object that hopefully motivates them to exercise more. For example, it is suggested that people thrive to be physically active to make a virtual plant grow and shine. However, living metaphor theory may not work in certain cases and could discourage users from doing the exercise. For example, in the fish-based metaphor, people did not want to look at the fish when they were inactive because they knew the sedentary activity would make the fish sad [37].

2.3 Interactive art displays

Recently Fan et al. [17] tried to utilize a variety of abstract visualization patterns to display physical activity data. They performed a study with novel and different visualization patterns such as spiral and ring and found people have different tastes when it comes to the abstract visualization of the physical activity data.

2.4 Physical metaphors

Similar to virtual metaphors, people have also explored the use of real life metaphors to make people aware of their sedentary lifestyle and prompt them to be physically active. In the sculpture based metaphor [28], the sculpture starts to yawn and begins to feel uncomfortable if the user remains seated for a long time.

After studying the related literature on visualizing physical activity, we found that most of them are focusing on virtual and metaphorical representations. We think there is an opportunity to investigate material representations to support physical activity as explained in the next section.

3. Motivation

Recent advancements in the digital fabrication have made the task of fabricating personalized material artifacts easier, accessible and affordable with 3D printers and laser cutters [1, 44]. Gershenfeld [21] envisions that 3D printers and scanners will soon be found in every home and people will regularly use them to make, copy, and share their custom made designs and material artifacts. As a result, design and HCI researchers are now considering the role of digital fabrication and materiality in HCI [6, 40, 44]. As a result, we found ourselves interested in investigating this domain further by identifying its significance for enriching the physical activity experience. After studying the related literature on materiality, we believe that material artifacts can offer the following opportunities that can enrich the experience of being physically active.

3.1 Self-expression

Self-expression refers to the assertion of one's individual traits usually through creative activities [41]. Within the context of physical activity, Sheridan [54] defined physical creativity as the ability to innovate through exertion, which involves the use of body and movements for self-expression, improvisation and imaginative play. The importance of self-expression is iterated in the works of Candy and Edmonds [10]. For example, Candy and Hori [9] stated that people exhibit physical skills and agility by breaking the simple routine and reconfiguring and extending the patterns of movements. However, we believe existing approaches have paid very little attention to self-expression and creativity while designing interactive technology to support physical activity. For example, many exertion-based interactive systems model a real world scenario by creating a virtual instructor where the user simply mimics the steps being instructed [14, 33, 55]. Similarly, in most exertion-based games [60], there is often a pre-defined mapping between bodily movements and actions inside a game. However, if the player does not make the correct body movement at the correct time, there is no defined action within the game [60]. As a result, many bodily movements go unnoticed inside such games. Sheridan [54] argued that this instilled vicarious nature of physical activity limits options for self-expression within physical activity.

Interestingly, it has also been observed that when an activity does not provide users with options for creativity and self-expression, users often alter its due course of action to make themselves feel autonomous and creative. For example, many runners in the UK tried to be creative with their running patterns by deliberately running in a pattern that resulted in a shape that resembles private body part on a virtual map [48]. Another example is FarmVille-based pixel art where the game players use their virtual farms as a canvas to create pixel-based art, with no particular advantage in the game except using it as a tool for self-expression [18]. There are also people who instill self-expression in physical sports and performance-based arts such as dance through body sculpting. Drawing inspiration from these performance-based arts where creativity and physical activities are interlinked, we believe there is an opportunity to intercept self-expression and physical creativity within forms of physical activity including everyday physical exercise.

We explore this opportunity by harnessing physical activity data for creating self-expressive material representations of physical activity.

3.2 Materiality

Miller [42, 43] argued that individuals like to express themselves with material artifacts that embody their lives, personalities, emotions and achievements. For example, results of one's crafts and achievements are often displayed on fridge doors, walls and shelves. Photographs of trips and events even though can be viewed on a digital screens, still gets printed, framed and hung on the wall [50]. Such an arrangement of material artifacts as physical signs spatially representing identity of an individual is called 'Autotopography' [24]. This autotopographical collection of material artifacts can also serve as a memory landscape to the owner triggering reminiscence [57]. Moreover, any material artifact, if put on display, becomes the public representation of the self and craftsmanship [22]. The material properties such as shape, form, texture and color may also provide opportunities to support being self-expressive. We therefore believe that material artifacts could inspire users to be creative with their exercise pattern rather than simply mimicking any steps being instructed. As a result, we envision that it could lead to an engaging experience, possibly even altering the monotonous nature of physical activity [20, 30].

3.3 Material rewards

According to Goal Setting Theory [38], incentives are important to sustain a user's interest in an activity. Previous works in the field of HCI have looked at virtual rewards and incentives to support physical activity among people. However, according to psychology studies [46], the virtual points and rewards are not always cherished. One could argue that a score of 10,000 virtual points might be satisfying for a moment but it may not be as memorable as any real world physical reward like a medal or trophy. Additionally, Goal Setting theory [38] suggests that reward structure should be set by the user rather than externally assigned to her.

The affordability of digital fabrication [6, 44] has prompted us to consider fabricating personalized material artifacts that can provide an alternate testimony to the invested efforts in performing physical activity. Previous research on archiving and souvenirs support this argument that material artifacts can be more cherishable and meaningful than virtual objects because of their higher visibility in the surrounding and low replication possibility [23, 31]. For example, when a person shares any digital object with someone, she also retains a copy, which she could later use for herself or even for others. Material artifacts, on the other hand, feel more unique as the original sender does not retain a copy. However, one could argue that with the rise of personal fabrication, the uniqueness property of the material artifacts can be lost as one can now easily make many replicas of the same object. We address this concern by fabricating material artifacts based on the physical activity data of the users during physical activity. We draw on the fact that the bodily response to physical activity is different for every individual and varies with each physical activity. Therefore, when utilized in the design process of material artifacts, chances are high that resultant material artifacts will bear a unique pattern. Therefore, we argue that these material artifacts will hold more meaning due to their distinctive quality and design for every individual and activities.

4. Challenges

Although material representations might offer opportunities to enrich the physical activity experience as listed above, there is a lack of understanding on how to design such representations for physical activity. In particular, we identify three key challenges in designing material representations, which could affect the user experience of physical activity.

1) Representation challenge: What could be the ideal way of representing physical activity data in material artifacts? For example, should we consider accurate or metaphorical representations of physical activity data in designing material artifacts?

2) Feedback challenge: When should we present the material artifact to the user? For example, should the digital fabrication be run in parallel with a physical activity or should it also be delayed until the user finishes her physical activity?

3) Implementation challenge: When and how should the material artifacts be printed? For example, should every physical activity be converted into material artifacts?

To explore these challenges we have created a design prototype called SweatAtoms that utilizes measured heart rate data during physical activity to create digitally fabricated material artifacts, whose design and implementation we explain in the next section.

5. SWEATATOMS

SweatAtoms includes a web application that builds 3D models using the heartbeat data, which can be accessed from both mobiles and PCs. This application provides a general framework that works with any physical activity with a requirement of a personal informatics tool that could feed the heartbeat data into the application. Figure 1 illustrates the working of the SweatAtoms application in the following six steps.

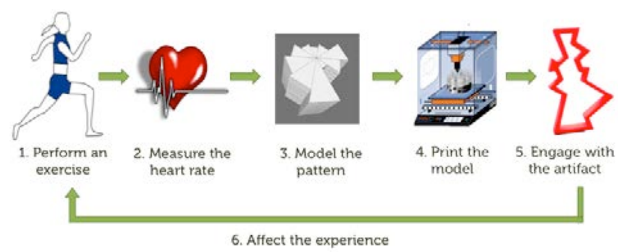

Figure 1: The SweatAtoms loop in actions: 1) User performs a physical activity. 2) The heart rate is measured 3) A 3D model is created based on the pattern 4) The 3D model is printed 5) The user engages the printed object 6) The ability to create new, novel patterns hopefully inspire the user to exercise again and in different ways.

5.1 Step 1: Exercise

Before starting any physical activity such as jogging, the user wears a heart rate monitor like Polar [51] around her chest, which records her heartbeats per minute. The user is free to perform any exercise of her choice as long as she is wearing the heart rate sensor, and feeding in the heartbeat data.

5.2 Step 2: Measure

While the user is performing the physical activity, the heart rate monitor attached to her body records the changes in the heartbeats. This recorded data is then sent over Bluetooth to a RunKeeper [52] application installed on her mobile. This application then communicates and sends the collected data to the SweatAtoms application using the HealthGraph API [26].

5.3 Step 3:
After receiving the heart rate data, the SweatAtoms application starts the 3D modeling process, which the user can visualize on her mobile. The SweatAtoms application generates a 3D model from the collected heartbeat data by using the constructive solid geometry [12]. In the current prototype, the constructed 3D model consists of triangular prisms of varied volume joined together to create an abstract shape. Rather than representing each and every recorded heartbeat, SweatAtoms attempts to represent only the significant variation in the values of heart rate during the completion of a physical activity. The rationale behind this approach is to give the user a snapshot about her overall experience with the physical activity reflected through her heartbeats.

In the current prototype, we have used the following algorithm for 3D modeling heartbeats as shown in Figure 2: For every large increment in the heart rate (±10 beats per minute), a new triangular prism is added to the model. The size of the triangular prism depends upon the reading of the heart rate. For example, for a higher reading of the heart rate, SweatAtoms inserts triangular prism of higher volumes. The modeling process continues as long as the heart rate monitor is sending the data. The user can also take a break in the middle of the physical activity by pausing the SweatAtoms application. This feature offers flexibility to the user for the building of 3D models. For example, the user can build one 3D object for every exercise or she can try several different combinations of exercises over a period of time before finalizing the 3D model.

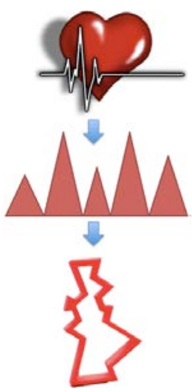

Figure 2: The 3D modeling process inserts a triangular prism of different volumes for each significant (+- 10bpm) variation in the heart rate. All the inserted prisms are then assembled together to print an abstract 3D shape.

5.4 Step 4: Print
When the user stops the SweatAtoms application, the resultant 3D model is saved as an STL file. This STL file is then fed to a 3D printer. Users can choose the printing material of their choice as well as alter the material properties such as size and color of the 3D model before printing.

5.5 Step 5: Engage
The printed material artifact, based on the 3D model, may act as a souvenir to the user's efforts invested in performing the physical activity. It can also be used for different utility purposes such as gifting it to someone. Figure 3 shows some of the printed material artifacts in different materials and design patterns.

5.6 Step 6: Affect
Since the design of the material artifact is based on the received heartbeat pattern of a physical activity, the user might get inspired to do exercise differently and to try out new forms of physical activity for creating newer 3D models.

Figure 3: Some of the printed material artifacts.

6. DISCUSSION
6.1 Representation strategy
We identify three possibilities in utilizing the heartbeat data in the 3D modeling process of material artifacts. They are discussed below.

6.1.1 Accurate representation
One way to model the heartbeat data is to convert the visual representation directly into the material one, as shown in Figure 4. A recent study done by Jansen et al. [29] shows the increased significance of material representation over the same representation in the virtual medium. However, our intention with this work is to make full use of the opportunity that materiality provides, which goes beyond the direct conversion from the virtual medium. Additionally, representing every heartbeat during a physical activity into the 3D model would involve high printing cost; hence we did not opt for this mode of representation.

Figure 4: Examples of an accurate representation

6.1.2 Abstract (metaphorical) representation
One can also think of more abstract and even metaphorical representations. In such abstract designs, data is communicated symbolically where accurate interpretation of the data is often difficult and subjective. Let us illustrate this with an example. One can utilize a predefined 3D model like a car and then use the measured heartbeat data as a way to fabricate it over time. In this case, 3D modeling and subsequent printing of the material artifact depends upon the amount of the physical activity the person performs. Abstract representations are useful because they can create empathy among users [37]. However, we did not opt for an abstract mode of representation because we wanted an interpretive representation, which could be difficult through metaphors.

6.1.3 Mixed representation
With SweatAtoms, we have followed a mixed representation of the heartbeat data, combining bits from abstract and accurate representations together as shown in Figure 5. This representation

is not completely abstract because it provides a meaning associated with the heartbeat data. Here, instead of representing each and every heartbeat similar to an accurate representation, mixed representation utilizes only the significant changes in the heartbeats during the physical activity. Our intention behind choosing such representation is to provide user with an opportunity to interpret how her heart rate has evolved over the entire physical activity session.

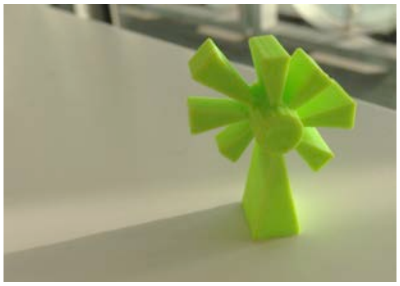

Figure 5: Mixed representation of heartbeat data from using the SweatAtoms application

6.2 Discussion on feedback strategy

An interesting question to explore with SweatAtoms is, when and how to present the feedback about the physical activity to a user in the form of material artifacts. There are two options as enlisted below.

6.2.1 Immediate feedback

With the immediate feedback strategy, the user can see the 3D printing of the material artifact as she is performing the physical activity. However, this immediate feedback may influence the physical activity as the user might try to deliberately change the course of her activity to see how it would be reflected in the design.

6.2.2 Delayed feedback

Another possible option is to provide delayed feedback to the user about her efforts by presenting a 3D model only after it has been printed. In this case, the user has to wait until the 3D printing is done. This strategy benefits from the surprise element that may encourage curiosity among participants.

The current prototype of SweatAtoms supports both feedback options as listed above.

7. PRELIMINARY FEEDBACK

SweatAtoms system has been demoed at an international conference to around 500 HCI practitioners and initial feedback of the system was highly encouraging, which has motivated to conduct an in-depth study of SweatAtoms to understand how it can influence and enrich the physical activity experience.

8. CONCLUSION

In this paper, we have investigated how material representations of physical activity can enrich the experience of performing physical activity. Such an investigation is not aimed at replacing existing techniques and approaches to support physical activity, but rather it is intended to aid the ongoing development on how technology could enrich the physical activity experience. By looking at material artifacts for representing physical activity, our aim is to provoke new thinking and support the development of design strategies within the design space. We hope that our work will help to promote the consideration of material outcomes of physical activity within the works of designers who work with interactive technologies.

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