Understanding Material Representations of Physical Activity

CONFIRMATION OF CANDIDATURE REPORT

ROHIT ASHOK KHOT

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Thesis supervisors:

Dr. Florian ‘Floyd’ Mueller & Dr. Larissa Hjorth

Exertion Games Lab,
RMIT University, Australia

RMIT UNIVERSITY

Exertion Games Lab
RMIT University
Melbourne, VIC 3000
Australia

“Humans are creatures who spend their lives trying to convince themselves their existence is not absurd.”

- *Albert Camus*

Abstract

Previous work in the field of Human Computer Interaction (HCI) has shown that interactive technology can enrich physical activity, however most of this work has concentrated on virtual representations of physical activity. Recent advancements in digital fabrication have prompted design researchers to consider the role of materiality in HCI inspired by its many opportunities, however there remains a lack of understanding on how to design such material representations for physical activity. In order to advance this understanding, I will follow a research through design approach; building and evaluating two systems that produce material representations as feedback and reward outcomes. Firstly, I have designed a system that constructs static 3D printed objects using the heartbeat pattern of the individual engaged in physical activity. Secondly, I seek to develop a system that makes such outcomes interactive. Finally, I will use my investigations of these to build a theoretical design framework for the design of material representations of physical activity. This framework will be evaluated using workshops targeted at design researchers working in interactive technology for health. The contribution of this work will be a conceptual understanding of the relationship between material representations and physical activity and how people experience it in order to design interactive technology for it. My work will help to situate material outcomes of physical activity within the context of interaction design.

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Introduction

1.1 Introduction

With the rapid advancements in sensing technologies, we are witnessing a growing interest in using technology to foster a healthy lifestyle (Campbell et al. 2008; Klasnja and Pratt 2011). Supporting this trend, studies have pointed out that a lack of awareness about physical activity may lead to a sedentary lifestyle (Tudor-Locke et al. 2004). 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 (Li et al. 2010). 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 inform users about their exercise intensity by measuring the changes in heartbeats during a physical activity session. Studies have shown that regular use of these tools can increase physical activity among people (Maitland et al. 2006; Bravata et al. 2007; Tudor-Locke et al. 2004).

Li et al. (2010) 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 particular biofeedback data such as heart rate and breathing rate "*has no natural counterpart that can be graphically reproduced*" Vande Moere (2008) 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. However, designing meaningful ways of representing physical activity is a challenge and forms the main focus of this thesis.

1.1.1 Research context: Physical activity representation

Over the last decade, the field of Human Computer Interaction (HCI) has seen various attempts at creating novel information visualizations of physical activity data (Anderson et al. 2007; Consolvo et al. 2009; Jafarinaimi et al. 2005; Lin et al. 2006; Fan et al. 2012; Curmi et al. 2013). The majority of the existing approaches appear to target an accurate portrayal of the physical activity to mostly prompt the user to aspire for the next health and performance goal. For example, the application associated with the Fitbit (2013) device[1] highlights the progress of users towards their goals using a graphical based representation: through leaderboards and badges the application allows users to compare and evaluate their progress. After reviewing most of the commercially available personal informatics applications I found that they mainly focus on raising awareness among users about their physical activity levels in relation to performance goals.

However, I 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. I believe there is opportunity for complementary design strategies surrounding physical activity and its representation (Zimmerman et al. 2007). In particular, I ask are there any alternate approaches to harnessing personal informatics tools to enrich the physical activity experience beyond virtual representations that target performance goals?

1.2 Approach: material representations

In this thesis, I advocate an innovative approach of representing physical activity data in the form of material artifacts. By material artifacts, I refer to physical objects that are constructed from digital designs using a digital fabrication process (Mota 2011). 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.

[1] Fitbit is a commercial pedometer that tracks numbers of steps taken in a day using embedded accelerometers.

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 (Anderson 2010; Mota 2011). Gershenfeld (2007) 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 (Mellis et al. 2013; Wellis et al. 2011; Buechley and Perner-Wilson 2013). According to Mellis et al. (2013) material artifacts can be useful as design tools and interfaces for online collaboration, for hands-on learning and as personalized items. Additionally, the DIY movement has also reflected a growing interest of people in digital fabrication (Kuznetsov and Paulos 2010). As a result, I found myself interested in investigating this domain further by identifying its significance for enriching the physical activity experience. After studying the related literature on materiality, I believe that material artifacts can offer the following opportunities that can enrich the experience of being physically active (as illustrated in Figure 1):

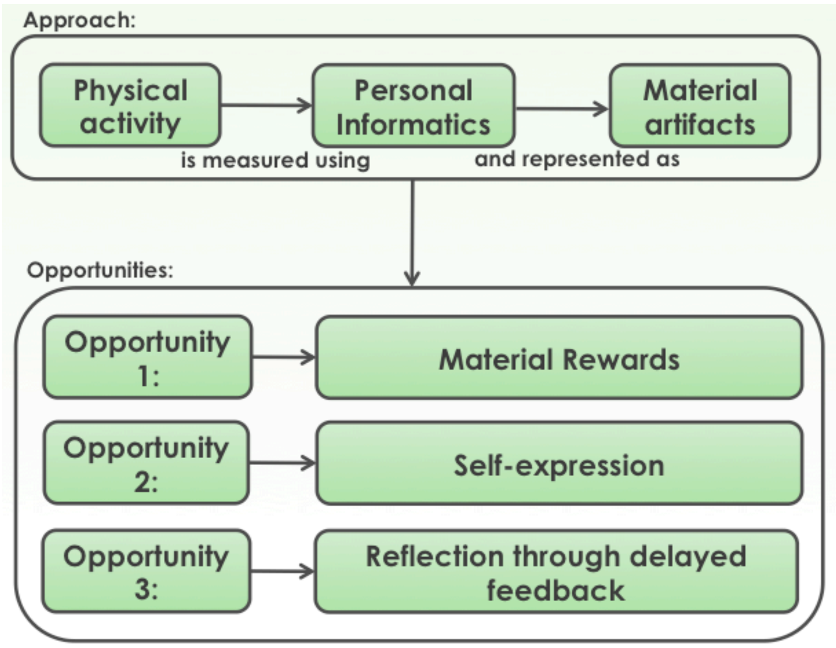


Figure 1: Summary of research opportunities and approach undertaken in this thesis

1.2.1 Opportunity to provide material rewards

Sennett (2008) refers to humans as "*homo faber: manufacturer and collector of objects and as creature who imbue sentiment in external artifacts*." This quote is useful to understand the significance of materiality in human life. Material culture has been studied in depth in social sciences (Dant 1999; Miller 1987, 2008; Woodard 2007) as well as in HCI (Kirk et al. 2006; Kirk et al. 2007; Van der Hoven 2004; Goljstein et al. 2012; Petrelli and Whittaker 2010), which shows a human fascination towards creating and collecting material artifacts. Previous research on archiving and souvenirs (Golsteijn et al. 2012; Kirk et al. 2011; Odem et al. 2009) provide a supporting argument that material artifacts can have more cherishable and meaningful value than virtual objects because of their higher visibility in the surroundings and low replication possibilities. 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. I, therefore, think material artifacts can be used as rewards that can provide meaningful testimony to the invested effort in physical activity.

1.2.2 Opportunity for self-expression

Miller (2008) 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 are often framed and displayed. Such an arrangement of material artifacts as physical signs spatially representing identity of an individual is called 'Autotopography' (Gonzalez 1995). This autotopographical collection of material artifacts also serves as a memory landscape to the owner triggering reminiscence (van der Hoven 2004). I therefore believe that an autotopography of material artifacts based on the physical activity data can be an external expression of the invested effort and achievements during the physical activity.

1.2.3 Opportunity for reflection through delayed feedback:

Halnas and Redstorm (2001) in their seminal work on slow technology emphasized the need for reflection and expression of use, while designing technology to support everyday activity. One way to support reflection is through a delayed feedback mechanism where the feedback on the activity is not instantaneous and I believe material artifacts can offer this opportunity. For example, unlike a virtual representation that calls for instant user attention, a material artifact can sit quietly in the surroundings and may not seek attention. Miller (2008) called this property of material artifacts "*humility of things*", because material artifacts have a tendency to disappear into the background. As a result, most people are unaware of the role that material objects play in our lives (Miller 2008). This property of material artifacts can thus be harnessed to provide users with opportunities for reflection and contemplation on their activity. Moreover, visualizing data through material artifacts has additional benefits as argued by Vande Moere (2008): He suggested that the tactile property of the material could convey meaning beyond the data and encourage users to reflect on the meaning. Hence, it could lead to a more pleasurable, engaging and educational experience. In addition, the digital fabrication of a material artifact (for example, using a 3D printer) currently requires considerable amount of time as does the process of achieving health goals. Therefore, the final constructed material output might appear as a good match for the temporal and longitudinal nature of health outcomes of regular physical activity.

1.2.4 Challenges of designing material representations

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, I 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?

I believe exploring these challenges can help gaining an understanding of the interrelationship between physical activity and material representation. I envision that the thesis will contribute to this understanding by providing the following:

- An explanation on how material representations can affect the physical activity experience.

- A rich set of design prototypes to study the interrelationship between material representation and physical activity.
- A conceptual understanding of how design can support this interrelationship.

By contributing this understanding, my work will help to situate material outcomes of physical activity within the context of interaction design.

1.2.5 Key Definitions

This section gives a brief idea of the key concepts and the terminologies that are used throughout the thesis.

Physical activity

Physical activity refers to any physical movement (Biddle and Mutrie 2008). Physical inactivity refers to both insufficient physical activity and sedentary behavior (Van der Horst et al. 2007). The focus of the thesis is on everyday physical activity, for example walking.

Personal informatics

Personal informatics is the term coined by Li et al. (2011) which refers to a set of tools that help people collect personally relevant information for the purpose of self-reflection and self-monitoring. These tools aim to help people gain self-knowledge about one's behavior, habits, and thoughts. Within the context of this thesis, personal informatics includes tools that collect physical activity data in the form of bodily movements and biofeedback.

Biofeedback and physical activity data

Biofeedback is the measurement of a person's quantifiable bodily functions, such as blood pressure, heart rate and skin temperature, using a personal informatics tools. Physical activity data refers to both biofeedback and data about bodily movements that occur during physical activity.

Materiality

I use the definition by Miller (2008), who has defined materiality as the relationship among an artifact, people and other artifacts. Materiality encompasses a broad range of values and effects that are elicited in the course of making and using material artifacts (Miller 2008).

Digital fabrication

Digital fabrication is a process of creating material artifacts from digital designs (Mota 2011). In a digital fabrication process, a computer-aided design (CAD) model is first designed and then fed into a fabricator, which then builds a physical replica from a stock material. Some of the commonly used digital fabrication tools are laser cutters, computer-numeric controlled (CNC) mills, and 3D printers.

1.3 Thesis statement

Located within the HCI tradition, this thesis explores material representations of physical activity. It involves investigations of the design space surrounding physical activity, personal informatics and material representations as shown in Figure 2.

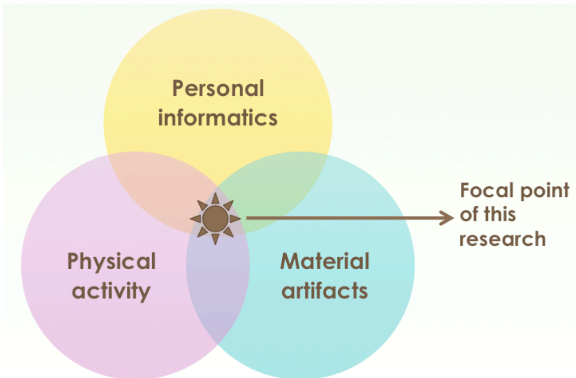


Figure 2: Focal point of the research is at the intersection of personal informatics, physical activity and material artifacts

The main research question explored in this thesis is:

"*How does the design of a material artifact – representing one's physical exertion – influence a person's relationship with physical activity?*"

I will utilize research through design (Zimmerman et al. 2007) and mixed method research (Creswell et al. 2003) practices to answer the research question of the thesis. I will explore physical activity data such as invested time and bodily responses to exertion as central design elements to develop two prototypes around physical activity representation. Firstly, I have designed a system called SweatAtoms that constructs static 3D printed objects using the heartbeat pattern of the individuals engaged in physical activity. Secondly, I seek to develop a system that makes such outcomes interactive. Finally, I will use my investigations of these to build a theoretical design framework for the design of material representations of physical activity.

1.3.1 Case study 1: SweatAtoms

The starting point of this investigation is a design prototype called SweatAtoms that utilizes measured heart rate data during physical activity to create digitally fabricated material artifacts. I have built a system that generates and then fabricates 3D models using the heart rate data of the user, engaged in physical activity. To understand the experiential difference that SweatAtoms can make to physical activity, I have proposed a mixed method study drawing upon qualitative and quantitative approaches (Ethics has been approved). The specific results from this investigation will inform the development of the next design prototype within the same design space.

1.3.2 Research objectives

The research objectives are described as follows.

Objective 1: Gather understanding of the relationship between physical activity and its representations from existing literature

This thesis will first enumerate existing issues and opportunities associated with physical activity and its representation using personal informatics tools, drawing upon previous works in the field of information visualization. It also includes related work on existing autotopography and digital fabrication practices to identify design opportunities and strategies.

Objective 2: Explore the design space of materiality in relation to physical activity

This thesis will present two design prototypes built upon the identified design opportunities and strategies associated with personal informatics and materiality. These design explorations will serve as research vehicles to develop insights into the user experience of engaging with materiality derived from physical activities.

Objective 3: Validate the design space

This objective involves an empirical evaluation of the experiences with the designed prototypes. Analysis of the user experience gained from the studies will help to formulate an understanding how material representations impact and can shape the experience of physical activity.

Objective 4: Create and validate a design framework

The insights gained from these investigations will result in a theoretical framework that offers an understanding of how to design material representations of physical activity using interactive technologies. This framework will be evaluated using workshops targeted at design researchers working in interactive technology for health in order to demonstrate its utility.

1.3.3 Scope

In order to focus on the research objectives listed above, the scope of this thesis is limited as follows:

- The focus of this thesis is on everyday physical activity, which includes jogging, running as well as walking. Other physical activity types such as sports are excluded from the discussion.
- I am utilizing 3D printing for the digital fabrication of material artifacts. Other fabrication tools like laser cutters are not considered in this work.
- This thesis does not focus on health goals such as weight loss, although positive health benefits as a result of the work is welcomed. Similarly, this work is also not aimed at maximizing individual athletic performance. Instead, this thesis focuses on enriching the physical activity experience, with an assumption that an engaging experience can lead to enhanced participation in physical activity, which in turn will contribute to health benefits.

1.4 Outline of the thesis

The remainder of the thesis is organized as follows (Refer Figure 3).

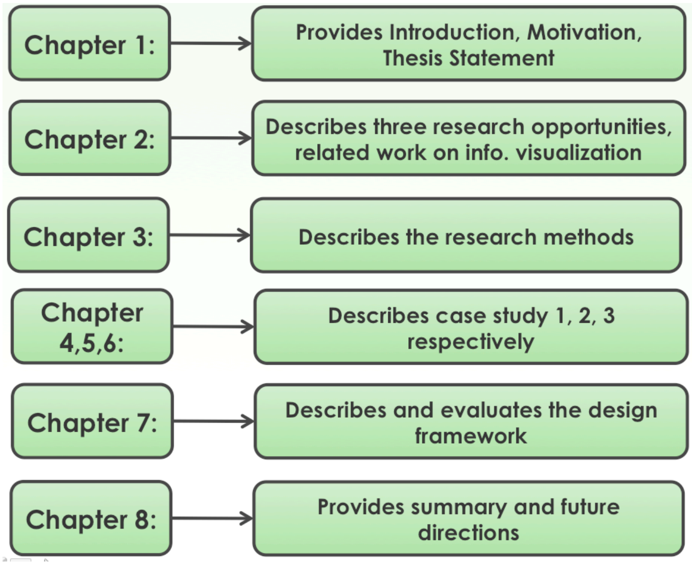


Figure 3: Outline of the thesis

Chapter 2 addresses Objective 1 of Section 1.3.2. Chapter 2 presents relevant background on physical activity and information visualization. I then enumerate issues and opportunities along with the rationale for considering the material representations through digital fabrication.

Chapter 3 describes the methods followed for conducting the research.

As a response to the Objective 2, Chapter 4 presents the first case study in the form of SweatAtoms.

Chapter 5 and 6 will describe the case studies 2 and 3.

Chapter 7 will describe the design framework and its evaluations using workshops conducted with design and HCI researchers and practitioners.

Finally Chapter 8 discusses contributions of this research, future directions and offer concluding remarks and discussions.

1.5 Contributions

This research contributes to knowledge about understanding material representations of physical activity both in practice as well as theory. This research makes the following contributions.

1) This research contributes to practice by providing implementation details and insights gained from the design and evaluation of two design prototypes that demonstrate how material representations can facilitate engaging physical activity experiences.
2) This work contributes to the understanding of the interrelationship between representations and physical activity.
3) This work expands the view of personal informatics tools and physical activity representation beyond efficiency and performance goals, by focusing on the activity experience and invested efforts.
4) By drawing key principles from materiality and HCI to support the physical activity experience, this work serves as a theoretical bridge that offers a language mediating between the two. It thus aims to situate the role of materiality in interaction design.

1.6 Related publications

Portions of the research presented in this thesis have been peer-reviewed and published in academic venues.

The publication list:

- Khot, R. 2013. Sweat-atoms: crafting physical objects with everyday exercise. In *Proc. CHI EA '13*, ACM, pp. 2701-2706.
- Khot, R., and Mueller, F. 2013. Sweat-atoms: turning physical exercise into physical objects. In *Proc. CHI EA '13*. ACM, pp. 3075-3078.

Public demonstrations:

- SweatAtoms was showcased at the Interactivity session happening at ACM CHI 2013, Paris, demonstrated to 200 interaction designers and HCI researchers.

2
Background and Related work

2.1 Related work on information visualization

I first describe the related approaches that have aimed to support physical activity through novel visualization techniques.

Information visualization focuses on making a large amount of data more accessible and understandable through visual media. Manovich (2010) defined visualization as a mapping between discrete data and a visual representation scheme. According to Card et al. (1999), information visualization is useful for following purposes:

- To make sense of data by identifying patterns and relationships within the data.
- To create or discover concepts and ideas that were previously unknown or only hypothesized.
- To communicate the results of the study and provide evidences of the inferred conclusions.

Information visualization techniques are mainly classified into the following two categories (Jansen et al. 2013):

1) Virtual visualization and

2) Physical visualization.

I discuss them below.

2.1.1 Virtual visualization

In this mode of visualization, the data is mapped to screen pixels and represented in the form of numbers, graphs and charts. The virtual screen medium allows representation of heterogeneous and multiple datasets at the same time and supports interactive explorations of data such as dynamic filtering and searching. Moreover, the dynamic frame rate allows quick and easy update of the data (Vande Moere 2008). As a result, virtual visualization techniques have become popular among expert users in work related settings and are widely used in a variety of domains for interpreting complex data. However, virtual visualization techniques are mainly suitable for 2D representation of data since onscreen 3D visualization suffers from problems such as occlusion, distortion and navigational issues (Shneiderman 2003). Other disadvantages of virtual visualization as listed by Vande Moere (2008) are the requirement of a flat display surface, lesser perception in daylight and task obstruction by grabbing visual attention. Vande Moere (2008) suggested that virtual visualizations are more useful for advertising and as a reminder tool while they are less suitable for contemplation and reflection.

2.1.2 Physical visualization

In physical visualization, data is mapped to physical form, which often includes paper, ink and physical matters. The disadvantages of the physical medium are cost, slow building process and static mode of operation (Jansen et al. 2013). As a result, this mode of visualization has been rarely used in the past. However, these drawbacks have started to diminish with the rise of digital fabrication (Mota 2011) and computationally augmented interfaces (Ishii et al. 2012; Rasmussen et al. 2012). For example, devices like 3D printers and laser cutters not only make the fabrication process easy but these devices are also getting cheaper, more accurate, smaller and faster (Andersen 2010). Similarly, computationally augmented interfaces allow dynamic updates of the data, thereby reducing the problem of static representation.

Physical visualization also benefits from the physical modality. It therefore allows easy exploration, handling and manipulation of the data in 3D space through touch-based interaction. Physical visualization can also be used for casual explorations (Vande Moere

2011). Table 1 compares virtual and physical visualization techniques on different parameters used for visualization (Vande Moere 2008).

Table 1: Comparison between virtual and physical visualization

Parameters of visualization	Virtual visualization	Physical visualization
Visual mapping of data	To screen pixels	To atoms (physical form)
Common used Representation method	Interactive and static	Static
Suitability	Mostly 2D visualization	Mostly 3D visualization
Target users	Experts	Non-experts
Common usage	Accurate visualizations and interpretations	Casual explorations and accurate visualizations and interpretations

2.1.3 Existing literature on visualizing physical activity

Previous works in the field of HCI have proposed different ways of displaying physical activity data, which I describe below.

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 (Klasnja and Pratt 2011). 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 values for specific intervals. As a solution, some commercial applications such as RunKeeper (2013) 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 present as number.

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 (Lin et al. 2006) or flower (Consolvo et al. 2009). The idea is, unlike charts or graphs, virtual metaphors are more engaging, motivating and easy to glance. Moreover, it is hoped that users will develop an empathy with the virtual object that hopefully motivates them to exercise more. For example, people thrive to be physically active to make a virtual plant grow and shine. However, living metaphor theory may also backfire and 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 (Lin et al. 2006).

3) Interactive art displays

Recently Fan et al. (2012) 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 and designers should consider the varied preferences of the users while designing visualization schemes.

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 (Jafarinaimi et al. 2005), the sculpture starts to yawn and begins to feel uncomfortable if the user remains seated for a long time. Other researchers (Taylor et al. 2013) have used a mirror metaphor to make users aware of their postures. For example, if the user is not sitting in a proper posture then the mirror (web camera screen) becomes blurry, thereby hopefully encouraging the user to sit in the correct posture.

After studying the related literature on visualizing physical activity, I found that most of them are focusing on virtual and metaphorical representations. I think there is an opportunity to investigate material representations to support physical activity as listed below.

2.2 Physical activity: Issues and Opportunities

Regular physical exercise is the key to maintain and regain physical health (Weinberg and Gould 2006). The American College of Sports Medicine (2000) recommends that to remain fit and healthy, an average adult should do 30 minutes of moderate physical activity every day. Miller (2002) noted that most people, including those who exercise regularly, often lack enjoyment or find some aspects of physical activity unpleasant. For example, most exercises involve setting up an exercise routine (which also means repeating similarly structured exercise everyday) and obeying the rules instructed by the physician, coach or fitness DVD program (which also means having an external control over our actions). This repetitive nature of exercise activities coupled with the perceived control of external factors on our actions can make physical exercise boring and non-engaging (Gavin 2006; Karvitz 2011). As a result, despite knowing the benefits of physical exercise, people who regularly exercise are significantly low. According to a survey conducted by Kruger et al. (2008), half of the US population does not perform any physical activity. This lack of engagement with physical activity can adversely affect health by increasing the risk of otherwise preventable diseases like obesity, high blood pressure and diabetes (Pete et al. 1999).

In this thesis, I identify and explore three opportunities that aim to make physical activity an engaging experience through material representation.

- Opportunity for self expression
- Harness delayed feedback
- Utilize material rewards

I now describe prior work related to each.

2.2.1 Opportunity for self-expression

Self-expression refers to the assertion of one's individual traits usually through creative activities (Merriam-Webster 2013), while creativity according to Vygotsky (1978) is a combination of reproduction and innovation and is closely related to play. Within the context of physical activity, Sheridan (2011) 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 (2002). For example, Candy and Hori stated (2003) that people exhibit physical skills and agility by breaking the simple routine and reconfiguring and extending the patterns of movements. However, I believe existing approaches around interactive technology have paid very little attention to self-expression and physical creativity around physical activity. For example, in most interactive exercise systems such as Switch2Health (2013), the designer often pre-tailors the exercise experience and the user is rewarded only when she follows the exercise instructions correctly as well as in correct order. In most exertion-based games[2], 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 (Wearn et al. 2013). As a result, many bodily movements go unnoticed inside such games. Similarly, many other exertion-based systems model a real world scenario by creating a virtual instructor where the user simply mimics the steps being instructed (Dance Central 2013; Konami Dance Dance Revolution 2013). Sheridan (2011) 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 their 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 of private body parts on a virtual map (Penis Running map 2013). 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 (Farmville Pixel Art 2013). There are also people who instill self-expression in physical sports and performance-based arts such as dance through body sculpting (Gonzalez et al. 2012). Drawing inspiration from these performance-based arts where creativity and physical activities are interlinked, I believe there is an opportunity to intercept self-expression and physical creativity within all forms of physical activity including everyday physical exercise.

I explore this opportunity by harnessing physical activity data for creating self-expressive material representations of physical activity. I believe the measured physical activity data, that

[2] In some exertion-based games, body movements are used as a controller (input) to the game.

is, the bodily responses to exertion such as change in heartbeats, is personal, non reproducible and a good indicator of the amount of effort and time invested by an individual in performing physical activities. Moreover, I believe each person brings her own unique flavor to exercise. In particular, how the body responds to the activity over time differs from person to person. However, these nuances within the physical activities are not easily noticeable. Fortunately, personal informatics tools can now measure these nuances, and I see this as an opportunity to support my endeavor. Moreover, any material artifact, if put on display, becomes the public representation of the self and craftsmanship (Goffman 1959). The material properties such as shape, form, texture and color may also provide opportunities to support being self-expressive. Therefore, I suppose in order to fabricate different material artifacts, the user might feel inspired to try out new forms of physical activity to express him-/herself. For example, users might be interested in figuring out how a push-up exercise would be reflected in the design and therefore might get motivated to perform the same. I 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, I envision that it could lead to an engaging experience, possibly even altering the monotonous nature of physical activity (Gavin 2006; Karvitz 2011).

2.2.2 Harness delayed feedback

Tudor-Locke et al. (2004) from their study on self-monitoring using pedometers suggested that lack of awareness about physical activity contributes to the sedentary lifestyle. Moreover, Wilson and Dunn (2004) claimed that people do not have complete knowledge about themselves and about things that affect their lives, mainly because of the limited memory and the difficulty in observing and understanding some behaviors. Moreover, their episodical memory is also shown to be inaccurate or incomplete (Li et al. 2011). There have been studies, which suggest that people tend to remember the negative (Frijda 1988) as well as positive events (Walker 2003) of their life. According to Lyubomirsky et al. (2005), remembering positive events is good for self-esteem, health and growth and therefore leads to higher motivation and greater perseverance (Clore and Huntsinger 2007).

Previous work in the field of HCI has therefore looked at personal informatics tools to provide feedback on physical activity for supporting self-monitoring and understanding of one's behaviors, habits, and thoughts (Li et al. 2011). For example, measured biofeedback data during physical activity helps users to understand the exercise intensity and guides them to next achievable health goals (Maitland et al. 2006; Intille 2004; Assogba and Donath 2009, Li et al. 2010, 2011). Studies (Bravata et al. 2007; Tudor-Locke et al. 2004) have also shown that increased awareness about physical activity using pedometers can increase the physical activity among people. However, most of the existing approaches focus on performance goals and raising awareness about the physical activity levels (Li et al. 2011; Klasnja et al. 2011). Although personal informatics tools have been quite successful in increasing physical activity among people (Tudor-Locke et al. 2004), some researchers (Klasnja et al. 2011; Hekler et al. 2013) have also argued against the constant monitoring and feedback of the physical activity. They suggested that it could lead to higher burnouts among people and thereby diminish the purpose of making people physically active. In addition to this, behavioral scientists (Hekler et al. 2013) argued that self-knowledge alone is often not sufficient to promote behavioral change. They advocate the need for new systems that allow for more flexible development and testing of different behavioral change strategies.

To address this need, I turn to slow technology (Halnas and Redstrom 2001) that emphasizes the need for thinking about reflection and contemplation in opposition to efficiency and performance while designing technology for everyday use. Interestingly, recovering and gaining personal health is also a slow and steady process, which demands time and consistency in terms efforts from the user (Weinberg and Gould 2006). For example, the result of burning body fats through an exercise is visible only after the user has followed many exercises regularly and for a sufficient amount of time. Therefore, I believe that there is an opportunity to support the slow and steady nature of physical activity by creating tools that offer reflection on the activity experience.

In this thesis, I explore this opportunity through digitally fabricated material artifacts that afford reflection through their inherent tendency of disappearing into the background (Miller 2008). Therefore, material artifacts will gather attention only when a user specifically glances at or looks for them. Additionally Kirk et al. (2011) argued that material artifacts also have personal reflective value. Therefore, using material artifact to represent physical activity data can possibly provide users with options for reflection on their performance.

2.2.3 Provide Material rewards

According to Goal Setting Theory (Locke and Latham 1990), 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 the psychology studies (Munson and Consolvo 2012), 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 (Locke et al. 2002) suggests that reward structure should be set by the user rather than externally assigned to him/her.

The affordability of digital fabrication (Buechley et al. 2013; Mota 2011) has prompted me 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 (Golsteijn et al. 2012; Kirk et al. 2011). However, one could argue that with the rise of personal fabrication (Buechley et al. 2013; Mota 2011) and easy to use 3D printers, the uniqueness property of the material artifacts can be lost as one can now easily make many replicas of the same object. I address this concern by fabricating material artifacts based on the physical activity data of the users during physical activity. I draw on the fact that the bodily response to physical activities 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, I argue that these material artifacts will hold more meaning due to their distinctive quality and design for every individual and activities.

In this thesis, I explore the opportunities through prototyping and using a research through design method (Zimmerman et al. 2007).

3 Methods

3.1 Introduction

This chapter presents a list of research methods that I plan to use during the course of my research. I will utilize research through design and mixed method research practices to answer the research question of the thesis.

3.1.1 Research through design

Research through design is a reflective practice where thinking occurs through prototyping to examine the process, invention, relevance and extensibility of the design (Klemmer and Hartmann 2006; Zimmerman et al. 2007). This approach helps interaction designers to integrate models and theories with the technical opportunities demonstrated by engineers to make the right artifact to transform the world from its current state to a preferred state (Zimmerman et al. 2007). The knowledge in research through design is in the production of the artifacts or the artifact itself (Zimmerman et al. 2007). Nigel Cross (2006) puts forward that a key research question in research through design is "*How would you design an <X>?*" This is relevant for this thesis, as the central research question could be reframed as a research through design question: "How would you design material representations of physical activity?" To answer this question, I will explore physical activity data such as bodily responses to exertion as central design elements to develop two prototypes around physical activity representation. Both these design prototypes are explained as a case study in the next two chapters.

3.1.2 Mixed method research

Mixed method research focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies (Creswell et al. 2003). Mixed method research is advantageous for the following reasons (Creswell et al. 2003):

- Variation in data collection leads to greater validity.
- Mixed method research answers the question from a number of perspectives.

Quantitative research collects objective data with predetermined instruments that yield statistical validity while qualitative research involves collection of open ended subjective data with an intent of developing themes (Creswell et al. 2003). The main objective of this thesis is to understand material representations of physical activity; therefore I will use the "in the wild" (Chamberlain et al. 2012) method to collect the subjective data about the experiences of participants with material artifacts, using semi-structured interviews. The quantitative research method will be used to gain insights on the physical activity data tracked using the personal informatics tools.

3.1.3 Data collection

In the wild studies are used to test and evaluate prototypes over time through actual day-to-day use. This allows us to gain a much clearer understanding of how the technology can be integrated into people's everyday routines and the real-world issues that arise, as opposed to lab-based studies that take users out of their normal setting into a tightly controlled environment, typically for only short periods of time. I am therefore employing an in the wild study method (Rogers 2011; Chamberlain et al. 2012) to investigate how people engage with material artifacts in their everyday lives. I will install the proposed design prototypes in the houses of participants and then study how they will interact with these prototypes. I will conduct semi-structured interviews with the participants to discuss and understand their experiences with the prototypes.

Interviews are commonly used to understand the mediated interactions of a user with technology. Interviews provide insights on the user experience that cannot be measured through quantitative data. I therefore opt for audio and video based interviews with the participants and I will also take notes during the interview process. The interviews will be semi-structured to leave room for follow-up questions and to support a deeper elucidation of participants' responses and thinking processes (Neuman 2006). The recorded videos will be imported into qualitative data analysis software. The footage will be coded and transcribed for analysis. Along with the interviews, I will also log the physical activity data for further analysis and identifying patterns.

3.1.4 Data analysis

From the gathered data (video recording of the interviews), I am trying to understand the personal significance of the material artifacts in relation to the physical activity. By personal significance, I am referring to the experiential difference and the behavioral change that might occur in the life of the individuals with the inception of material artifacts that denote their physical exertion. To address this, I am using recently proposed HCI-Q methodology (O'Leary et al. 2013). HCI-Q methodology is based on Q-methodology, founded by Stephenson (1953). There are two main advantages of Q-methodology over earlier proposed methods of data analysis. First Q-methodology proposes a systematic (quantitative) way of capturing personal significance of technology. Secondly, it is a small sample technique (< 50 participants), and provides statistical validity to the qualitative interpretations of subjective data (for example, extracts from interviews). Below is a short summary on Q-methodology before explaining the HCI-Q method. For detailed explanation on Q-methodology, refer to the works by Brown (1980) and Watts and Stenner (2012).

3.1.5 Q-methodology

Q-methodology was originally developed for the systematic study of subjectivity, a person's viewpoint, opinion, beliefs, attitude, and the like (Brown 1993). Q-methodology investigates the perspectives of participants who represent different stances on an issue, by having participants rank and sort a series of statements. These individual rankings (or viewpoints) are then subjected to factor analysis (Kim and Mueller 1978). In Q-methodology, the variables for the factor analysis are individuals and not their traits. By correlating individuals, Q factor analysis gives information about similarities and differences in viewpoint on a particular subject. Q-methodology has been used in social, behavioral and health sciences. In the last few years, it has also found use in understanding the attitudes and perspectives of people towards technology. For example, Anandarajan et al. (2006) have presented a Q-methodology approach to understand personal web use in workplaces, while Best et al. (2009) studied mobile phone usages in Liberia using the Q-methodology. I present below three key concepts of Q method called Q set, Q sort and factors, which are also used in the HCI-Q method.

Q set

Q set is the collection of all possible statements (about 40 to 50) made by the participants about the subject at hand (Brown 1980). It may consist of self-referent statements (i.e., opinions, not facts), objects, and pictures. The typical way of obtaining them is through interviews, observations as well as extracting statements from news articles, magazines and scientific journals on the subject matter.

Q sort

Q sorting is the process used by the participants to rank the statements from the Q deck by arranging them in a table using a predefined distribution. The most commonly used distribution is 'forced distribution' where participants arrange the statements from Mostly Disagree (-4) to Mostly Agree (+4) with statements that are relatively insignificant are placed in the middle of the table (around the point 0) as shown in Figure 4 below.

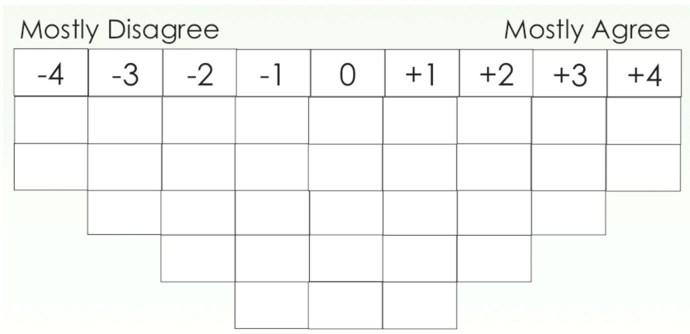


Figure 4: Q sort table that uses forced distribution for ranking statements from Q deck

Factor

A factor represents a cluster of Q sorts, which have received similar values (-4 to +4) to each statement in the Q set. In other words, it is a unique point of view among all other factors. Each factor is defined by average sum of its Q sorts. Factor analysis (Kim and Mueller 1978) is used to cluster Q sorts that are statistically similar. Factor extraction is then achieved using principal component analysis or a centroid method (Kim and Mueller 1978). Next, to maximize the correlation of each Q sort with a single factor, factor rotation is performed objectively (O'Leary et al. 2013).

3.1.6 HCI-Q methodology

HCI-Q is a lighter version of Q-methodology, with a target use in the field of HCI and design (O'Leary et al. 2013). The key alternation is in the Q-set sample. In Q-methodology, Q-set sample contains extracts from interviews and literature. While in HCI-Q, Q-set sample can also contain prior hypothesis and discussion over the designs. It contains both positive and negative implications of the design. This is because it has been argued (Dunne and Raby 2001) that incorporating negative implications of a design can also allow for a realistic and critical reflection of the design in people's life.

The involved steps in HCI-Q methodology (O'Leary et al. 2013) are briefly summarized as follows.

- Prepare Q set of greater than 30 statements on the proposed design (Focus equally on both positive and negative aspects of the design). These statements are a designer's hypotheses on how the particular design will affect the individual and social behavior.
- Recruit participants (< 30). Ideally the number of participants should be less the number of statements in the Q set.
- Ask the participants to Q sort (rank) the statements according to their personal significance in a forced distribution from (-4: strongly disagree to +4: strongly agree).
- Derive factors from the sorted set of statements using a factor analysis technique that reveals the attitudes of participants towards personal implications of a design.

3.2 Study design

Empirical studies have been proposed to evaluate both design prototypes. Each study will follow a mixed method drawing on qualitative, "in the wild" and quantitative approaches to understand the impact of material artifacts on the everyday physical activity. A summary of the study design is provided in Table 2.

Table 2: Proposed study design for the two prototypes and the design framework

Empirical study	Design prototype 1 and 2	Design framework
Research method	Mixed method research	Mixed method research
Data source	"In the wild" study with participants	Workshops
Data collection	Semi structured interviews, activity logging, audio and video recording	Semi structured interviews, activity logging, audio and video recording
Data Analysis	HCI-Q method, video transcribing	Design cards[3]
Purpose	Address research questions	Demonstrate the utility of the framework

3.3 Summary

To summarize, I am taking a mixed method approach to understand the material representations of physical activity. This thesis will include design and evaluation of three design prototypes that serve as research vehicles for a series of studies on their use. These studies focus on the experience of users with material artifacts that represent their physical activity data. I have chosen semi-structured interviews as the method for data collection and HCI-Q as the method to evaluate the significance of the material artifacts on the behavior and experience of the individual in relation to physical activity.

[3] Design cards are specially made cards that describe individual design elements that can help design researchers demonstrate the utility of their framework.

4

Case study 1: SweatAtoms

4.1 Introduction

Everyday physical activity involves regular investment of efforts to achieve certain health benefits. I believe that such a subtractive process could be combined with an additive manufacturing process where the continuous subtraction of energy during a physical activity is analogous to the way a 3D model is constructed by adding materials on a flat surface layer by layer (Figure 5). This synergy between the two processes inspired me to think about interlinking them together in order to create material representations of physical activity.

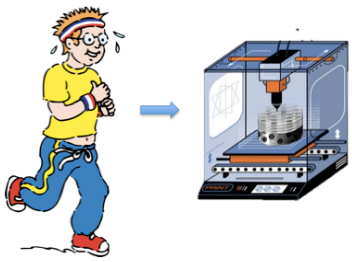


Figure 5: Motivation for this work stems from the synergy between the energy expenditure during a physical exercise and the additive manufacturing process of digital fabrication

As a first exploratory study on this topic, this case study looks at the impact of material artifacts on everyday physical activity. I have created a system, SweatAtoms, which utilizes the energy expenditure identified using heart rate data measured using a heart rate monitor. In this system, the user performs his/her everyday physical activity while wearing a heart rate monitor around her chest. The heart rate monitor records the heartbeat data and sends the data to the developed application for 3D modeling. This 3D model is then printed using a 3D printer.

4.1.1 SweatAtoms: Proposed application

Figure 6 illustrates the working of the SweatAtoms application in the following six steps:

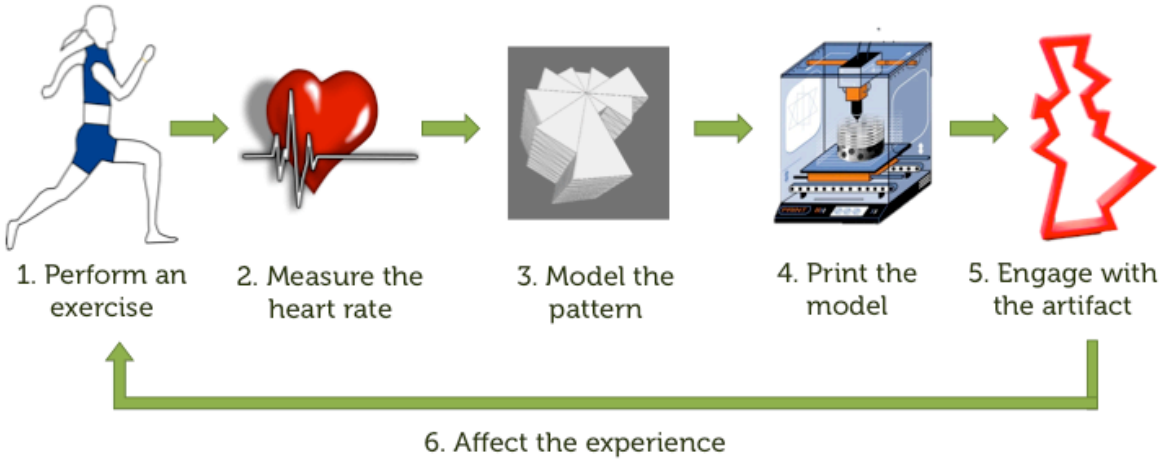


Figure 6: The SweatAtoms loop in actions: 1) user performs a physical activity 2) The heart rate is measured 3) A 3D model is created based on the pattern 4) The 3D model is printed 5) The user engages with the printed object 6) The object affects the physical activity experience

Step 1: Exercise:

The user wears a heart rate monitor around his/her chest, which records the heartbeats per minute. The user is free to perform any exercise as long as she is wearing the heart rate sensor.

Step 2: Measure:

While the user is performing the physical activity, the heart rate monitor records the changes in the heartbeats. This recorded data is then sent over Bluetooth to the RunKeeper (2013) application installed on her mobile. This application then communicates and sends the collected data to the SweatAtoms application using the HealthGraph API (2013).

Step 3: Model:

After receiving the heart rate data, the SweatAtoms application starts the 3D modeling process. The SweatAtoms application generates a 3D model from the collected heart rate data by using constructive solid geometry (2013). 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 of his/her overall experience.

In the current prototype, we have used the following algorithm for 3D modeling heartbeats as shown in Figure 7: 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.

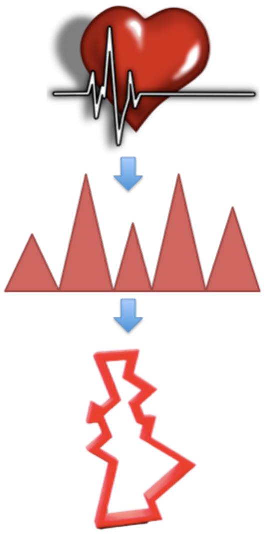


Figure 7: The 3D modeling process inserts a triangular prism of different volumes for each significant (+- 10bpm) variation in the heart rate. All the inserted prisms are then assembled together to represent an abstract 3D shape

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 3D printer for getting it printed.

Step 5: Engage:

The printed material artifact, based on the 3D model, may serve to help engage with the physical activity. Figure 8 shows some of the printed material artifacts in different materials and design patterns.

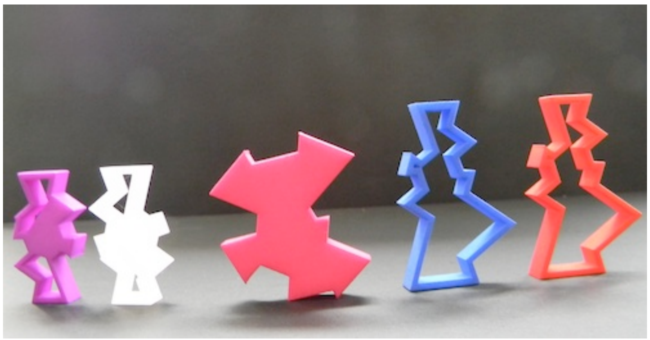


Figure 8: Some of the printed material artifacts representing different physical activity data

Step 6: Affect:

The design of the material artifact may affect the way user performs the 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. For example, users might be interested in figuring out how a push-up exercise would be reflected in the design. As a result, I envision that it might lead to an engaging experience.

4.2 Discussion on representation strategy

I identify three possibilities in utilizing the heartbeat data in the 3D modeling process of material artifacts. They are discussed below.

4.2.1 Accurate representation

One way to model the heartbeat data is to convert the visual representation directly into the material one, as shown in Figure 9. Doing so seems reasonable as a recent study done by Jansen et al. (2013) shows the increased significance of material representation over the same representation in the virtual medium. However, my 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 it does not seem to be a reasonable option for representation.

Figure 9: Example of an accurate representation

4.2.2 Abstract 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 me illustrate this with an example. One can utilize a predefined 3D model like a car (Refer Figure 10) 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 representation can create empathy among users, when appropriate metaphors are used to represent the data as seen in the study by Lin et al. (2006). However, I did not opt for abstract representation because through subjective interpretation, it might be difficult for the user to justify the invested effort in a physical activity.

Figure 10: Example of an abstract representation that uses car as a metaphor

4.2.3 Mixed representation

With SweatAtoms, I have followed a mixed representation of the heartbeat data, combining bits from abstract and accurate representations together as shown in Figure 11. 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. The advantage of this representation method can be that the user will be able to visualize how her heart rate has evolved over the entire physical activity. As a result, I believe that the mixed representation suits reflection on activity and performance, which I mentioned earlier in Chapter 2 as one of the missed opportunities.

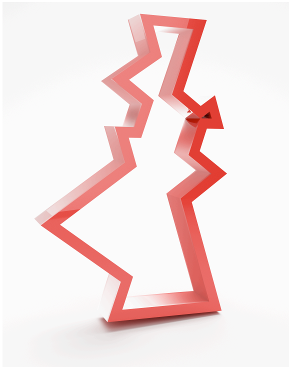


Figure 11: Mixed representation of heartbeat data from using the SweatAtoms application

4.3 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.

4.3.1 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.

4.3.2 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.

4.4 Mixed method study

I propose a mixed method approach to understand the impact of SweatAtoms on everyday physical activity.

The research will take place in 20 different homes in Melbourne for the period of two weeks. For this duration, participants will wear a Polar Heart rate monitor (2013) around their chest during the day and will carry out the physical activities that they normally perform in their respective homes. The participants will decide the duration as well as the nature of their activities.

For the physical activities of the participants, their heartbeats data will be recorded and sent to the SweatAtoms system. At the end of two weeks, interviews will be conducted with the participants to discuss their experience with the system. I will then use HCI-Q method discussed in Chapter 3 to analysis the personal significance of these artifacts in relation to physical activity. Results of the analysis will reveal key perspectives on how SweatAtoms has supported physical activity among participants. These perspective will then help me to gain a better understanding of the interrelationship between material artifacts and physical activity, which I will utilize in the design of the next prototype.

5 Preliminary Conclusion

In this thesis, I am investigating 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, my aim is to provoke new thinking and design strategies within the design space.

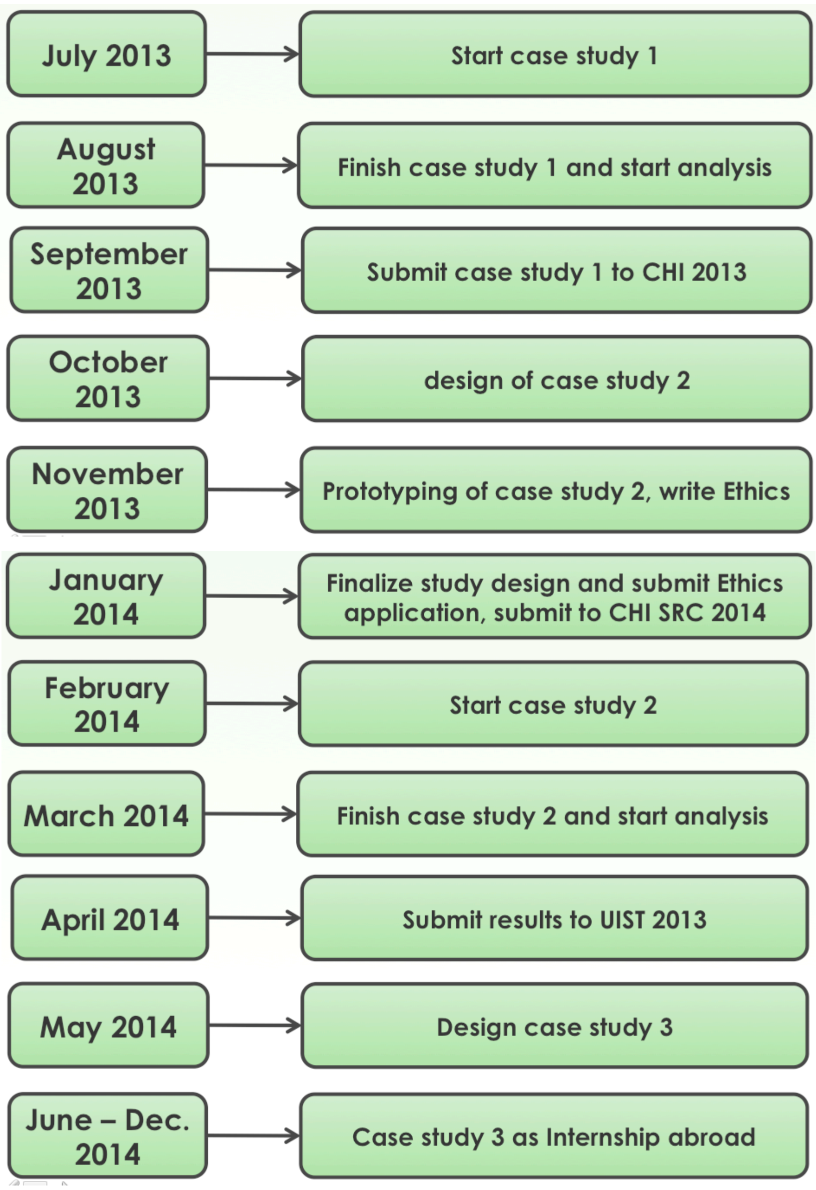
As a first exploratory case study, I am examining the impact of material artifacts on everyday physical activity. The design of these material artifacts is based on the measured heartbeat data of a physical activity. A mixed method study is planned to evaluate it. The results of this investigation will inform and guide further development, especially the second design prototype. Finally, I hope that my work will help to situate material outcomes of physical activity within the context of interaction design.

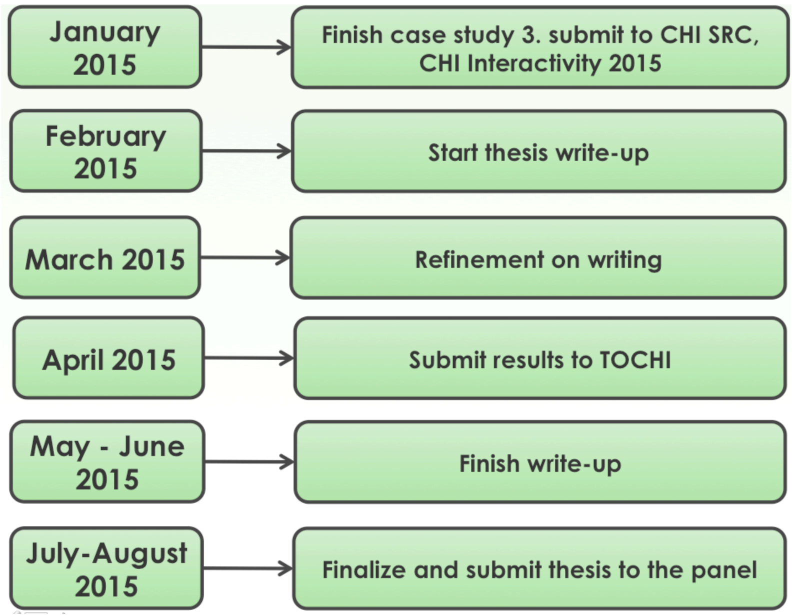
A
Project Website

All the works mentioned in this thesis are available on the following link:

http://exertiongameslab.org/sweatatoms.

B
Timeline


July 2013
Start case study 1
August 2013
Finish case study 1 and start analysis
September 2013
Submit case study 1 to CHI 2013
October 2013
design of case study 2
November 2013
Prototyping of case study 2, write Ethics
January 2014
Finalize study design and submit Ethics application, submit to CHI SRC 2014
February 2014
Start case study 2
March 2014
Finish case study 2 and start analysis
April 2014
Submit results to UIST 2013
May 2014
Design case study 3
June – Dec. 2014
Case study 3 as Internship abroad


January 2015
Finish case study 3. submit to CHI SRC, CHI Interactivity 2015
February 2015
Start thesis write-up
March 2015
Refinement on writing
April 2015
Submit results to TOCHI
May - June 2015
Finish write-up
July-August 2015
Finalize and submit thesis to the panel

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