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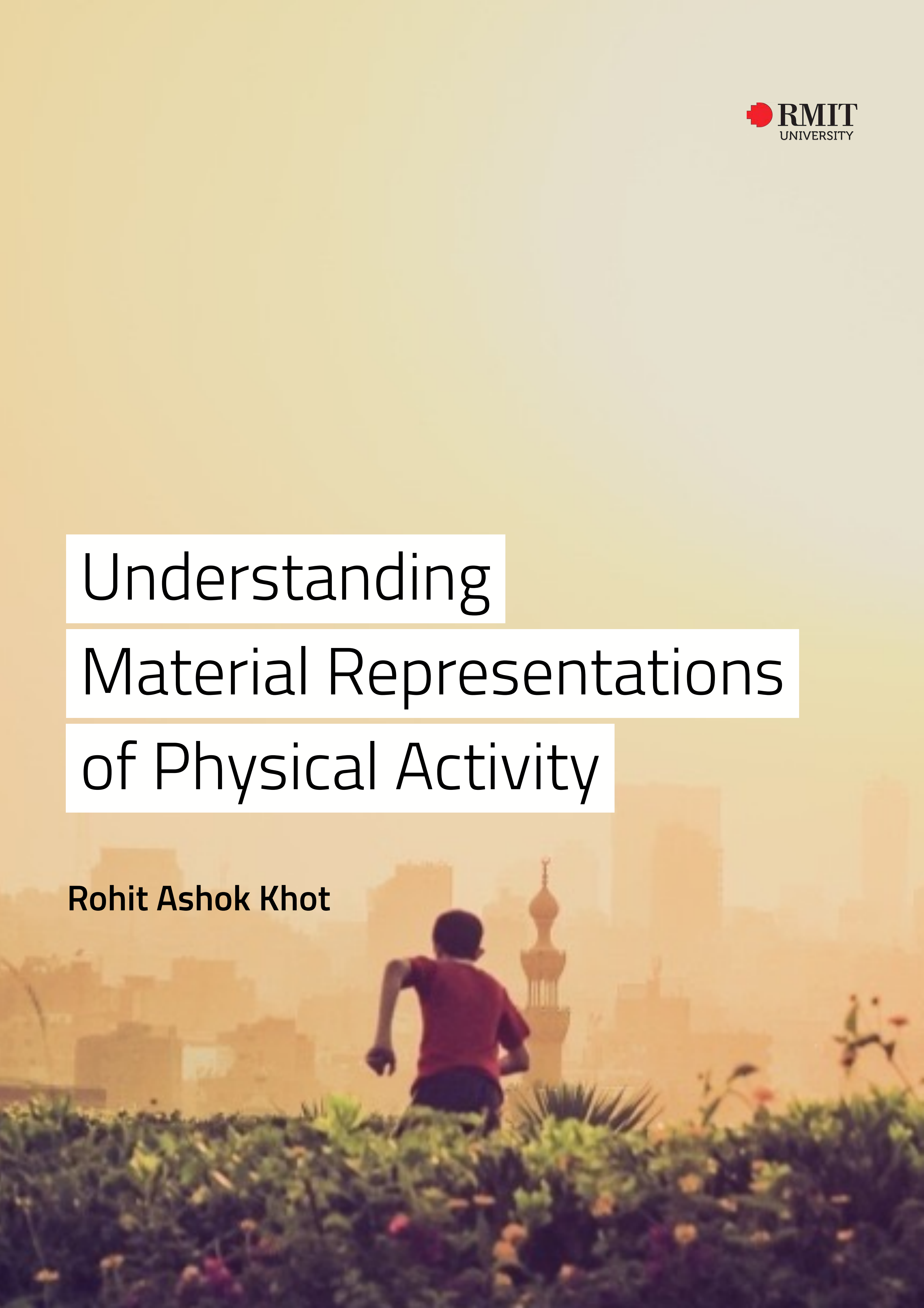

Understanding Material Representations of Physical Activity

Rohit Ashok Khot

Understanding Material Representations of Physical Activity

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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M.S. by Research in Computer Science

School of Media and Communication

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Rohit Ashok Khot

June 2016

Abstract

Self-monitoring devices that sense and collect data about an individual's life are becoming increasingly common. These devices are used to gain a better understanding of the active self and individuals use this gathered knowledge to fulfil their self-derived health and fitness goals. Currently, self-monitoring devices mostly adopt a data-centric view of quantifying information related to physical activity. As such, physical activity data is presented mainly on screens in graphical or numerical formats. However, this data-centric view of representing information may cause individuals to miss out on other ways of engaging with their own data. Embracing the possibility of affording users' greater interaction with their data, and fuelled by the various engagement opportunities at our disposal through material representations and digital fabrication, this research orchestrates new representation strategies that make use of different materials to make physical activity data more memorable, enjoyable and fulfilling. The aim of this research is to understand how these new forms of physical activity representations would affect the ways in which people experience and understand their own physical activity data.

To this end, I describe the design and study of three exemplary systems that turn physical activity data into plastic artefacts, sports drinks and 3D printed chocolates. The first system – *SweatAtoms* – constructs 3D printed plastic artefacts from the measured heart rate data of users' physical activity. The second system – *TastyBeats* – creates a personalised sports drink, transforming one's physical activity efforts into an interactive water fountain installation. The third and final system – *EdiPulse* – transforms the heart rate data from users' physical activity into 3D printed personalised chocolate treats. Following "in the wild" field deployments, I investigated how these systems positively influence the experience of being physically active, finding that key material representation aspects can make the experience memorable, enjoyable and fulfilling. Finally, the thesis invites future explorations in the area of material representations of physical activity data by defining a conceptual design framework, *Shelfie*. *Shelfie* presents key themes of designing material representations through 16 design cards.

Through three systems and the conceptual framework, this thesis contributes to the current literature in the following ways. Firstly, this thesis extends the current understanding on visualisations of self-monitored data through the novel approach of material representations. As such, this work brings together three areas: personal informatics, physical visualisation and human material interaction, in order to make the physical activity data more enjoyable. Secondly, this thesis discusses practical implications and challenges of designing material representations of physical activity data, and guides future explorations through a conceptual design framework. To conclude, this work inspires designers to consider new engagement possibilities afforded by material representations to support the experience of being physically active.

Thank you...

Acknowledgement

"At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us"
- *Author Unknown*

Words cannot express how grateful I am to so many people who generously supported this work. I take this opportunity to express my gratitude and respect.

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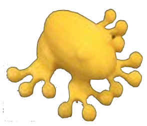
Acknowledgement



"At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us"

- *Author Unknown*

I am also grateful to the *School of Media and Communication* and *RMIT University* for providing me with an inspirational research home. I would like to thank - *Bianca Valentine, Lisa Dethridge, Jonathan Duckworth, Janette Chantry, Lyn Wilkosz, Corliss Mui Suet Chan, David Beesley* and *Suzana Kovacevic* for their support. Special mention to *Kelly Ryan* for bringing my work to the media. I have very fond memories of my media interviews and articles - enjoyable and breathtaking at the same time. Thank you for handling all the media queries and allowing me to enjoy a celebrity status for a short-while. I am also thankful to *Alex Joseski, Ruwan de Silva, Alex Zemtsov* and their team for making beautiful videos of my work. Also, I gratefully acknowledge the funding received from - *Exertion Games Lab, School of Graduate Research, IBM Research, Association of Computing Machinery (ACM)* and the *Australian Research Council, DP110101304*. The financial support helped me to present and attend several academic venues.

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#1 Introduction

CHAPTER 1

Introduction

This chapter outlines and contextualises the main research question of the thesis. I define the research objectives, scope, contributions and I conclude by describing the outline of the rest of chapters.

"Art in the blood is liable to take the strangest of forms"
– Sir Arthur Conan Doyle

Introduction

With the recent advancements in sensing and wearable technologies, we are witnessing a cultural trend towards self-monitoring, commonly discussed under the umbrella terms of "Quantified self" (Choe et al. 2014; Neff and Nafus 2016) and "Personal informatics" (Li et al. 2010). The central premise behind self-monitoring is the Delphic maxim: 'know thyself', or in other words "self-knowledge through numbers", where individuals seek knowledge about the self in order to understand and optimise their lifestyle (Lupton 2015; Ruckenstein 2014).

Supporting this trend, various self-monitoring devices like Fitbit™[1] have emerged in recent years that sense and collect data about individual's life and offer opportunities for self-reflection. Prominent amongst these devices are health and fitness trackers such as heart rate monitors and pedometers that enable tracking of heart rate and steps respectively. These devices are becoming increasingly smaller and energy efficient thereby allowing continuous monitoring and feedback. Moreover, earlier research suggests that regular use of these devices can increase user motivation for physical activity (Maitland et al. 2006; Bravata et al. 2007; Tudor-Locke et al. 2004).

As a result of this phenomenon, a lot of people are showing a keen interest in using these devices to support their health and fitness related aims. For example, according to a recently published survey by Ledger and McCaffrey (2014), 10% of the adult population in the USA owns a self-monitoring device of some kind while the PEW research centre report (Fox and Duggan 2013) indicates that 21% of Americans use some form of technology to track their health-related data. Additionally, major companies like Apple[2], Google[3] and Microsoft[4] have taken a keen interest in developing platforms to support these devices, suggesting that further proliferation in this field is expected.

The growing popularity of self-monitoring has contributed to a wider availability of previously inaccessible physical activity data, such as an individual's heart rate, but there exists only a limited knowledge of how, and for what purposes, this data could and should be used. Currently, this data is mainly used to increase awareness about an individual's physical activity levels and to support motivation for physical activity with a predominant use of screens to visualise this data (Choe et al. 2014).

However, I find that the use of screens and the emphasis on quantification restrictive to individuals' engagement with their own physical activity data. For example, commercial self-monitoring devices offer a comprehensive display of tracked physical activity data using numbers and graphs as shown in Figure 1.

[1] *http://fitbit.com*

[2] *https://developer.apple.com/healthkit/*

[3] *https://www.google.com/fit/*

[4] *https://www.microsoft.com/microsoft-band/en-au*

For a person with a limited experience in data visualisations and statistical reasoning, the depth of communicated information may appear overwhelming to generate insights and actionable knowledge about oneself (Yang et al. 2013; Kay 2014). As such, poor representation, lack of context and an overload of information can create confusion and discouragement among users (Hansel et al. 2015; Choe et al. 2014). To this end, Anthropologist Ruckenstein argues in favour of a more meaningful interpretation of data, highlighted by her study findings, by saying,

> "[...] because of the many possible interpretations allowed by the visualisations, it was important that they are not simply passed on to the participants" (2014, p.9).

Secondly, earlier research by DiSalvo and Roshan (2014) highlighted the importance of medium to support the meaningful interpretation of the data. Following McLuhan (1994), the authors argue for a careful selection of a medium as it can impact the reception and interpretation of the communicated information. Existing works on self-monitoring predominantly use a digital medium such as a smartphone screen or a desktop screen to visualise physical activity data. This digital medium has benefits in terms of providing interactive capabilities such as zooming into the data and updating data in real time. However, the digital medium also incurs some limitations as to what can be experienced with it (Vande Moere 2008; Victor 2013). For example, screens are less perceivable in daylight and they demand attention whenever information is projected onto it.

In addition, while on-screen visualisations offer the capacity to stimulate our visual senses, they ignore the abundance of other senses that can also be potentially used to enrich our own engagement with personal data. Victor (2013) refers to this limitation as the "picture under the glass" effect. Here Lupton's work (2016) on the limitation of graphic representations of corporeal multi-sensorial experience is insightful. Lupton notes,

> "...numbers and graphs as a source of knowledge serve to represent bodies and selves in a very limited, impoverished way. Compare these flat forms of data materialisation with the complexities of the affective embodied knowledge that is a response to a scent, taste, or the touch of skin" (2016, p.125).

This problem of trying to represent the complex and multi-sensorial nature of the body motivates this thesis. In particular, this dissertation seeks to explore the role of new forms of media and their representational potentialities to redefine how we understand the physical activity experience by going beyond the screen and quantified outputs. This thesis explores alternate feedback strategies to complement the current data-centric view on representing data using numbers and graphs.

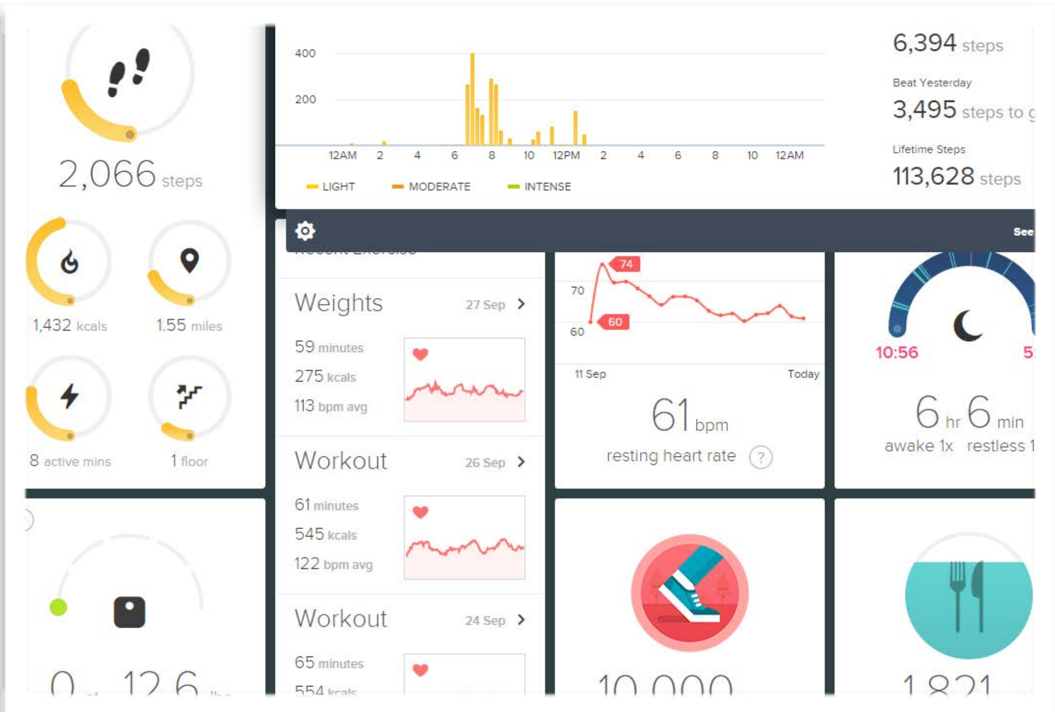


Figure 1: A variety of detailed information about a physical activity can be overwhelming to individual with limited statistical knowledge.

Taking inspiration from the recent advancements in digital fabrication technology and fuelled by the various engagement opportunities that material representations offer, I explore design strategies for representing physical activity data in different material forms. To this end, I unite three strands of significant design areas, namely: Personal Informatics, Physical Visualisation and Human Material Interaction (HMI). With this work I offer a new interdisciplinary perspective on understanding physical activity through material representations.

Approach: Material representations

This thesis advocates an innovative approach of representing physical activity data in the form of material artefacts. By material artefacts, I refer to physical objects that are constructed from digital designs using a digital fabrication process like 3D printing. I explore three distinctive materials for constructing these artefacts: biodegradable plastic, drinkable fluids, and food in the form of chocolate.

The use of plastic is motivated by the synergy I see between physical activity and 3D printing. Physical activity involves the expenditure of energy, without any material gain. Whereas 3D printing follows an additive manufacturing process where a material artefact is created by additively depositing plastic layer by layer on a print bed. If we blend them together than it could lead to a "physical – digital – physical" mode of interaction where the physical energy of an individual is first invested to generate digital data such as heart rate, which is then converted back again into a physical form to make a re-entry into the physical world. This artefact could then serve as a physical souvenir or testimony to invested efforts in physical activity.

I use consumable materials such as chocolate and sports drink fluids to provoke thinking about the significant relationship between physical activity and food, and the role of technology in supporting this relationship. For instance, self-monitoring technologies typically provide data about how much energy has been expended in physical activity (i.e. energy-out), while food printing technologies focus on ways of producing food that is meant for consumption (i.e. energy-in). As such, these representations also contribute to the "human energy cycle", where the energy invested in doing physical activity is given back to the body though edible artefacts. Additionally, related work around self-monitoring technologies and their representations seems to indicate a lack of exploration into "physical-digital-physical interaction" and "energy cycle", which I also attempt to address with this thesis.

I ground my interest in the literature on material culture studies in Human Computer Interaction (HCI) (Kirk and Sellen 2010; van den Hoven 2004; Goljstein et al. 2012; Petrelli et al. 2008) and anthropology (Miller 1987, 2008, 2010; Woodward 2007; Dant 1999), which signify a human fascination towards collecting and making objects. Sennett (2008) refers to humans as "homo faber" – a manufacturer and collector of objects who imbues sentiment in external artefacts. As Miller (2008) notes, people can glean great feelings of comfort through the meaningful role of material representations within their everyday lives and as Kopytoff observes, material objects have their own biographies much like people (1986). Material objects can embody lives, personalities, emotions and achievements. For example, the results of one's crafts and awards are often displayed on fridge doors, walls and shelves. Photographs of trips and events are often printed, framed and displayed despite the fact that they could just as well be seen on a screen.

Arrangement of material artefacts to spatially identify an individual is called "autotopography" (Gonzalez 1995). Autotopography can serve as a memory landscape to the owner, triggering reminiscence at a later point of time (van den Hoven 2004). In this work, I also capitalise on the tangible nature of the physical medium that allows constructed representations, "to be touched, explored, carried or even possessed" (Vande Moere 2008, p.472). Vande Moere (ibid) further argues that since material representations require time and effort to explore and understand the embedded data, then the time can also be used to encourage people to reflect on their behaviour, thereby yielding a more engaging and educational experience for them.

Despite these known benefits, the current exploration on designing material representations is limited (Jansen et al. 2015). Although sports capitalise on the rewarding aspects of material representations by rewarding an individual with physical medals and trophies on successful completion of certain fitness or sports goal. These artefacts focus on objective facts and key milestones such as achieved fitness goals. However, their design does not embody any personal data and as a result they may miss out on being a representation of one's active self. Although rewards are not meant to serve as representation, there is a definite learning value in blending rewards and representations together as it could lead to more meaningful and enjoyable interpretation of one's data. Drawing inspiration from this, this work aims to emphasise, preserve and celebrate self-monitoring experience through material representations.

However, in advocating the use of personal data, I am also aware of the potential ethical and sociocultural issues that may sneak in as highlighted by earlier literature (Purpura et al. 2011; Lupton 2016). Lupton (2016) for instance, shed lights on critical topics such as ownership and data surveillance whereas other works (Purpura et al. 2011; Fritz et al. 2014) criticise the long term persuasive qualities of self-monitoring devices which may rather alienate individuals from the actual physical activity. They worry that instead of making the activity an end in itself, it may turn into a mere means to accumulate steps and satisfy metrics.

The main research question explored in this thesis is:

> "How do we design material artefacts that represent one's physical activity to affect a person's relationship with physical activity?"

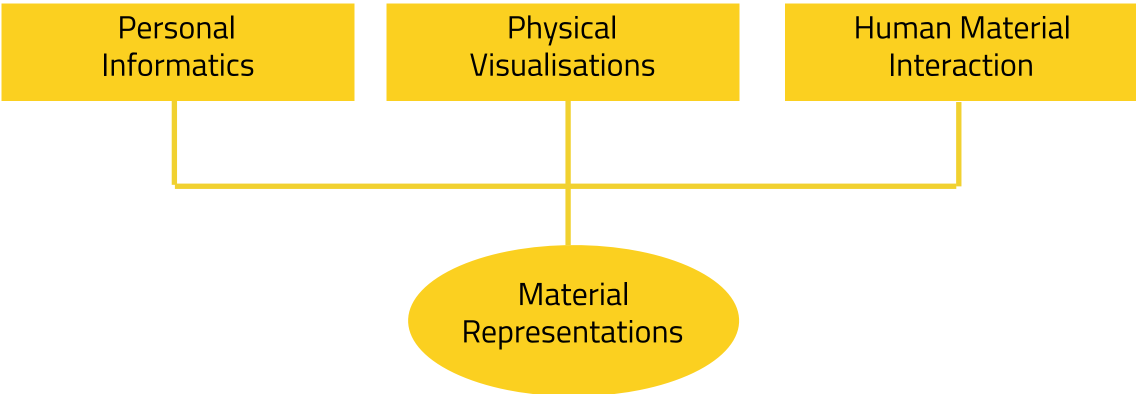


Figure 2: Three design areas: personal informatics, physical visualisation, and Human Material Interaction contribute to the thesis.

Hassenzahl et al. (2016) raise concern that in the long term, numbers could make exercise feel like work, and we need better, richer ways to represent this data. I agree with these notions and therefore aims to make self-monitoring a more playful experience while embracing the rich qualities of living an active life. For instance, instead of "boring users to death with numbers" (Hassenzahl and Laschke 2015), I ask, what if we turn this data into something more delightful like chocolate or a plastic artefact?

Fortunately, with the recent rise in the digital fabrication technologies, we now have a way to embed data in a material and edible form using devices such as 3D printers and food printers (Anderson 2010; Mota 2011). Gershenfeld (2007) envisions that 3D printers will soon be found in every home and people will use them to create, mix and design material artefacts of their choice rather than buying them from the market. Consequently, design and HCI researchers are now investigating the role of digital fabrication in HCI (Mellis et al. 2013). This research therefore is a timely endeavour to investigate the significance of digital fabrication for supporting physical activity.

Thesis statement

Located within the HCI tradition, this thesis explores material representations of physical activity. It involves investigation of the design space surrounding Personal Informatics, Physical Visualisation and Human Material Interaction (HMI), as shown in Figure 2. The aim is to understand how material representation could affect the ways in which individuals experience and reflect on their own physical activity, and how this understanding could expand the conceptual foundations and approaches to design quantified self systems.

Answering this research question is not straightforward because, as a designer, multiple challenges must be overcome to design meaningful material representations of physical activity data. I identify the following four key challenges when designing for material representations of physical activity data.

Key challenge 1: Choosing the right mapping

Choosing the right data mapping is important because any feedback using technology would require some level of information processing from the user. Designers need to think about how the data should be presented to the user using material representations. For example, should the mapping be informative to give users comprehensive details into their physical activity or should the mapping be more abstract, making users more curious and speculative about their physical activity? There is no definite answer in the literature to suggest an appropriate mapping. Davis et al. (2005) argue for a direct and informative feedback as it offers opportunities to learn about the self and to improve the performance. Conversely, however, Consolvo et al. (2008), argue for a more abstract form of feedback to support positive engagement with the data. In this thesis, I therefore explore both forms of feedback to identify their suitability for material representations.

Key challenge 2: Choosing the right outcome

The outcome refers to the final design of the artefact, in terms of its form and interface. A material representation affords many design possibilities – starting from how it looks to what it should convey. Existing literature puts equal emphasis on aesthetics and readability of the artefact e.g. according to Desmet (2003) and Jorden (1997), a user will touch and engage with a product only if it looks good and feels good in the hand. As such, aesthetics play an important part in driving the initial interactions and shaping the user experience. However, aesthetics alone are not sufficient to sustain user engagement (Forlizzi et al. 2003). The aesthetics must complement a user's needs and intentions, which in this case is to improve the understanding of physical activity. However, unlike a digital medium, a physical medium offers less flexibility in embedding information. Embedding too much data can make the material artefact less readable, whereas embedding little data can not serve the intended purpose. In this thesis, I therefore experiment with multiple forms of representations to understand their efficacy and trade-off between aesthetics and readability.

Key challenge 3: Choosing the right material

According to Ashby and Johnson (2010), the functionality of the resultant artefact is dependent on the choice of material and process to meet the technical requirements of the design.

The possibilities for choosing the material are numerous. A case in point would be that material artefacts do not have to be confined to only solid-state materials like plastic or metal; other materials that are in a liquid or gaseous state can also be explored as a potential material for creating engaging representations.

Additionally, the use of materials to represent physical activity could afford other functionalities besides visualisation. For example, a durable material like plastic affords use as a decorative piece within a home, whilst an edible material offers new opportunities for consumption satisfying new tastes and providing energy to the individual. While choosing the suitable material for representations, designers need to consider the underlying properties of the material, which can be both advantageous and disadvantageous, to serve the intended purpose. For example, a material like plastic is more durable but may not be eco-sustainable (environmentally friendly) while edible materials like chocolate are tasty and tempting but they are perishable and may not last long. Therefore, designers must strike a balance between these qualities of the material and the intended purpose of serving as a physical representation of data. I am also keen to understand varied functionalities of material artefacts and their relations to the user by harnessing the underlying properties of the chosen material.

Key challenge 4: Choosing the right process

The final key challenge is to identify the means of creating material representations. Selecting the right process involves consideration about time and place, which according to Intille (2004) are essential for effective data communication. Patel et al. (2015) suggest that feedback on data should be presented at times when the user is most likely to notice it. Existing literature also does not speak about user's involvement in the creation process of the material artefact. Most often the data is simply displayed to the user without any explicit involvement from the user. I see benefits to involving users in the making process because material artefacts can become more valuable by virtue of the time and emotion that the user has invested in them (Petrelli et al. 2008; Kirk and Sellen 2010). Gauntlett (2013) further suggests that creating an artefact can also be an enjoyable experience as it gives individuals the feeling of wonder, agency and satisfaction during the making process. In this regard, the following questions need to be answered. When and how should the material artefact be presented to the user? Should the process of creating material artefacts run in parallel with the physical activity or should it be delayed until the user finishes his/her physical activity? Should we involve users in the creation process of a material artefact or should we simply hand over the artefacts to the users? In this thesis, I seek to answer these questions.

In summary, the interplay of the above four challenges makes my PhD endeavour exciting. I explore different strategies to address the above challenges and to gain an understanding of the interrelationship between the different aspects of material representation (as mentioned above) and physical activity. To this end, this thesis has following research objectives.

Research objectives

The research objectives are described as follows.

Objective 1: Gather an understanding of the existing literature

This thesis will first enumerate existing issues and opportunities associated with physical activity and its representation using self-monitoring devices by drawing upon the previous works in the field of Personal Informatics, Data Visualisations and HMI. It also includes related work on different materials (plastic, food and fluids) to identify design opportunities and strategies for this research.

Objective 2: Explore the design space of material representations

This thesis will present three design prototypes built upon the identified design opportunities associated with self-monitoring devices and the use of different materials to construct material representations. These design explorations will serve as research vehicles to develop insights into the user experience of engagement with material artefacts of physical activity.

Objective 3: Validate the design space

This objective involves empirical evaluations of the designed prototypes through “in the wild” deployments, where the developed prototypes will be deployed and studied in participants' homes. These investigations and the insights gained through the studies will then be utilised to develop a conceptual understanding of how material representations can impact and shape the experience of physical activity.

Objective 4: Create and validate a design framework

The insights gained from the design and investigations of the prototypes will help to shape a theoretical design framework that offers guidelines and a set of themes for interaction designers on how to design material representations of physical activity.

Scope

In order to address the research objectives listed above, I have limited the scope of the thesis to the following aspects:

1. As a first exploration into the territory of material representation this thesis only investigates the use of heart rate data for creating material artefacts. Other physical activity data such as bodily movements and physiological responses such as breathing rate and skin temperature are not considered in this work.
2. I am using 3D printing for the first and third case studies and designed a new hardware system for the second case study. Other tools that can also create material artefacts like laser cutters are not considered in this work.
3. Being the first exploratory work on the topic of material representations of physical activity, I have only looked at three materials: plastic, drinkable fluids, and chocolate, which I believed were worthy of investigations. However, I am confident that other researchers can benefit from the discussed three case studies and explore other materials to extend this work in different dimensions.
4. This thesis does not directly seek to achieve health goals such as weight loss, although positive health benefits as a result of the work are welcomed. Similarly, this work is also not aimed at maximising individual athletic performance. Instead, this thesis focuses on supporting the physical activity experience with an assumption that an engaging experience can lead to enhanced participation in physical activity, which in turn could lead to health benefits.

Research methodology

I have utilised Research through Design (Zimmerman et al. 2007) and qualitative research practices (Roger 2012; Neuman 2006) to address the research objectives of my thesis. I have designed three working prototypes that explore distinctive materials to represent heart rate data of physical activity. These three prototypes are then studied individually through in the wild deployments across different homes in Melbourne, Australia. I have used semi-structured interviews and diaries as the method for data collection and thematic analysis as the method to analyse participant's experiences with each of the systems. More details of the methods are discussed in Chapter 3. These deployments and investigations have guided me towards the first conceptual understanding of the interrelationship between material representations and physical activity, which I have framed as a conceptual design framework, I call *Shelfie*. Below, I briefly describe each of the three case studies and the framework.

Case study 1: SweatAtoms

The first case study revolves around a system called *SweatAtoms* (Khot et al. 2013, 2014) that transforms the heart rate data of physical activity into five unique 3D printed material artefacts (refer Figure 3). These artefacts are: *Graph*, *Flower*, *Frog*, *Dice* and *Ring*. Each of these five representations captures a different aspect of physical activity and also offers a different utility. I have deployed this system in six different homes in Melbourne, Australia for a period of two weeks. On each day, participants 3D printed all five material representations of their physical activity. These deployments led to many key insights, particularly relating to the importance of personalisation and identifying the utility and context for material artefacts. These insights are explained in Chapter 4. I also found that participants were initially engaged in the slow process of creating material artefacts as it gave them time to reflect on their data. However, their interest slowly faded because of the fixed and detached process of 3D printing. The second case study therefore attempts to improve the printing process by offering a drinkable artefact created from an individual's heartbeat, and prepared as an interactive spectacle.

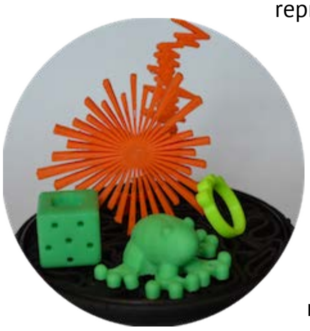


Figure 3: SweatAtoms

Case study 2: TastyBeats

The second case study is called *TastyBeats* (Khot et al. 2014) and explores representing physical activity data as a drinkable fluid

Figure 4: TastyBeats

(refer Figure 4). *TastyBeats* is an interactive water fountain installation that creates a mix of energy drinks from the measured heart rate data of physical activity. The use of drinkable fluids like sports drinks to represent physical activity also served an additional benefit of replenishing the loss of body fluids due to physical activity. In Chapter 5, I articulate the experiences in designing the system as well as findings gathered through public exhibitions as well as field deployments of the system in different homes. I found that the *TastyBeats* system increased participants' awareness of physical activity while facilitating a shared social experience of reflecting on each other's physical activity. Moreover, the prepared drink was treated as a hedonic reward that motivated participants to exercise more. To this end, participants found both the drink and the process of creating the drink engaging. This inspired me to explore whether the same results could be obtained through 3D printed edible artefacts, and would participants find the process engaging as a result of it? In consequence, I decided to use chocolate to represent physical activity data for the final case study.

Case study 3: EdiPulse

The final case study explores an appealing food material, chocolate, to represent physical activity data. I designed and studied *EdiPulse* — a system that generates four different representations of physical activity from heart rate data in the form of 3D printed chocolate. In line with earlier studies of SweatAtoms and TastyBeats, I deployed the EdiPulse system in seven households for a period of two weeks where thirteen participants interacted with the system on a daily basis. The field study identified how treats as a result of physical activity positively influenced further participation in physical activity, and highlights participants' interest in getting pleasurable rewards for their efforts.

Figure 5: EdiPulse

Framework: Shelfie

I utilised the insights gained from the design and evaluation of above three systems to articulate a conceptual design framework, *Shelfie* (refer Figure 6). The *Shelfie* framework is presented in the form of 16 design cards that convey 16 key concepts behind the design of material representations to designers.

Figure 6: Shelfie

The intention behind creating a deck of design cards was to make the knowledge and the experience I gained over the last three years working on my PhD accessible to interaction designers who wish to take the field of material representation forward. Rather than offering strict guidelines or strategies, the deck of design cards acts as a catalyst to stimulate and support the divergent imaginations of designers during the ideation process.

Contributions

This research contributes to knowledge on understanding material representations of physical activity both in practice as well as in theory in the following manner:

1. This thesis extends the current understanding on visualising self-monitored data by presenting a novel approach of material representations of physical activity data. As such, this work brings together three strands of research: Personal Informatics, Physical Visualisation and Human Material Interaction (HMI) to make the physical activity experience more memorable, enjoyable and fulfilling.
2. This research contributes to practice by providing implementation details of the design of three systems - *SweatAtoms, TastyBeats,* and *EdiPulse*. Each system presents a different approach to designing material representations varied across the four dimensions: used material, mapping of data into physical artefact, process of creating the artefact, and the final outcome. To this end, *SweatAtoms* creates plastic based material artefacts, *TastyBeats* provides a personalised sports drink based on one's physical activity efforts, and finally *EdiPulse* constructs 3D printed chocolate treats from physical activity data.
3. This thesis contributes to theory by defining a conceptual design framework, *Shelfie*. The framework guides designers to explore engagement possibilities afforded by material representations through 16 design cards, where each card describes one key aspect of designing material representations.
4. This work also contributes to the field of Personal Informatics by providing an understanding of the interrelationship between material representations and physical activity. I provide an explanation of how different characteristics of a material (e.g., taste, and durability) and how the design of material representations (e.g., abstract and informative) can affect the physical activity experience.
5. This research also contributes to the growing field of 3D printing of food. By discussing the relationship between food printing and self-monitoring technologies, this work provokes thinking towards whether and how food should

be quantified based on one's physical activity. As such, this work opens up opportunities to design future systems that aim to support the human energy cycle through the amalgamation of food and technology design.

Related publications

Major portions of the research presented in this thesis have been peer-reviewed and published in academic venues. The full paper on *TastyBeats* has also won the best paper honourable mention award at CHI 2015. Additionally, this work has also been showcased in six international academic events that attract large audiences. *TastyBeats* was a finalist for the student innovation contest at UIST 2013 and SweatAtoms was a finalist for the student research competition at CHI 2013. I have also presented my PhD work at two doctoral schools (Ubicomp 2013; DIS 2014). Finally, the provocative relationship between chocolate and physical activity gathered ample media attention and EdiPulse was featured on Mashable, Channel 9 News, ABC news, SpringWise and PSFK among others. The *TastyBeats* and *EdiPulse* system were finalists for the Premier's design awards and AAMIA awards respectively. The complete list of publications is presented below.

Full papers

1. **Rohit Ashok Khot**, Josh Andres, Jennifer Lai, Juerg von Kaenel, and Florian Mueller. 2016. Fantibles: Capturing Cricket Fan's Story in 3D. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16). ACM, New York, NY, USA, 883-894. (Acceptance rate: 23%)
2. **Rohit Ashok Khot**, Jeewon Lee, Deepti Aggarwal, Larissa Hjorth, and Florian Mueller. TastyBeats: Designing Palatable Representations of Physical Activity . In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15). ACM Press (2015), 2933-2942 (Acceptance rate: 23%) **(Best paper Honourable mention award)**.
3. **Rohit Ashok Khot**, Jeewon Lee, Larissa Hjorth, and Florian Mueller. TastyBeats: Celebrating Heart Rate Data with a Drinkable Spectacle . In Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction (TEI'15), ACM Press (2015), 229-232 (Acceptance rate: 22%).
4. **Rohit Ashok Khot**, Larissa Hjorth, and Florian Mueller. Understanding Physical Activity through 3D Printed Material Artefacts. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14), ACM Press (2014), 3835-3844 (Acceptance rate: 22%).
5. Florian Mueller, Sophie Stellmach, Saul Greenberg, Andreas Dippon, Susanne Boll, Jayden Garner, **Rohit Ashok Khot**, Amani Naseem, and David Altimira. Proxemics Play: understanding proxemics for designing digital play experiences, In Proceedings of the 2014 conference on Designing interactive systems (DIS '14), ACM Press (2014), 533-542 (Acceptance rate: 27%).
6. Simon Stusak, Aurélien Tabard, Franziska Sauka, **Rohit Ashok Khot**, and Andreas Butz. Activity Sculptures: Exploring the Impact of Physical Visualisations on Running Activity, In Visualisation and Computer Graphics, IEEE, 99 (1), 2014.
7. **Rohit Ashok Khot**, Larissa Hjorth, and Florian Mueller. SweatAtoms: Materialising Physical Activity. In Proceedings of The 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death (IE '13), ACM Press (2013), Article 4.

Short papers

1. **Rohit Ashok Khot**, Ryan Pennings and Florian Mueller. EdiPulse: Turning Physical Activity Into Chocolates, In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15), ACM Press (2015), 331-334.
2. Florian Mueller, Joe Marshall, **Rohit Ashok Khot**, Stina Nylander, and Jakob Tholander. Understanding Sports-HCI by going jogging at CHI. In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15), ACM Press (2015), 869-872.
3. **Rohit Ashok Khot**, Ryan Pennings and Florian Mueller. EdiPulse: Supporting Physical Activity with Chocolate Printed Messages, In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15), ACM Press (2015), 1391-1396.
4. **Rohit Ashok Khot.** Exploring Material Representations of Physical Activity. In Proceedings of the 2014 companion publication on Designing interactive systems (DIS Companion '14), ACM Press (2014), 177-180.
5. Florian Mueller, Joe Marshall, **Rohit Ashok Khot**, Stina Nylander, and Jakob Tholander. Jogging with Technology: Interaction Design Supporting Sport Activities. In Proceedings of the 32nd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '14), ACM Press (2014), 1131-1134.
6. **Rohit Ashok Khot**, Jeewon Lee, Larissa Hjorth, and Florian Mueller. SweatAtoms: Understanding Physical Activity through Material Artefacts. In Proceedings of the 32nd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '14), ACM Press (2014), 173-174 (**CHI 204 Video showcase finalist**).
7. **Rohit Ashok Khot**, Jeewon Lee, Helmut Munz, Deepti Aggarwal, and Florian Mueller. TastyBeats: Making Mocktails with Heartbeats. In Proceedings of the 32nd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '14), ACM Press (2014), 467-470.
8. **Rohit Ashok Khot**, and Florian Mueller. Sweat-Atoms: Turning Physical Exercise into Physical Objects, In Proceedings of the 31st Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '13), ACM Press (2013), 3075-3078.
9. **Rohit Ashok Khot.** Exploring the Role of Materiality in Physical Activity. In Proceedings of 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'13), Doctoral school, 1-4.
10. **Rohit Ashok Khot.** Sweat-Atoms: Crafting Physical Objects with Everyday Exercise. In Proceedings of the 31st Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '13), ACM Press (2013), 2701-2706 (Citation count: 5) (**Finalist for ACM Student Research Competition**).
11. Alan Chatham, Ben AM Schouten, Cagdas Toprak, Florian Mueller, Menno Deen, Regina Bernhaupt, **Rohit Ashok Khot**, and Sebastiaan Pijnappel. Game Jam, In Proceedings of the 31st Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '13), ACM Press (2013), 3175-3178.

12. Florian Mueller, **Rohit Ashok Khot**, Alan Chatham, Sebastiaan Pijnappel, Chad Toprak, and Joe Marshall. HCI with Sports, In Proceedings of the 31st Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '13), ACM Press (2013), 3301-3306 (Citation count: 9).

Journal articles

1. Florian Mueller, David Altimira, and **Rohit Ashok Khot.** Reflections on the Design of Exertion Games, Games for Health Journal, 2015, 4(1): 3-7.

Workshop papers & Technical reports

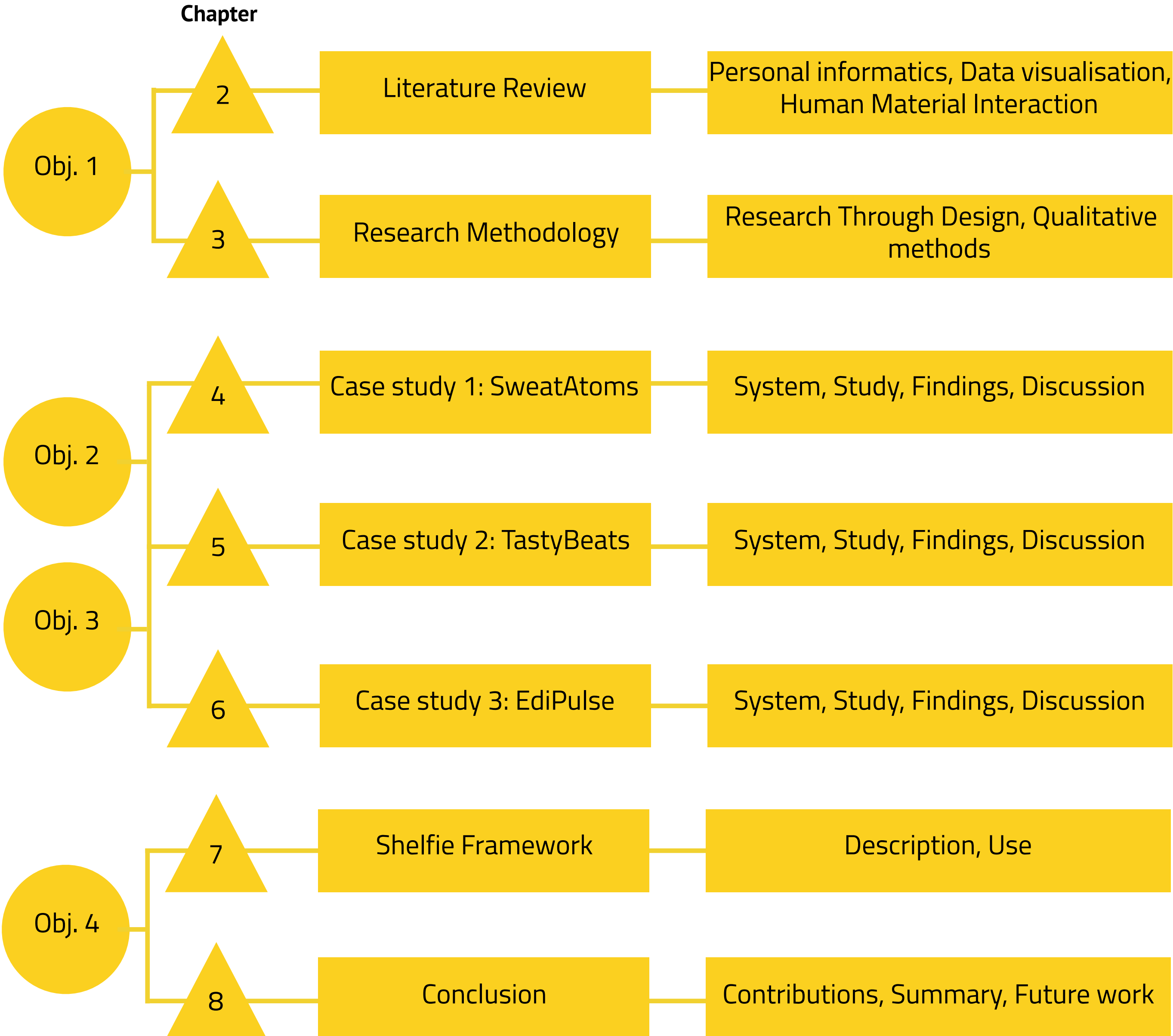
1. **Rohit Ashok Khot**, Larissa Hjorth, Deepti Aggarwal, and Florian Mueller. Supporting Autonomy in Physical papers Activity through Material Artefacts. In Proceedings of CHI'14 workshop on Positive Computing, ACM Press (2014).

Thesis outline

The remainder of the thesis is organised as follows (refer Figure 7).

Chapter 2 addresses Research Objective 1 by giving an overview of existing works in the areas of Personal Informatics, Data Visualisation, and HMI. The chapter also illustrates opportunities to design material representations. Chapter 3 describes the methods I followed when conducting my research throughout the PhD. As a response to Objective 2, Chapter 4 presents the first case study in the form of *SweatAtoms*. Chapter 5 describes the case study 2 in the form of *TastyBeats* while Chapter 6 describes the case study 3 in the form of *EdiPulse*. Chapter 7 describes the *Shelfie* design framework. Finally, Chapter 8 discusses contributions of this research, presents future directions and offers concluding remarks.

Figure 7: Thesis outline



#2 Related work

CHAPTER 2

Related work

This chapter covers related work in three topics of interest, namely, Personal Informatics, Data Visualisation and Human Material Interaction (HMI). It ends by listing two opportunities for creating and studying material representations.

"The real voyage of discovery consists not in seeking new landscapes but in having new eyes."
— Marcel Proust

Introduction

This thesis ventures into three fields of research, namely, Personal Informatics, Data Visualisation and HMI. In this chapter, I discuss the related work in all three areas and how they motivate my work. I conclude the chapter with a list of opportunities associated with durable and consumable materials to represent physical activity data. I begin with a brief summary of current explorations on personal informatics to understand its relationship with physical activity.

Personal informatics tools for tracking physical activity

Regular physical activity is a key to maintaining physical health. It offers cardiovascular fitness benefits and reduces the risk of obesity (Haskell et al. 2007). Additionally, physical exercise also boosts cognitive abilities and contributes to emotional and social well-being (Deslandes et al. 2009; Tomporowski 2003). Despite knowing these benefits, people who regularly exercise are low in numbers (Pate et al. 2002; Miller 2002) and those who do exercise only partially achieve their physical activity goals (Colley et al. 2006). As a result, health remains at risk amongst many people (Pate et al. 2002). Fortunately, recent research suggests that personal informatics tools that increase awareness about physical activity can motivate individuals to be more active (Maitland et al. 2006; Bravata et al. 2007; Tudor-Locke et al. 2004).

Personal informatics are a set of self-monitoring tools that capture physiological responses and behaviour through body-worn sensors (Li et al. 2010). These tools provide users with an opportunity to monitor and reflect on their physical activity levels. One commonly used personal informatics tool is a heart rate monitor (Pantzar and Ruckenstein 2014). Heart rate monitors[1] inform users about their exercise intensity by measuring heart rate as they perform physical activity. Another widely used personal informatics tool is a pedometer, such as the Fitbit[2], that captures an individual's daily step count. Personal informatics tools can take different forms such as armbands, wristbands, clip-on models and smart watches (Swan 2012). Most of them track only one particular type of data, e.g., most heart rate monitors only track heart rate data. Some devices like Fitbit however, offer insights into a wide range of personal data such as sleep patterns, steps taken, and calories burned as shown in Figure 1. These devices communicate with smartphone apps through a Bluetooth[3] or ANT[4] protocol, and these apps then display the tracked data to the user. Some devices also provide an embedded digital display that shows certain summarised information about the wearer's physical activity, such as current heart rate or steps taken in the day, and provide an accompanying app for the purpose of displaying more detailed activity information.

[1]http://www.polar.com/au-en

[1]http://fitbit.com

[3]https://www.bluetooth.com/what-is-bluetooth-technology/bluetooth-technology-basics/low-energy

[4]https://www.thisisant.com/developer/ant/ant-basics

Self-monitoring devices are becoming increasingly smaller, affordable and energy efficient, allowing continuous sensing and feedback. A PEW Research centre study from January 2013 (Fox and Duggan, 2013) indicates that seven in ten adults in the United States keep track of certain health aspects such as their weight, diet, and exercise routine. An earlier report on "Mobile health" (2012) also revealed that one in five smartphone owners in the United States have at least one health-related app installed on their phone – diet and weight related apps being the most popular ones (Fox and Duggan 2012). The advent of smart watches, along with the increased focus of companies on developing platforms to support different functionalities for these devices, suggests that there is likely to be further proliferation in this field.

As data is becoming an integral part of people's everyday life, a huge amount of effort is being invested in developing personal informatics tools and applications (Swan 2012). Numerous studies have also surfaced that investigate the use of personal informatics tools in an everyday context (Rooskby et al. 2014; Fritz et al. 2014; Li et al. 2011; Choe et al. 2014; Lazar et al. 2015). On one hand, these works highlight the benefits of encouraging health related goals through different strategies such as creating awareness, providing constructive feedback, encouraging personalised goals, and by encouraging social interactions (Klasnja et al. 2011). But on the other hand, these works also pinpoint challenges and issues that individuals encounter in having sustained use of these devices (Lazar et al. 2015, Rooskby et al. 2014). These studies suggest that existing devices place the emphasis more on data collection than on assisting users in gaining a better understanding of their active self through reflection of the collected data (Elsden et al. 2015; Lupton 2015).

Interestingly, most of the data measured by these devices are abstract in nature and does not hold any one-to-one relationship with real world objects (Edward et al. 2010). As a result, creating an appropriate visual mapping of the tracked data using data visualisation techniques becomes crucial. In response, a variety of works in both academia and practice have explored different data visualisation techniques. In the next section, I explore such techniques in depth.

Data visualisations to understand tracked data

Visualisation is very central to our understanding of data. "Seeing" makes knowledge credible (Bloch 2008) and "*greater visibility of information puts an added responsibility to act*" (Viseu and Suchman 2010, p.163). According to Card et al. (1999), visualisation is useful to make sense of data by identifying patterns and relationships within the data and then to create or discover concepts and ideas that were previously unknown or only hypothesised. Within the context of physical activity, visualisation offers insights into physical activity levels by making them comprehensible and actionable in terms of health-related aims. Below I have categorised the existing works based on the medium used for visualisation. I begin with on-screen visualisations, which occupy the majority of the existing literature, and later describe explorations in the form of auditory and physical visualisations.

On-screen visualisations of physical activity data

In this mode of visualisation, the tracked data is mapped to pixels on a computer screen or device. On-screen visualisation allows representation of both heterogeneous and multiple datasets at the same time, and also supports interactive explorations of the data such as dynamic filtering and precise searches. As a result, virtual visualisation techniques have become popular amongst expert users in work-related settings and are widely used in a variety of domains for interpreting complex data (Van Wijk 2005). However, on-screen visualisation is mainly suitable for creating 2D representations of data since onscreen 3D visualisations suffer from issues related to occlusion, distortion and navigation (Shneiderman 2003). Other disadvantages of virtual visualisation, as listed by Vande Moere (2008), include the need to have a flat display surface, difficulty in perceiving on-screen data in daylight and task obstruction because of the demand for visual attention. In summary, Vande Moere (2008) suggested that virtual visualisations have greater use for advertising and as a reminder tool, while they are less suitable for contemplation and reflection. Existing literature put forward following ways in which physical activity data can be displayed on screens.

Representing data using numbers and graphs

The most commonly used method for representing physical activity data on screen is through the use of numbers, charts and graphs (refer Figure 8). The advantage with numbers is that they require a small display space and they are easy to interpret (Van Wijk 2005).

Figure 8: Numbers and graphs are commonly used to represent physical activity data

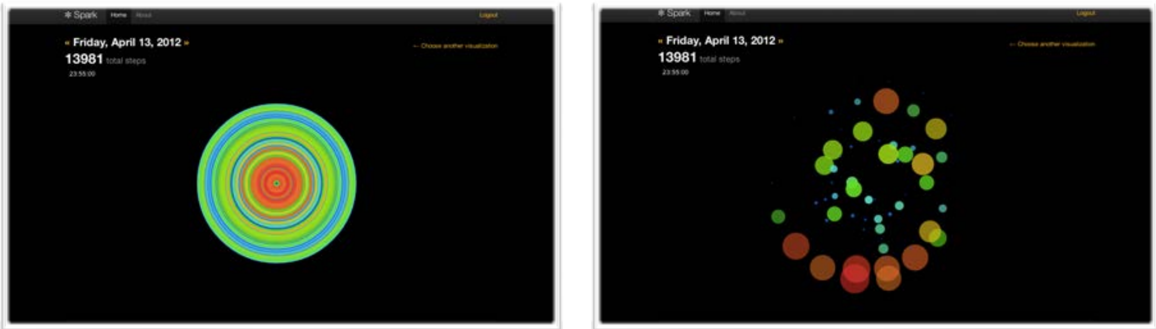
However, interpreting numbers can become difficult with an increased amount of tracked data. Graphs, on the other hand, are easier to glance at but identifying accurate values for specific intervals can be difficult (Yi et al. 2007). As a solution, some commercial applications such as RunKeeper[1] have 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 the corresponding numerical value. Nevertheless, the task of interpreting the statistical information is often left to the users. Ironically, different studies indicate that most users are not very skilled at interpreting statistical data (Ancker and Kaufman 2007; Galesic and Garcia-Retamera 2011). To them, the accumulated numerical data might appear overwhelming to generate new insights or actionable knowledge. Lazar et al. (2015) report in their study that participants rather preferred some form of simple report card that tells them how good they have performed. Addressing this, various works within HCI have looked into alternate ways of summarising the captured data, I briefly mention some of the key works below.

Representing data using living metaphors

Existing works within HCI have looked at representing data using living metaphors such as animated fish (Lin et al. 2006). Unlike charts or graphs, living metaphors are believed to be more engaging, motivating and easy to interpret (Lin et al. 2006). Additionally, the underlying idea is that users will develop an empathy with these virtual living organisms, and therefore, will get motivation to exercise more. Consolvo et al. (2008) designed a system called "Ubifit" garden that uses the home screen on a smartphone to display physical activity as a visual representation of a garden. The flowers in the garden grow and shine when users perform different physical activities. In a study of "Ubifit" garden, Consolvo et al. (2008) found that the garden-based display helped participants in better maintaining their physical activity levels, reporting that participants were motivated to make the virtual flowers grow and shine. Another related system is "Fish'n'Steps" (Lin et al. 2006), in which an individual's step count is mapped to the size of an animated fish. The animated fish grows in size and also becomes happy or sad based on how many steps the user has taken throughout the day. The study findings highlighted that participants did not want to look at the fish when they were inactive because they knew their sedentary activity would have made the fish sad. These works therefore suggest that care must be taken in how the visualisations are displayed to the user because negative framing of the data might upset the user as seen in earlier example.

Representing data in abstract form

Similar to living metaphors, researchers have also explored abstract visualisation techniques to make people aware of their sedentary lifestyle and prompting them to be more physically active. Anderson et al. (2007), for example, developed "Shakra", a system which represents users' physical activity using a GSM cell signal icon. In a study of "Shakra", the authors found that abstract visualisations encouraged reflection and increased motivation for achieving high physical activity levels. In a similar vein, Fan et al. (2012) designed and studied Spark that offers various abstract visualisations of physical activity data inspired from informative art as shown in Figure 9. They found that people have different tastes when it comes to appreciating and relating to abstract visualisations.



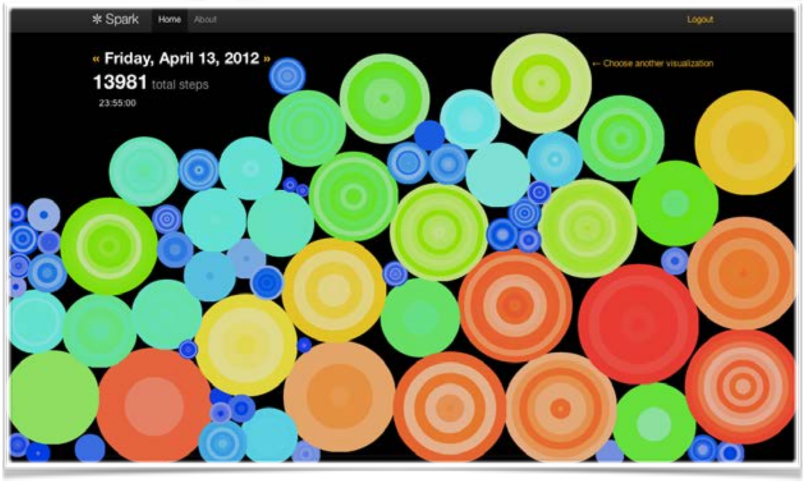


Figure 9: Screenshots of Spark that show abstract visualisations of step count.

Images © Chloe Fan.

[1] *http://runkeeper.com*

In another system called "QS Spiral" (Larsen et al. 2013), the periodic properties of measured personal data are captured using spiral time-series based visualisations, which allow recurring patterns to emerge. These works suggest that while designing abstract visualisations, it is important to pay attention to users' personal preferences to avoid disinterest.

Representing data using text

Systems like Jawbone Up[2] and "Health Mashup" (Bentley et al. 2013) provide textual feedback on the correlations formed within the self-monitored data set. For example, text-based feedback could be of the form: "*this weekend, you walked 30% further than your average walking on weekdays*". Similarly, systems like "Houston" (Consolvo et al. 2006) acknowledge progress towards set goals and congratulate users with gratifying messages like "you broke your previous record of jogging". Accompanying studies of these works illustrate that textual feedback on physical activity can increase awareness and motivation for physical activity.

Representing data through play elements

Prior works have explored is the use of Gamification (Deterding et al. 2011) to make physical activity playful. Examples of such system include "A Step Ahead"[3] and "Zombies, Run!"[4] – story-based jogging apps that, for example, encourage users to jog in order to escape a zombie apocalypse. Berkovsky et al. (2008) created a system called "Play, Mate!" where marbles move in the digital 3D world towards a goal as players move their body. "Heart Burn" (Stach et al. 2009) is a digital car racing game where the real-time heart rate values define the car speed in the game, while Tennet et al. (2011) explored using breathing to control a game. Oliveira and Oliver (2008) developed a mobile app, "TripleBeat" that allows runners at different location to compete for achieving a target heart rate zone during a run. Finally, Walsh and Golback (2014) have converted user's steps to a currency, which can be spent within an online explorer game. Fogg (2002) worked on a similar gamification idea, where a user's step count is turned into game points, which help a virtual "Pikachu" to grow. These works highlight that introducing play elements can make exercise both more enjoyable and engaging.

These works have inspired me to consider both abstract and playful design representations within my work. I have utilised three living metaphors - *Flower, Emoji* and *Frog* across three case studies conducted as part of the thesis. The final case study, *EdiPulse* also explore textual feedback in the form *Slogan*.

Physical visualisations of physical activity data

Jansen et al. (2013, p. 2594) define physical visualisations as "*visualisations that are made of physical matter*". Physical visualisations benefit from the physical modality of the material, which makes the visualisation easy to explore, handle, and manipulate in physical space. The use of physical matter is particularly motivated by the existing knowledge of its affordances, and opportunities of embodiment (Vande Moere and Patel 2010). While traditional digital visualisations are limited to the visual sense, physical visualisation offers numerous opportunities for interactions where the material properties such as texture, temperature and weight can provide different information about the artefact. The popularity of physical visualisations in various settings such as art installations and museums (Dragicevic and Jansen 2012) further suggests that physical visualisations have the potential to engage people for a longer duration and sustain their interest in exploring and understanding the represented data.

Creating physical visualisations has several challenges. Some of these challenges include a significant production cost, slow development process, and the fact that material artefacts offer a static mode of interaction (Jansen et al. 2013). These shortcomings have started to diminish with the availability of digital fabrication techniques (Mota 2011) and computationally augmented interfaces (Ishii et al. 2012; Rasmussen et al. 2012). For example, devices like 3D printers and laser cutters have made the fabrication process easier and cheaper. Additionally, since these devices are also getting cheaper, more accurate, smaller and faster with time, frequent use of these devices in everyday life is expected in the near future (Andersen 2010). Physical visualisations are constructed in following ways.

Representing data as data sculptures

One popular type of physical visualisations is the data sculpture. Zhao et al. (2008) define data sculptures as "*data based physical artefacts, possessing both artistic and functional qualities that aim to augment a nearby audience's understanding of data insights and any socially relevant issues that underlie it*" (ibid, p. 343). Within HCI, "Breakaway" by Jafarinaimi et al. (2005) is one of the first works in which a data sculpture is used as an ambient visualisation to provide feedback on the proper sitting posture of the user. In a similar vein, Haller et al.

[2] *http://jawbone.com/fitness-tracker/up3*

[3] *http://www.astepaheadchallenge.com/a-step-ahead-zombies*

[4] *http://zombiesrungame.com*

(2011) and Hong et al. (2015) use flower-shaped physical ambient avatars to increase the awareness of incorrect body postures. Stusak et al. (2014) designed and studied 3D printed representations of running data (refer Figure 10) while Lee et al. (2015) created a “Patina Engraving System” that represents physical activity data through engraved patina like patterns on a wristband. These works report that physical visualisations support individual’s self-expression and reminiscence, besides increasing awareness of physical activity. In addition to these academic works, Dragicevic and Jansen (2012) curate an extensive list of existing explorations in physical visualisations on ‘dataphys.org’ website. The majority of the discussed works on this website, however has been art projects with no empirical studies. Additionally, physical activity data has not been the focus of most of these visualisations.

Figure 10: Activity Sculptures creates 3d printed representations of running data. Image © Simon Stusak

Representing data through augmented interfaces

There are also some works that combine physical and digital visualisations using augmented interfaces. For example, Mauriello et al. (2014) display running data on the back of a runner’s T-shirt using e-ink screens, while Walmink et al. (2014) augmented helmets with LED lights to display a cyclist’s heart rate data as they rode. Zhang et al. (2013) created augmented reality glasses that display potential UV damage to the skin while cycling. Pels et al. (2014) designed “Fatbelt" that shows consequences of overeating through inflating a waist worn device. Other researchers (Taylor et al. 2013) have used a mirror metaphor to make users aware of their posture. For instance, if the user is not sitting in a proper posture then the on-screen mirror becomes blurry, thereby encouraging the user to sit in the correct posture. Lim et al. (2011) created “Pediluma”, a shoe worn pedometer that provides light based feedback about an individual’s physical activity through varying intensities of light on the shoe.

Above physical visualisation techniques focus on improving the user’s understanding through the tactile experience of handling data presented in physical form (Stusak et al. 2016). However, existing literature on material culture informs us about the polyvalent values of material artefacts within our everyday life, and how it shapes our identity within personal and social contexts (Jung et al. 2011; Miller 1998). As such, physical visualisations should not be looked at purely as visualisations but also as substances to enrich our interaction with materials and artefacts. This thesis unveils the distinct pattern and importance of our interactions with each material. I call this interaction: Human Material Interaction, which I cover in more detail in the next section.

Human Material Interaction

Over the years, human material interaction has been explored in different ways, such as: tangible bits (Ullmer and Ishii 2000), computational composite (Vallgarda and Redstorm 2007), organic user interfaces (Holman and Vertegaal 2008), transitive materials (Coelho et al. 2009) and inspirational bits (Sundstrom et al 2011). Anthropologists like Miller (1998) describe such interactions as “Materiality” and define them in terms of a broad range of values and affects that are elicited during the course of making and using the artefacts. Although the current understanding of materiality is partially biased towards physical and functional aspects of artefacts, researchers have recently started exploring the affective and experiential qualities of materials that define how individuals domesticate and make use of these artefacts in everyday settings (Jung et al. 2011). Materials are an important part of our life. We express ourselves not only through our appearance, but also the way we decorate our surroundings. For example, we demonstrate our family affection and sense of belonging by decorating walls of our living rooms with photographs from different life events. Additionally, our social interactions also revolve around food, drinks, and physical artefacts.

Given the availability of computing technologies, I am particularly interested in exploring how engaging with different materials may influence the overall experience of being physically active. For instance, learning from digital metaphors for representing physical activity data, what values would a physical metaphor add to the overall experience? Can the physical activity become more meaningful if representations help users to talk about their active self using materials like plastic? Can we make physical activity more valuable by using materials that are essential for living e.g., water? Or can we make physical activity more cherishing or enjoyable by exploring materials with which users share special affection e.g., chocolate? To this end, this thesis explores material representations of physical activity data using both durable and consumable materials, which I discuss below.

Opportunity with durable materials

According to the Goal Setting theory (Locke and Latham 1990), incentives are important to sustain a user's interest in a physical activity. Following this, previous works in the field of HCI have looked at virtual rewards and incentives to support physical activity experience. For example, the use of virtual rewards, points, leaderboards and badges are popularly used to encourage users towards achieving their health goals (Bravata et al. 2008; Walsh and Goldsmith 2014). A study by Munson and Consolvo (2012), however, suggested that physical rewards are more cherished and meaningful than virtual rewards. For example, badges and trophies won in different competitions are always more cherished than 10,000 virtual points. Similarly, people collect and archive souvenirs from different trips and events to cherish their memories afterwards. These artefacts when put on display become a public representation of the self (Goffman 1959). As such, material artefacts are more valuable than digital objects because of their higher visibility in the surroundings and low replication possibility (Golsteijn et al. 2012; Kirk et al. 2011). In response, this research explores different forms of real world material rewards that are constructed using the measured physical activity data of individuals, making them both unique and personalised.

I draw on the fact that bodily responses to physical activity, such as heart rate values, are not only different for each individual, but also vary based on different types of physical activity. Moreover, these bodily responses to exertion are personal, non-reproducible and a good indicator of the amount of effort and time invested by an individual in performing physical activities. However, these nuances within physical activities are not easily noticeable. Although personal informatics tools can measure these nuances, they do not put any emphasis on doing so. For example, commercial pedometer based systems like Fitbit mark 10,000 steps in a day as a significant achievement but ignore personal and contextual details that fuelled that outcome. What made the person take 10,000 steps on that particular day? What was the walking pattern for that day? Was there anything novel in the walking pattern on that day? These contextual and personal inferences are essential to sustain engagement (Li et al. 2011; Epstein et al. 2014), but are not always captured by existing systems. I believe that these nuances can be better acknowledged by designing personalised material artefacts. The unique pattern that the resultant material artefact bears may hold more meaning to the individuals as it becomes a personalised souvenir or testimony to their invested effort in being physical active (refer Figure 11). This thesis attempts to capture these nuances in the design of material artefacts by focusing on less known information (such as heart rate data) and making the design more speculative rather than informative.

This thesis also builds upon the existing work on slow technology (Halnas and Redstrom 2001) that emphasises 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 the effort from the user (Weinberg and Gould 2006). For example, the result of burning body fat through exercise is only visible after the user has followed the exercise regularly and for a sufficient amount of time. Therefore, I believe that there is an opportunity to support the slow and steady nature of improving health by creating tools that support slow and steady reflection.

In this thesis, I explore this opportunity through digitally fabricated material artefacts that afford reflection through their inherent tendency of disappearing in the background (Miller 2008); where material artefacts gather attention only when users specifically look at them. Additionally Kirk et al. (2011) argued that material artefacts also have personal reflective value and therefore, using material artefacts to represent physical activity data can provide users with options for reflection on their performance.

Figure 11: With 3D printing and durable materials lies an opportunity of creating personalised material rewards.

In the first case study (described in Chapter 4), I have designed five different 3D printed material representations of physical activity, each exploring a different aspect of physical activity. For example, the *Dice* model (Khot et al. 2014) was specifically created to highlight the amount of time a user has been sedentary. Conversely, the *Flower* model captures the variations in the heart rate on particular day that could signify how eventful (physically active or stressful) that day was in comparison to other days.

Opportunity with consumable materials

Food has a rich cultural and social history. Its preparation, as well as consumption, provides opportunities for bonding and interaction among individuals (Lupton 1998; Grimes et al. 2008). French gastronome Brillat-Savarin (2015) notes that pleasures associated with eating and drinking constitute some of the life's most enjoyable experiences. In recent years, the field of "Human Food Interaction" (HFI) is gaining currency within the HCI community with a focus on understanding existing food practices (Comber et al. 2014). For instance, researchers are looking into different aspects of our interactions with food, i.e., how we grow (Lyle et al. 2013), shop (Reitberger et al. 2014), cook (Paay et al. 2015), eat (Hupfeld and Rodden 2012; Ohara et al. 2012) and dispose of food (Ganglbauer et al. 2015).

Food is not only a fundamental pleasure that we interact with in everyday life, but it is also an essential part of the human energy cycle. In the context of physical activity, introducing food-based representations of physical activity data can unveil new design opportunities. The amalgamation of food and technology design breaks the notion of physical activity data merely consisting of unintelligible numbers, and affords a new way of presenting the data. For instance, physical activity data is a unique and personal outcome that reflects the amount of energy expended and efforts invested by the user - which I believe should be emphasised. I see self-monitoring and food printing technologies as an intriguing blend, where self-monitoring tools inform us about how much energy has been expended in the physical activity (i.e., energy out), while food printing technologies support new ways of producing food for consumption (i.e., energy in). For example, after intense physical activity sessions causing loss of body fluids and energy, sports drinks help in recovering lost body fluids (Sawka et al. 2007) (refer Figure 12).

Figure 12: With consumable materials lies an opportunity of replenishing the loss of energy and to positively reinforce active lifestyle.

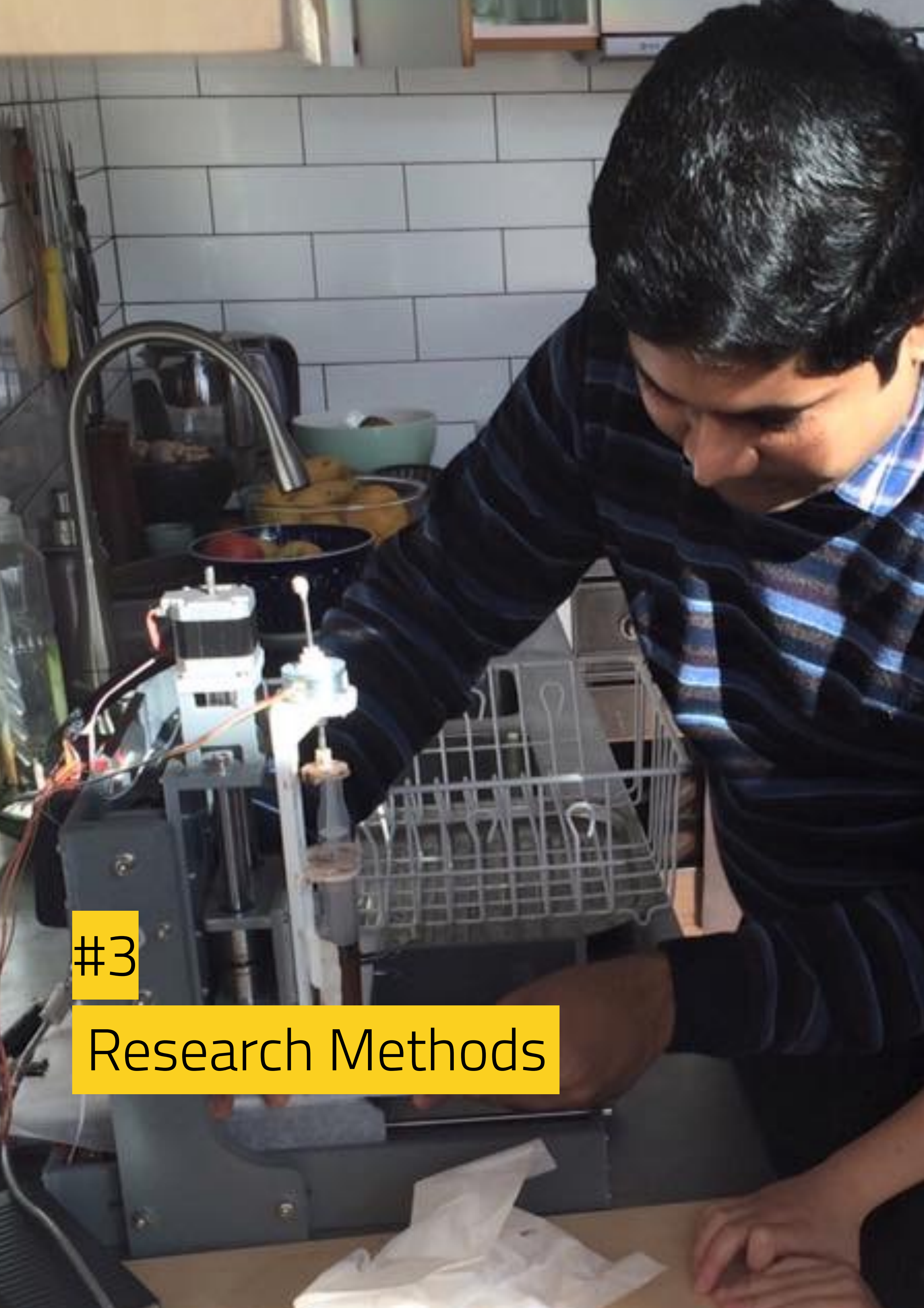
When it comes to relating food to health, the majority of existing works are centred around dietary monitoring. For example, Mamykina et al. (2008) created a system to track eating habits using a mobile phone and a glucose meter. Likewise, Siek et al. (2006) created a food journal that allows participants to scan the barcodes of the foods they are having for a particular meal. "MyFitnessPal"[5] is a popular smartphone app that counts calorie intake through the manual recording of consumed food. Similarly, work by Fortmann et al. (2014) quantifies the amount of water a user is drinking in a day and provides reminders to drink more if necessary. " The Chocolate Machine" (Kehr et al. 2012) is a system that dispenses chocolate at scheduled intervals, challenging a user's patience. Apart from these works, researchers (Spence and Piqueras-Fiszman 2013; Comber et al. 2014) speculate on various interaction possibilities with food in the near future and desire more seamless integration of food and technology design. The recent development in devices such as food printers is a step towards achieving this dream (Schoning et al. 2012).

This thesis explores the potential of food-based representations through the use of drinkable fluids and chocolate as materials to support the physical activity experience. Consequently, I have developed and studied two systems, *TastyBeats* and *EdiPulse* that respectively provide an appetising drink and chocolate treats to celebrate the experience of being physically active. These case studies are discussed in greater detail in Chapters 5 and 6 of this thesis.

Conclusion

In this chapter, I presented existing approaches that attempt to support the physical activity experiences through different visualisation methods including on-screen, auditory and physical visualisations. Through the literature review, I identified two opportunities to design material representations that aim to enrich the experience of physical activity through human material interactions. To leverage on these opportunities, this research leans towards research through design practice (Zimmerman et al. 2007; Koskinen et al. 2011) where I develop and evaluate three research prototypes exploring three different materials - plastic, drinkable fluids, and chocolate. These prototypes are discussed individually in three chapters.

[5] *http://www.myfitnesspal.com*



#3 Research Methods

CHAPTER 3

Research Methods

This chapter presents the research methods that I have used to answer my research question.

"Methodology should not be a fixed track to a fixed destination but a conversation about everything that could be made of happen"
— JC Jones, Design Methods

Introduction

This thesis includes the design and evaluation of three design prototypes that serve as research vehicles to understand user experience with material representations. In this chapter, I present a variety of research methods that I have used to answer my research question. I will start the chapter by describing the Research through Design (Zimmerman et al. 2007) approach that I have taken to design the three prototypes discussed in the thesis. I then describe the field deployments and qualitative research methods that I utilised to understand the user experience with each prototype. Later I describe the need of having frameworks to guide future explorations, particularly design cards, that are useful in generating design knowledge.

Approach: Research through Design

Research through Design (RtD) is increasingly practiced across engineering-informed and art-based design research (Krogh et al. 2015, p.39). It is a reflective practice of examining the process, invention, relevance and extensibility of the design through prototyping (Zimmerman et al. 2007). This approach helps interaction designers to integrate theoretical models with the technical opportunities demonstrated by the design engineers, allowing for the creation of the right artefact. Zimmerman et al. (2007) suggest that this is a step towards transforming the world from its current state to a preferred state. According to Lowgren (2013, p.31), "*the essence of research is to produce knowledge while the essence of design is to produce artefacts*." Building on this sentiment, the knowledge in Research through Design is in the production of the artefact or the artefact itself (Zimmerman et al. 2007). However, unlike traditional design practices, where artefacts and systems are designed to make specific cultural and economic impact, in Research through Design, artefacts are designed and used as objects of inquiry into a probable future (Gaver et al. 2004). Research through Design is also an attempt to understand the artefact's relationship with people in a given context (Fallman 2003). As such, the design of artefacts is driven by the main research question and not by the user needs (Frens 2006). To this end, Research through Design involves explorations into how and why people interact with design artefacts (Koskinen et al. 2011;Fallman 2003).

van den Hoven et al (2007) considers Research through Design as a form of action research. Archer (1995, p.6) defines action research as "*systematic investigation through practical action calculated to devise or test new information, ideas, forms, or procedures to produce communicable knowledge*". He highlights the difficulties in translating the findings from "situation specific" action research to a wider context. He therefore encourages design practitioners to position themselves in opinion and theory concerning the specific domain to which they are contributing and refrain from generalising the gained knowledge to a wider domain.

Frens however points out the dissimilarities between Research through Design process and prototype testing (Frens 2006). As such, many researchers argue that the research contribution should not solely be in terms of the produced design artefacts, but it must be complemented by critical insights, reflected as design specifications or guidelines for future products within the specific context (Koskinen et al. 2011; Gaver et al. 2012).

According to Zimmerman and Forlizzi (2008), there exist two methodological approaches for conducting Research through Design. The first approach is a philosophical one, where researchers investigate "*previously articulated theory through the process of making*". The second is through a grounded approach, where researchers focus on "*real world problems by making things that force a concrete framing of the problem*". In this thesis, I lean towards the second approach – seeking knowledge which is, in turn, grounded in data. Cross (2001) suggests that a key research question to explore in Research through Design experiments is "*How would you design an <X>?*" This thesis asks:

> "How do we design material artefacts that represent one's physical activity to affect a person's relationship with physical activity?"

As discussed in Chapter 1, I divide this question into four sub-questions to aid the design of material representation:

1) Mapping: How should you translate physical activity data into a material artefact?

2) Outcome: What should that material artefact look like and how should it feel?

3) Material: What kind of material should you use to create such material artefacts?

4) Process: What kind of process should be followed in creating these material artefacts?

To answer these questions, I began by following the Research through Design approach where I designed three systems to represent physical activity data through material artefacts. The three prototypes use heart rate data of physical activity as a central design element and explore different mappings, materials, processes, and outcomes of material representations. To investigate how the developed systems will affect physical activity experience, I utilised in the wild field deployments where I deployed each system individually at different households. During each deployment, I aimed to understand the user experience with the developed system as described next.

User Experience

User experience (UX) refers to the experience of users of a technology. UX is defined as a subjective, situated and dynamic encounter of a person with a product, system or service (Hassenzahl and Tractinsky 2006). They defined UX as the result of user's internal state (such as perceptions, expectations, motivation, and mood), characteristics of the product (such as usability, functionality, and purpose), and the context (such as organisational and social setting) within which the interaction occurs. User's experience with a product will depend on their motivation to achieve specific goals with the product, how they anticipate the use of product, and later how the product fulfils their expectations. Users have an abstract definition of what they want in the interaction. Most of the time, they are not vocal about their needs and they base their opinion on what they see and understand at the particular moment of interaction (Sanders and Williams 2001). Additionally, previous encounters with similar systems, past memories, expertise abilities and other preferences, also influence user's opinion about a system (Azzawi 2014; Hassenzahl and Tractinsky, 2006).

Evaluating UX with a given product provides an understanding of the types of user interactions that a system should support to accomplish a given task in specific situations of use. Several frameworks and theories have been proposed to understand the complex and subjective notion of UX (Azzawi 2014). To begin with, Karapanos et al. (2009) talk about the temporality of user experiences i.e., how user experience with a product develops over time. For instance, a new release of iPhone creates a huge hype, but the phone is also appreciated over long run. Several questions get raised here: what do users like in the phone? is it mostly the initial excitement that motivates the prolonged use? How important is the user familiarity with the product? Does with learning, the product become more useful? What is the journey of user adopting the product? The authors suggested to use methods such as day reconstruction and experience narration, to understand participants' both satisfactory and unsatisfactory experiences with the product.

On the other hand, Forlizzi and Battarbee (2004) describe how experience transcends from unconscious to a conscious state and contribute to form a memorable and communicable interaction, "an experience". "An experience" is episodic in the way that it has a beginning, middle and end e.g., watching a movie. An experience can be articulated or named. They further explained user experience in social context, i.e., how the experience of an individual gets influenced by the physical or virtual presence of others, they call as 'co-experience'. For example, playing a Kinect game with friends will form co-experience with Kinect. They further explained that social interaction with other people and surroundings can influence our emotions with the products and may alter the meaning of "an experience" from pleasant to unpleasant and vice-versa. If the product allows an easy way to perform some activities, the interaction becomes pleasurable; whereas any interruptions on the way result in unpleasing experience.

McCarthy and Wright (2004) based their framework on the idea that experience is a process that keeps on evolving and unfolding. Thus, the relationship between users and technology should be interpreted in terms of "felt life", where felt life refers to the "*emotional and sensual quality of experience*". They defined six processes from anticipation to reflection to recounting that helps the user in making sense of the given product. Lastly, Hassenzahl (2004) suggested beauty and goodness that helps in evaluating the quality of given product. According to him, goodness is affected by pragmatic aspects i.e., usefulness and usability. While, beauty provides a social aspect of identification i.e., the product ability to address the need of self-expression.

In this thesis, I particularly, utilise the framework of Forlizzi and Battarbee (2004). I aimed to understand how user experience the three developed systems for physical activity as "an experience", and how their experience evolve as "co-experience" in social context. I gathered a rich set of information from participants around the four essential aspects of the research question, namely, mapping, outcome, material and process. In particular, I explored user experience with the developed systems by understanding their personal aspects such as motivation, preferences; interactions with the system and with other people around; physical environment for the interaction; and interactions with the given material representations. Since user experience is best understood with time-based investigations in real or realistic context of use, I have utilised field deployments to study their interactions with system in real setting, i.e., home. In each deployment, I have utilised qualitative methods to gather a rich understanding of their experience, that I describe later in the chapter. Below I briefly give an overview of field deployments.

Field Deployments

Field deployment is a method of investigating the use of system in real world situation with real users (Siek et al. 2014; Rogers 2011). It enables researchers to evaluate the interaction among multiple factors such as given technology, target population, activities and tasks simultaneously, while studying the context of use. Field deployment also provides an iterative approach to study a prototype, which involve redefining the research questions, improving the study design, changing the prototype, and lastly reporting the findings of the interactions with the prototype to inform future innovations. As such, field deployment is a step prior to bringing the system in real use by understanding the generalisability of findings beyond the study environment.

Unlike a traditional lab based experimental studies, field deployment is time and resource intensive but provides a richer understanding of how the user interaction with technology happens, and how users adopt, use, or abandon the technology in real world context. With the growing interests towards ubiquitous computing, interaction designers and researchers are relying upon field deployments to design technologies and interaction for everyday context. For instance, Toprak et al. (2013) created a game called "Cart-Load-O-Fun" to engage commuters in a social playful experience in a public tram. This game could have been tested in a laboratory setting, as lab setting offers easy control over the study parameters such as space and players interaction. Setting up the game in a real world tram allowed authors to gain useful insights such as: 1) perception of time changed when players (commuters) were engaged in the gameplay. For example, some commuters did not realise when they crossed one zone and reached another. 2) Movement of tram affected the gameplay. Such deeper insights would not have been possible with lab-based study.

Field deployments can be conducted in three ways as summarised by Siek et al. (2014). First is the convenience sampling where the new technology is deployed within one's own convenient social network such as family, and lab mates. Here, the study environment is known, and hence maintaining the system is simpler. However, such a sampling is not considered as a representative of real users of the new technology, and may provide favourable yet biased feedback to the research. Secondly, semi-controlled studies involve participants who know the research team and those who are unknown to the team during the start but become familiar with time. As the relationship between the participants and researcher tends to grow with time, this also brings the similar issues of acquiescence biases and lack of generalisability as the first one. And lastly, in the wild study implies deploying the prototype in an almost naturalistic environment with participants being unknown to the research team; and hence are considered to be more critical about the prototype. The prototype must be robust enough to withstand the abuses and criticism of the participants.

The key aspect of this research is to study and understand how the proposed prototype gets integrated into the everyday experience of physical activity, and what potential benefits it can offer to users aiming to achieve their health goals. I followed the reflective "in the wild" study method (Rogers 2011; Chamberlain et al. 2012) to investigate the user experience with developed systems in real setting, i.e., at participant's home. In the wild field studies are derived from ethnographical and anthropological practices that include field observations, note taking, interviews as well as audio recording that are later synthesised for detailed analysis. However, unlike the traditional ethnographical practices, "in the wild" studies when combined with Research through Design practices allow the liberty of explicit interventions. For instance, a design artefact is created and introduced in a context to understand its subsequent effects (Gaver et al. 2004). I particularly, followed semi-structured interviews to collect the data, which I describe next. This research also involves "Domestication Theory", first defined by media scholars (Silverstone and Hirsh 1992), which seeks to explore how objects become part of a person's identity and social life. Additionally, the Domestication Approach focuses on technologies in everyday life and their symbolic role.

Qualitative Inquiry

Given the exploratory nature of this work, I lean towards qualitative research practices to understand the user experience of material representations. Oliveto (2008) defines qualitative research as the use of unstructured exploratory techniques to understand a problem in greater depth. Within HCI, qualitative inquiry plays an important role in conducting different phases of research: starting from the data gathering where researchers interact with the potential users to understand their needs, to developing research prototype where researchers conduct informal discussions or focussed group workshops with experts to get feedback on prototype, to evaluating the developed prototype in practise where researchers study how the developed prototype had made a difference in the given context (Patton 2002). Qualitative inquiry is based on understanding the lived experiences of users with special attention given to the context where the events occur.

In qualitative inquiry, the researcher is the main instrument who relies on his or her skills to uncover different meanings of a given context. As such, qualitative inquiry is explained through the phenomenon of "constructivism" and "interpretivis" where the researchers first construct the meaning of different events from the perspective of users, and then interpret it personally through the gained evidences. Blandford et al. (2016) reports that there is no single right way to conduct a study, nor is there a prescribed value of an ideal number of participants. How a researcher chooses a particular method depends on the researcher's personal positions concerning ways of creating new knowledge (Zhao et al 2008). While Woolrych et al. (2011) mention that "the art of conducting an effective study is in pulling together appropriate ingredients to construct a recipe that is right for the occasion. That is the one that addresses the purpose of the study while working with available resources". Qualitative research therefore, demands creativity where the researcher needs to go to the depth of the context by making sense of the complex data.

A qualitative study starts with a research question or problem and involves collection of rich subjective data through different methods such as participant observations, interviews, and informal discussions. Such research generally allows the themes to emerge from the data without following any hypothesis or theory to confirm. The essence of a qualitative research lies in collecting thick descriptive details from participants and extending the application of the generated findings across different contexts through design implications (Creswell et al. 2003). Yardley differentiates qualitative research with quantitative research by stating: "Quantitative studies [...] ensure the 'horizontal generalisation' of their findings across research settings [...] qualitative researchers aspire instead to [...] 'vertical generalisation', i.e., an endeavour to link the particular to the abstract and to the work of others". (2000, p.220). Below I mention the qualitative methods that I have utilised in my research.

Qualitative interviews

I opted for semi-structured interviews (Neuman 2006) to collect participants' responses to each of the systems during field deployments. Interviews are commonly used to understand the mediated interactions of a user with the given system (ibid; Blandford et al. 2016). Interviews involve conversations and face-to-face discussions between at least two people. Interviews provide greater insights on the user's experience with a system, something that cannot be easily measured through quantitative data. During interviews, users narrate different stories around their bad and good experiences with the system, which help researchers to reflect on different aspects of the system. Such stories are a great medium to reveal human artefact relationship, as people disclose several other life situations and emotional meanings that are invoked by the given system. As such, interviews helps in uncovering personal opinions about comfort, issues and satisfaction of the user with the given system.

Interviews can be less or more structured (Blandford et al. 2016). A structured interview is like a questionnaire where researcher strictly follows a predetermined set of questions. On the other hand, a completely unstructured interview, also called as open-ended interview, is more like a conversation on a specific topic where both participant and researcher ask questions and learn new things about the related avenues through the discussion. Finally, the middle ground of both is the semi-structured interviews where the researcher follows a set of questions to guide the interview, while also following up with participant on the interesting topics that emerge during the conversation. Semi-structured and open-ended interviews have been effectively used in the field of design to explore questions related to people's thoughts, beliefs, attitudes and emotional feelings about a product in use. Charmaz (2006) further highlighted the important aspects of an "intensive interview" and suggested that an interviewer should encourage the participant to talk more by asking open questions, while the researcher's main responsibility should be to steer the discussion towards the research aims by being less attentive to avenues that are out of scope.

During the field deployments, I kept the nature of the interviews semi-structured in order to leave sufficient room for topics to emerge, and to support a deeper elucidation of participants' responses and thinking processes. During each interview, I carried a list of questions (topic guide) related to my research aims that helped me to remain on track, while leaving sufficient flexibility in the discourse. As Blandford et al. (2016) highlighted that people's ability to self-report facts is limited, I therefore, also utilised visual materials to further support rich expressions and articulation of experience. For instance, I discussed photographs (voluntarily) shared by the participants on social networks, and snapshots of the material representations that participants received during the study period. Additionally, I also welcomed opportunities to discuss any other illustrations and recordings that participants voluntarily captured during the course of study, e.g., video recording of the system preparing the material representations. Supporting interviews with multiple medium resources helped me to investigate how people reacted and integrated the developed prototypes into everyday practise. It also allowed me to explore how the interactions with systems affected participant's behaviour and their relationship with physical activity. I audio recorded all the interviews for later analysis. Figure 13 shows a snapshot of the interview session.

Tools for self-documentation

Inspired by the cultural probe methodology (Gaver et al. 2004), I asked participants to record their own experiences in a provided diary to elicit deeper provocative and evocative incidents that they may not recall during the interview process. This task however was not compulsory. Participants were also free to use other methods of recording, such as and not limited to taking videos, photos and audio recording. To my surprise, in the *TastyBeats* study, a couple of participants voluntarily audio-recorded their experience on daily basis, and shared the audio file with me via email. In all the studies, majority of the participants voluntarily took photographs of the system or the constructed artefacts, created video recordings of the system printing artefacts, and took photographs of their visitors engaging with the system. I found it extremely heartening to see such commitment and interest from the participants. The data collected via these methods was used to supplement the interviews (refer Figure 14).

Focus group

Focus group is a kin to interviews that utilises the potential of multiple people to generate ideas or data related to a topic (Kitzinger 1995). Unlike interviews, focus group is an appropriate form of data collection method when the researcher is not looking for individual biographies and preferences related to a given product. Rather the researcher is aiming to learn from the knowledge and experiences of several people to form a collective understanding of to a topic. In situations, when the researcher has a series of open-ended questions related to a topic and the researcher wants to evaluate them in a quick but critical manner, focus group comes to rescue.

Figure 13: A screenshot of one participants talking about his experience with the SweatAtoms system.

Composition of focus group studies can vary from only a few people to a huge group of fifty people, with ideal size recommended as 4-8 participants. The researcher's role during the focus group is to facilitate the group discussion such that everyone gets an opportunity to bring their points, while steering the conversation such that the discussion does not move away from the main topic.

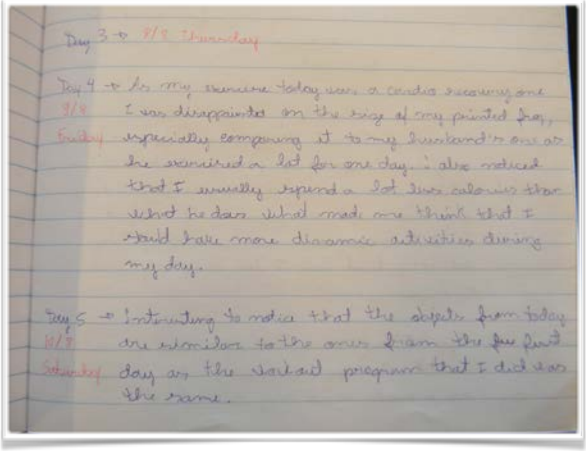


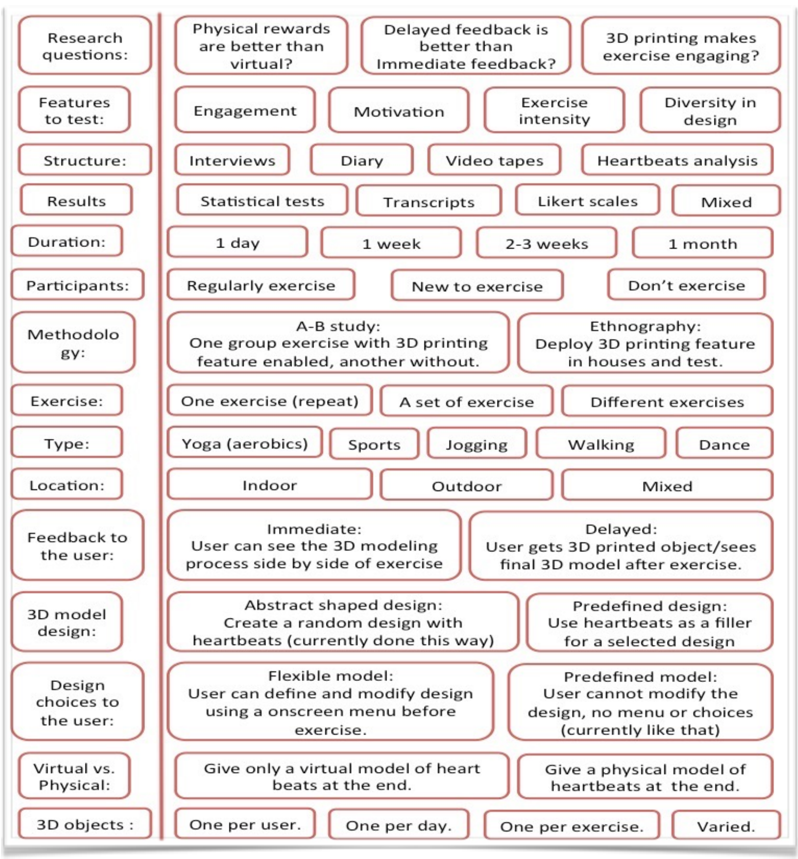
Figure 14: Few participants articulated their experiences in the provided diaries, whereas a couple of participants provided me voice memos and emails.

Focus group taps into the dynamics of group communication where instead of asking every individual to respond in turn, the discussion emerges with people voluntarily participating, sharing their experiences, commenting on each other's viewpoints, and asking questions (Watts and Ebutt 1987). Focus group allows participants to express their concerns, generate questions, develop answers around them and then converge to key points to answer the given question. It is due to the social dynamics that focus group allows people to explore and clarify their views that they can not do in one-to-one interview. As such, focus group not only allows the researcher to know what people think but also provides knowledge of how and why they think that way. Group discussions are typically relaxed and participants are allowed to bring forms of communication from everyday routine, e.g., teasing and arguing. The idea behind the informal environment is to make people comfortable with each other, so that they can participate in the discussion to their full potential. Given the informal nature, focus groups may become an appropriate venue to discuss even the embarrassing and negative concerns related to the topic.

Focus group methods utilise participants as an active part of the research process. To this end, the composition of a focus group highly impacts the dynamics and topics that emerge for discussion, and finally the quality of outcome (Hughes and Dumont 1993). Therefore, participants of focus group should be carefully selected. To this end, making the group homogenous with participants from different expertise, and different range of professions, helps in bringing in different perspectives within a group setting. However, the hierarchy of position and power should be considered to allow maximised exploration with unbiased responses. For instance, it might be difficult for a staff member or a student to give true comments about the administration in the presence of their manager or teacher. To keep the discussion ongoing, researchers often take notes and make flow charts on boards so that the participants also get informed on the key themes that emerged. Group discussions are generally video or audio recorded for later analysis.

I have utilised focus groups across different phases of my research. These discussions were conducted with HCI experts, industrial designers and interaction designers working in the related domain. For instance, I conducted focus group with HCI experts to get feedback on different parameters of case studies such as duration of study, tasks for participants, and number of artefacts to offer. Figure 15 shows a snapshot of the ideation sheet that I utilised to evaluate the study design of *SweatAtoms*.

Figure 15: I brought printed sheets of the ideas and related concepts at the focus group discussions to refine and finalise ideas and study design.



Every participant of the focus group filled their responses on the sheet, and later everyone discussed their priorities to confirm the best study design. Similarly, I conducted focus group with interaction designers while designing different models of material representations where I run through the designers with different models and their significance with physical activity. The designers provided insights on how to improve the models. Finally, I have conducted focus groups to evaluate the utility of the proposed framework, *Shelfie*. During these sessions, I asked participants to design material representations for any sports data of their interest through the design cards of the framework. Later in the session, everyone discussed their design and the reason behind their options. The discussion helped me to understand the importance of different cards, and the ease to understand them.

Thematic Analysis

Qualitative data analysis is the process of transforming the collected data into meaningful interpretations related to system, context, and interactions under investigation (Braun and Clarke 2006). Data analysis is the most challenging phase of qualitative research as the quality of the conducted research depends on the rigour of analysis. The researcher has a huge data to work on, for example, hundreds of pages of interview transcripts, diary notes, and detailed field notes from focus groups. A good quality of analysis includes different iterations of the data to discover patterns, linking them together to form coherent themes, and finally linking different themes together to form a coherent story. Making sense of the complex data, is therefore, considered as a creative task, as the patterns and themes do not directly emerge from data.

Rather it requires cognitive skills to interpret the data and reflect upon it such that the reported data not only present the commonalities across the participants' but also the variations in a concise and non-repetitive manner.

Thematic analysis is a method for identifying, analysing, and reporting patterns (themes) within the collected data (Braun and Clarke 2006). A theme is a label that captures something important about the data in relation to the research question. The authors identified six phases of conducting thematic analysis (ibid, p.87). In the first phase, researcher familiarises himself with the data by simply reading and re-reading the data, and taking notes on the way with different ideas that emerge. In the second phase, researcher generates initial codes throughout the dataset, and collects data related to each code together. The code refers to a label that describes an interesting feature of the data. In the third phase, the researcher gathers different codes to form candidate themes, and draws a visual mind map to make meaning across different codes. The fourth phase is dedicated to review the generated themes to refine them. Here, depending upon the data available for each theme, some themes need to be broken down into sub-themes, some will be combined with other themes, while some may need to be removed. By this phase, the mind map begins to reflect a story of the data. In the fifth phase, the researcher writes a detailed narration related to each theme. The researcher again reviews that each story is unique and is related to the research aim. If not, the researcher refines the theme again. Lastly, in the sixth phase, the researcher writes narration of all the themes together to provide a logical, coherent, and interesting account of the story.

In this thesis, I have utilised thematic analysis to analyse the collected data from field deployments (transcripts of interviews, and participants diaries), and focus groups (notes). I manually performed the coding across the dataset and utilised post-its and board to label the data. Figure 16 shows a snapshot of the thematic analysis performed to formulate themes for the initial version of *Shelfie* framework. As such, the iterative and reflexive process of reading through the data and interpreting it, helped me in gaining deeper insights from the collected data. Reading and re-reading the data, have also helped me to refine my research question and also guided me towards my next study. For instance, through the interview quotes, I gained insights on the affordance of different materials, and the relationship of users with materials - which in turn, helped me to think about different potential material that could be used in the subsequent studies.

Justification on study choices

I next describe the rationale behind some of my study design decisions.

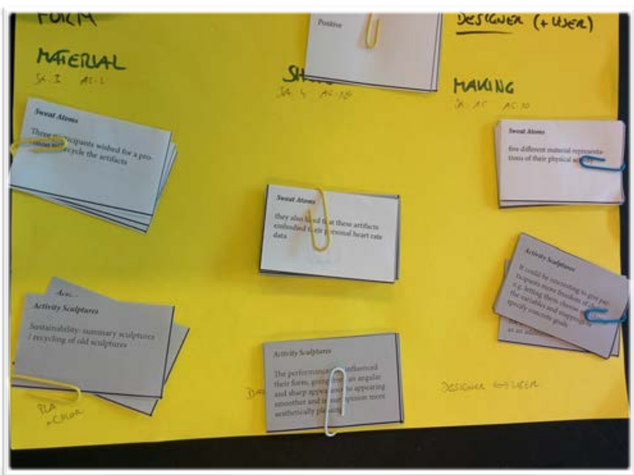


Figure 16: A screenshot of collected data used during thematic analysis.

Rationale for choosing everyday physical activity

Previous research on self-monitoring by Pantzar and Ruckenstein (2014) suggests that people take an interest in personal informatics tools and tracking of their physical activity data as long as it supports and promotes their health related goals. However, existing personal informatics tools have given less emphasis to everyday physical activity and are more geared towards specific physical activity such as dedicated exercise sessions and team sports events. Recent research by Duvivier et al. (2013) suggests that short intense exercise is not necessarily good enough to result in health benefits; rather an individual needs to be active throughout the whole day.

Everyday physical activities such as walking to the office, standing, shopping, and cleaning involve light to moderate levels of physical activity and can contribute to health benefits by burning body fats (Fan et al. 2013). Levine (2002) refers to these activities as non-exercise activity thermogenesis (or NEAT), which is an easy way of turning mundane activities into calorie burning opportunities. Inspired by these studies, I have chosen to support physical activity as it is a popular area of research, and people seem to enjoy using new technology in their physical activity pursuits.

Rationale for choosing heart rate data

I chose heart rate data to represent physical activity because of its popular use to analyse physical activity performance and progress towards a set health goal (Connelly et al. 2006). I also chose to record an entire day's data, and not just the time spent performing physical activity, so that I can present an overall picture of one's active lifestyle. Using heart rate data also allowed me to create novel and very personal material representations of one's physical activity owing to the fact that two individuals with equal physical capacity can have different maximum heart rate and threshold values, creating very different data points for different people. I discussed the finer details of heart rate data with physical activity trainers and looked into how six heart rate zones can be utilised to convey varied information related to physical activity. I briefly discuss the key terminologies such as maximum heart rate, resting heart rate and the heart rate zones in Table 1.

The discussions gave insights into how exercise affects the functioning of the heart. When a novice individual begins to exercise, heart rate increases in proportion to the level of exertion. However, an individual's cardiovascular fitness improves over time with regular aerobic exercise. As a result, a fitter individual would not encounter such rapid changes in heart rate. Rather, the heart rate would stay in a desired heart rate zone for longer. Secondly, fitter people also tend to have lower resting heart rates. The average resting heart rate is 60-80 beats per minute (BPM). To this end, a given exercise (e.g. walking up a flight of stairs) will result in different patterns of elevated heart rate for different people. Heart rate might also increase in response to stress, anxiety and shock. In certain cases, heart rate patterns could also reveal an underlying illness. However, to obtain this level of detailed analysis would require more explicit interventions in one's life and greater logging commitments from participants. Considering these difficulties and following the focus of this work, I chose to explore the playful side of self-monitoring, without going deep into the reasons behind heart rate elevation. This was justified as none of the study participants were deemed unhealthy, neither I recruited serious athletes and runners who exercise extensively every week. The participants of the studies were moderately healthy users who exercise 2-3 times in a week. To this end, the pattern of their heart rate was fairly consistent, except for a couple of participants who observed irregularities in their heart rate as a result of medication and underlying illness. However, I encourage designers of the future systems to pay attention to heart rate values and think carefully while mapping them to material artefacts.

	ZONE NAME	PERCENTAGE OF MAXIMUM HEART RATE
1	Resting zone	Less than 50% of the maximum heart rate
2	Recovery zone	Between 50% to 60% of the maximum heart rate
3	Aerobic zone	Between 60% to 70% of the maximum heart rate
4	Anaerobic zone	Between 70% to 80% of the maximum heart rate
5	Speed zone	Between 80% to 90% of the maximum heart rate
6	Alarming zone	Over 90% of the maximum heart rate

Table 1: Summary of the six heart rate zones

Rationale for choosing home environment

The selection of "home environment" for the studies is fuelled by the engagement opportunities with material artefacts inhibited by the environment. As pointed out by Blythe et al. (2012), home is a major site not only for consumption of media but also for possible production.

This private space leverages new challenges as well as opportunities for product development. Getting a deeper understanding of how a proposed interaction or product will fit into the home ambiance is crucial and can open up possibilities for future designs. For example, the home can facilitate a space for an autotopography (Gonzalez 1995) of material artefacts, and it is also a safer and creative environment for cooking and eating related tasks. In this safe and personal space, study participants can be more imaginative while articulating the uses of material artefacts that embody their physical activity.

From design to knowledge generation

Research through Design projects are increasingly being practiced within the field of HCI. Existing works point out various ways of disseminating knowledge in such design led research. This includes creating design dimensions (Löwgren 2013), design guidelines (Lidwell et al. 2003), annotated portfolios (Gaver and Bowers 2012), strong concepts (Höök and Löwgren 2012) and design frameworks (Löwgren 2013). Löwgren (2013, p.32-33) refers to them as forms of intermediate-level knowledge which occupy a crucial territory between the general theory and designed artefacts. However, translating these intermediate forms of knowledge in practice is always the biggest challenge. In this regard, Hornecker (2010) raise concerns over the lengthy, dense and jargon-laden nature of design frameworks. Similarly, Rogers (2004) invites more "lightweight and accessible" ways of transferring knowledge from design theory to practice. In response, I lean towards using Design cards to make the generated knowledge accessible to design researchers.

Design cards

A deck of design cards is a useful tool for discovering ideas, capturing a diverse set of possibilities for designing in a certain context. Rather than offering strict guidelines or strategies, the deck of design cards acts as a catalyst to stimulate and support divergent imaginations of the designers during the ideation process. Interestingly, design cards do not follow any order - giving more flexibility and freedom to designers to come up with different sequences of design themes as per their preferences. Design cards provide designers with a common vocabulary about a certain context during the ideation phase. The tangibility of design cards acts as a "physical anchor" and helps in generating concrete design knowledge (Bekker and Antle 2011; Deng et al. 2014).

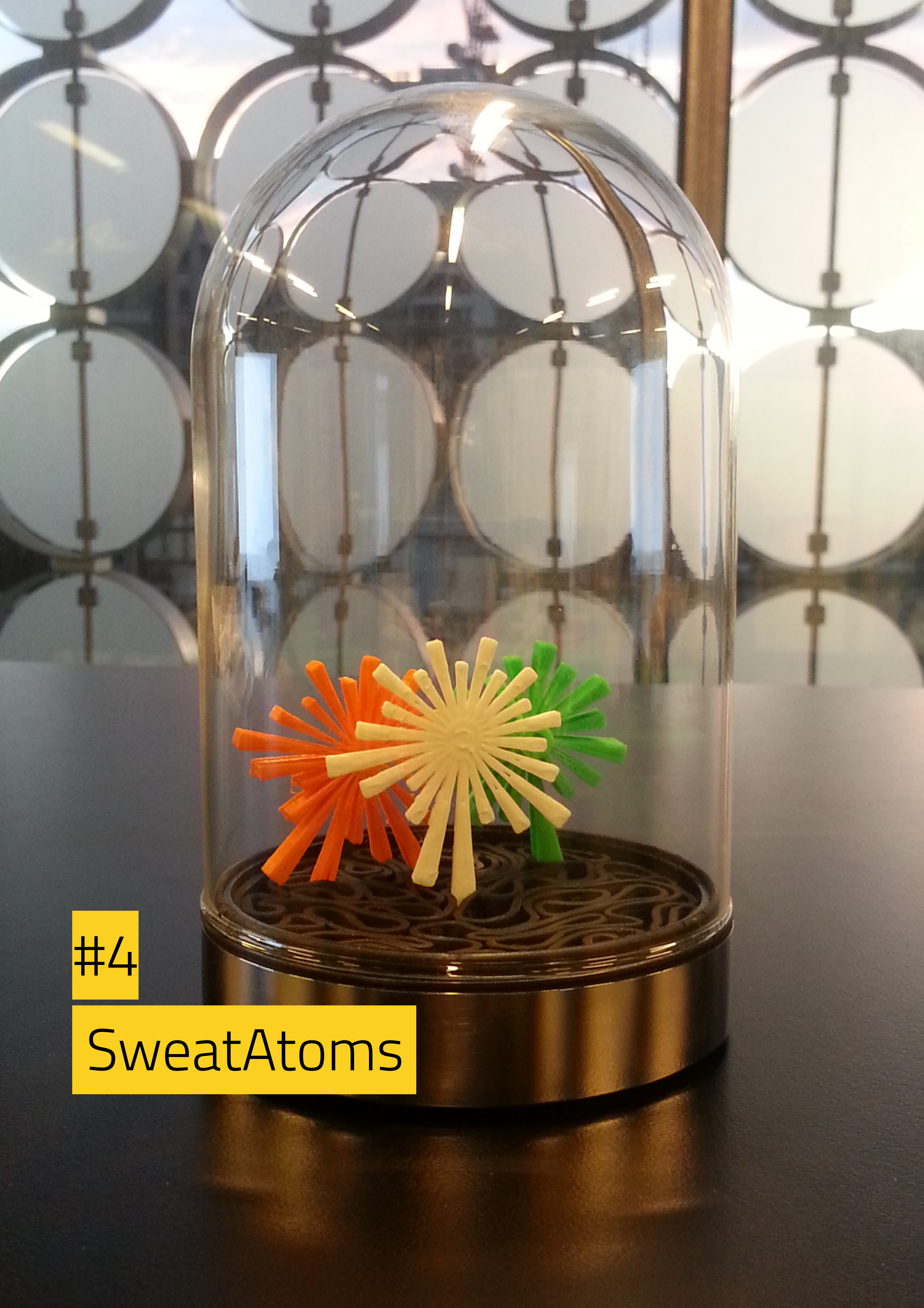
Cards also help in speeding up the refinement and iteration of ideas by keeping the discussion centred on a given design task - making the ideation phase productive (Halskov and Dalsgaard 2006; Hornecker 2010). To this end, cards offer a fun tactile experience of ideating and discussing ideas collaboratively.

Numerous works in the past have looked into card based design tools to support brainstorming and ideation process during the early stages of design research (Bekker and Antle 2011; Deng et al. 2014; Mueller et al. 2014; Hornecker 2010; Lucero and Arrasvuori 2010; Chung and Liang 2016). For example, Mueller et al (2014) created exertion cards that allow the creation of exertion games, while Lucero and Arrasvuori (2010) created PLEX cards for creating pleasurable designs and playful game experiences. Hornecker (2010) created ideation cards for creating tangible interactions. Deng et al. (2014) created Tango Cards to enable the creation of tangible learning games. Halskov and Dalsgaard (2006) created two sets of inspiration cards — Domain cards and application cards — to support ideation of new concepts for design. IDEO (2002) created a deck of 51 cards, where each card illustrates a user-centered design process. Lockton's 'design with intent' toolkit (Lockton et al. 2008) is another deck of cards to influence behavioural change. Finally, Wolfel and Merritt (2013) provide a comprehensive survey of design cards used in academia and practice, whereas *Deckaholic*[6] is a great online library that curates a list of design cards used in practice. Each of these card-based design frameworks allow different perspectives to emerge to support designing for a specific context. I took these works as an inspiration to ground my understanding within the interaction design and to explore an unknown design space of creating material representations. The "form-driven interaction design" framework by Jung and Stolterman (2012) was particularly, influential in grounding my understanding of material culture and framing the key concepts.

Summary

This chapter presented different methods that are utilised to address the research aim of this thesis. Embracing Research through Design approach, I have developed three systems that are discussed in the next three chapters. Each system was deployed at participant's home from where I collected rich qualitative data on their experience with the deployed system. I also utilised qualitative methods to design the framework *Shelfie* that is discussed in Chapter 7.

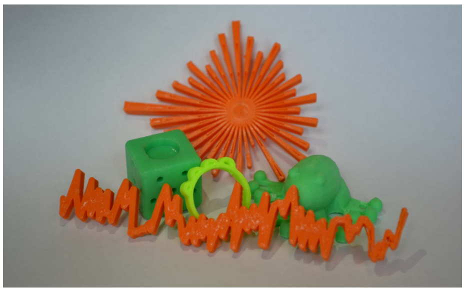
[6] *http://deckoholic.com*



#4 SweatAtoms

CASE STUDY 1

SweatAtoms



Material used
Biodegradable Plastic (PLA)

Process followed
3D Printing

Produced outcomes
Five artefacts: Graph, Dice, Flower, Frog and Ring

Key Publication
Rohit Ashok Khot, Larissa Hjorth, and Florian Mueller. Understanding Physical Activity through 3D Printed Material Artefacts. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14), ACM Press (2014).

Other Publications:

IE 2013; CHI Work in Progess 2013; CHI Student Research Competition 2013

Ethics Approval number:

CHEAN A-2000858-03/13

Public Exhibitions

2013 – ACM CHI Interactivity 2013, Paris France.

2016 – Design & Play, RMIT Design Hub, Melbourne, Australia

This chapter describes the first case study that investigates 3D printed material representations of physical activity data through a system called *SweatAtoms*.

Introduction to this chapter

My first case study looks into 3D printed material representations of physical activity data. I have designed and studied *SweatAtoms*, a novel system that constructs 3D printed material artefacts from heart rate data of physical activity. This chapter describes the system, along with the insights gained from field deployments of the *SweatAtoms* system. I conclude the chapter by discussing the key concepts that emerged from the study and how these concepts sketch out portions of the *Shelfie* framework.

Recent advancements in digital fabrication (Anderson 2010) have made the task of fabricating personalised material artefacts easier, accessible and affordable with 3D printers and laser cutters. According to Gershenfeld (2007), 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 artefacts. Their rapid growth has captured the attention of design and HCI and they are now investigating possible ways of using it to support their design and research processes (Mellis et al. 2013; Buechley and Perner-Wilson 2013). According to Mellis et al. (2013) material artefacts can be useful as design tools and interfaces for online collaboration, for hands-on learning and as personalised items. Additionally, a DIY movement led to a growing interest of people in digital fabrication (Kuznetsov and Paulos 2010).

The growing affordability of digital fabrication (Mota 2011) has prompted me to consider fabricating personalised material artefacts that can provide an alternate testimony to the invested efforts in performing physical activity. I was also inspired by the synergy between the way we exercise and the way a model is 3D printed. I believe the lost energy during the physical activity could be utilised in the 3D printing process to influence and shape the design of a particular artefact.

I also drew inspiration from previous research on archiving and souvenirs, which suggests that the material artefacts can be more cherishable and meaningful than virtual objects because of their higher visibility in the surrounding and low replication value (Golsteijn et al. 2012; Kirk et al. 2011). For example, when a person shares (gives) any digital object with someone, she also retains a copy, which she could later use for herself or even for others. Material artefacts on the other hand feels more unique as the original sender does not retain any copy of those objects once she has gifted them to someone. However, one could argue that with the rise of personal fabrication and easy to use 3D printers, the uniqueness property of the material artefacts can be lost as one can now easily make many replicas of the same object. I address this concern by fabricating material artefacts 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 utilised in the design process of material artefacts, chances are high that resultant material artefacts will bear a unique pattern. Therefore, I argue that these material artefacts will hold more meaning due to its distinctive quality and design for every individual and activities. Motivated by this, I created and studied *SweatAtoms*, which I explain next.

SweatAtoms

SweatAtoms is a 3D modelling and printing system that transforms physical activity data into five different 3D printed material forms. I have utilised the constructive solid geometry techniques (Requicha and Voelcker 1977) to generate 3D designs. These models are then printed using a 3D printer, forming an aesthetic and informative expression of physical activity data in material form (refer Figure 17).

Graph: The first artefact is *Graph*; it mimics a virtual graph. *Graph* takes the average of the recorded heartbeats per minute and represents them as points on an XY space. The plotted points are then extruded along the Z-axis to achieve the suitable thickness (4mm) for 3D printing.

Flower: The second artefact is *Flower*. This artefact unlike *Graph*, captures only the significant (substantial) changes in the heart rate and represents them in a floral pattern. The number of petals in a flower corresponds to observed fluctuations in the heart rate, in the range of +-20 beats per minute (bpm). The length of the petal describes the heart rate value at a particular instance when a rise or fall in heart rate occurred whereas the width of the petal signifies the duration of the fluctuation. For example, an increase in heart rate by 20 bpm for 1 minute will make the corresponding petal longer by 4mm and wider by 2mm.

Frog: The third artefact is *Frog*, which serves as a playful reward for doing physical activity. The size of the *Frog* corresponds to the amount of physical activity done in a day. As such, with an increase in physical activity, *Frog* becomes bigger. The amount of physical activity is calculated based on the number of times a user's heart rate was above the recovery zone (above 60% of the maximum heart rate) successively for at least 10 minutes, in accordance with ACSM guidelines (American College of Sports Medicine 2013).

Dice: The fourth artefact is *Dice*. The six faces of the *Dice* represent the six heart rate zones. Each face of the *Dice* has a central hole, where the diameter depicts the amount of time spent in that particular heart rate zone. For example, if a user has been sedentary for most of the time, then the central hole of the face that represents the 'Resting' zone will be widened, whereas if the user has been highly active with a heart rate value constantly above 80% of the maximum heart rate, then the central bubbles of the faces corresponding to the "Anaerobic" and "Speed" zone will be widened in diameter.

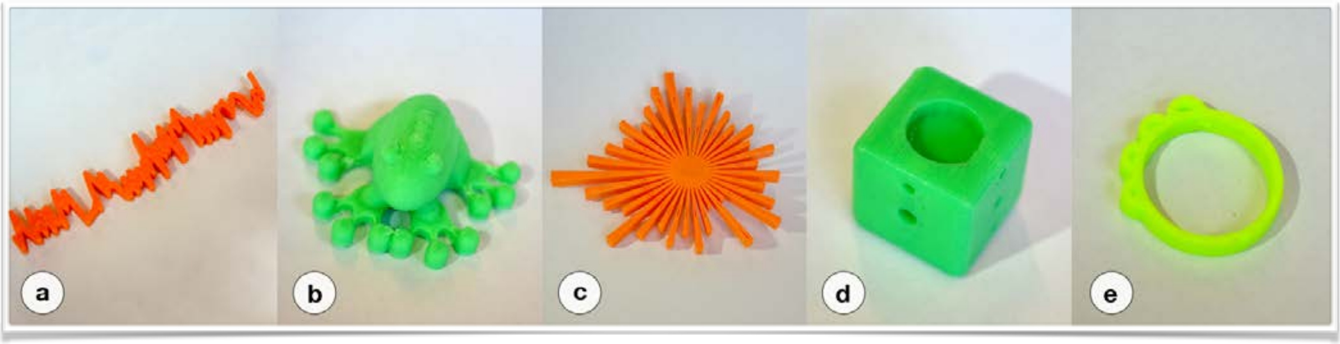


Figure 17: Five 3D printed representation of physical activity: a) Graph b) Frog c) Flower d) Dice and e) Ring.

Ring: The final artefact is *Ring*, which can be worn on a finger and offers a summary of how active a user has been during the day. The circles around the *Ring* denotes the number of hours of recording heart rate data, whereas the diameter of each circle corresponds to the amount of physical activity done in that particular hour. Again, the amount of physical activity is measured in terms of duration where the heart rate was successively above the recovery zone for at least 10 minutes.

Table 2 gives a summary of the maximum dimensions and the average time required to print each of the five artefacts.

	REPRESENTATION	MAX. DIMENSION IN MILIMETERS	AVG. PRINT TIME IN MINUTES
1	Graph	120 × 80 × 4	20 minutes
2	Flower	40 × 40 × 4	25 minutes
3	Frog	20 × 20 × 20	30 minutes
4	Dice	16 × 16 × 16	35 minutes
5	Ring	20 × 20 × 4	10 minutes

Table 2: Summary of the selected five representations in terms of maximum dimensions and average print time

Design process

The design process involved an investigation into the design space surrounding material representation, 3D printing and physical activity. To help me explore each of these design spaces, I held regular meetings with design experts in each of the above-mentioned areas. For example, I had lengthy discussions with two junior level interaction designers (1 male and 1 female) and three senior contemporary artists (1 male and 2 female) on possible representation choices. I also talked to an expert (1 male) in the field of 3D printing, who had been prevalent in the field for at least two years, to identify the current limitations and possibilities of state-of-the-art 3D printers. Finally I also spoke to three designers of exertion games (3 male, 1 senior and 2 junior) as well as two physical activity trainers (2 male) to identify the aspects of physical activity that could be highlighted in a material form.

Choosing the input: heart rate data of physical activity

I chose heart rate data to represent physical activity as heart rate data is commonly used to analyse physical activity performance and progress towards a set health goal (Benson and Connolly 2011).

I discussed the finer details of heart rate data with two physical activity coaches to uncover interesting patterns and insights on physical activity routine. They suggested the use of heart rate zones to convey different aspects of physical activity. For example, they suggested that the resting heart rate is a good indicator of a user's physical in-activity, hence, highlighting it in the design of a material artefact could make users aware of their sedentary lifestyle. For example, I chose the *Dice* artefact to denote the time that users spend in each of the six heart rate zones each day (explained further below).

Choosing the five designs

I ran a one-hour brainstorming session with five interaction designers to help me in selecting the final designs for my chosen material artefacts. I used 25 artefacts in this session in total in order to aid the discussion. Some of the artefacts were 3D printed and some of them were off the shelf products as shown in Figure 18. Additionally I also employed the following five design strategies, inspired by Consolvo et al. (2009) to finalise the designs:

Abstract and reflective: The material representation should reflect crucial aspects of physical activity but in an aesthetically pleasing way. Supporting this, I chose *Frog, Flower, Dice* and *Ring* that the designers believed metaphorically represented key information about user's physical activity. Additionally, the displayed data was abstract in nature, and would require help from the wearer to unlock its meaning to others.

Public: Users should be able to wear the artefact or keep them on display in their home. To achieve this, all artefacts from the *SweatAtoms* system had some inbuilt utility. For example, *Flower, Graph* and *Ring* can be worn as jewellery, whereas Frog and *Dice* can be displayed as in home decorations.

Unique: Each artefact should appear unique and differentiable from the rest of the artefacts. To support this strategy all chosen designs were distinct and personalised for each individual due to their unique heart rate pattern.

Figure 18: 3D printed and off the shelves artefacts were used during the ideation process.

Positive: The material artefact should be a positive reinforcement for doing physical activity. To support this strategy I set a default minimum size for each artefact and users received all five artefacts from the *SweatAtoms* system - irrespective of physical activity undertaken by them during the day.

Choosing the digital fabrication process

My motivation behind using a 3D printer to create these artefacts stems from the synergy I see between exercise and 3D printing. Exercise involves the expenditure of energy without any material gain. 3D printing, however, follows an additive manufacturing process whereby a material artefact is created by additively depositing plastic layer by layer on top of a print bed. Therefore, the idea of combining the two came to my mind.

I looked into current 3D printer technology in order to understand their limitations and capabilities to print different shapes. For example, I realised that the current printers are not capable of printing complex shapes, which limits possible representation choices. Additionally, I also considered the printing time, which increases with the complexity and density of a selected shape. I also took into consideration the environmental sustainability by using biodegradable plastic filament (PLA) to create these artefacts.

SweatAtoms in action (field study)

I conducted an "in the wild" study (Rogers 2011; Brown et al. 2011) to understand the impact of material artefacts on the behaviour and experience of individuals engaged in everyday physical activity. Given the exploratory nature of this design work, I leaned towards the idea of "in the wild" studies that aim to encourage reflective thinking about a system and where the focus is on gathering a rich set of opinions.

Recruitment

I deployed the *SweatAtoms* system across 6 households in Melbourne, Australia for a period of two weeks and participants were recruited using the snowball method (Biernacki and Waldorf 1981). In most cases for each household one person participated in the study, however, in one instance two participants – Frank and Kate (names changed to preserve anonymity) – participated together. There were 4 male and 3 female participants in total, aged 26 to 52 years (average 34 years). The sample size was in line with previous studies (Lee et al. 2015; Gaver et al. 2013; Odom et al. 2014; Brown et al. 2011). On the first day of the study, we asked the participants about their level of physical activity in a typical week and the kind of physical activities they do on regular basis. Figure 19 describes participants' demographics along with their self-stated level of physical activity per week. Low physical activity corresponds to 1-2 days of physical activity per week while medium activity corresponds to 3-4 days of physical activity per week. A high level of physical activity is when participants engage in physical activity for more than 4 days per week.

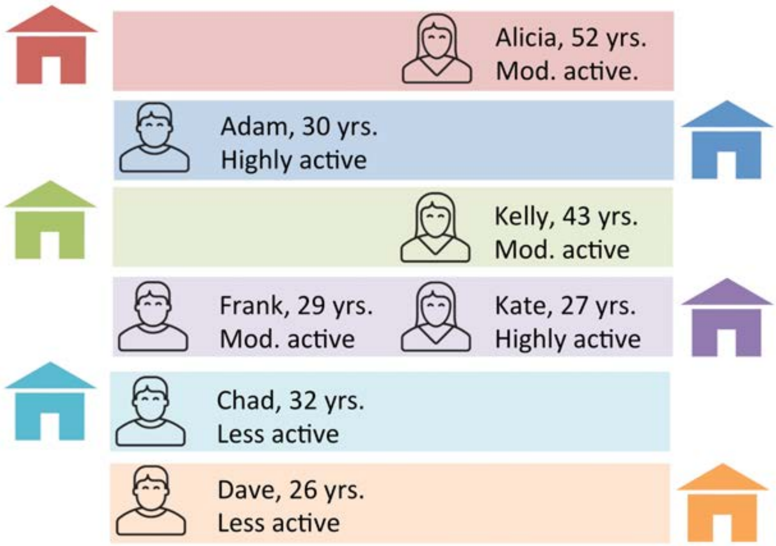


Figure 19: Demographic details of the study participant along with their level of physical activity. Mod. active means moderately active

Setup

Each participant received a heart rate monitor (Polar H7), an iPod Touch (5th generation) with the installed Polar Beat application and a Cube 3D printer[7] with 2-3 PLA plastic filament tubes as printing material. The heart rate monitor was paired up with the iPod using the Bluetooth low energy protocol. Following the cultural probing practice, I also provided diaries and asked participants to use them to reflect upon their experience with the system. Participants were not compensated for participating in the study.

Procedure

On the first day of the study, I installed the *SweatAtoms* system in each different household. I introduced the participants to the system, study procedure and explained the meaning of each artefact. As my intention was to make the printer a part of the home I placed the printer in the home according to the participants' wishes, noting the location.

[7] *http://www.3dsystems.com/shop/cube*

I also went through the process of printing one artefact to make participants familiar with the printing process. I then interviewed participants about their daily routines in terms of physical activity. I also provided every participant with an A4 poster detailing the study steps to be followed as shown in Figure 20. Participants were requested to perform the following tasks on each day of the study:

Tasks in the morning

I asked the participants to wear the heart rate monitor and start recording their heart rate data using the Polar Beat application, installed on the iPod. Participants then continued their daily routine as usual whilst the monitor was recording. It was not explicitly required for participants to be overtly physically active during the day, rather the monitor would record their regular activity. and thus I asked the participants to follow their normal routine.

Tasks in the evening

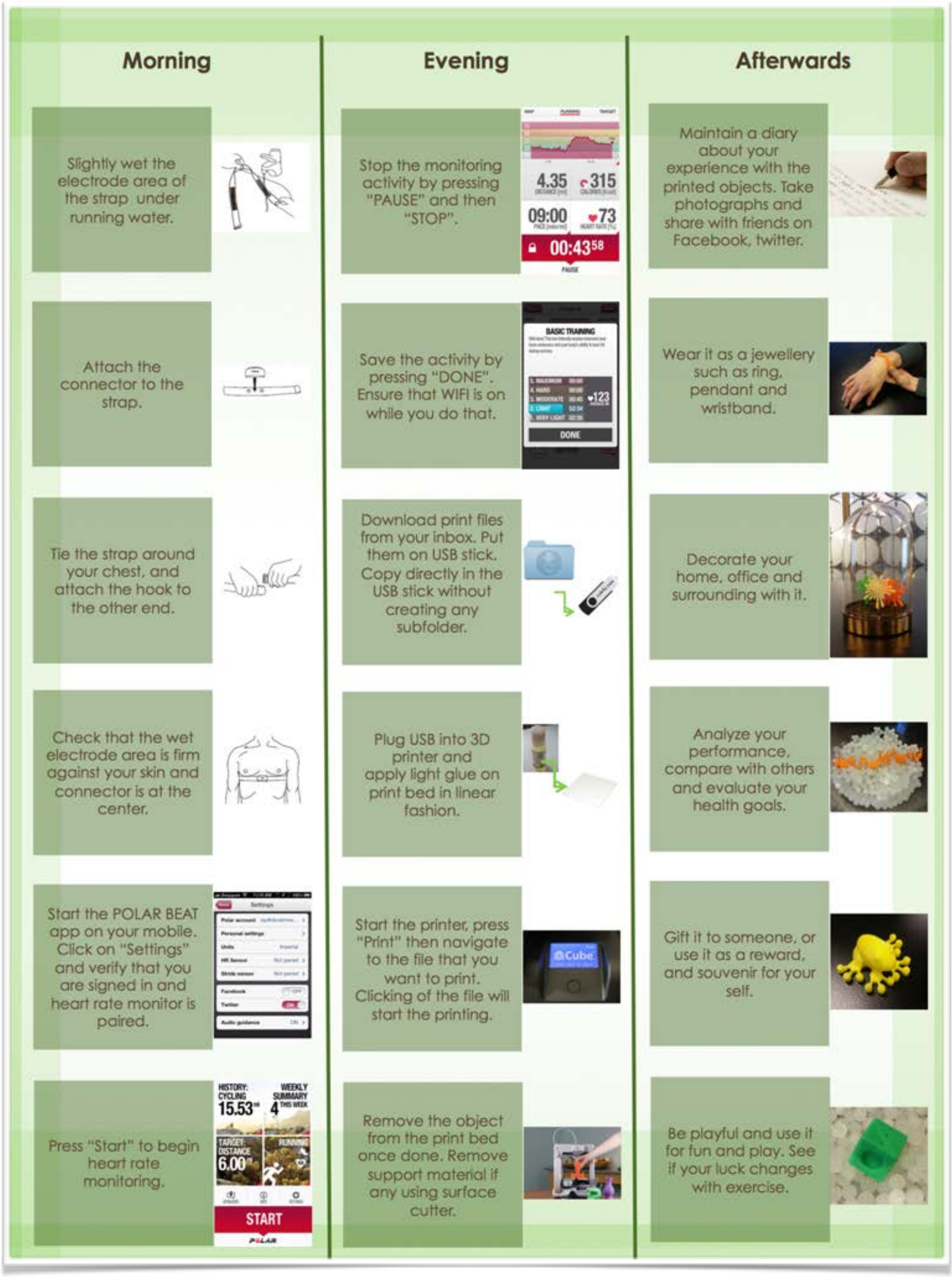
I asked the participants to stop the Polar Beat application and to take off the heart rate monitor in the evening (usually around 5-7 pm). Once the heart rate monitor was stopped the recorded data was sent automatically to the Polar website. I then downloaded and parsed the data to generate five material representations in the Stereo- Lithography (STL) format. Due to the taxing nature of the study, I did the conversions for the participants. I then manually converted the STL files into the required print file formats (.cube) and emailed the converted files back to the participants.

To print the material representations, participants were required to copy these files onto a USB stick and print them one by one by attaching the USB stick to the 3D printer. The printing time varied for every object based on the participants' level of physical activity (and thus the object size) every day, but typically took around 90-120 minutes to print all five objects.

Data source

To gain insights into the underlying motives and experiences of the participants I asked the participants to maintain a daily diary. I visited each household twice (on the first and last day of the study) and spent around 4-5 hours with each participant. Based on the participants' needs (such as difficulty in running the 3D printer), I visited two houses more frequently.

Figure 20: Detailed instruction sheet was printed as A4 sized poster and given to each participants.



Additionally, I was in contact with each participant through emails and phone calls if they needed help. At the end of the study, I conducted semi-structured interviews with each participant that lasted around 40 minutes. In the conversations, I focused on how they used the *SweatAtoms* system and gathered their thoughts and experiences with it. I also took notes and recorded audio to aid the analysis.

Findings

The deployment of material artefacts representing physical activity not only led to identifying new insights and opportunities, but also raised some interesting questions. Below, I describe my key findings from the deployment of the system across five key sections.

Intervention

The size of the 3D printer was key to finding an appropriate place within the household. Most participants usually placed the 3D printer in their living room space, close to a window or vent to reduce the potential print smell as seen in Figure 21.

Figure 21: Participants tried to make the 3D printer fit into their home ambience by placing it on a desk or next to the window.

Smell was another reason why placement was near a open ventilation (window).

Alan (name changed), however, kept the printer along with his other tech gadgets in a separate room. Kate was particularly happy with the size of the printer as it fitted nicely into an empty window space. Interestingly, Kelly considered the printer as a precious part of her household and kept the printer on a table near to an open window. In order to conceal the printer's appearance from the outside world, Kelly also surrounded the printer with cardboard to prevent theft. The printer worked smoothly for the entire study duration in all households except one. At Alan's house, the printer was not aligned properly so I had to realign it by changing the offset (where it prints) and change the filament, I had to recalibrate the print offset and replace the print filament.

Relating to physical activity

The second set of findings discusses participant's reactions to material artefacts in relation to their physical activity.

SweatAtoms raised awareness about physical activity

Most participants became more conscious about their physical activity routines and started to take their heart rate data more seriously with time. Alan said: "*I used to see my heart rate data on my mobile, but this is different, now I can not only touch and feel my data, but I can also show it to the world, I care more about my heart rate now.*" Alicia confirmed: "*My trainer was so happy to see my progress, thanks for letting me participate.*" This supports findings from previous research where participants gained awareness about themselves from a visualisation method (Li et al. 2010; Fan et al. 2012).

Interpreting artefacts was difficult at first but improved with time

Besides understanding their physical activity levels, participants also tried to understand their daily routines from the printed material artefacts. Frank said: "*It was great to know about the self and my activities throughout the day from the printed artefact (Graph): when I went to university, when I came back (by looking at large peaks in the graph) when I sat idle (by looking at lower peaks)*".

However, Frank and Alicia initially had difficulties in interpreting the *Flower*. Alicia thought the *Flower* was like a clock that shows her physical activity of the entire day. Referring to a large petal in the *Flower* she said, "*I can see that my heart was really pumped around 2 pm when I had to rush twice to the office for urgent work*." After discovering that the *Flower* does not work like a clock, she felt slightly disappointed and suggested if I could update the *Flower* design. Kelly and Chad expressed the need of designing artefacts that are easier to interpret, similar to the *Frog* artefact.

Increased motivation and interest in physical activity

Although this work did not target an immediate behavioural change among the participants, there was anecdotal evidence of increased physical activity amongst all participants. For example, Alicia and her fitness coach both were happy to see increased physical activity. She wrote to me in an email, presented in Figure 22: "*I am out on my bike and am aware of my heart. In the past, if I exercised on Saturday I would have said that I deserve to rest on Sunday :)*" Dave resumed his weight training routine after a long period to see the routine reflected in the artefacts. He mentioned: "*It's been ages since I did weight training but now this study prompted me to start weight training again*". I find these examples illustrative of people's rekindled interest in physical activity. Kelly emphasised that "*It's the Frog, that makes me jog more*", while Frank and Kate said that they did more physical activity to get a bigger *Frog* artefact at the end of the day.

Personalisation and tangibility was important

During the follow-up interviews, I asked the participants what difference a material artefact made over the virtual counterpart. Most participants answered positively that the physical form and the support for sensory capabilities like touch and feel make the material artefacts more special than the virtual ones.

Kate added that "*[on a mobile phone] You look at your heart rate and then forget about it, here [addressing the material artefact] you cannot, it is more persistent*". Participants also mentioned that they care more about these artefacts because they contain their personal data and are printed on them at home. Referring to the *Flower* and *Graph* artefacts, Kate mentioned, "*This is me and my data, you cannot get this form in the market*."

Accommodating the SweatAtoms system

Frank bought a box to keep all his *SweatAtoms* together (Figure 23) while Kelly utilised the envelopes of promotional campaigns to keep objects sorted according to each day.

Figure 23: Frank bought a box to keep all his SweatAtoms together.

I found it noteworthy that a participant went out of their way and bought a box, as I had not previously seen such commitment in some of my prior work with participants. Other participants gave some of the artefacts away to their loved ones or arranged them as decorative pieces in different corners of their household.

Figure 22: SweatAtoms encouraged participants to do more physical activity.

For example, *Frogs* were placed on top of the home computer's desktop screen (Figure 24), while *Flower* and *Dice* usually occupied a table space in the living room. It was encouraging to see that participants took an interest in correlating and arranging the objects together (Figure 25). All participants were happy with the selected design choices for representing their physical activity.

Figure 24: 'Frog' was the favourite artefact and it usually occupied a space on top of the desktop.

Engagement with heart rate monitoring

Participants felt that heart rate was an appropriate measure of representing their physical activity. Five participants were curious to see how their physical fitness was reflected in the artefacts at the end of the day while the remaining two participants tried to confirm whether the artefacts correctly portrayed their exercise intensities and duration. Two participants had previous experience of wearing a heart rate monitor, but stated that although they had never worn the monitor continuously for 8 hours, doing so was not a big problem for them. Four participants, however, felt a little uncomfortable in wearing the heart rate monitor continuously and they wished for a better and less restrictive way of recording data.

Engaging with the 3D printing process

Most participants printed artefacts every night before going to bed, although two participants skipped printing on a couple of days, choosing to bulk print on the weekend instead. All participants were excited initially to see the printing process, however, their interest in watching the print process faded over time. Frank mentioned, "*In the beginning, it was exciting to see how objects are being printed in different sizes, small, big, it felt like a recap of my physical activity, sometimes really intense and sometimes not so much... but later on it became too time consuming*." He further added that he would prefer to have objects delivered to him in a mailbox rather than doing the printing at home daily. Kelly and Chad also pitched the same idea. Alan on the other hand got excited about 3D printing and tried to learn more about the printer's capabilities and current trends in 3D printing. All participants enjoyed the process of changing colours of the plastic filament and wished they had more colours to choose from. Participants were also satisfied with the size of the artefacts although Kelly wanted to print bigger *Flowers* so that she could use them as coasters.

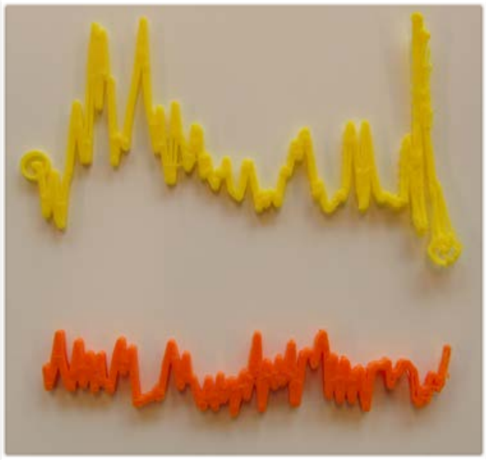
Four participants, however, did not like the idea of printing objects every day; rather, they wished for a more flexible printing schedule. For example, Chad added: "*I should be able to choose when and what data I can print*", while Frank and Kate inquired: "*Can we print an object representing heart rate from both of us?*"

Engaging with the artefacts

The participants had several ideas about how to use the printed artefacts (refer Figure 26). The *Frog* was the favourite artefact and all participants suggested they were affectionate with it. Participants particularly liked the idea that they get a bigger *Frog* if they exercised more.

Figure 25: Participants arranged their artefacts according to the day and were amazed to see how their shape differed based on the activity done in a day.

Kelly felt "*It was like burning your body fats and putting them on the frog*". The majority of the participants kept frogs stacked on top of their computer screens or near to their working desks. The *Frog* also initiated a healthy competition between Frank and Kate, who tried to do more physical activity than the other in order to get a bigger *Frog* in return.



Flower was appreciated for its aesthetic qualities

Four participants found the *Flower* artefact aesthetically pleasing and mentioned to me various ways of incorporating it into their everyday life.

Alicia felt that she could wear them as earrings. Dave, on the other hand, was interested in an idea of an activity flower garden.

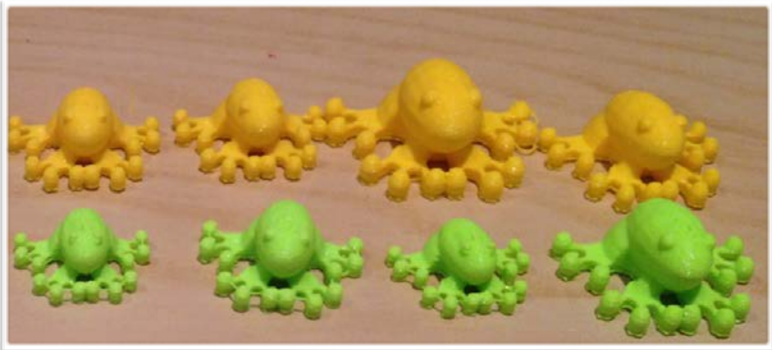


Figure 26: Each artefact highlighted a different aspect of engaging with one's physical activity data.

Graph provided insights into the day's activity

Alan liked the *Graph* for its informative qualities. He particularly enjoyed the frequent high and low peaks in the *Graph* showing how active his work life is. Chad stacked all his *Graph* next to each other, to compare and contrast his progress towards a set fitness goal. Chad had a great physical workout session on one day of the study. Looking at the printed artefacts of that day, he happily said: "*I am going to cherish today's graph [...] see how dynamic it is [...] I would put it on my shelf to remind me that I did well.*" Interestingly, Frank and Kate had different views about the *Graph*. Kate mentioned "*The graph is not very exciting as we can see the same on a screen. It would be like printing something that we have already seen. I don't like that.*"

He placed all of the *Flowers* next to each other on a desk to create the appearance of a garden. Kate, who thought of using the *Flower* for decorations said: "*I am going to fill a glass bowl with water and then I will put candles on these printed flowers and let them float on the water surface - it would make a great decoration for my house.*"

Ring and Dice offered insights but they were less appreciated

Three participants found the *Dice* informative as it made them aware of their sedentary lifestyle. Kate was particularly unaware of the time she spends sitting each day and the *Dice* artefact communicated this information to her. Noticing her sedentary life, she said positively that she would not continue sitting for long hours and would take frequent breaks for walking or standing during the day. The *Ring* artefact however was less appreciated as participants felt it did not convey much meaning to them. Moreover, participants also questioned its utility. Dave replied, "*One has only 10 fingers, [...] how many rings can he wear?*"

Conversations around artefacts

Many participants showed their printed artefacts to neighbours and visitors to their home. Dave, for example, created a clock using all his printed artefacts as shown in Figure 27. He hung it on the wall of his study room. Interview data suggested that artefacts generated a sense of curiosity and sparked conversations among the visitors who did not know what the design represented. Participants were enthusiastic to explain the meaning of the artefacts to the visitors. Kate, for example, does voluntary work for young girls at a school on weekends, and at an annual science and technology event of the school, which happened during the first week of the study, she enthusiastically spoke about the system to the girls. She said that she plans to give some artefacts to the girls "*as a token of her heart*". Chad similarly gave a few of his artefacts to his mom and sister who came to visit him one day during the study.

Figure 27: Dave created a clock with all his SweatAtoms. This clock prompted conversations among visitors to his house.

Alicia is planning to incorporate the system into her IT services office. She says: "*I would like to use an approach like this for a reward and recognition program that we are starting. We were thinking about giving out big stars but that is lame in comparison with these personalised 3D trinkets. I also liked the idea of rewards getting bigger with an increase in the physical effor*t."

Issue of sustainability

Four participants raised issues of sustainability and pondered over the utility of objects in their life. For example, Kelly asked what would she do with so many artefacts if she keeps on printing them each day. Three participants wished for a provision to recycle these artefacts. Frank and Chad had a common suggestion of making them all interlock with each other to create a bigger sculpture. Kelly put forward the idea of Lego bricks to construct a skyscraper of physical activity over time, while Dave suggested printing of the objects only on specific days.

Printing noise and smell was unpleasant

As most participants kept the printer near a vent or open window, there were no complaints about the plastic smell in general but the smell was considered unpleasant; however, Frank and Kate commented about the lengthy and noisy printing process, which was affecting their studies. As a result, they moved their study activity to a different room while the printing was taking place.

Discussions

3D printing was new for all the participants, although all of them had heard about it. I have worked with the vision that in 10 years time, most people will have a 3D printer in their home just like a 2D printer today, and therefore, I intended to explore the future interactions associated with today's technology. Although further studies are needed to understand any novelty effects, this interview data suggests that participants' interest in the printing process faded over time; however, participants' interest in the artefacts appeared to have persisted over time. Participants mentioned that the objects matter to them because they reflect their personal data and activities, making them unique, as they cannot be "*bought at a market*" as mentioned by Kate. Furthermore, the statement made by three participants that they would rather get the objects delivered to them in the mail rather than printing them at home (to avoid the printing noise), further suggests that the participants were able to differentiate between the appeal of 3D printing and personalised 3D artefacts. These anecdotes illustrate the fact that giving a physical form to the ephemeral experience of physical activity can facilitate a deeper engagement with the data. In addition, personalised material rewards also prompted physical activity amongst people who otherwise were spending time being sedentary.

Designers can also learn from the *Frog* design to map a similar reward structure into their designs. For example, the participants welcomed scaling the size of an artefact as a reward for the invested effort in physical activity. Participants took an interest in decorating their homes with the artefacts.

These artefacts also became a topic of conversion. The *Frog* also prompted healthy competitions among participants for getting a bigger *Frog*. These narratives suggest that personalised artefacts if designed carefully, have an ability to extend engagement with physical activity. Although participants appreciated the aesthetics of artefacts, their utility as well as sustainability was equally important.

Following are four key themes that emerged from analysing the study findings.

Importance of aesthetics, utility and context

Miller (2008) argued that individuals like to express themselves with material artefacts that embody their lives, personalities, emotions, and achievements. Similarly, study participants expressed themselves by placing the *Frogs* on their computer monitors and decorating their home with *Flowers*. Such an arrangement of material artefacts as physical signs to spatially represent the identity of an individual is called "autotopography" (Gonzalez 1995). Material artefacts such as *Frog* and *Flower* were not only readily displayed in participants' surroundings (Figure 26) but they also served as a memory landscape to the participants triggering reminiscence about their physical activity and events that happened during the study. As such, this study supports the theory of autotopography.

Interestingly, autotopography was driven mainly by the aesthetic rather than the embodied information in the artefacts. For example, the *Frog* was readily displayed in the home ambience despite containing very little information about an individual's activity; in contrast, other more informative models like *Graph* and *Dice* did not become a part of people's home ambience except for Chad, who placed his *Graph* on the living room wall for public display to cherish his best workout day. Designers, therefore, should consider building artefacts that are easy to interpret, although the embodied information can be as little as "*Today, I did more physical activity than yesterday*".

Importance of personalised rewards

Participants liked getting artefacts at the end of the day as a reward and a testimony to their invested physical efforts. It seemed that material rewards could contribute to an increase in physical activity for a couple of participants. Participants enjoyed how the *Frog* grew based on their physical activity and they did more physical activity to get a bigger *Frog*. Participants appreciated this scaling, even though a bigger *Frog* required more printing time. I believe that the perceived value of the artefact among the participants also increased with the time they waited for it to get printed. Therefore, in future works, it could be interesting to examine the relationship between printing time and size of the reward.

In this study, participants also liked these artefacts not only because they were "*cute*", or tangible in nature, but because they embody their own physical activity data and represent their past activities. Participants often discussed with their families and visitors during the study how these artefacts made sense in their life. The fact that these artefacts make a unique and authentic self- representation in material form and something that they cannot purchase from elsewhere appears to be a key factor behind the liking of these artefacts. As a result, I see further opportunities for using material artefacts as personalised and unique rewards for being physically active.

Importance of material and its lifetime

Despite the use of biodegradable plastic material (PLA) for digital fabrication, participants raised the issue of sustainability and wished for the material or a system for easy recycling. One way to deal with the issue could be in terms of selective printing, i.e. letting participants choose and print data on selective days or for special events. Another way could also be with the use of temporal or edible materials. Taking inspiration from this finding, I built a prototype system that creates 3D printed personalised chocolates from the measured heart rate data of physical activity. This system is discussed in Chapter 6.

Importance of the printing process

In this work, I particularly supported a delay in feedback for participants' physical activity. Rather than seeing the heart rate on a phone or a watch whilst performing a physical activity, I chose to make users wait to see how their material artefacts from the day's physical activity would look. The slow fabrication process also contributed to the delay. This waiting was sometimes frustrating for the participants but it also made participants felt rewarded and raised curiosity and sparked conversations over the outcomes. In recent times, efforts were being made to tackle the slowness of 3D printing and make the digital fabrication process more efficient (Mueller et al. 2014). In contrast, I would like to suggest design researchers embrace the slowness to support a delayed feedback on physical activity as a useful design resource. Moreover, designers should make the process of creating material artefacts engaging to sustain user's interests. The second case study, *TastyBeats* looks into one possible way of making the process more engaging by the use of interactive water fountains.

The above themes were fundamental in shaping the final *Selfie* framework explored in Chapter 7.

The next two case studies build upon this work. Particularly, I tried to investigate whether changing the material and the process of creating material artefacts would support these themes or whether new themes would emerge as a result of it.

Conclusion

In this chapter, I introduced a novel system, *SweatAtoms*, that creates 3D printed material artefacts of physical activity data. With the deployment of the system *SweatAtoms* through an "in the wild" study, I explored how participants' relationship to physical activity can be affected through the design of material representation. I hope that this work inspires different ways of reflecting upon material representations, especially in the context of physical activity and sensing technology.

I also encourage design researchers to consider and incorporate digital fabrication in their HCI design practice: in particular, designers should consider not only trying to print things that already exist in the material world, but rather consider that there is an opportunity to print things from data that exists only in the digital world, such as heart rate. I also foresee an opportunity of having personal 3D printers at home, as these printers can produce unique material artefacts that are never as good as coming from large fabrication houses, but offer more personal representations of one's life. In the future, I envision people crafting their world with moments from their lives, using data that was previously only seen in digital form but is now re-entering their physical world in a material form.

After the first case study was completed there were multiple research direction in which to continue my work. My initial inclination was to explore shape-changing interfaces (Rasmussen et al. 2011; Yao et al. 2013). With this idea I would create dynamic material artefacts that change shape in accordance with an individual's physical activity. As I was exploring different ideas for the potential design and material I could use in this prototype, I became aware of and more interested in the medium of food as an interesting design material for creating material representations of physical activity. Because of the crucial role food plays within the human energy cycle, exploring food based representations for physical activity data seemed uniquely appealing. The next two case studies take my work forward by introducing consumable material representations based on my explorations with food as a design medium. The next chapter describes the first case study that uses sports drinks as a material to represent physical activity data.

#5

TastyBeats

CASE STUDY 2

TastyBeats

Material used
Sports drink and water

Process followed
Interactive water fountains

Produced outcome
Personalised sports drink

Key Publication
Rohit Ashok Khot , Jeewon Lee, Deepti Aggarwal, Larissa Hjorth, and Florian Mueller. TastyBeats: Designing Palatable Representations of Physical Activity . In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15).

Other Publications

TEI 2015, UIST 2013 Student innovation contest

Finalist at Premier Design awards 2015

Ethics Approval number:

CHEAN A 0000018602-04/14

Public Exhibitions

2014 – ACM CHI Interactivity 2014, Toronto Canada.

2015 – IIT Bombay TechFest, Mumbai, India

This chapter describes the second case study that investigates the use of drinkable fluids to create material representations of physical activity data through a system called TastyBeats.

Introduction to this chapter

This case study is the first of two explorations on consumable material representations of physical activity. This work extends my previous investigation on the *SweatAtoms* system where I designed and studied the use of 3D printed plastic artefacts to represent physical activity. In this case study, I introduce "palatable representations" that turn physical activity data into an appetising sports drink. Palatable representations expand the view of visualising physical activity beyond the screen by providing not only a real-time and interactive fluid based visualisation of heart rate data, but also a representation that can later be consumed. Palatable representations involve the use of drinkable fluids such as sports drinks to represent physical activity data.

Since intense physical activity sessions can cause loss of body fluids, sports drinks can help in the recovery of such body fluids (Swaka et al. 2007). However, I am also aware that the human energy-cycle is much more complex as the literature on exercise and nutrition suggests (ibid), I therefore do not portray that a created sports drink exactly matches the energy expended during an hourly exercise, for instance. Rather my interest in the sports drink is driven mainly from the experiential angle.

As a proof of concept, I have designed a system called *TastyBeats* where one or two participants engage in a fluidic spectacle of creating an energy sports drink that matches their heartbeat patterns. *TastyBeats* provides an interactive representation of a person's heartbeat in the form of an energy drink created by mixing different flavours.

Rather than simply mixing different flavours based on one's efforts, I see an opportunity to create a fluidic spectacle that celebrates the experience of being physically active. Additionally, a fluid fountain is more public and visible and can also be touched, explored, and even tasted; thus supporting some of the essential aspects of material representations as discussed in Chapter 1 and 2. As a consequence, I also believe that such a public display of physical activity data could reveal new aspects of engagement.

Fluidic Interfaces

To the best of my knowledge, there has not been any exploration on using fluids to represent physical activity data. However, past works however have explored fluids for creating novel interactive experiences. The most popular example of a fluidic interface is a public spectacle in the form of a choreographed musical water fountain, the "Fountains of Bellagio"[8] Similarly, the "Data Fountain"[9] shows relative currency rates using a water fountain display. Within academia, Wanatabe (2007) created a system called "Vortexbath" that utilises tangible interactions with water in common areas like kitchens and toilets to enable playing videos and browsing photos on a water-based interface. Mine et al. (2011) worked on a similar idea to control the interaction of multiple video streams through the physical mixing of water. In other works, Richter et al. (2013) designed water jets for providing tactile feedback on virtual touch screen elements, while Sylvester et al. created a "Soap Bubble Interface" (2010) to control sounds and room light.

Fluidic interfaces have also been used to support interactive play experiences. To begin with, Geurts and Vanden Abeele (2012) created splash controllers that manipulate water flow within a receptacle for interactive play. Peres et al. (2005) created different water games to encourage children to play together. "Water Ball Z" (Hoste and Signer 2014) is a virtual fighting game where children and young adults 'fight' each other in a virtual world using water streams. Additionally, Mann designed various fluidic musical instruments such as the "Water Hammer piano" (Mann et al. 2011) and "Hydraulophone" (Mann et al. 2006) for interactive entertainment, where user interactions with water create musical tones. The Student Innovation Contest at UIST (2013) also featured various fluidic interaction possibilities developed using the Pump Spark water fountain kit (Dietz et al. 2014).

These works illustrate the potential of fluidic interfaces for creating engaging experiences, yet there has not been much work on using fluids to represent personal data, which I consider as a missed opportunity. Inspired by this opportunity, in this chapter, I propose *TastyBeats*, which is an interactive system that utilises heart rate data of physical activity to create a personalised sports drink. The system is described in the next section.

TastyBeats

TastyBeats is an interactive system that transforms heart rate data of a physical activity into a personalised drink, using a fountain-based interaction that not only provides visualisation of physical activity but also turns the preparation process into a spectacular event.

Setup

The *TastyBeats* setup includes a central glass and four containers (Figure 28). Each container contains a food graded water pump (2015) fitted at the bottom of the container, which shoots drinks from the containers into the central glass.

Figure 28: TastyBeats is a water fountain based system that creates a fluidic spectacle of mixing sports drinks based on heart rate data of physical activity.

[8] *http://www.bellagio.com/en/entertainment/fountains-of-bellagio.html*

[9] *http://www.koert.com/work/datafountain/*

These pumps are driven by an Arduino Uno micro-controller[10].

Working

For clarity, I explain the working of the *TastyBeats* system in two parts. In the first part, I explain the mapping of heart rate data to different drinks, while in the second part I describe the dynamics of the fluid spectacle as facilitated by the pumps.

Part 1: mapping heart rate to different fluids

I first divided the measured heart rate values into four zones based on the intensity level of physical activity. I have followed Fletcher's classification of physical activity levels according to heart rate values (2001), however, I have adjusted the range of values slightly to suit the proposed interaction. For each zone, I assign a drink of different flavour and colour as explained below. In the prototype, I have used Mio[11] liquid enhancers for preparing the drinks because they contain zero sugar and zero calories. Therefore, drinking such drinks may not add any calories to the body. In addition, these drinks come in a variety of tasty flavours.

1) Low activity zone: Water

The first zone describes activities where the user is mostly sedentary or performing a light physical activity such as standing and walking. This zone corresponds to a range of heart rate values varying from 60 to 95 beats per minute (bpm). Since there is not much physical activity happening in this zone, I chose water to represent this zone.

2) Moderate activity zone: Lightly flavoured water

The second zone corresponds to aerobic activities with a range of heart rate values between 96 to 130 bpm. I chose lightly flavoured water (Figure 29) such as mango-peach flavour to represent this zone. The rationale behind doing so was to reward a user for starting a physical activity with an appetising flavour.

Figure 29: Light flavoured liquid enhancer

3) High activity zone: Electrolytes

Figure 30: Electrolytes drink

The third zone describes aerobic activities with high intensity and corresponds to a range of heart rate values between 131 to 165 bpm. Such activities if done for a longer duration may require electrolyte supplements (Sawka et al. 2007). I, therefore, chose Mio liquid enhancer (Figure 30) containing electrolytes to represent this zone.

4) Intense activity zone: Rich flavoured water

Figure 31: Rich flavoured liquid enhancer

The fourth zone corresponds to very intense physical activities with heart rate values between 166 to 195 bpm. Such activities usually do not last more than 10 minutes (Fletcher 2001). I choose a dark red and rich flavoured (Mio fruit punch flavour, Figure 31) drink to describe its occurrence in a physical activity session. I discard the values below 60 BPM and above 195 BPM as they occur very rarely.

Dynamics of a fluid spectacle

I use a Polar H7 heart rate monitor along with its accompanying mobile app, Polar Beat to record the heart rate data of a physical activity session. The Polar Beat app saves the heart rate data on the Polar website, from where I download the heart rate data in XML format. I have written an application in Processing that identifies the pattern of heart rate zones from the XML file and then sends this pattern to the *TastyBeats* system via serial communication. This pattern enumerates all the heart rate zones in which the heart rate data fell in along with its frequency. For example, assuming that the measured heart rate values are [69, 75, 83, 102, 150] the identified heart rate pattern will be [(zone: 1, freq.: 3), (zone: 2, freq.: 1), (zone: 3, freq.: 1)] as 69, 75 and 83 corresponds to zone 1, 102 corresponds to zone 2 and 150 corresponds to zone 3.

The user first sets up the system by pouring the described drinks into the provided containers. The *TastyBeats* system reads the heart rate pattern sequentially and accordingly drives the pumps from the corresponding containers. The pumps shoot the drink into the central glass for 2 seconds, so that the central glass can accommodate multiple shots from every container. The central glass is full with 30 shots with a total of 400 ml.

The volume of the drink depends upon how much heart rate data has been recorded while the flavour of the drink depends upon the variation found in the identified heart rate pattern. For a longer period of physical activity, for example 7-8 hours, I optimised the system so that it shoots the drink only when the heart rate pattern moves to a different zone. For example, if the heart rate data started in zone 1 and stayed in the same zone, shooting will happen only once from pump 1.

[10] *http://www.arduino.cc*

[11] *http://makeitmio.com*

The volume of the drink is based on the duration of the physical activity and monitored data. I programmed the system in a way that it stops when the recorded heart rate pattern is over or the glass becomes full with 30 shots.

Since heart rate data varies over time and differs between different individuals the flavour of the drink will be distinctly personalised for different activities. For example, an activity comprising of transitions between low and moderate activity zones will add water and light flavoured water respectively into the central glass, while an activity causing rapid transitions between different zones will add more flavours as well as electrolytes to the drink (refer Figure 32). The user is then welcome to taste the prepared drink that summarises his/her physical activity.

Figure 32: TastyBeats in action.

Design process

I have taken an incremental and exploratory approach for designing the *TastyBeats* system where the data gathered from an earlier trial would inform the design of the system in the next trial. The design inquiry for *TastyBeats* was carried out in three phases. In the first phase, the main concepts of the prototype were fleshed out through group discussions and iterative prototyping. In the second phase, I exhibited early versions of the *TastyBeats* systems at three different academic venues where more than 400 participants interacted with the system and over 3000 bystanders have watched the interactions as they happened.

Each of these exhibitions helped to refine the design, extending the system and resolving any usability issues. In the final phase, I field deployed the system in various houses to study its use in an everyday context. I describe the activities that are carried out in each of these three phases in detail below:

Phase 1: Focussed group discussion and prototyping

I conducted a focus group discussion to generate and refine the ideas around the design of the *TastyBeats* system. The focus of the discussion was mainly on the fountain based interaction, which lasted about an hour and had 7 (4 male, 3 female) participants aged between 25 to 40 years.

The participants were recruited from the community surrounding a research lab and came from varied academic backgrounds: HCI, industrial design, and media arts. I draw from their experience and discuss advanced topics, such as engaging aspects of the water fountain interface.

Each focus group discussion started with debriefing and explanation of the system along with its motivation. To guide the discussion mainly on the interaction part, I fixed some of the parameters of the system such as that the used data for interactions was heart rate and I limited the choice of drinks to flavoured waters and sports drinks.

During the focus group, I asked the participants to collectively or individually come up with different possible designs on paper for a water fountain based interactive system. Various ideas emerged for the possible interface as shown in Figure 33.

Figure 33: Other potential design ideas that were discussed but not considered due to a) less interaction with equidistant pumps b) self-priming issue with the pumps.

Having access to digital fabrication tools like 3D printers helped to quickly turn the paper sketches into an early working prototype. However, I was limited by the hardware (pumps) available to me, which lead to discarding some of the design ideas. For example, the pumps I had were not self-priming (the pump casing must be filled with liquid before the pump is started, or the pump will not be able to function. If the pump casing becomes filled with vapours or gasses, the pump impeller becomes gas-bound and incapable of pumping), they needed to be immersed in the water to function properly. As a result, I had to discard some designs that had pumps separated from the water with a tube. After a few rounds of iterations and discussions, I decided on the following design that had all pumps at equidistance from the central glass as shown in Figure 32. Choosing this design also allowed for better use of varied heights when shooting drinks into the central container.

Phase 2: public exhibitions

TastyBeats was exhibited in three different international academic exhibition events that cater to large audiences. In total, more than 400 participants directly interacted with the system, while audiences cheered on the participants. Figure 34 shows an example of *TastyBeats* being exhibited at the academic exhibition. In these demonstrations, I have used a finger worn Pulse heart rate monitor to record the heart rate data, instead of a chest strap based heart rate monitor.

Participants were from a diverse background of academics and professionals from engineering and HCI backgrounds. Their age varied from 18-60 years. Participants shared their experience through verbal conversations while interacting with the system. I also had a brief discussion with about 70 participants afterwards to understand the potential of how *TastyBeats* could integrate into their day-to-day activity. I describe below the insights gained from observations and conversations with participants.

The overall response from the participants was positive and encouraging. Participants appreciated the novelty and playful nature of the interaction with *TastyBeats* in comparison to the routine way of checking heart rate data on a screen. Participants particularly enjoyed the fact that the interaction was not just a visualisation of their heart rate data, but there was also a drinkable reward associated with it. They were able to correlate the created drink with their heart rate: "*It's really cool to see how what I just did is now somehow in the glass*!" Unfortunately, one caveat of the exhibition was that participants were not allowed to taste the created drink due to the exhibitions' policies on food regulation. Participants showed interest in knowing the ingredients and wanted to know if they can choose their favourite flavours if they were to use the system at home.

Furthermore, dynamics of the fluid interaction provided a momentary pleasure of being physically active, while the visual and sound effects of fluids intrigued people and motivated the use of the system. Participants were mostly excited about how many different coloured drinks they could get in a glass and what activities could increase their heart rate in a short period of time. In consequence, they were enthusiastically engaged in the interaction to beat each other's heart rate and joked about the different outcomes. Participants tried different physical activities such as push-ups, jumping and running to raise their heart rate, whereas some utilised "tricks" such as controlled breathing to achieve the same outcome. Sometimes the heart rate was also raised with emotions such as thrill and surprise related to experiencing the system socially. The audience also got involved by tickling their friends who were interacting with the system and by loudly cheering them on.

Figure 34: Participants were thrilled to see how their heart rate data is turned into a fluidic form in the early version of the TastyBeats system.

As a result, the interaction became a public spectacle of someone's physical activity and every attempt was encouraged and applauded by the audience.

Sometimes, due to accidental movements or low levels of fluids inside the containers, the fluid was spilled on the nearby surface of the system. To my surprise, spilling made the interaction more dramatic. Participants considered it as a part of their performance to get the desired outcome of shooting the fluid correctly into the central glass. For example, one participant felt that she did not deserve the drink because of an "average" performance and that was why the drink spilled over the table surface.

Although users could identify the heart rate zone in which their heart rate was falling in, they could not see the exact heart rate value. Furthermore, there was a short delay between the measured heart rate and the fluidic outcome because of the lag in reading the sensor data and initiating the water pumps. As a result, participants did not know what would happen and when: "*From where does the water come out and how much will spill?*". On the one hand, the delay was sometimes frustrating as participants felt that there was something wrong with either their body or the system. On the other hand, the delay also invoked fun conversations as participants teased each other, "*You are a zombie!*", "*You don't have a heart (beat)*". But it also encouraged more efforts from the participants as they tried to increase their heart rate through different activities.

Some participants raised concerns about the safety of the created drink. The interaction also challenged their notion of whether it is good to play with food (drinkable fluids). In follow-up discussions, some participants also hinted towards a clean and tidy setup, where the fluid interaction could be akin to a coffee machine setup and fluid will flow downward rather than shooting upwards.

In summary, the public rendering of heart rate data in a fluidic form made participants laugh, cheer, expressive and playful with their personal heart rate data and encouraged different physical activities. This suggested to me that there is a potential to use fluidic interaction to support the experience of being physically active, however, there were also a few concerns regarding the design and spilling of drinks when exploring the fluidic interaction with the data. Hence, I decided to hold another focus group discussion before deploying the system in the field.

Phase 3: Focus group discussion and field deployments

I conducted another round of focus group discussions to understand the usability aspects of the design.

The participants also mused on the possible design considerations for home-based deployments of the TastyBeats system.

A group of 5 participants (4 male and 1 female) participated in the discussion to discover potential problems and opportunities to ensure that the deployments were well executed. The group was mostly comprised of PhD students and academics with experience in the field of HCI. The review took on the shape of a more formal usability inspection, where the group discussed the merits and weaknesses. In particular, participants did not like keeping all four containers at equidistance from the central glass. They suggested that putting containers in sequential order rather than in circle around the central glass would give more interaction flexibility. For example, containers that are further apart from the central glass can have higher elevation for the water arc than the containers that are closer to the central glass. Some members suggested using different colours for different drinks but some were also sceptical over the colour composition of the drinks and instead prompted to use transparent flavours so that the end drink appears as a surprise. Some members suggested using carbonated water and ice along with the flavoured water, but I had to discard this suggestion as the pumps I had did not work with carbonated water.

I redesigned the system using the feedback I got from the group as well as taking into considerations the suggestions made by the participants from the public demonstrations of the system. The final version of the system can be seen in Figure 28 and is described earlier. I next conducted a field study with the redesigned system to understand its use in an everyday context.

TastyBeats in action (field study)

I conducted an exploratory "in the wild" study to understand how *TastyBeats* could integrate into everyday physical activity experiences and what effect it could have on individuals and their relationship with everyday physical activity. Given the exploratory nature of this work, which targets fluidic media to visualise physical activity, my method focused on gathering a rich set of opinions rather than a majority opinion over whether, and in what ways, fluidic media could support the visualisation of physical activity. As such, I lean on the ideas of cultural probing and "in the wild" explorations that aim to encourage reflective thinking about a system and its usage in everyday context.

Recruitment

The study took place in five households across Melbourne, Australia for a period of two weeks. In total, eight participants (names changed) took part in the study: 1 couple in their mid thirties (Chad: 37 yrs., Male, Sarah: 34 yrs., Female), 1 couple in their mid twenties (Dave: 28 yrs., Male, Sarah: 26 yrs.), two housemates (Adam: 26 yrs. Male, Rahim: 29 yrs., Male) and two students from separate houses (Daisy: 27 yrs. Female, Gavin: 26 yrs.). The fact that some of the houses had more than one person participating in the study allowed me to investigate the social dynamics of the *TastyBeats* system as explored in previous work on material representations (Stusak et al. 2014). Figure 35 provides demographic details of the participants along with their level of physical activity every week (low: 1–2 days, moderate: 3–4 days, high: more than 4 days). Dave, Chad, Daisy, and Rahim had previously used heart rate monitors while Dave, Chad and Sarah have also used a physical activity related app such as RunKeeper and MyFitnessPal previously. Participants mentioned that they have used electrolytes-based sports drinks before, but mainly they relied on water as a resource for rehydration. I also asked in pre-study interviews about the participants' preferences in terms of drinks and what features they think are vital for selecting a drink. Most participants noted that taste is the key aspect for them to choose the drink while, for Rose and Sarah, drink packaging was important as well as colour and taste.

Study setup

I supplied each participant with a bag containing a MacBook Air, a Polar H7 heart rate monitor and a 5th generation iPod touch to record heart rate data along with the TastyBeats setup. I refrained from using the participants' smartphones because I did not want to drain smartphone batteries from constant heart rate monitoring. I gave participants sanitisers and napkins for cleaning and managing accidental drink spills. Participants were not compensated for participating in the study. Following cultural probing practice, I also supplied diaries and asked participants to reflect upon their experiences with the system.

Procedure

I installed the *TastyBeats* system in every household in a location of the participants' choice (which I noted). I explained the study procedure and gave participants a hands-on demo on how to use the system. An A3 poster detailing the study steps, as shown in Figure 35, was given to the participants. Participants were asked to perform the following tasks:

Tasks in the morning

I asked the participants to put on the heart rate monitor and start recording the data using the Polar Beat application installed on the iPod touch. Usually, participants began the recording around 8 am in the morning. Once the recording was started, participants continued their day as usual while carrying the iPod with them. I did not deliberately ask participants to start any new physical activity but they were welcomed to do so. I asked them to spend their day during the study as they normally would do, which may or may not involve physical activity.

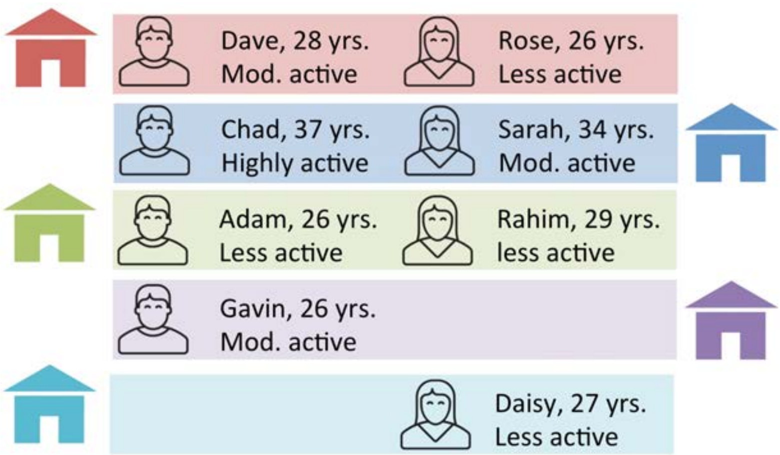


Figure 36: Demographic details of the study participant along with their level of physical activity. Mod. active means moderately active

Tasks in the evening

In the evening, usually around 6 pm, I told participants to stop the Polar Beat application and take off the heart rate monitor. Once the recording was stopped, the heart rate data from the day was synced to the Polar website.

Figure 35: Each house received a kit containing the TastyBeats system, iPods and a A3 poster detailing the study steps.

Participants then prepared the *TastyBeats* setup, which involved pouring water into the four containers and adding the liquid enhancers (two drops) into three of them as explained earlier. The provided laptop was used to download the data and start the *TastyBeats* program. The program then started the *TastyBeats* interaction, which involved shooting drinks into the central glass based on the heart rate data. The fluidic interaction usually lasted around 3-4 minutes, giving users between 200 and 400 ml of drink. Participants were then welcomed to taste the drink and had the opportunity to reflect on their experience in the provided diary.

Figure 37: The TastyBeats system occupied the kitchen slab space in Dave and Rose's house.

Data source

Complementing the pre-study interviews, the main source of data were the diaries and the post-study interviews conducted at the end of the study in participants' homes. The pre-study interview lasted around 30 minutes while the post-study interviews lasted for about 60 minutes per participant. In the post-interviews, I focused on eliciting participants' experiences with the *TastyBeats* system to supplement their written feedback in the diaries. I also utilised photos and videos taken by the participants to further support the interviews. I visited each household two times (on the first and last day of the study) and spent around 4 hours in total with participants at each house. During the study, I also maintained contact with everyone through emails and phone calls in case they needed any technical support. However, the study ran smoothly and the required technical support was minimal. I also took notes and recorded interviews, which were later coded and analysed for common themes.

Findings

Given the long time frame necessary to achieve health benefits as a result of physical activity, it is often difficult to judge the efficacy of short design-led study interventions (Brynarsdttir et al. 2012; Klasnja et al. 2011; Purpura et al. 2011). Instead, it has been suggested that such interventions should be judged based on their impact on practices (Brynarsdttir et al. 2012) and how they brought about changes in people's attitudes (rather than behaviours), fostering mindfulness and leaving room for stories (Purpura et al. 2011). I describe below key insights gained from the deployments.

Accommodating TastyBeats

All participants welcomed the system with curiosity and considered it a part of their kitchen ambiance. The system occupied a space on the kitchen slab in both couples' homes (Figure 37). Adam and Rahim, however, placed the system in a private room as one of their other roommates had a cat and they thought she might mess with the system.

Experiencing TastyBeats

All participants tracked their data for around 7-8 hours in the time period between 9 am to 6pm. The couples preferred to have their drink after dinner usually around 9 pm. Dave mentioned that the drink was like a personalised dessert or pleasurable treat for the tiring activity of the day. Referring to the sweet taste of the drink Sarah said: "*It is like having a grape juice before going to bed*". Adam and Rahim did not have a preferred time for the drink; sometimes they had it just after coming back from work and some other times a little later. To my surprise, Adam even maintained voice memos on his iPod to log his as well as Rahim's interactions with the system.

Enjoying the interaction

All participants actively took part in making the drink every day and keenly observed how the drink was being made through the fountain-based interaction. As such, the system became a part of their daily routine. According to Adam, the system was "*Something you always want to see, once you come home*", to which Rose added, "*It's nice to see the machine making a drink and the taste of the drink is also very good, but it is also very healthy, that way you feel good about it.*" The drink was appreciated and interaction was found rewarding by the participants: "*The best part of it is watching the interaction, shooting into the cup*", Dave commented. Rose was delighted to see her heart rate transformed into a drink, she mentioned, "*Compared to regular apps which only show the data, this* *prepares the drink, and that way it's kind of special, it feels that you are getting energy back.*"

Taste as a surprise

Sarah mentioned, "*Seeing the drink is one thing, but if it's the same colour every day, then there is no surprise. The surprise is the taste, which is different on a daily basis.*"

Taste as a satisfaction

Chad also commented, "*Tasting it [drink] adds an element of satisfaction. It would have been less engaging if I was not allowed to drink it.*" Adam felt, "*it is like drinking your own progress, literally.*"

Witnessing the interaction

Chad mentioned, "*This (TastyBeats) is kind of neat where I can see the different levels mixing in. You actually get to interpret how active your day was based on the drink being mixed. So, I think it's more of an incentive to see it mixed because you get a better understanding of why the drink is the way it is.*" (Refer Figure 38). For Rahim, it was like watching a favourite TV show. He added, "*It is something that you want to enjoy as entertainment. It is like watching a show that you like.*"

Relating TastyBeats to physical activity

Participants mentioned that the presented data in its fluid form offered new insights into their physical activity routines. As a result, they became more attentive to their bodily responses and everyday activities.

Trying out different activities to get a better drink

Participants were able to correlate different days' activities with the drink that was created in the evening, which in turn encouraged them to try new physical activities. Rose tried different physical activities such as running, cycling and household cleaning on different days. She was able to differentiate how her heart rate data in these activities was reflected in the drink. Rahim confirmed this by saying: "*I did see the differences [in the drink] when I had a more active day, there were subtle changes in the taste.*"

Identifying bodily signals from the drink colour

The dark rich flavoured drink that Sarah received on three consecutive sedentary days made her realise that she had very high heart rates. She told her husband about it and consequently they investigated "normal" heart rate values on the Internet and possible reasons for higher heart rate values. They then tried to swap around the heart rate monitor on the next day to see if there was a fault with it. Sarah said: "*What it [TastyBeats] made me aware of was my heart rate. It is not something that I think of. When I saw my high heart rate [through the dark red coloured drink], I felt my pulse for the first time. It made me think about the reasons and found that medication is one of the factors [she was on a medication for a while during the study period].*"

Figure 38: Watching the interaction was both fun and rewarding. The image is taken from one of the exhibitions of the TastyBeats system.

Motivation for exercise

A recurrent theme was the motivating quality of the system, linking to the theme of fulfilling the energy-cycle. Participants reported that the system encouraged them to not miss their daily workouts. Rose said: "*Just to see what drinks you get and how much, you feel like going out and running, sometimes it's like an inspiration.*" Adam responded similarly, "*It motivated me to exercise more*". Daisy added, "*Watching the drink actually gives you motivation, like seeing the 3 (one of the drink zones) and 4 going, you want more from 4*".

On a sedentary day, Chad received a drink containing mostly water, to which he replied, "*It was a little bit frustrating to get a watery drink, but it was not unexpected. That kind of motivated me to want more physical exercise the next day. I would try something to get drinks from level 3 and 4.*"

Taking health more seriously

Dave spoke extensively about how TastyBeats made him be more serious about his as well as his wife's health. He said, "*I will continue cycling to work from now onwards*". Other participants also reported that the system encouraged them to not miss their daily workouts.

Dave, Rose, and Chad started walking or cycling to work instead of driving or taking public transport.

Nudging towards healthy eating habits

Rahim mentioned that "*It feels like maybe I should eat less and drink more*." Gavin noted similarly that, "*I earlier used to eat junk food after returning home from work but now I only drink the drink made by the system and that is enough, it somehow prohibits me from eating junk food*." Daisy felt the system is like, "*Walking around with a nutritionist, telling me what I did and what I should eat.*"

Social dynamics around TastyBeats

Participants said that they often prepared their drinks together, laughing and discussing their activities with each other. Usually, participants saw each other only in the evening when the recording of the data was over. As such they did not know precisely how active the other person was during the day: the understanding came by watching the interaction when the other person's drink was being made. Chad said in the interview, "*It's good that me and Sarah doing it [the study] together, as I get to see each other's heart rate from the drinks being made" [with a smile], "in that way, Sarah now knows much more about me and my activities*."

Facilitating competition

Adam felt the system was highly competitive (refer Figure 39): he competed in terms of who will burn more calories and get a better drink. He recalled a funny incident that happened through his voice memo. "*On Saturday, I stayed at home reading and watching TV, I did not go anywhere, but my friend Rahim went and played some sport [football with friends] and did some jogging and stuff like that, so it was very physically active day for him and for me it was very, very inactive, just the opposite. When he came back, I did our drinks [together]. I started with him and his drink was pretty amazing and very concentrated, using a lot of drink from [container] 3 and 4 and almost nothing from 1. After that it was my turn since there was no activity by me, I did not get anything, just a little bit of water [from container 1] and nothing from the other. It was just funny. It was so obvious that he did a lot of activities and I got what I deserved. So I started laughing, it was so fun!*" .

Rahim responded, "*I actually had a competition, I am doing better than you and you are doing better than me. Every day I sat down (in front of the system setup) to see who did what. If I had a good day, it felt good, I defeated you. It got me into an athlete mood where you always want to compete*."

Drinks became personal and cheating felt bad

Adam added, "*Later on, the same day when I was having dinner, I felt like having a drink. So what I did, I cheated the system. I uploaded Rahim's data and got the same drink that he got. Kind of funny that he did the activities and I got the drink. But actually, to be honest, it didn't feel good at all, I felt that what I told Rahim too, you know what, this drink is personal, I feel like it is yours and I am drinking it. It feels like drinking something that does not belong to me. So it did not taste good, really honestly*."

Personal affection with the drink

Participants from the other houses felt that the drink was personal to them and is not something to be shared: Rose said, "*Sharing my drink with others is a bit weird, I will tell others about it [my drink], but I will not share the drink, definitely*."

Watching the interaction was a rewarding experience

Most participants spoke enthusiastically about the system as well as about their participation in the study with their friends. Interestingly, participants found the interaction equally rewarding as the drink. Sarah said: "*Even if you had a pretty inactive day, you can get a little bit of juice from container 2 along with water*". Chad added, "*I think it's better to see the interaction. If I was thirsty, it's a little bit frustrating that you have to set it up and then you have to wait. But seeing the interaction is quite rewarding*."

Rahim recalled that "*One day I came home running from my office, I was exhausted and needed something to drink, I could have picked something from the fridge, but instead, I poured the drink into the glasses and then drank it once the interaction was over, that way I knew what my heart rate was." Gavin said every day while returning home, it was like "I cannot wait to see the results, let us see what happens [today]*".

Figure 39: TastyBeats facilitated a healthy competition in terms of who will get a better quality drink.

Appreciating the palatability

During the post-study interviews, I discussed various possible scenarios in which certain aspect of the interaction could be missing. I asked what if I take away the drinkable aspect by just mixing colourful water based on heart rate data. To which, all participants responded negatively. Chad said, "*It would probably be less of incentive especially when you are wearing the heart rate monitor for exercise and at last you can't drink it. It is like producing something but you won't get a reward out of it, other than some water which you can't keep with you*" Dave worried that "*Having a drink is something like a reward for what you have done. But if it was just water, which you have to throw away, the beauty of interaction would have disappeared*."

Welcoming the abstract form of visualisation

Dave appreciated the abstract nature of TastyBeats and mentioned, "*For a non-athlete like me, detailed data does not make much sense, once in awhile you may want to know what your heart rate details are, but on a daily basis abstract interpretation of data is good enough*".

The drink afforded the "feel-good" factor

Most participants felt good about themselves as the study intervention allowed them to learn more about themselves. Adam said, "*After watching my heart rate (as conveyed in the drink) and the kind of activities that I do, it made me feel better about myself. I thought I was in a bad shape because I eat a lot of junk food, but even after eating a lot of junk food, it made me realise that even if I do little activity my heart rate is good and I burn a few calories. I am in not in a bad shape, which makes you feel good*."

Issues with the TastyBeats system

Below I mention some of the issues raised by the participants about the system.

Cumbersome heart rate monitoring

Rose and Sarah found wearing the heart rate monitor for the whole day cumbersome. Sarah said, "You need a little bit of discipline for putting it on every day during the rush hours in the morning." Gavin and Daisy felt skin sensitivity with the strap to be a major issue during the study. Rahim added, "*Somehow I subconsciously felt like I am being tested. I would prefer a less obstructive system*." Adam proposed a solution: "*Eventually I will come to know what drink I get for what activity. So next time when I had a similar activity, I can just look back in history and plug in the data to get a similar drink, that way I do not need to wear the heart rate monitor*."

Doubling the calories

Since the system did not have any component that could measure the food participants had during the day, the drink components felt like having additional calories to drink. "*It gives me the feeling that whatever fat I have burned, I am putting them back on by eating the same food because that is not the only time I eat or drink, so the timing should be flexible. So the calories are now doubled, it should somehow monitor what else I am eating throughout the day*." Daisy was similarly somewhat skeptical, she mentioned, "*It feels like all the work that I did, I drink it back into myself*."

Irregular sized drinks

With the *TastyBeats* system, the volume of the drink is based on the duration of physical activity and its type. As participants' activities varied during the study period, they received drinks of different volume. However, Dave did not like getting drinks of different volumes and wished to have a standard size drink irrespective of the duration of his physical activity.

The leftovers

Participants also raised questions in terms of the openness of the system, which leads to the wastage of leftover drinks. Dave and Adam asked if the system could somehow be sealed from the top so that they can reuse the remaining drinks on some other day rather than throwing them out.

Mess and Spilling

Spilling occurred occasionally, which was perceived as playful but was not appreciated, as it required not only cleaning but also is related to the wasting of food (refer Figure 40). Rose said, "*Little droplets are kind of okay. But not too much*." Rahim thought maybe it was his fault that he did not set up the system properly.

Figure 40: Spilling was an issue which on one hand made system playful but on the other hand required cleaning and caused wastage of drink. Figure shows an early prototype of the TastyBeats system.

Study limitations

There were two main limitations to the study. Firstly, *TastyBeats* creates a drink only at the end of the day. There are situations when such a drink might be needed right after completing some physical activity, an aspect I did not explore in this case study. The current system was not portable so the drink was served sometime after completion of some physical activity. Secondly, the study reports on results from 2-weeks. Longitudinal studies might be needed before drawing conclusions on the motivational aspects of the system. Despite these limitations, I believe this work offers first insights into a palatable representation that could inform future systems around the idea of supporting the human energy cycle.

Discussion

The deployment and development of *TastyBeats* led to many interesting insights. Participants seemed to enjoy the system although as explained there were limitations to the study and system itself. Here, I further articulate the possible opportunities revealed from the deployment of this case study.

Importance of personalisation and ephemerality

The *TastyBeats* system offers an appetising drink and a visceral spectacle of creating the drink, both of which participants found rewarding. In Chad's case, even though he was dehydrated from cycling, he waited for the interaction to end to get a drink. Participants found watching the interaction to be the best part of *TastyBeats* and were very keen to witness the interaction not only for their own benefit, but to also witness their partner's physical activity for that day.

I found that participants had a personal affection for the drinks. Rose was motivated to perform different physical activities to see how the different activities would be reflected in the drink and how the taste would be altered. One participant, Adam, even tried to cheat the system by creating drinks from his friend's data, but that drink did not taste good for him. Lastly, there was always a surprise element associated with how the drink would taste. I, therefore, encourage designers to equally focus on the interaction aspects as well as the palatability of the resultant drink when designing palatable representations of physical activity data.

Importance of visibility and interactivity of the process

Most of the existing works in visualising physical activity is geared towards individual use (Lupton 2016). Physical activity data is often collected and shown on a private computer or smartphone screen. In this work, I explored a public display of data in a private setting, such as the home, through a shared system of seeing a drink being created. Often, participants came together to see their drinks being made. In witnessing this process, the participants became more aware of each other's physiological state, which in turn triggered discussions and playful social interactions between them. Participants often competed to get a bigger drink which resulted in moments of laughter when the prepared drinks were drastically different from each other. Recently, some work has also started to explore public consumption of heart rate data. For example, Walmink et al. (2014) created an augmented helmet that projects heart rate data of the wearer in real time to fellow cyclists while Curmi et al. (2013) allowed for a public display of heart rate data over social networks. These works also suggest the potential for social interaction around the public sharing of heart rate data. However, public displays of heart rate data raise issues of privacy. Within this study, participants did not raise such a concern, as the data was very abstract. Therefore, I believe, one way to address privacy could be to deploy abstract forms of visualisations, supported by systems like *TastyBeats*, which provides only basic information about the physical activity in terms of four heart rate zones, hiding details from the user and observers.

Importance of autonomy and self-expression

Sheridan (2010) defines physical creativity as the ability to innovate through exertion to acquire skills and agility; it involves the use of body movements for self-expression, improvisation, and imaginative play. In the TastyBeats system, participants liked how a drink became a celebration of their physical activity along with an opportunity to express themselves in front of a large cheering crowd. As such, the fluidic spectacle of one's heart rate data becomes a public display of the self (Goffman 1959), allowing the participants to be imaginative and creative with their movements. Designers, therefore, can utilise public display to nurture physical creativity.

The public fluidic display of heart rate data facilitated creative and exertive self-expression among participants even when the system did not reveal the exact values of heart rate data or the information about how it attains a fluidic form. For participants, the dynamics of the fluidic interaction were more engaging then the actual activity information. Following the framework of Reeves et al. (2005) on spectator experience, I recommend to designers to consider abstract visualisations of data using fluids by being "secretive" (on how data gets transformed into a new representation) and "expressive" (to support exertive self- expression and spectator engagement).

In TastyBeats, spilling was accidental and often caused a mess on nearby surfaces. On the one hand, participants welcomed the spillage as a dramatic outcome of the playful interaction. On the other hand the messiness challenged participant's notion of playing with drinkable fluids, since for some of them, food is normally not to be played with.

Encouraging the users to play around with drinkable fluids could provide an opportunity to facilitate immersive engagement that can further entice the user to fulfil a daily need of obtaining appropriate fluid intakes (Sawka et al. 2007).

Conclusion

The main contribution of this work is the first conceptual understanding of the design of palatable representations of physical activity data. I presented results from an "in the wild" field deployment of the *TastyBeats* system that offers insights into how people understand and react to personal data when presented in a palatable form. *TastyBeats* served as a mediator for reflective thoughts and discussions besides offering a public and vibrant spectacle of heart rate data.

Recent advancements in food printing have opened up new possibilities for creating engaging interactions and experiences around food (Schoning et al 2012; Spence and Piqueras-Fiszman 2013, Comber et al. 2013). However, existing explorations mainly utilise mechanical and time-consuming techniques to produce food. Through this work, I explore another dimension of producing personalised food using a vibrant, attractive and familiar setting of water fountains, which I think would guide designers towards thinking differently about food printing methods. As such, this work also informs the design of food printing machines, highlighting an opportunity to print things we do not currently have such as heart rate. My work brings to the fore the idea that one can eat one's own data such as heart rate data. This might inspire a discussion of the role of HCI in the human-energy cycle. In the future, it would also be interesting to see how *TastyBeats* is applicable in other settings such as in gymnasiums or public events like marathons. Finally, this work has scratched only the surface of palatable representation, and I encourage designers to consider new possibilities afforded by such representations to support user's experience with the physical activity. In the next case study, I explore one such possibility with the use of chocolate as a representation medium.

#6

EdiPulse

CASE STUDY 3

EdiPulse

Material used
Chocolate

Process followed
3D food printing

Produced outcome
3D printed chocolates

Key Publications:
CHI Work in Progress 2015

Ethics Approval number:
CHEAN A 0000018602-04/14

Public Exhibitions
2013 – ACM CHI 2015, Seoul, Korea.

Key Media Coverage
Channel 9 News, ABC News 24, Mashable, SpringWise, 3WM Radio, PSFK

Finalist at AAMIA awards 2016

This chapter describes the final case study that investigates the use of chocolate to create material representations of physical activity data through a system called EdiPulse.

Introduction to this chapter

The final case study continues my exploration on food as a representation medium. Ingold (2013) and Nissen et al. (2014) argue that individuals can relate to material artefacts by having a sensuous engagement or an emotional resonance with its integral materials. Building on this idea, I explore an opportunity to represent physical activity data in a unique material form – chocolate – with which most individuals share an affective relationship (Lupton 1998).

In the words of Lupton (1998), "*chocolate is culturally understood as the symbol of love, packaged with high emotions to inspire the feeling of self-indulgence and hedonistic ecstasy*". Besides, it has been shown that a moderate amount of chocolate can improve mood and even offers cardiovascular benefits (Steinberg et al. 2003). Interestingly, chocolate is associated with both positive and negative connotations, especially in relation to supporting an active lifestyle. For example, chocolate, on one hand, is desirable, while on the other hand, it is also considered calorie laden. Therefore, using chocolate to represent physical activity data might appear to conflict with one's fitness goals. I, however, think that this contrast adds playfulness and intrigue to one's perspective on looking at self-monitored data. As such, using chocolate as a material becomes an interesting case to study how individuals react to seeing their physical activity data in chocolate form.

To explore the relationship of chocolate based representations of physical activity data I present a system called *EdiPulse*. *EdiPulse* amalgamates food and physical activity data in a unique playful way and by offering 3D printed chocolates as activity treats, whose quantity remains the same irrespective of the user's physical activity, but these treats become more gratifying with an increase in physical activity.

Related Work

Several works within HCI have explored food as a celebratory technology (Grimes et al. 2008). Resner (2001), for example, introduced the concept of an "Edible User Interface" (EUI) that utilises multi-sensory experiences of food to create novel interfaces such as "TasteScreen", where users interact with a system by licking liquid residue of different flavours that drips onto the LCD screen (Maynes-Aminzade 2008). Murer et al. (2013) designed "LOLLio", a gustatory interface for playing games. "Qkies" (2007) is a system that embeds QR codes on cookies while "Meta Cookie" (Narumi et al. 2010) is an augmented reality based system that aims to control nutritional intake by changing the size of the food (cookie) through a head-mounted display.

Dietary monitoring is another dimension of exploration. Some researchers have also looked at tracking food consumption from the way it is prepared and served. For example, Chang et al. (2006) created a dining table that tracks food consumption using RFID and weight sensors. Similarly, Kranz et al. (2007) designed augmented kitchen knives and cutting boards. Finally, there are also a number of playful systems that promote healthy eating habits through persuasive games such as "Escape from Diab" (Thompson et al. 2010) and "LunchTime" (Orji et al. 2012). These works highlight the potential benefits from the amalgamation of food and technology design to support health and wellbeing.

Advancements in food printing technologies have brought us new interaction possibilities with food. Food printing follows an additive manufacturing process where an object is created by placing the edible material (currently in the form of a paste, extruded using a syringe) layer by layer until the object, based on a 3D model, is fully formed. As such, this process connects digital information with cooking. The area of food printing is still relatively new and has not yet gained mainstream popularity in the way that 3D printers have.

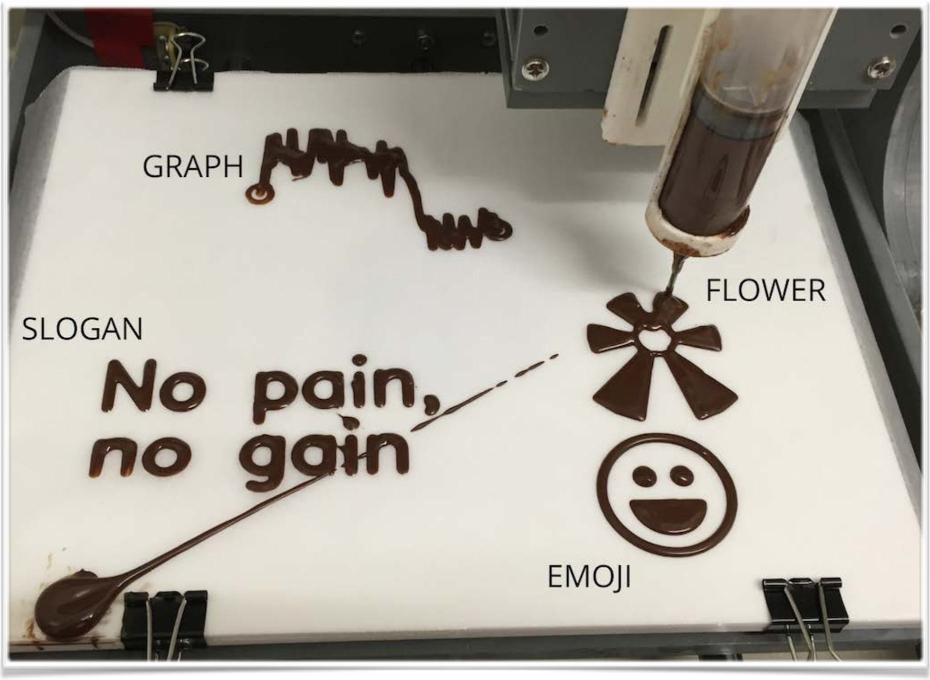
However, attempts are being made to explore what kinds of food can be printed and how to utilise 3D printing to create decorative edible objects.

For example, Biedermann and Thill utilised food printing to create smooth easy-to-eat foods for the elderly who have difficulty in swallowing food (2015). Wei et al. (2014) harnessed food printing as a social food based messaging system for friends and relatives to communicate with each other. In a similar vein, Fukuchi et al. (2012) invented laser cooking that uses the laser cutter and image processing techniques to cook food according to the shape and composition of the ingredients. To date, there has not been any exploration on using food printing to support physical activity experiences, which I explore in this case study.

EdiPulse

EdiPulse is a provocative system that translates heart rate data from a person's active life into 3D printed chocolate treats. I refer to these 3D printed chocolates as activity treats, as they come in a moderate amount and offer a unique playful representation of one's physical activity data. These activity treats are constructed with less than 20 grams of dark chocolate and they embody four different forms: *Graph, Flower, Emoji* and *Slogan* (Figure 41). While this quantity remains the same irrespective of the user's physical activity, these treats become more gratifying with an increase in physical activity. The design of *Graph* and *Flower,* is similar to those found in the first case study SweatAtoms while I introduce two new representations in the form of *Emoji* and *Slogan* in this study.

Figure 41: Activity treats comes in four forms: Graph, Slogan, Flower and an Emoji.



Implementation of the EdiPulse system

EdiPulse uses a Polar heart rate monitor and its accompanying mobile app, "Polar Beat" to record heart rate data. The *EdiPulse* application (written in JavaScript) downloads heart rate data from the Polar web site and then parses this XML data to identify heart rate zones within the recorded data. The application takes an average of every 10 minutes of recorded heart rate data. If this value is above 65% percent of the maximum heart rate, the application considers those 10 minutes as active time, in accordance with The American College of Sports Medicine (ACSM 2013) guidelines. The system then uses this information to algorithmically construct all four activity treats using OpenJSCAD[12] software as follows. Figure 42 describes the activity treats in detail.

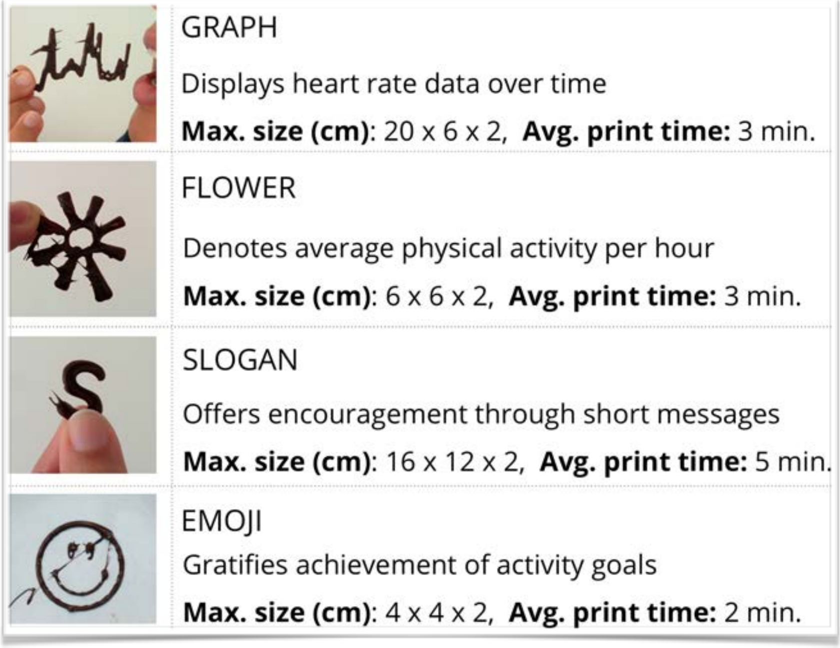


Figure 42: The four activity treats.

Graph: *Graph* shows recorded heart rate values over time. I first map the recorded heartbeat per minute to a point in XY space and I then extrude the resultant 2D shape along the z-axis to achieve a suitable thickness.

Flower: *Flower* provides a summary of physical activity across each hour of recording. Each petal of the flower corresponds to an hour and its length denotes the amount of physical activity in that particular hour. I chose not to add a starting point, as I wanted the *Flower* to be ambiguous, allowing participants to reflect and identify the starting hour on their own.

Emoji: *Emoji* communicates an individual's progress towards a self-driven activity goal through an emoticon face. At the start of the day, users can enter their physical activity goal for the day into the *EdiPulse* application. This goal is a chosen duration for doing moderate to high level of physical activity and it could span over the day. The *Emoji* bears one of four faces: sad face, straight face, happy face and super happy face based on how close one gets to the set goal. For example, achieving and exceeding the goal respectively results in a happy and super happy *Emoji*, while failing to meet the goal results in a sad or straight face *Emoji* as shown in Table 3.

	TIME SPENT EXERCISING	RECEIVED EMOJI
1	Less than 50% of the set activity goal	Sad Emoji
2	Between 50 to 99% of the set activity goal	Straight face Emoji
3	Equals the set activity goal	Happy Emoji
4	Greater than the set activity goal	Super Happy Emoji

Table 3: Emoji communicates an individual's progress towards a self-driven activity goal through different emotions

Slogan: *Slogan* makes a cheerful comment based on the amount of physical activity done by the user in a day. For example, if the user has been inactive during the day, then the *Slogan* will contain motivating words and will communicate the benefits of an active lifestyle as shown in Figure 43. On the other hand, if the user has been active, then the *Slogan* will be more gratifying, an example can be seen in Figure 43.a and 43.b.

I next describe rationales behind my design decisions.

Mapping physical activity data to chocolate

In line with the previous two case studies, I chose to record an entire day's worth of data and not just the time spent performing a physical activity so that I can present an overall picture of one's physical activity throughout the study period. I also decided not to map the exact amount of calories burnt during an exercise to the amount of printed chocolate (Khot et al. 2015), because a high amount of chocolate could reverse the benefit of performing some form of physical activity.

12 *http://openjscad.org*

Figure 43: Participant receive a different 'Slogan' based on their level of physical activity in a day.

Baking paper allowed for the easy removal of the cooled chocolate. For thinner prints, I used a 20 ml syringe with an external removable needle tip (opening: 30mm).

Equipment & the printing process

For the prototype, I used a ChocEdge V1 3D printer[13] to print the activity treats. During the exploration, I found that chocolate, as a print material, requires care and attention concerning the correct temperature setting. For a good quality print, the temperature of the tempered chocolate and outside room should be in the range of 25-32 degree Celsius (Leffer 2016). Extensive tempering of the chocolate results in watery prints, similar to the one in Figure 43.c. Cold weather also creates issues as it hardens the chocolate within the syringe, which either results in no prints or can even damage the extruder motor. Additionally, air bubbles in the syringe also affect the quality of the print. This was a crucial problem because my study participants had no prior experience with 3D printing. I therefore explored different ways to simplify the printing process by keeping the chocolate consistent and warm during printing. For instance, I tried attaching custom fans and cold plates to the printer so that the chocolate hardens quickly after printing. However, printing with these alterations did not give consistent results. As a remedy, I gave participants a food thermometer for the accurate tempering of chocolate and asked them to keep the room temperature in the range of 25 to 32 degree Celsius during printing. Figure 44 provides the four-step process that was provided to the participants.

Instead, I focused on making the representations more beautiful and gratifying with an increase in the amount of physical activity performed. For instance, with *Slogan* my emphasis is on the content rather than its length. To this end, I see and utilise chocolate only as a positive enforcement technique for physical activity. Moreover, owing to its cardiovascular health benefits (Steinberg et al. 2003), I have used dark chocolate for printing and kept its quantity to a maximum of 20 grams a day.

Representation choices

The design of the activity treats evolved iteratively due to both discussions and printing trials. I started by reading prior literature (Stusak et al. 2014; Consolvo et al. 2007) and taking into account lessons learned from case study 1 and 2 to identify potential representations that effectively reflect someone's physical activity. I also took into account the technical capabilities of current food printing technologies, which, for example, cannot print tall structures easily. As a result, I had to restrict the design explorations to rather flat models. I also considered the printing time, amount of chocolate and size of the print bed (20 x 24cm) for print efficiency in terms of time and space. Additionally, I tried printing chocolate onto different food materials such as bread and biscuits but the printing results were inconsistent in quality. Hence, I used a flat acrylic sheet with a baking paper as a print surface (Refer Figure 44, step 3).

Figure 44: Chocolate printing process.

Step 1: Tempering

Melt dark chocolate to a right temperature (32⁰C) to ensure print consistency.

Step 2: Filling the syringe

Fill the 20ml syringe with tempered chocolate while ensuring there are no air bubbles.

Step 3: Setting up to the printer

Attach baking paper to the print bed (20 cm x 24 cm) using clips. Next, attach a needle tip (30mm) to the syringe and then attach the syringe to the printer.

Step 4: Printing

Use PrintRun program to start the printing.

[13] *http://chocedge.com*

Concealing digital display and ad-hoc printing method

I used Printrun[14], an open source program to drive the printing. Under normal settings, this program displays a 3D replica of the object currently being printed on the screen. However, I altered the program settings to conceal the digital display of the activity treats. My intention was to keep the treats as a surprise so that they are revealed only during the actual printing. Furthermore, I also orchestrated the printing to keep users engaged in the printing process. For example, *Slogan* is printed in an ad-hoc manner, where letters from different words (within a *Slogan*) are printed randomly. To elaborate, if the *Slogan* was 'Just do it' then it would be printed progressively as:

1. '_ _ _t _o i_'
2. '_ _st do i_'
3. '_ust do it'
4. 'just do it'.

EdiPulse in action (field study)

I conducted an exploratory "in the wild" study to understand the user experience with the *EdiPulse* system in an everyday context, and the role of activity treats in supporting physical activity goals. The study took place in seven households across Melbourne, Australia for a period of two weeks where thirteen participants interacted with the system on a daily basis. Figure 45 provides the demographic details of the participants along with their physical activity goals for each day of the study. In total, there were thirteen participants (names changed): 2 couples in their early thirties (Harry & Fiona and Rohan & Diya), 1 couple in their mid forties (Josh & Karen), 2 couples in their mid-twenties (Adam & Helena and Gavin & Daisy), two housemates (Jayden & Samantha) in mid twenties and one participant in their early fifties (Frank). Frank's roommate Kelly also wanted to participate but she dropped out of the study because of personal reasons. The sample size and study period are in accordance with earlier field studies (Brown et al. 2011; Lee et al. 2015; Stusak et al. 2014). Ten participants had previous experience with self-monitoring devices and nine participants that include all female participants had a sweet tooth for chocolate. The recruitment was open and followed a snowballing method. There was no financial compensation for participation. However, as I only had access to one working chocolate printer, longer deployments of *EdiPulse* were limited. Overall, the deployments took more than four months where I proceeded with a sequential order of installing the EdiPulse system at different households.

[14] http://pronterface.com

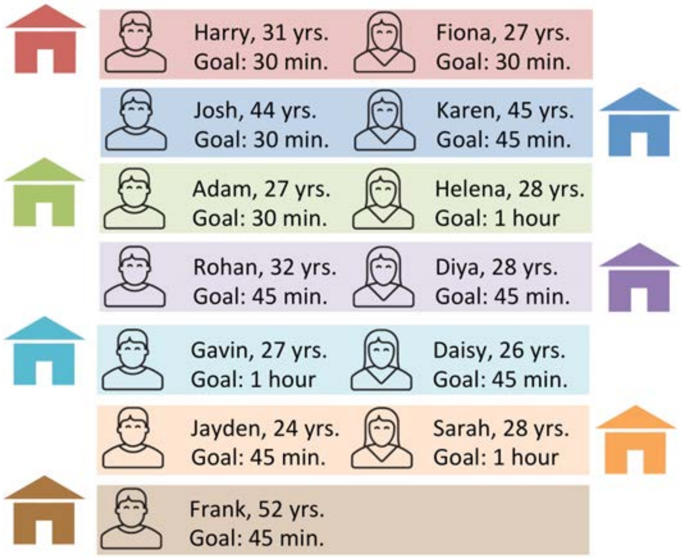


Figure 45: Participants' details along with their activity goal for the day.

Study setup and procedure

I provided each participant with the following supplies: 1) a Polar H7 heart rate monitor and an iPod touch to record heart rate data; 2) ChocEdge printer 3) MacBook Air that contains the PrintRun program; 4) Chocolate tempering machine and a food thermometer; 5) Printing material: 20 syringes, 20 needle tips, five dark chocolate bars of 200g each, tissue paper, and pre-cut baking paper, 6) instructional manual on study steps. Figure 46 displays the study setup at one participant's household.

On the first day, I explained the study procedure with a demonstration of how to use the system. I asked the participants to perform the following tasks every day:

Morning Tasks: Participants put on the heart rate monitor and started recording data using the Polar Beat app, installed on the iPod Touch. Once the recording started, participants continued their day as usual while carrying the iPod with them.

Evening Tasks: Participants stopped the recording around 6pm. Their heart rate data then got automatically synced to the Polar website. I downloaded the data from the website and prepared the 3D models of activity treats using the *EdiPulse* application. I then emailed the 3D models as a single print file (.gcode) to the participants. I kept the task of 3D modelling myself in order to reduce participants' workload and to keep the activity treats as a surprise. After receiving the files, participants followed the steps outlined in Figure 44 to print their treats. The preparation took around 15 minutes while the printing took an average 13 minutes.

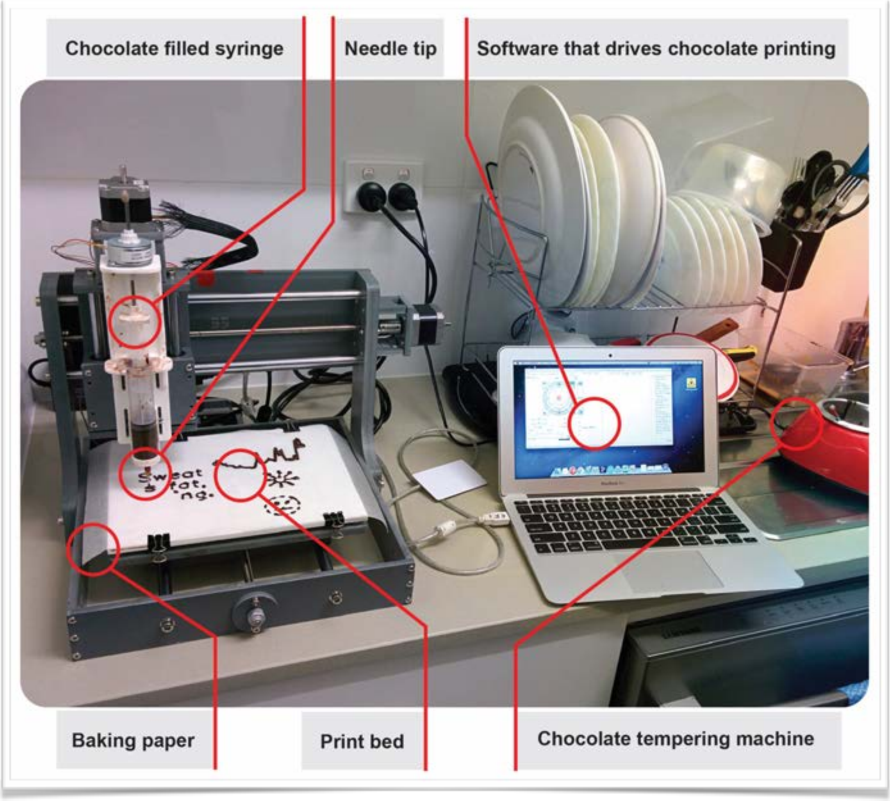


Figure 46: Study setup at Harry's house.

During the study, I maintained contact with all study participants via email and via the phone, to provide technical support whenever needed.

Findings

All participants welcomed the system with curiosity and placed it in their respective kitchens as shown in Figure 47 Five households preferred to print and eat the chocolate after dinner, usually around 9 pm, as a desert, while 2 households did their printing the following morning. Participants from each household printed their activity treats each day, one after the other. Interestingly, participants not only showed keen interest in printing their own activity treats, but they were very much interested to see how the activity treats of their housemate's (partner) was getting printed.

I reflect on the findings across four categories in total: overall experience with the *EdiPulse* system, use of chocolate as a representation material, appeal of the four representations of activity treats, and feedback on the printing process.

Data source and analysis

The data collection started after I installed the *EdiPulse* system at the participant's household. I visited each household on the first and last day of the study and spent around 4 hours in total with participants from the same household. The main source of data from the study was the post-study interviews. These interviews were conducted at the participant's home on the last day of study. Each interview lasted around 45 minutes and the participants were interviewed individually. During the post-study interview, participants described their experiences of using the *EdiPulse* system and their reactions to seeing their physical activity data appear in an edible form. The interviews addressed the motivations, expectations, utility and experiences of the *EdiPulse* system in relation to their personal set of physical activity goals. I also made use of photos and videos that participants captured voluntarily during the course of study as evidence of engagement to further support the interviews. All the interviews were audio-recorded to support further analysis after the interviews were complete.

Reflections on EdiPulse system as a whole

I start by narrating how the *EdiPulse* system helped participants in supporting their physical activity goals.

Figure 47: EdiPulse occupied the kitchen space in most houses.

	PARTICIPANT	SUPER HAPPY EMOJI	HAPPY EMOJI	STRAIGHT FACE EMOJI	SAD EMOJI
1	Harry	12	2	0	0
2	Fiono	9	3	2	0
3	Josh	6	4	2	2
4	Karen	2	6	3	3
5	Adam	2	5	4	3
6	Helena	10	2	1	1
7	Rohan	6	4	2	2
8	Diya	5	5	2	2
9	Gavin	7	5	1	1
10	Daisy	6	5	2	1
11	Jayden	6	3	3	2
12	Sarah	6	3	2	3
13	Frank	12	1	1	0

Table 4: Participants received happy and super happy 'Emoji' 74% of the time by achieving their set physical activity goals.

EdiPulse facilitated reflection on physical activities

Participants used the *EdiPulse* system to understand their daily routines. For most participants, the study was an "eye-opener" of their level of physical fitness. Rohan reflected: "*It was a clash of realities, let me put it in this way, when I saw a sad Emoji, I felt, God dammit, is this me? I have to do more exercise.*" Adam similarly was sad to realise the kind of sedentary life he is living now. He said with a sigh, "*When I was younger I had a very active lifestyle, these days I am more sedentary in comparison. I need to kick off my activities a bit more.*" Harry, on the other hand, took *Emoji* as his inspiration and tried to remain consistently active during the study period. As a result, he received a super happy *Emoji* almost on all days of the study (refer Table 4), which made him feel good about himself. He said with a smile: "*I thought I live a pretty lazy life but the Emoji inspired me to do some physical workout each day. That felt good.*"

When participants fell short of their desired goal, the *EdiPulse* system delivered a *Slogan* such as "*the gym is waiting for you*", "*Tomorrow is a great day to work out*" and "*Do not forget your morning exercise*" All participants liked such encouragements and reminders and often did more exercise the next day as a result. Daisy said, "*The EdiPulse system really helped me to create a routine. Now I regularly go to the gym. I think I badly needed that kind of push. I am really happy that I got the kick now*". Helena and Frank had similar thoughts as Daisy. Josh changed his everyday routine by reflecting on the activity treats: "*Now, I walk more during the day. When I go to lunch I try to take stairs.*"

Delayed feedback encouraged being active throughout the day

The printing schedule was designed to deliver the activity treats at the end of the day. Participants appreciated such a delayed but fixed time of feedback to print their activity treats. Rohan said, "*I really wait for the evenings these days. The first thing I want to do after I am back from the office is to print my treats. I want to see if I have done sufficient exercise to get a smiling Emoji, or to get a long petal Flower.*" Diya mentioned that the hidden aspect of the *EdiPulse* reward kept her active throughout the day, "*I did not know whether I have achieved my goals for the day or not. I used to calculate how much should I walk to get a smiling and a really boosting message. The other day, I anticipated getting a smiling 'Emoji' but I was really happy to see the super smiling Emoji, and the fully-grown Flower. That day I walked twice every time to get my coffee, that should have exceeded my goal [laughing].*"

EdiPulse served as a visual reminder to do physical activity

Participants felt that the presence of the system in their household worked as a constant reminder to remain active. Sarah said: "*It is not easy to turn away from it if it is sitting on the kitchen bench printing delicious chocolate and reminding you to do exercise. A mobile app can be a bit of a fad - you use it for a while and then you don't.*"

Diya similarly said, "*I feel like I am answerable to this machine. Even when I am outside, I kind of hear the printing sound and smell of chocolate that reminds me of my activity goal.*"

The edible component of the feedback was appreciated

For Harry, the edible aspect of the system was the standout component. He recalled his previous experience with a cycling app: "*I used to track my cycling using an app. After the cycling was over I used to check the distance and speed. But my interaction with the app stopped there, it did not go any further. Now with EdiPulse, I got a chocolate printed 'Emoji', totally different than the numbers and much pleasing to the heart.*" Daisy added, "*It's unbelievable that EdiPulse not only tells you how much exercise you have done through different shapes, but you get to eat those shapes too*". Josh concluded by saying: "*I like the way it uses the chocolate instead of digital screens to display data. In that way, it takes you away from the screens, where you spend most of your time due to work anyway*".

EdiPulse was dearly missed

I met Gavin 10 days after the end of the study. He told me how much he misses the system "*I was so habitual to the system that gave me sweet rewards for my exercise - now I miss all that. There is no reward waiting for me in the evenings now. The other day I had a very active day and I was really missing my sweet treats. Thankfully there was a little chocolate left from the study, so I created some treats for myself and Fiona.*" (Refer to Figure 28).

Reflections on chocolate as the representation material

All participants appreciated the edible aspect of the system, facilitated by the use of chocolate and described it as a core contributor to their overall positive experience.

Chocolate was at first considered counterproductive

Six participants initially felt that representing physical activity data in chocolate can be counterproductive but as they used the system on a daily basis, they were surprised to see the positivity and fun that it brought to their exercise. Gavin reflected in the interview how his perception towards chocolate changed over the course of the study. He mentioned, "*To be honest, I was initially skeptical over the chocolate, but now I realise that how exercise becomes more fun with chocolate and a little bit of chocolate does not harm anyone*".

Sarah had similar thoughts: "*You normally think you should not have chocolate if you are doing exercise, but getting a moderate amount of chocolate was kind of good that it broke the barrier.*"

Chocolate was considered to be a deserved reward

Chocolate felt like a win-win situation for nine participants, as it became a prize for being active. Fiona saw the chocolate as a celebratory reward for her efforts: "*Food is an important part of the celebration. We often reward ourselves by going to restaurants to celebrate, and what can be better than a chocolate to cherish my 40 minutes run!*" Interestingly, their eating behaviour was influenced by the content of the treats. For example, five participants did not eat chocolate on days when they received the sad face *Emoji*. Instead, they ate the chocolate only on days when they received happy or super happy *Emoji* to celebrate their success. Diya said, "*It was challenging at first not to eat the chocolate, but I was determined to achieve my goal on the next day, which I did.*"

A moderate amount of the chocolate was appreciated

All participants appreciated receiving the same amount of chocolate every day irrespective of how active they were on each day. Helena commented: "*Having an edible reward is good, but you can really get cheeky with it like you burned 2000 calories and here is 2000 calories in return. But I like that the system is not tailored in that way.*" Jayden similarly said: "*I kind of liked that it gave me a small reward or energy for the next day's exercise. It was not a lot but just enough to put a smile on my face and to keep me motivated to exercise.*"

Figure 28: Gavin manually created activity treats to reward himself, mimicking the EdiPulse system.

Thinner forms of chocolate supported guilt free eating

Three participants found eating activity treats quite different to eating a solid block of chocolate because of the thin size (2mm in height). Interestingly, four participants felt that eating this way was more fun because it diminished their guilt of eating chocolate. Daisy said: "*It is this arrangement and also the quantity of chocolate, so when you are eating it, you feel the flavour but you do not feel that you are eating a lot of chocolate, not in the way that will make you guilty or something.*" (refer Figure 49).

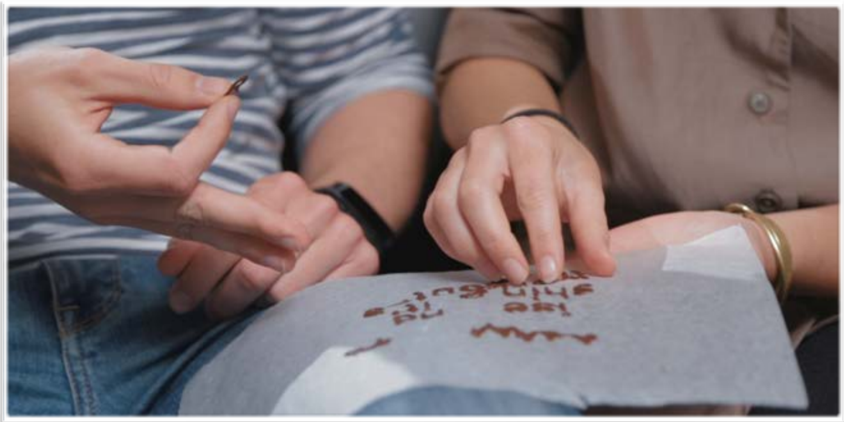


Figure 49: Thinner forms of chocolate were fun to eat.

Chocolate treats moderated cravings for something sweet

All female study participants were fond of chocolate, but *EdiPulse* helped them in controlling their temptation for chocolate. Diya said: "*Although chocolate was so accessible, you also knew that every night you would have a bite of chocolate. And when I did not exercise, I knew from the system that my body did not ask me to eat more chocolate. So it really made me eat less chocolate than what I normally do.*"

Activity treats were rarely shared

Eleven participants ate their activity treats and never shared them with others. Helena said: "*It is a personal reward for what I have done. I would not give it to others since I did all the hard work. I know, it sounds really bad but I kept these treats to myself.*" Jayden similarly commented, "*Food is generally shared, but once it has data elements to it, it becomes more personal.*"

Reflections on representations of activity treats

Next, I describe how each of the four representations appealed to the participants.

Emoji was the favourite activity treat

The Emoji was the favourite activity treat for all participants. Helena was happy that "*When I see a happy 'Emoji' face, I feel that I did a good job.*"

Karen similarly reflected her affection towards the *Emoji* by saying: "*Receiving a smiling 'Emoji' feels like someone liking your photo on Instagram. It's a nice encouraging thing for the day and I think we kind of rely on such encouragements a lot more these days.*" Besides the "feel-good" factor, nine participants found the *Emoji* was a motivational anchor to achieve their desired goals. Gavin emphasised: "*For me the Emoji was the strongest motivator, others were nice too but for me the Emoji' was sufficient.*" All participants also wanted to avoid getting a sad face 'Emoji' at the end of the day. In consequence, they tried to be more active. For example, Diya received a straight face *Emoji* for two subsequent days, which was disappointing for her. She said, "*Through the study I learned that you have to go an extra mile to get a happy smiling Emoji.*"

Activity treats drove healthy competition

Ten participants felt that the system encouraged healthy competition between couples. Gavin and Daisy competed with each other in terms of who would get a super happy *Emoji*. Daisy reflected, "*On one of the study days, I did not exercise but Gavin did a lot. So I got a sad 'Emoji' and he got a super happy one. The next day I was so motivated to do exercise and to also get a super happy 'Emoji'.*" Helena mentioned: "*I loved when Adam got the printed 'Slogan' as 'Helena is getting all the happy 'Emoji'. I liked how it reflects my competence*". Her partner, Adam, who was less active than Helena took this fact sportingly and manually wrote the following message on top of Helena's Slogan: "*Adam is getting all the chocolate*" (Refer to Figure 50).

Figure 50: Adam altered Helena's message to show competence

Slogan made activity treats serendipitous

After the *Emoji*, participants enjoyed the *Slogan* mainly for the suspense that it carried during printing and the motivational push that it offered. Karen liked the way the system prints *Slogan*, "*I enjoyed the writing, getting a new motivational 'Slogan' every day meant a lot to me*."

Josh added: "*We kind of knew whether we will get a happy 'Emoji' or what will be the shape of the 'Graph' at the end of the day, but Slogan always offered something new*." Participants considered guessing the *Slogan* as a challenging and exciting activity. Frank mentioned, "*I continue on watching the Slogan getting printed. It's funny that I am always wrong in guessing it. The system keeps on adding alphabets [letters], and like a small child, I keep on guessing it [laughing]*."

Positive and personalised Slogans were appreciated

Most participants found that the *Slogan* had more appeal when it was positively framed and had a close relation with their life events. Josh mentioned one story where he received the message 'H*ow about jogging together tomorrow?*' He said, "*Yes, I would love to jog with Karen but the system did not know that tomorrow I have heaps of meetings, so I can't*." For Frank, the positive framing of the *Slogan* created more emotional connection with the *EdiPulse* system. He said, "*The messages were like icing on top of the cake. Most of the messages reflected well on my daily routine. I felt as if EdiPulse was a human who was handpicking and crafting the messages based on my data - just the way I needed*."

The Graph was informative but familiar

The *Graph* did not receive the same appeal as other treats. Rohan and Gavin found it familiar to what they usually see on a screen. However, for Adam and Daisy, the *Graph* was essential to identify and reflect on their activities. Daisy summed this up by saying: "*I like how it really shows the ups and downs. It is really expressive. You look at it and you can recollect what happened during the day. I really liked that*." *Graph* was particularly appreciated when there were visible highs and lows in the heart rate due to the different amount of physical activity. When the *Graph* had nearly linear patterns it had little appeal amongst participants.

The Flower raised awareness of sedentary hours

Frank, Daisy, Gavin and Rohan found the *Flower* informative as it offered a more reflective picture of their lifestyle, particularly highlighting their sedentary hours. Gavin and Daisy were particularly unaware about the amount of time they spent sitting each day and the *Flower* effectively communicated this information. Frank was happy to see his exercise schedule being reflected in the *Flower*. He compared the *Flower* petals with sun rays and said "*When I do exercise, I feel like the sun is smiling at me and sending me blessings through longer rays (as represented by the long petals of Flower)*."

Reflections on the chocolate printing process

Participants from the same household did printing together and showed a keen interest in each other's activity treats.

Printing offered slow reflection on data

Participants particularly enjoyed standing next to the printer and guessing, "what the printer is telling tonight", as explained by Frank (refer Figure 51). Josh added: "*Because of the nature of the machine, you keep watching it doing the print. It is a much nicer process to see how it reveals my data as opposed to directly knowing what it is going to say.*"

Karen, Harry, and Frank voluntarily took a lot of photographs of the printing process. For them, the combined experience of watching the print and taking photographs was nothing short of a thrill. Karen said with a smile, "*Taking photographs of the print raised my heart rate and in that way I am burning more calories, I wished I had the monitor on*".

The sound and smell of the printing process was pleasant

Eleven participants appreciated the mechanical qualities of the printer. They found the printing sound quite pleasant, especially during the printing of circular shapes like an 'Emoji'. Besides the sound, they also enjoyed the sweet smell of the warm chocolate during the printing process. Frank, who sometimes did the printing during the morning, said, "*My roommate Kelly commented that it was the first time ever she woke up with the smell of chocolate, which she liked a lot. It gave both of us the motivation to start an active day with a smile*".

Figure 51: Participants loved watching the slow reveal of their data from the day

Figure 52: EdiPulse resulted in healthy competition to get a bigger smile as a reward at the end of the day

Printing activity treats together was fun

All participants enjoyed preparing activity treats together (Refer Figure 52). Rohan compared printing activity treats with cooking and enjoyed doing it together with Diya. He said: "*It was like cooking but with more fun because we also get to talk about what treats we will get and then compare our treats*." Guessing the *Slogan* together was one of the favourite activities of the participants. Harry recalled the involved complexities in guessing the *Slogan* "Take yesterday for example, when I started printing, it initially printed the letter 't', then 'a' and then 'e', so we thought the word is 'eat' and the message is something about food. But then slowly it added two more letters before 'eat', it suddenly became 'sweat', so our guess was wrong and we had to start from scratch, but it was fun". The printed *Slogan* was: '*Sweat is fat crying*'. Rohan felt that doing the study together with Diya strengthened their relationship, "*It would not have been fun if I could not compare our values and it would not have strengthened the bond to go together to the gym*."

Issues with EdiPulse system

Participants also highlighted certain issues with the *EdiPulse* system that I discuss below.

Diversity in food materials was desired

Fiona and Daisy sympathised over the lack of food diversity that *EdiPulse* offered. Fiona pointed out: "*We eat a variety of food on a daily basis. This is a particular device that prints only chocolate. But I am sure in 10-20 years, I could see everything 3D printed*." Helena and Josh, on the other hand, wished to print healthier foods such as carrots. They appreciated the chocolate treats, but having the chocolate treats daily did not seem an appealing idea to two of them. Diya was slightly nervous about the idea of getting chocolate every day, she said, "*I think I would like to receive chocolate treats when I have been really active for continuously one week or so. Getting chocolate treats every day may spoil me. I am not a good girl every time, and I can eat chocolate treats even when I was not active. I would love to get other healthy but tasty food on days when I am not active, so that I am punished in a good way*."

Concern over wasted chocolate

Participants never wanted to share their activity treats, sharing happened only under the concern of wasting chocolate. All participants did not want to waste chocolate, and therefore came up with different strategies to save chocolate.

Samantha created chocolate bunnies from the left over chocolate, "*I love chocolate, and I can not see someone wasting it. It's not only that it is chocolate, you wouldn't really want to waste any food. Right! So I created these chocolate teddies and bunnies from the remaining chocolate, and I can eat them later on. But the problem is that I do not know how much chocolate each bunny is made up of, will it suit my activity level or not? I will probably gift these bunnies to my friends*." At Karen and Josh's home their son mostly ate activity treats from Josh's data. Josh explained the reason: "*I suppose, I am concerned over the wastage of the remains of chocolate in the syringes, plastics, and the paper, but it's good that the chocolate is never wasted. Even if I do not eat it, my son would eat it*."

Printing was sometimes messy

Print results were not always consistent. There were instances when participants over-tempered the chocolate or left air bubbles in the syringe (see Figure 53). As a result, the treats did not print as expected, which annoyed most of the participants. Karen complained: "*It was quite disappointing to* *see the prints becoming messy. If EdiPulse does not print it correctly, you feel like you haven't done the task properly*." Interestingly, most participants did another round of printing to get satisfactory and good looking treats. Diya said: "*I don't know why but getting perfectly printed activity treats made me happy. There were a couple of times when I received messy prints on days when I was not active. That time, I felt like the system is angry on me and therefore, punishing me with bad prints. But I printed them again so that I can eat them on other active days*."

Tempering chocolate and the print setup were considered laborious

All participants found the preparation steps time consuming. Fiona mentioned: "*Loading the syringe and setting up the printer was kind of labour work that one should do to get their activity treats*." Helena echoed similar concerns: "*The preparation needs to be faster and easier*." Harry pointed out that besides being time-consuming the process sometimes also caused a mess. He said, "*Many times when I tempered the chocolate, I got chocolate all over my fingers, which by the way was not a bad thing (laughing)*."

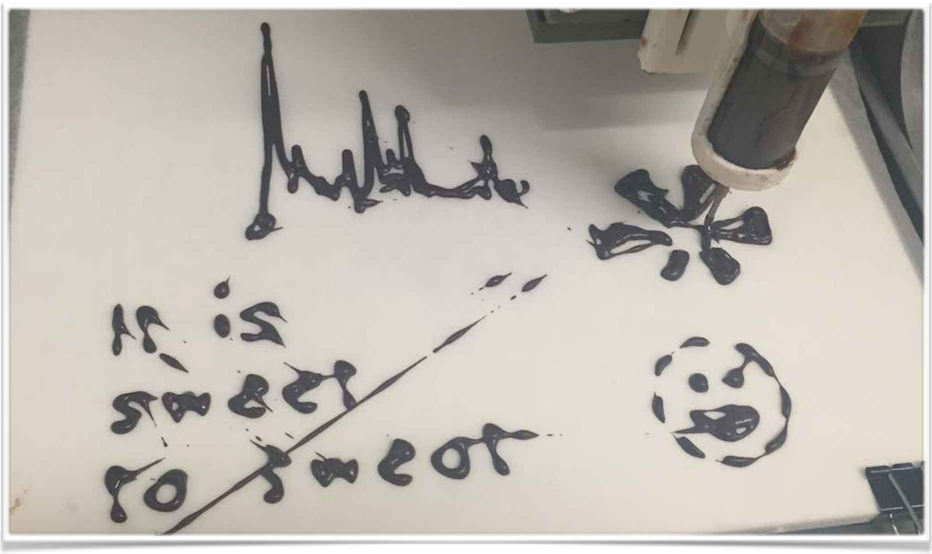


Figure 53: Participants did not like bad prints, they often did another round of print to get the perfect deserving treats

Discussions

Based on the study insights, I put forward key aspects of food-based representation that designers should consider to design systems for physical activity.

Utilise appealing materials to make physical activity goals pleasurable

The study reveals that the use of chocolate as a deserving reward for the physical activity efforts helped participants to achieve their goals most of the time. Participants appreciated receiving an edible reward every day irrespective of their performance and applauded that the system did not punish them if they failed to achieve their goals. The quantity of chocolate was just right to enjoy the flavour of the chocolate without feeling guilty of eating chocolate or consuming more calories after their workout. Moreover, getting chocolate as a reward also helped participants in managing their cravings for sweets. To this end, the primary reward was the edible aspect of the representations. Being edible encouraged participants to reflect on their personal data, as well as their lifestyle, in a playful way. Further studies, however, are required to understand reasons behind participants' interest in receiving a reward in edible materials like chocolate, compared to healthier materials.

The *EdiPulse* system served a dual function, a joint pursuit for hedonic (pleasurable) and eudaemonic (meaningful) experiences. *EdiPulse* allowed participants to consider their self-driven activity goals, whilst also keeping them motivated to lead an active life. Earlier studies have shown that individuals approach self-monitoring techniques in a pursuit of virtue, i.e. to identify and develop character strengths in relation to certain fitness-related goals (Li et al. 2011; Lupton 2016). Psychologists describe such activities as eudaemonic pursuits (Huta 2013; Henderson et al. 2013). In this regard, self-monitoring technologies help individuals by monitoring their performance and progress towards fitness related goals. However, earlier studies also highlight that self-knowledge alone may not be sufficient to inspire users towards achieving their fitness goals (Lazar et al. 2015; Klasnja et al. 2011). As a result, many people struggle to maintain focus and consistency with their physical activity routines. To keep people motivated, designers may need to paint physical activity experience with a 'hedonistic gloss'. The importance of pleasurable rewards is also iterated in earlier works (Henderson et al. 2013; Hassenzahl et al. 2013) that highlight revitalisation functions of rewards in encouraging people to pursue their goals. Food is one of the fundamental pleasures that we interact with every day (Cabanac 2009; Lupton 1998). I, therefore, suggest creating pleasurable rewards by using appealing materials, believing that doing so can improve individual's relationship with understanding physical activity, and will help to encourage and motivate people in achieving their goals.

Make the first sight of activity treats appealing to support positive feedback

The study highlighted that the visual aspect of activity treats was very crucial. I found that participants wanted to get appealing and perfectly printed activity treats. To achieve this result, participants were happy to repeat multiple prints in instances where the initial print was not as good as expected. One participant even considered the bad prints as a form of punishment for being sedentary. Additionally, seeing the *Slogan* printed triggered the game of guessing, which every participant mentioned as a fun activity that they followed almost every day. Furthermore, the *Emoji* and *Flower* representations helped participants to view a summary of their active self. This is in line with recent study findings where participants voiced interest for a representation like a report card, which summarises their exercises in terms of good or bad (instead of giving raw data) (Lazar et al. 2015).

Another interesting finding was that getting a sad face *Emoji* or a short petal *Flower* did not discourage the participants – rather, it served as an aspirational goal to do more exercise. This finding contrasts with previous studies that highlight the human tendency to avoid negative data (Lin et al. 2006). For instance, in the Fish'n'Steps study (ibid), participants did not look at the fish-based representation of their data when they were inactive because they knew their sedentary activity would make the fish sad. The findings suggest that participants were very much interested in seeing and reflecting upon the data, possibly because of the involvement of chocolate.

Chocolate or any other food is difficult to ignore (Dumas 1958). The visual appeal of the activity treats should, therefore, be appealing for both active and sedentary days, because the sight of beautifully presented food always has greater appeal (Dumas 1958; Delwiche 2012). Designers should also consider an incremental approach to printing activity treats where each layer positively adds to the feedback being printed.

Schedule the consumption of activity treats to develop an exercise routine

In the study, participants appreciated getting delayed feedback on their daily activity in the form of activity treats that were to be printed at the end of the day. Getting feedback in such a manner kept participants away from screens and the continuous streaming of heart rate data being captured by the heart rate monitor. Additionally, having to wait for their chocolate representations moderated their cravings for chocolate and gave them anticipatory reasons to look forward to their activity treats. Participants wanted to get a positive *Slogan* and a super happy *Emoji* every day by completing their set activity goals. Since there was uncertainty in accurately predicting whether they have done enough activity, they unknowingly did more exercise and as a result got a super happy *Emoji*. As such, the fixed patterns of seeing the data at the end of the day might have helped participants in building a health routine.

The above-mentioned findings highlight the peculiarities of our interactions with food. Our interactions with food are very different from our interactions with screens and other non-edible physical artefacts. For example, digital screens are used frequently and for a long time, but the data consumed from them is brief and forgotten once the task is over (task-based), i.e. you've read the news article, or finished the paper writing, or watched the TV show. – Artefacts at home are always on the shelf, but you have brief interactions with them, but often and over many years – looking at a photograph, a medal, etc. So you see briefly, but get nice memories and then a few months later you do the same thing for the same effect, etc. Food, in comparison, inhibits a scheduled pattern of interaction. For example, most cultures eat food three times a day. Moreover, once satiety is reached, food is no longer consumed. Taking this into consideration, food makes a good case for scheduling interactions and feedback on self-monitored data in fixed intervals, for example, around meal times. Structuring interactions in such a way also means that feedback on data is not immediately available, rather it is delayed to a certain time of the day.

This will further add a feeling of anticipation to look at the feedback. I, therefore, encourage designers to consider offering activity treats to the user in fixed intervals.

Harness the characteristics of food and the printer to make the process an engaging one

The *EdiPulse* system involved users in the preparation and printing of the activity treats. All participants enjoyed the printing sound of the printer. The sight and smell of the chocolate being slowly overlaid on the print bed further added to the sensorial experience of watching the entire process. Additionally, the randomness of guessing the different parts of *Slogan* while it is being printed, added fun and intrigue to the overall experience. Watching the print process also gave participants time to reflect on their exercise achievements for that day. Although the preparation in terms of getting the chocolate ready for printing was felt to be laborious at times and considered an annoyance. Participants' interest in activity treats, however, was sustained throughout the study, because participants felt that the benefits like the excitement of seeing their data in an edible form was bigger than the "duties" they had to perform.

These findings speak to the earlier works that highlight the importance of slow reflection (Grosse-Hering et al. 2013; Hallnas and Redstorm 2001; Odom et al. 2009) that emphasises 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 improving health by creating tools that support slow and steady reflection.

I draw designers' attention to four factors that influenced the interest in the printing process: 1) printer sound, 2) choice of representations, 3) surprise element due to the ad-hoc printing of letters, and 4) the pleasant smell of chocolate. As such, I encourage designers to accommodate both printer and food characteristics in their design e.g., choosing foods that produce pleasant aromas during printing. Additionally, to reduce the preparation time, I suggest using pre-filled syringes and a heated platform to keep the food warm for printing.

Conclusion

In this chapter, I presented EdiPulse system that transforms heart rate data of an individual into 3D printed chocolate. *EdiPulse* provided four activity treats: *Graph, Flower, Emoji* and *Slogan* as rewards for being physically active. I conducted an in the wild field deployment to understand the influence of *EdiPulse* on one's physical activity experience. The study insights illustrated that activity treats can positively influence an individual's behaviour and attitude towards physical activity. Participants enjoyed getting chocolate treats on active days, whereas on sedentary days, they preserved the activity treats for later consumption. The quality of the printed activity treats was crucial since participants wanted to eat "good looking" chocolate. As such, the *EdiPulse* system encouraged healthy competition between participants from the same household, and motivated participants to develop a persistent routine for exercise.

The reflections presented in the chapter were based on the repeated interactions with the system for 14 consecutive days with each day involving data monitoring of 7 hours and chocolate printing of 25 minutes. Participants expressed missing the system after the study was over, further suggests that their interest in *EdiPulse* could have persisted if the study ran for longer. I believe that the gathered understanding of the relationship between food printing and self-monitoring technologies will provide alternate perspectives that would complement current task or data-driven approaches to designing self-monitoring technologies within HCI.

As such, my work also opens up opportunities to design future systems that aim to support the human energy cycle through the amalgamation of food and technology design. I encourage design researchers to explore the potential of food printing beyond creating beautiful looking 3D printed food to create meaningful experiences for everyday practices.

#7 Shelfie

CHAPTER 7

Shelfie

This chapter describes *Shelfie*, a design framework that presents 16 design themes for designing material representations of physical activity.

"Attention to the qualities of things resurrects the old idea of notitia as a primary activity of the soul. Notitia refers to that capacity to form true notions of thing from attentive noticing."
— James Hillmand

Introduction

In this chapter, I present a conceptual design framework *Shelfie* that aims to guide future explorations in the domain of material representations of physical activity. *Shelfie* offers 16 design themes that are represented in the form of design cards. Each theme highlights an important aspect of the design of material representation. Through this framework, I intend to make the knowledge, gained in different phases of my candidature, accessible to interaction designers who wish to take the field of material representation forward.

This framework is valuable because despite the recent emerging interest in creating a physical manifestation of personal data (Lee et al. 2015; Nissen et al. 2015; Vermeulen et al. 2016; Yu et al. 2016), there is only a limited understanding of how to design such material representations. With *Shelfie*, I aim to fill this gap in knowledge by providing a conceptual understanding of designing for the vital aspects of the material representations of physical activity data. This understanding was accumulated over three years through designing, studying and analysing three different systems (described in chapter 4, 5, and 6) that explore different types of material representations. To this end, this framework also provides a foundation for investigating the meaning and relational effects of material representations for people and also for the representations' context of use. It also provides an analytic lens with which designers can look at digital fabrication as a design resource for materialising personal data.

I start this chapter by discussing the existing frameworks designed to support material representations in different contexts.

Related Work

In the past, various frameworks have been developed to establish an understanding of material (both physical and digital) within interaction design. For example, Jung and Stolterman (2011) proposed "form driven interaction design research" that highlights form and materiality aspects of digital artefacts. Wiberg (2014) articulated four dimensions of material-centred interaction design that include: materials, details, texture and wholeness. Ashby and Johnson (2010) help product designers in selecting the right material by proposing the following five dimensions of material information: engineering, usability, environment, aesthetics, and personality. Giaccardi and Karana (2015) proposed a framework on material experience that highlights how interactions with material influence our practises around four dimensions: sensorial, interpretive, affective, and performative levels. Similarly, Doring (2016) constructed "the interaction material profile" to support a structural analysis of our interactions with materials and to help build a catalogue of interaction materials.

Fuchsberger et al. (2015) offered an artefact oriented perspective on understanding the relationship between users and objects, whereas Wagner et al. (2012) offered a "material-iconographic lexicon of artistic materials" to describe unconventional and traditional uses of materials within art and how their selection adds meaning to art work.

The above works help in establishing a theoretical foundation of material-centred interaction design. However, there remains a lack of understanding of how to take these theoretical strands forward and apply them in practice and to a specific context. Considering this, I have developed a framework *Shelfie* that illustrates 16 key design concepts through design cards. The *Shelfie* design cards are created to make the framework prescriptive and easy to use for design researchers and students interested in exploring material representations of physical activity data further.

Towards designing a framework

I used an iterative approach towards designing a framework aimed at supporting future explorations in material representations for physical activity. The core strategy used to build this framework was to analyse findings from the three case studies, *SweatAtoms, TastyBeats* and *Edipulse*. I started with the lessons learnt from designing and studying these systems, and formulated an initial draft of important design concepts. I conducted multiple informal and focussed group discussions with colleagues to strengthen and refine these concepts. I was particularly interested in developing a tangible framework because tangibility enables the physical manipulations of ideas and allows for the designer to focus their mental processes in an actionable way upon physical objects (Antle et al. 2009). Supporting this idea, I explored different tangible forms such as Lego bricks, wooden trays, and finally settle down onto design cards, to represent the framework.

One of the initial designs of the framework included 18 design concepts defined across two lenses - *production* and *consumption* lens (Refer Figure 54). However, the in-lab evaluation of the framework with experts highlighted that the model was very descriptive, and utilising the concepts in design process was not straight-forward. These insights motivated me to refine the framework in order to make it easier to use in practice. To achieve this, I utilised design cards to describe the concepts of the framework, drawing inspiration from existing literature within HCI (Bekker and Antle 2011; Deng et al. 2014; Mueller et al. 2014; Hornecker 2010; Lucero and Arrasvuori 2010) that uses design cards as a "lightweight and accessible" way of transferring knowledge from design theory to practice (Rogers 2004). The refined framework *Shelfie* has 16 key design concepts defined through design cards, which designers can directly utilise during the ideation phase of their project. Next I discuss the initial version of *Shelfie*, highlighting the key insights that motivated me to revise the framework.

Initial design of the Shelfie framework

The first design of the framework had the key design concepts mapped across two broad lenses: *production* lens and *consumption* lens. The *production* lens described how a designer could shape the physical appearance of a representation. While the *consumption* lens was crucial in understanding the intrinsic cognitive relation and value of the representation as driven by the user's data and properties as described in Table 5.

Each lens had 9 design properties (18 in total), distributed equally across 3 nested layers. Priority of these design properties decreased when moving away from centre. To represent the key concepts and three layers across two lens, I made use of Lego bricks (that denote the concepts) and wooden circular tray (that represents the layers) as seen in Figure 54.

Figure 54: Initial version of the Shelfie framework had two lens: production and consumption lens that acknowledge the shared agency between user and designer while creating material representations.

	LAYER	PROPERTY	DESCRIPTION
1	Function	Purpose	Designer's intended purpose for the material representation, e.g. to enable richer reflection on physical activity.
2		Qualities	Qualities of the material representation that go beyond the intended purpose, e.g. sustainability.
3		Use	Values of the material representation concerning its use, e.g. decorative or practical object.
4	Form	Data	Aspects regarding the used data, e.g. data type.
5		Physical variables	Physical properties that can be used for representing data, e.g. size or texture.
6		Visual mapping	Process of mapping abstract data to a material form, e.g. mapping size to amount of physical activity.
7	Fabrication	Process	General process of 3D printing, e.g. manual or automatic.
8		Timing	Duration and point in time the material representation is printed, e.g. during a physical activity.
9		Frequency	How often the material representation is printed, e.g. every month or on special occasions.

	LAYER	PROPERTY	DESCRIPTION
1	Identity	Self	Extent to which a material representation is in line with the user's identity, thoughts and likes.
2		Authenticity	Identification and mapping of distinctive characteristics of individuals in material form.
3		Autonomy	Innate abilities to affect the design of material representation by experimenting with physical activity routines.
4	Meaning	Information	Perceived understanding of the material representation and the mapped data.
5		Motivation	Incentives provide by material representations to encourage physical activity.
6		Utility	Other imagined uses of material representations by the users.
7	Ecology	Context	Contextual settings that affect the interactions with material representations.
8		Pairing	Association of material representations with other material artefacts and people.
9		Attachment	Level of engagement with material representations in terms of time.

Table 5: Detailed description of the initial Shelfie framework.

The framework was designed to be used during the ideation phase, and the basic use of the framework was as follows:

1) Designers choose a Lego brick related to a design concept.

2) Designers place the brick in a corresponding level defined on the wooden tray.

3) Designers step back and visually get a summary of design concepts that they have moved into the tray. This summary allows the designers to quickly reflect on what other properties need to be considered to design for their specific context. Figure 55 illustrates the arrangement of Lego bricks in the wooden tray.

4) The process repeats until all bricks are used.

To evaluate the effectiveness of the framework, I conducted a workshop with eight participants (6 male, 2 female) from the nearby research community, comprising of academics as well as IT professionals with their age between 21-45 years. I received mixed feedback from participants during the workshop. On one hand, participants appreciated the tangible aspect of the framework that supports a quick visual summary of the key concepts of material representations, and gives a broad perspective on the variety of dimensions to consider during the ideation phase. However, at the same time, participants found the framework overly complicated. They highlighted that the framework needed to be simple and more accessible if it is to be used in practice. The biggest concern was the ambiguity of certain terms and I found that some design themes carried different meanings to different people. As an example, the term *production* and *consumption* was confusing to some participants. Participants wanted to have a well-defined description of each design concept with depicted illustrations on how to use it in their design. A couple of participants suggested to place descriptive cards alongside the Lego bricks to offer supplementary information about those design concepts. Another concern was the lack of order, which made participants wonder on how to move across different design concepts, e.g., should the designer start with the *production* lens and then move to *consumption* lens or vice versa. One participant suggested using Lego bricks of different sizes to solicit priority in terms of the design choice. Similarly, it was also not clear if participants should incorporate all design concepts in their design or they could omit some depending on their requirements.

Considering the feedback of participants, I revised this framework by using design cards that carry descriptive text and a visual illustration of the design theme. Additionally, I also decided not to use layers and hence dropped using the circular wooden tray and opted for a flat Lego sheet instead. I also worked on the textual content for each card in order to make the cards simpler and not having any complicated terminology, in order to improve understanding of the underlying design theme. The revised design framework is presented below.

Shelfie: The framework

Shelfie stands for on-shelf (material) representations of the self. The aim of *Shelfie* is to help designers in designing material representations of the physical activity data. Shelfie consists of a deck of 16 cards divided equally among four categories: *Mapping*, *Outcome*, *Material*, and *Process*. Each card represents a key design aspect that designers should consider while designing material representations.

The framework also utilises Lego bricks and flat Lego sheet as physical props to arrange the design cards. The Lego bricks are labelled after the design themes such that for each design theme, there are five Lego bricks. The aim of these physical props is to enhance the ideation phase with physicality of Lego bricks, which not only provide a visual summary of the all design concepts, but also allows designers to manipulate different design themes as per their needs. A copy of the framework is available here: *http://rohitashokkhot.com* and *http://exertiongameslab.org/projects/shelfie*.

The final deck of 16 design cards is the result of careful sorting, synthesising and discussing each card with 4 interaction designers working in a similar domain. I paid special attention to the content and layout of the cards such that the cards are more easy to understand and applicable in practice. To begin with, while choosing the layout for each card, I worked on different possibilities for the font size, colour and content length. My aim was to strike a balance between the depth and clarity of the presented information. I took inspiration from earlier design cards like Tango cards (Deng et al. 2014) and IDEO cards to design the framework cards.

Figure 55: Setup of the Shelfie 1.0 used during a focus group.

I then iteratively engaged in informal discussions with colleagues for feedback on the layout and content of the card. For example, to highlight the importance of ageing of material, initially the theme was named as "ephemerality" - which I renamed as 'lifetime' based on the feedback. The rest of the cards are similarly phrased in easy to understand language.

Similarly, I carefully chose a representative image for each design theme. Previous research on design cards suggests that accompanying picture on each card plays an important role in representing the card, as it provides a visual summary of the card (Deng et al. 2014). To this end, the image should not be too specific to restrict the ideation space to a particular context; and at the same time, it should not be too general that designers find it hard to relate to the design task at hand. Consequently, I picked up majority of the images from the three case studies detailed in this thesis. The other sources of images include Pexels[15] and Unsplash[16], which are repositories of stock-free images.

Layout of the design cards

Each design card of *Shelfie* is approximately 64mm x 100mm in size and is colour-coded by category. The card displays the following five sets of information related to the design theme described on the card. A Blueprint card is shown in Figure 56.

1) **Design theme:** The first piece of information on the card is the name of the design theme. In one word, the design theme describes the key aspect of designing material representations for physical activity data. The theme is written in bold and occupies the top-left corner of the card. If the name of the design theme is X then the designer should read the card as, "Consider X in the design". Designers should focus on the 'design theme' first, before moving to other pieces of information displayed on the card.

2) **Aim:** The second piece of information, written just beneath the design theme is the aim. The aim describes the resultant outcome of the given design theme. As such, if X is the design theme and Y is the prescribed aim, then the card should be read as, "Consider X in the design to achieve Y"

3) **Illustrative image:** The third piece of information is an example image of the design theme, selected either from the three case studies or from the public repositories such as *Unsplash* and *Pexels*. The intention of displaying an image is to support the design theme with a visual cue.

4) **Theme description and strategy:** The final piece of information is the 'theme description' that resides underneath the picture and describes 'the design theme' in a couple of lines. The theme description also mentions a 'strategy', which suggests possible ways of implementing the design theme in real-world context. These suggestions are formulated from the findings of the three case studies as well as from the design of these systems.

Framework Categories

Shelfie is defined through four categories, which I explain next.

1. Mapping: The first category is *Mapping* that helps designers in identifying different ways of translating physical activity data into a material form. This category includes four design themes - *Purpose, Framing, Personalisation* and *Timing'* which are illustrated through four design cards represented by the colour orange.

2. Outcome: The second category is *Outcome* that aids designers in choosing the look and feel of a material artefact. This category includes four design themes:*Newness, Readability, Utility* and *Pairing*, and the corresponding four design cards are coloured blue.

3. Material: The third category is *Material* that helps designers in choosing the right material for representing physical activity data. This category includes four design themes: *Lifetime, Frequency, Necessity* and *Multi-sensory* represented through 4 green coloured design cards.

4. Process: The final category is *Process* that places an emphasis on the selection of an appropriate manufacturing process for creating material artefacts of personal data. This category includes cards belonging to four design themes: *Involvement, Visibility, Duration* and *Autonomy*. The cards are coloured red.

Next, I describe the 16 design cards (refer Figure 57) one by one, and describe in detail how they were derived from my findings and analysis of my three case studies.

[15] *http://pexels.com*

[16] *http://unsplash.com*

Figure 56: Each Shelfie card contains four set of information.

Figure 57: Shelfie deck at a glance

1. Mapping - Purpose

The first card in the *Mapping* category is *Purpose*, which draws the designer's attention to think about the overall aim of creating material representations of physical activity data. To this end, one key *Purpose* would be to help people start or maintain a physically active lifestyle. This broad purpose can be fulfilled in various ways. For instance, the *Purpose* could be framed as a pursuit of virtue where individuals identify and develop character strengths in relation to their fitness-related goals, through material representations of their data (Li et al. 2011; Lupton 2016). Psychologists termed such activities as eudaemonic pursuits (Huta 2013; Henderson et al. 2013). As such, while creating material representations, the focus should be on collected data such that the created knowledge can lead to improvements in self. Earlier studies highlight that self-knowledge alone may not be sufficient to encourage users towards their goals (Lazar et al. 2015; Klasnja et al. 2011). To keep people motivated, designers may need to paint their physical activity with a 'hedonic gloss'. By hedonic gloss, I am referring to pleasures, joy and satisfaction associated with receiving material representations as rewards. The importance of pleasurable rewards is also iterated in earlier works, which highlight the revitalising function of rewards in encouraging people to pursue their goals (Henderson et al. 2013; Hassenzahl et al. 2013, Locke and Latham 1990).

In all the three systems, I worked with the aim of making physical activity a pleasurable experience through different forms of material representations. In the case studies, I found that participants treasured receiving these material representations and considered them as a reward to their invested efforts. Their inclination towards material representations was not just for achieving knowledge about self, but it was also for having a positive outlook and some form of encouragement at the end of the day. In this regard, they appreciated receiving feedback in the form of an *Emoji*, and *Slogan* through *EdiPulse*, and a *Frog* in *SweatAtoms*. For many participants, the pursuit for getting a bigger glass of sports drink or super happy *Emoji* contributed to an increase in physical activity amongst said participants. As such, all three systems served a joint pursuit of receiving hedonic (pleasurable) and eudaemonic (meaningful) experiences from physical activity. On one hand, these systems allowed participants to create and attain their self-driven activity goals, while on the other hand, the produced material representations (reward) also kept them motivated to lead an active life.

Although the material representations created by the developed systems provided extrinsic motivation to the participants, they proved to be a form of supplementary motivation in addition to the intrinsic motivations that several users already had. I found that participants with predefined targets (such as losing weight or going back to their old active routine) were more willing to take advantage of the motivational features provided by the representations. As a result, they adjusted their routine to incorporate different forms of physical activity to become more physically active.

For such users (i.e. who have an intrinsic motivation for being physically active), setting *Purpose* as an eudaemonic pursuit with the focus on data might be sufficient enough where material representations help them to keep track of their progress. However, users who wanted to change their behaviour but did not commit to taking actions could benefit from setting *Purpose* as hedonic pursuit with the focus on external rewards, where hedonic material representations could provide them a necessary initial push. Although, the reward structure of material representation should be tailored to suit an individual's needs and aspirations, setting *Purpose* as a joint pursuit for both 'hedonic and eudaemonic' experience might offer the best of both worlds.

1

PURPOSE

To make physical activity pleasurable

Showing data to make actionable changes in one's life should not be the only reason behind creating material artefacts. Create artefacts that make people happy and feel good about their investment in physical activity.

2. Mapping - Framing

The second card in the *Mapping* category is *Framing*. This design theme describes the way of structuring the feedback on one's physical activity through material representations. This theme is important to consider because raw unexplained data can lead to discouragement amongst users (Gockley et al. 2006). I classify the *Framing* in two categories: positive and negative framing. Positive framing presents the feedback in an encouraging way, giving more emphasis on what the user has achieved than the unachieved goals. The negative framing highlights on the unachieved goals and the losses associated with it. As an example, missing an exercise session in the gym can be framed as follows: "No worries mate! Tomorrow is another day!" - (Positive framing); and "You missed the session again. You seem to be bit lazy lately!" - (Negative framing). Positive framing of the data can be more persuasive towards achieving goals than negative framing. On the other hand, negative framing can grab user's attention. Earlier works by Lyubomirsky et al. (2005) and Taylor and Brown (1988) highlight that positively framed feedback supports self-esteem, health, growth, and perseverance. However, an overly positive framing creates an illusion of the self, which is dangerous as the individual fails to critically reflect on their activity goals (Robins and Beer 2001). Therefore, negative framing is also important to convey information about certain aspects of one's life that needs attention, such as sedentary time. However, the disadvantage is that the user can feel guilty of not achieving their goals, thereby leading to disinterest in physical activity (Lin et al. 2006).

In this thesis, I have utilised a mix of positive and negative framing across all three case studies. My overall aim was to positively reinforce participants in achieving their health goals. Consequently, I focussed on creating material representations that are fun, enjoyable and follow affective benefits with the user. As an example, *SweatAtoms* construct different sized *Frog* depending upon the participant's physical activity level. Similarly, the petals of the *Flower* in *EdiPulse* and *SweatAtoms* changed depending on how active the participant was across different hours of the day. An important aspect of these systems was that participants were never punished for not doing physical exercise, but the quality of representations increased with more physical activity. For instance, when the participant was active throughout the day, the *Frog* became bigger in size, and the sports drinks of *TastyBeats* had more flavour. Additionally, irrespective of whether the participant was active or inactive throughout the day, each system provided participants with all the material representations - which participants found very positive and encouraging.

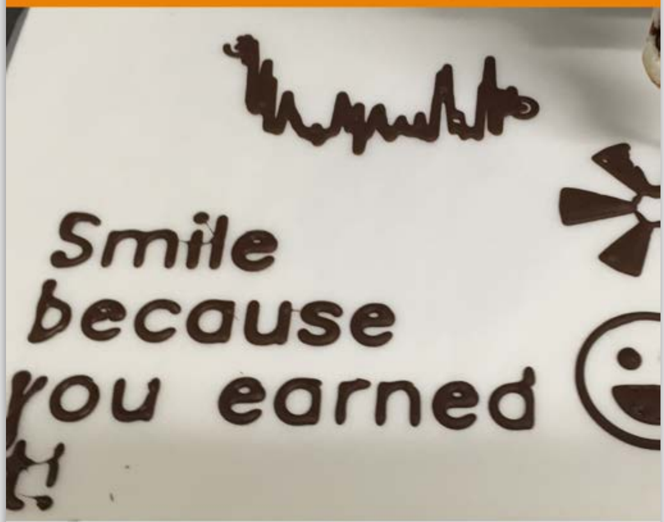
I argue that material properties play a very important role in making the feedback as negatively or positively framed. Since I used materials like chocolate, and sports drinks, with which participants share immediate affection, even the negatively framed feedback served as an aspiration goals to become active. For instance, getting a small quantity of drink from the *TastyBeats* system, and getting a sad *Emoji* printed in *EdiPulse* system did not discourage participants, rather motivated them to be active on the following day. This is contradictory with the findings of Fishn'Steps system (Lin et al. 2006) where participants did not want to look at the fish based avatar of their data when they were inactive because they knew the fish would have been sad. This difference in participant's attitude towards negatively framed feedback was also contributed by the serendipity that all three systems offered to participants. For example, the material representations of these systems were different everyday, therefore, there was always an element of surprise of not knowing what the representations may look like. For example, even though the participants were aware of their sedentary hours in a day, they did not know how the drink prepared by the *TastyBeats* would taste until they consumed it. Therefore, the interest in these representations persisted even in situations where the feedback was 'negatively framed'.

Negative framing became challenging when the interactions with the system were in social settings, that is, in the presence of other people. Participants did not want to expose themselves as inactive. They, felt the pressure to partake in greater amounts of physical activity. For instance, in the *TastyBeats* study, when one participant received a weak-flavoured drink for being less physically active than their partner, it often felt worse to then see their partner receive a fully-flavoured drink. Balancing the positive and negative aspects of the data is a key in social context, especially when personalisation becomes part of the broader design considerations, as I describe in the next design theme.

2

FRAMING

To make feedback meaningful



Providing timely and accurate feedback on data is crucial. Strike a balance between positive and negative framing of feedback to support appropriate reflection. Use appealing materials to gloss negative feedback, if required.

3. Mapping - Personalisation

The third card in the *Mapping* category is *Personalisation*. This design theme highlights the importance of customising the material representation to suit the recipient. Personalising material rewards according to individuals is essential because everyone follows different health-based goals, and achieve these goals differently according to their lifestyle. Creating a standard representation would therefore not be appropriate since users may not consider the representation as an accurate representation of themselves. This theme also looks at reflective qualities of material representations, synonymous with the individual's understanding of the self. Since the constructed material artefact serves as another manifestation of the self, it becomes important to support self-expression through these artefacts such that they reflect the user's identity properly.

In all three case studies, I tried to harness and highlight the distinct aspects of individuals in the design of the created material artefacts. For example, the *Flower* artefact in the *SweatAtoms* and *EdiPulse* was specifically designed to capture and to signify the unique patterns of an individual's heart rate. Significant increases or decreases in the heart rate were mapped to an evolving floral pattern. Since these shifts in heart rate differed from person to person and also from one day to another, the resulting floral pattern in the *Flower* artefact varied for each participant everyday. Participants appreciated the *Flower* representation because it represented their physical activity data in a unique personalised material artefact.

Interestingly, the personalised material artefacts from these systems became very personal to participants. Participants developed affection for the sports drink created through *TastyBeats* and for the chocolate treats created by the *EdiPulse* system. They happily showed these representations to their friends, and posted them on social networks. To this end, the artefacts from *SweatAtoms* readily became part of home ambience. Participants decorated their home with *Flower* and *Frog* artefacts of different days. They even showed off the *TastyBeats* and *EdiPulse* systems to visitors. However, they rarely shared (or gifted) these artefacts to others. For instance, participants preferred to preserve their chocolate treats and sports drinks to consume later, but never really gifted them to others. This contrasting behaviour of participants leads to an interesting question that whether the designers should focus on personalising the design of material representations or whether they should try to focus on nurturing social interactions around them.

Another interesting highlight was that participants generally did not want to trick the system and they were satisfied with getting what they deserved for the day. In one instance, however, one participant did trick the *TastyBeats* system by using data from his more active. Interestingly, however, he described how cheating the system felt bad and that he considered himself as undeserving of the created sports drink. There were also instances when participants wanted to include more personal elements into the material artefacts. For example, participants wanted to use their favourite colour to print *SweatAtoms* artefacts. In *EdiPulse*, participants wanted to use their favourite drinks, and similarly, in *EdiPulse*, participants desired to receive activity treats made of their favourite food. Similarly, in *EdiPulse*, participants appreciated receiving a *Slogan* that reflected their schedule rather than getting general, custom-made messages. For instance, in one example, when *EdiPulse* printed a *Slogan* to encourage a participant to jog the following day he felt bad since his following day was packed with different meetings at office, and therefore, it was not an appropriate message for him.

To conclude, material representation can be personalised in different ways: by incorporating individual's preferences related to different shapes, colours and materials. Another level of personalisation can be achieved by getting deeper access to participant's everyday life, e.g., contextual information related to their work life, using demographics and individual's motivation towards set goals. In such scenarios, physiological measures such as heart rate may not be wholly sufficient. The system would require access to a greater amount of sensors, such as GPS from their smartphone, or access to their personal or social life through applications like FaceBook or digital calendars. Such additional tracking practices obviously raise greater privacy concerns and can affect the ambiguous nature of the artefacts (i.e. a *Flower* artefact means nothing to someone who doesn't themselves have one, but a *Graph* may indicate to an observer that the individual has been really inactive, or active at times they should have been working) Special attention must be paid in abstracting out the personal aspects of the data so that it offers meaning to the individuals but remain esoteric to other bystanders.

3

PERSONALISATION

To support self-expression

An artefact on display is an expressive public representation of the self. People like artefacts that highlight their data and achievements. Identify personal elements and contextual cues from the data and highlight them in the design.

4. Mapping - Timing

The fourth and final design card under the *Mapping* category is *Timing*. This design theme puts emphasis on the timing of the feedback, communicated through the creation or delivery of the material representations. This theme is important because providing accurate, positive and timely feedback on data is crucial to sustaining user's engagement in physical activity. Patel et al. (2015) in particular, suggest that feedback on data should be presented at times when the user is most likely to notice it.

Using these suggestions, *Timing* considerations for feedback would be: 'before', 'during' and 'after' a physical activity. To begin with, the 'before' option seems impractical, as there would be no data available to create material representations. We can create good looking material representations without embedding any data in them, such artefacts would remain primarily to serve the purpose of external tangible rewards. Participants may not carry any personal connection or association with such artefacts, as embedded personal data was one of the major engagement factors identified through all three of my case studies.

The second *Timing* option 'during' allows the user to get feedback on their ongoing performance. The advantage is that such a strategy enables user to think ahead of their next action, and adjusting the activity as it unfolds based on the feedback - thus helps in improving the user efficiency. Now, if the material representations are created 'during' or in parallel to physical activity, then a user can directly influence the material representation by changing the course of their activity. However, this would assume that the physical activity takes place near the fabrication process such as 3D printing, which is not always suitable as managing the 3D printing process in runtime requires technical expertise. As such, the 'during' option is not currently viable with 3D printing. However, this would work in custom made systems like *TastyBeats*, where the visceral process of displaying data through interactive fountains kept participants engaged in the physical activity. This was particularly, found in the public demonstration of *TastyBeats* when the interactive fountain invited social interactions, and people started having fun around the water shoots that a user was creating by doing different sorts of exercise on real-time. This has also been shown to be true in screen based representations such as Versus gym[17] where gym trainers get real time feedback on the actions on the screen. Translating these current on screen practices to tangible material representations is exciting, and as *TastyBeats* illustrates, could be possible.

The final option, 'after physical activity', allows the possibility for users to think and reflect on their physical activity performance and then alter their approach or make different choices next time they partake in that activity In exploring my research objectives, and in an attempt to answer my research question, I followed this temporal option: delivering the material representations to participants after they have completed some amount of physical activity. Fortunately, my participants also appeared to appreciate this delayed mode of receiving feedback.

Giving feedback in a delayed manner kept participants away from the continuous stream of data and allowed them to concentrate on the activities at hand. Additionally, having to wait for their material representations gave them anticipatory reasons to look forward to their material artefacts from the day. Participants always wanted to get a positive *Slogan* and a super happy *Emoji* from *EdiPulse* system every day. Similarly, in *SweatAtoms*, participants wanted to get a bigger *Frog*. Since there was uncertainty in accurately predicting whether they have done enough activity to receive better looking material representations, participants continued to be active throughout the day and unknowingly did more exercise.

As such, 'during' strategy of feedback supports reflection on the go and is suitable when the individual is interested in improving upon specific parts of exercise. Therefore, they need to see the emerging process of exercise. This is the case with majority of the existing self-monitoring devices where users can see the continuous stream of physiological data through a mobile app or on the small screen embedded on the device. On the other hand, 'after' strategy can support slow reflection (Odom et al. 2014) on the daily mundane routine when the user is interested to reflect upon how the day went, and then use this knowledge to bring actionable changes in the lifestyle.

[17] *http://versus.com*

4

TIMING

To provide timely reflection

Feedback during an activity, should be less obstructive yet engaging. To support slow reflection after an activity, focus on appealing materials and novelty in representations.

5. Outcome - Newness

The first theme in the *Outcome* category is *Newness*. This design theme invites designers to pay attention towards incorporating novel factors in the design of material representations. Earlier studies highlight the importance of the look and feel of an artefact in grabbing user's attention and driving its initial use (Wrigley 2011). Users consider the first look of an artefact to make judgments related to its use, whether it is good or bad, safe or dangerous (Norman 2004). Newness of an artefact plays a crucial role in making it desirable. One might argue how newness is different from novelty. Novelty could be because of the thrill of owning a brand new possession, which lends a short-term value to the artefact. But newness is related to a continuous element of surprise that the artefact offers to users. *Newness* in the design (or look) of an artefact helps in creating sustained engagement of the user with the artefact. According to Dinnin (2009), three factors create the perception of newness in an artefact: situational product involvement, a sense that the product is pristine, and the physical possession. The immediate value of a new artefact is derived from the hedonic experience of being the first user of a product. The important point here is that, if the artefact only had novelty, the thrill of possessing the new artefact fades away over time (Dinnin 2009). On the other hand, artefacts that continue to have newness may move to the background after a certain period of time. But that does not mean that the artefact has lost its value, rather it has become an integral part of the individual's life.

In all three case studies, *Newness* of material representations played an important part in sustaining participant's engagement with the system and in relation to their physical activity. Some of the representations were considered fresh, while others were considered to be familiar. Interestingly, participants appreciated representations, which they considered to be good looking, such as the *Frog* from SweatAtoms, which every participant adored; and the chocolate printed *Emoji* that was compared to a human smiling on their achievements. Representations such as the *Graph*, and *Dice* did not gain the same appreciation, however, as they were familiar and not so visually appealing. Additionally, since representations could change daily based on the participant's daily activity, participants always found *Newness* in these representations. As such, these systems offered an emergent way of representing data where the forms or content of representation changed daily, thus adding a sense of serendipity in the overall experience.

Some might argue that the overall positive experience with material representations was partly due to the involvement of new technologies like 3D printing or appealing materials like chocolate and sports drinks. I believe that these aspects - material and process - had a significant role in inviting user's attention in the first place. Using materials that were familiar to users in their daily lives (e.g., plastic and food), to create material representations for physical activity intrigued participants in trying out the system. Their initial interest was to see how an artefact could reflect one's personal data such as heart rate. However, their interest persisted mainly because these materials allowed their physical data to manifest in a physical form - which made them unique and more desirable.

Regarding the process, all the systems utilised a new process to create the artefacts, which initially invited user attention. Although 3D printing and chocolate printing was new for participants, they all expressed some level of familiarity with the technology due to the technologies being increasingly reported on in the media, although none of the participants had ever used 3D or chocolate printers prior to the study. At the start of the study, some participants were very excited with the opportunity of having a 3D printer at home and being able to use it daily. However, their interest in the printing process faded over time, while their interest in the constructed artefacts persisted throughout the study period, possibly because, as explained, the material artefacts embodied their personal data and were new every day. To this end, three participants even expressed an interest in receiving the artefacts directly in their mailbox rather than printing them at home. This interest further suggests that the participants were able to differentiate between the appeal of 3D printing and personalised 3D artefacts. However, in the case of *TastyBeats*, participants' interest in seeing the fountain interaction sustained throughout, as the interaction was always new based on the activities of a day. It was not only "eye candy" to them, but was also helpful in allowing them to reflect on their daily activity. For instance, seeing what pumps were shooting the drink ingredients provided a visual summary of the individual's activities. I therefore, suggest using appealing materials, and novel representation strategies to sustain user's interests in the created material representations.

5

NEWNESS

To create sustained engagement

The look and feel of an artefact often define initial interactions with it. Add surprise and novelty to the representations to make the artefact desirable even after a long time. If possible, offer multiple representations.

6.Outcome - Readability

The second card in the *Outcome* category is *Readability*. This design theme places an emphasis on creating the material representations so that they are easy to interpret, yet provide essential information related to user's physical activity. Raw and complex representations of the collected data do not support essential reflection, as interpreting such information requires cognitive expertise, which users may not have (Hansel et al. 2016). As such, a representation should be able to offer key insights at a glance. The form and functionalities of the design may not always encourage the required action, as users often have different expectations and interpretation abilities when it comes to understanding a design (a material representation, in this case). According to Ham and Midden (2010), a subtle and ambient presentation of the data are key in motivating and subconsciously triggering a behaviour change, because such representations require less conscious attention, as well as cognitive efforts from user. As a result, they can be more persuasive. However, representing data in a physical form includes technical and cognitive challenges, since embedding complex data into the artefact may not be easy to interpret (Stusak et al. 2016). Embedding too much information within artefacts might make them less readable, while embedding less data might make the artefact less meaningful.

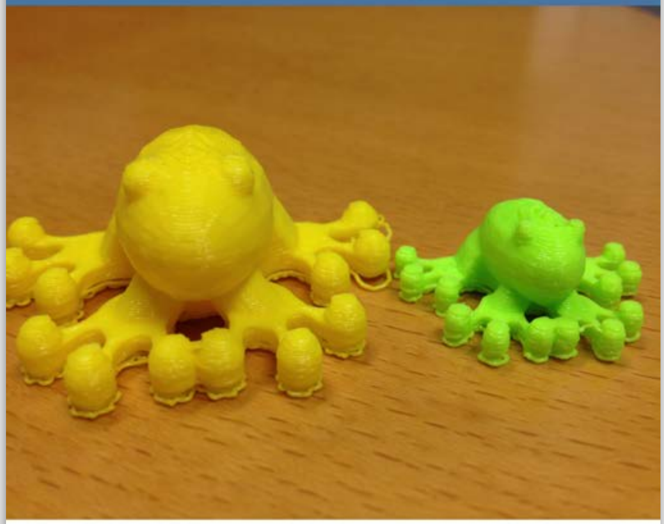
In all three systems, I have focused on representing lesser-known information (such as heart rate zones) as well as making the design more speculative than informative. In all three case studies, participants preferred metaphorical ambient representations of their data rather than a more informative counterpart. For instance, in the *SweatAtoms* study, the *Frog* was the favourite of all representations and it was readily displayed in the participants' surroundings, despite the fact that it contained very little obvious information about their physical activity. Instead, the *Frog* supported the comparative reflection of user's physical activity in a very simple way, and was easy to interpret even from a distance. More informative representations like the *Graph* and *Dice* did not receive much appreciation from participants. In EdiPulse, the *Emoji* and *Slogan* representations were found to be more appealing than the *Graph* and *Flower* representations. The chocolate *Emoji* provided a very quick summary of the participant's day in what was considered to be a humane manner. This suggests that the material representations should be easy to read and interpret, although the embodied information can be as subtle as "*I did more physical activity today than I did yesterday*." This is in line with earlier study findings by Lazar et al. (2015) where participants reported preference towards a simple report card. However, the abstract representations might initially require a little effort from participants, as I found in my own case studies, in terms of: 1) understanding which representations relay what information, and 2) how their shapes differ to represent the change in data. However, if the data is simple, these difficulties diminish within a couple of days as participants receive more representations to learn from.

While deciding the *Readability* of material representations, it is also crucial to understand the level of abstraction required to map the data into material form. For instance, an individual might desire more abstraction and privacy in a public setting, whereas the same individual might appreciate a more detailed mapping between the data and material representation to enable an in-depth understanding of the self in a private setting. In the *SweatAtoms* study, participants liked the idea of having a physical object that cannot be identified as being related to their physical activity easily; and therefore its significance is only revealed if the user wants to reveal it. In order to create varied levels of abstraction, designers can explore different properties of a material such as colour, shape, texture, and design. Additionally, abstraction can also be explored through multiple layers where multiple material artefacts, each carrying a different data, can be joined together to reveal more insights about an individual's active life. Unlike screen-based systems, material artefacts can afford distributed interactions with several material artefacts in a large confined space (Hornecker 2005). Users can join, interlock, and mix material artefacts to generate additional meaning (Khot et al. 2016; Nissen et al. 2014).

6

READABILITY

To allow reflection at a glance



Embedding too much information within artifacts makes them less readable. Instead focus on key bits of information. Use familiar metaphors that are easy to perceive from a distance and allow exploration through senses.

7. Outcome - Utility

The third card in the *Outcome* category is *Utility*. This design theme relates to the additional utility values that material representations offer besides the main purpose of providing feedback on physical activity. If the material artefact affords different purposes in everyday life, the user will engage and interact with them more often - thereby, making the artefacts an integral part of their life. Unlike digital representations, a material representation carries the benefit of fulfilling other practical purposes such as being a decoration piece or a personalised gift. Designers should consider how users could embed the material representations in everyday life when designing the artefacts. The interesting point here is that the user may not necessarily utilise the material artefact in accordance with the use expected by the designer. Users often bring their creativity and imagination into play when sketching use cases of different material artefacts in their life.

While designing material representations of physical activity data through three different systems, I expected to observe several practical utilities of each representation. The use of sports drinks and chocolate in the *TastyBeats* and *EdiPulse* case studies were considered as straight forward, i.e I expected that they would naturally serve the purpose of drinking and eating respectively. However, I also thought that participants will gift their personalised drinks and chocolate treats to their loved ones, in cases that they didn't want them themselves. Surprisingly, however, these representations were considered very personal and participants never shared them with others. In a few instances, when the chocolate treats were instead eaten by participants' family members, the main reason was so that the food (chocolate) would not go to waste. One reason as to why this occurred could be that these representations did not afford the utility of being a gift, for example, the chocolate treats were very thin and followed a stretched structure. Packaging these representations as a gift would not only be difficult, but would also not look as good as a bought chocolate from the market, however, with improvement to chocolate printing process, it could be possible to print better shaped chocolates that can be gifted. As such, with consumable materials like chocolate and sports drink, the intention should be to serve immediate consumption. I describe this aspect in more details in the *Necessity* design theme.

In contrast, the participants' reaction with durable materials, as used in *SweatAtoms* was quite different. In *SweatAtoms*, I designed the *Frog* to serve as a decorative object, whilst I designed the *Ring* and *Flower* to serve as fashionable jewellery. Participants, to my surprise and delight, explored different uses of these representations. The *Flower* and *Frog* were immediately displayed in the surroundings as adorable decorative pieces. More creatively, one participant turned the *Flower* model into a floating candleholder, allowing their candles to float on water, whereas another participant wanted to stack his entire set of *Dice* models in the form of a skyscraper, publicly advertising his physical activity performance. One participant even transformed all of the constructed artefacts into a clock to be used as a decoration piece. However, for representations such as the *Ring* and *Graph*, participants could not identify any immediate use. Although participants explored different utilities for their material representations, their interactions with artefacts like the *Ring* and *Graph*, and food artefacts would have been different if they revealed any extra utility. For instance, if the *Graph* has loops on both ends, it might have been a bracelet. Similarly, if the chocolate treats were thicker in size, they could have served as personalised gifts. However, making chocolate thicker might have defeated the overall purpose of rewarding, i.e. a small amount of dark chocolate is healthier than a lot of dark chocolate. Therefore, designers should aim to support creative usages of the material representations, through either explicitly prescribing the *Utility*, or keeping the design open to encourage user experimentation. However, care needs to be taken since the additional utility should not overcome the main purpose of the representations.

7

UTILITY

To make artifacts a part of everyday life

Material artefacts can fulfill practical purposes in everyday life. Identify and support different practical needs within the design while keeping the main purpose of representation intact.

8. Outcome - Pairing

The The final card in the *Outcome* category is *Pairing*. This design theme is concerned with the context in which the artefact fits in, and highlights the importance of designing artefacts so that they complement the existing schema of artefacts already part of the surroundings. Jung (2011) emphasised that user experience with the use and ownership of artefacts is interleaved with the underlying context and surrounding. This theme therefore, identifies how individual's interactions with material artefacts differ in different environments. *Pairing* of an artefact within the surroundings derives its *Utility*, which I discussed in the previous design theme.

Goffman (1959) attributes humans as actors that take on various identities for different audiences, and where the goal of social interaction is to seek approval from these audiences. Borrowing Goffman's analogy of the public and private stage (Goffman 1959), there is a clear distinction in terms of how an individual presents himself to others in a public or private setting. A material representation, similarly, has a different role to play in a public and private context. Unlike a digital visualisation that is represented on a 2D flat surface of a computer or smartphone screen, physical visualisations require consideration of its surrounding context, in which it will be placed. For example, placing a material representation within a home ambiance has to satisfy and cater to existing aesthetic details and surroundings of that home, while an object that has been designed to be worn should complement the personality, body type, and dressing style of an individual. As such, our interactions with material artefacts also depend on the extent to which a material representation participates within the system of artefacts. Verbeek (2005) brings forward the tendency of artefacts to adjust and act according to the environment in which they were situated. Similarly, Latour (1999) suggests that artefacts work in a close relationship with people and other artefacts, creating networks that shape each other.

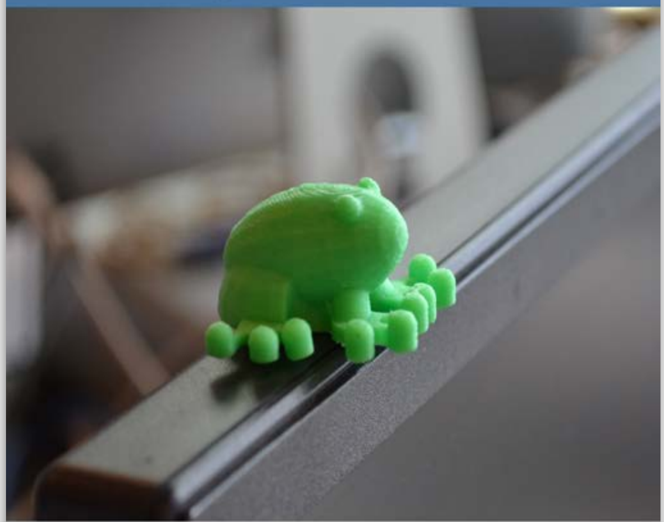
The findings of the *SweatAtoms* study revealed that one of the reasons why participants appreciated the *Frog* and *Flower* over other representations was that participants found immediate applications and places where they could place these representations. For example, the *Frog* was placed on the top of a computer screen and the *Flower* was used as a coaster on the dining table. Participants expressed this was because the colour, design and shapes of these artefacts complemented their home ambiance. As such, the suitability of the material representations, in pairing with existing decorations, was strongly dependent on the physical characteristics and the type of material used. For example, participants did not appreciate the *Ring* model mainly because they did not like wearing plastic-made rings. Alternatively, however, the sports drinks and chocolate treats became a part of participants energy needs, and participants expressed a want to track and represent their food to complement their needs.

When considering the pairing it is not just the material representations that need to be considered, but the systems that create them also need to match the existing environment. For instance, while *SweatAtoms* resided in the lounge room of participants, *EdiPulse* and *TastyBeats* found their place in participants' kitchen work surfaces.. Participants also expressed their interest in making the 3D printers look less mechanical so that they look like a part of their home ambiance. For *TastyBeats*, participants wanted to make it a part of their refrigerator, allowing them to receive their sports drinks when needed, and keep all the drinks fresh and tasty. Interestingly, *TastyBeats* grabbed different levels of attention in private and public settings. For instance, when *TastyBeats* was used in a social setting, with several viewers watching the user interacting with the system, spilling of water was considered fun. Contrastingly, when *TastyBeats* was placed in the home for daily use, spilling was considered as an annoyance. It is therefore important to identify the context where the material representations will be used. People appreciate such material artefacts that match or pair with belongings they already have.

8

PAIRING

To design for a specific context



Identify context where material representations will be used. People appreciate material artifacts that match or pair with things that they already have. Think about different contexts of use and design artefacts to match them.

9. Material - Lifetime

The first card in the *Material* category is *Lifetime*. This design theme emphasises the ageing property of the material artefacts, and how it affects an individual's relationship with them. Previous literature on archiving suggests that material artefacts have a longer life and are more valuable in personal life than their digital counterparts (Petrelli et al. 2008; Golsteijn et al. 2012; Kirk and Sellen 2010). These objects gain value by progressive appropriations, that is, their value increases over time and even if they get worn or cracked, they continue to be the prized possession of owners (Lee et al. 2015). Every material has a shelf life after which they decay or lose their beauty. The lifetime of durable materials is usually longer than consumable materials like food but over time, durable materials lose their lustre and may break. While, materials like food perish in a relatively short space of time.

The study of *SweatAtoms* also reflected that most participants wanted their material representations to age well, and hence appreciated the use of plastic that could resist wear and tear. However, they also raised concerns related to the sustainability of these artefacts. For instance, if users receive these material representations every day, then the question is what should they do with them? With artefacts made up of plastic like materials that do not decay directly, there is a responsibility of creating and destroying them properly, since not all materials are biodegradable. But the interesting point here is that since these material artefacts stay with participants for a longer duration, they afford the user a greater chance of reminiscence, and reflection upon their efforts, for a longer period of time. Users can preserve the artefacts as a reward of their physical efforts and may interact with them afterwards.

On the other hand, using materials like food tackles some of the problems associated with sustainability. Food based representations, however, highlight distinct user interactions. Firstly, our interactions with food are ephemeral — once it's consumed, the "prize" for being active fades from the sight. Additionally, people respect food, and do not ignore or waste food served to them. Consequently, the message communicated through food grabs greater attention, even if the message reflects negative aspects of personal life. For example, in the *EdiPulse* study, participants did not ignore a sad face *Emoji* highlighting their inactive day, rather it became a source of motivation to do more exercise the next day. Similarly, participants never wasted the representations from the *EdiPulse* and *TastyBeats* systems. Participants were also very careful in using the supplied food materials (different flavours of juice and chocolate bars), and made certain the use the leftover materials the following day.

Varying lifetimes of different materials suggest different types of interactions with them. While interactions with long-lasting materials can support reminiscence and ad-hoc interactions with personal data, interactions with perishable materials bring a sense of urgency in users' interactions with their data. Designers could mix and match different types of materials to enhance the user experience. One possible option could be that participants print plastic based representations for days when they were happy with their performance, and therefore would want to preserve memories as souvenirs. While food based representations may be used to highlight alarming or negative aspects of one's daily life, e.g. that participants find unavoidable or non-engaging, in raw form.

9

LIFETIME

To define moments of interactions

Perishing materials like food become stale with time but people do not like wasting them. Use such materials to bring urgency in interaction. Use permanent materials like plastic for reminiscence and undefined interactions.

10. Material - Frequency

The second card in the *Material* category is *Frequency*. This design theme describes an aspect of how often we interact with different materials, which defines the frequency of constructing these representations. Our interactions with different materials such as screen-based, physical artefacts and food-based representations show distinct patterns. We interact with screens in short bursts of time. With physical artefacts, we follow ad-hoc interactions. For instance, we can hold an artefact, keep it in our palm for a long period and talk about it, whenever there is a memory associated with it. While food can inhibit a scheduled pattern of interaction, for example, most cultures consume three meals a day. Once the satiety level is reached (i.e. people are satisfied and full), a meal is no longer consumed. Similarly, people also have habits and particular patterns of consuming things. For instance, many people drink 2 cups of coffee in a day, some drink tea before going to bed. While certain consumption comes as recommended guidelines (Sawka et al. 2007). For instance, an adult should drink 8 glasses of water each day.

In *SweatAtoms*, interactions with the constructed physical artefacts were not defined. Participants majorly utilised these artefacts to decorate their home in the form of a clock, coasters or simple decorations. These decorative pieces remained in the background of their surroundings and came to foreground as a conversation piece, when the participants explained their purpose to visitors. The important point here is that every representation did not become a part of the surrounding, as it's use was derived by the utility that representation afforded, and how well it paired with the participant's surroundings, which I discussed earlier. With *TastyBeats*, the interaction was scheduled in the evening. Some participants enjoyed the drink after the evening meal as a refreshing drink before going to bed. While others make it a major part of their evening snack to follow a healthy lifestyle. However, participants wanted the *TastyBeats* system to provide the drink they deserve after a regular interval of time as a replacement of other drinks. With EdiPulse, the interaction was also scheduled in the evening, mainly as an evening snack, so that the chocolate treat served as a dessert. Because of the use of chocolate, participants were happy with printing these representations once a day, particularly, in the evening as it gives a sweet ending to the day.

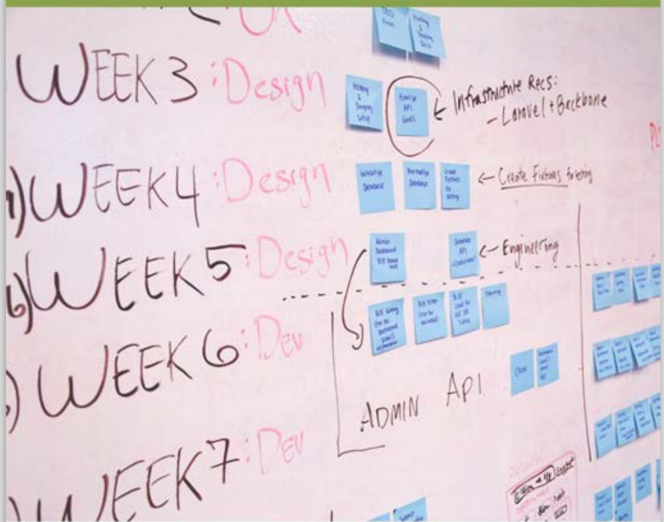
The frequency of our interactions with different materials therefore highlights the need to think about how frequently we should offer material representations to users. If the representation is mainly for fun, then construction requires careful consideration before printing. For instance, in the *SweatAtoms* study, participants printed their representations every day for the purpose of the study. Participants mentioned that printing these artefacts daily was not only time consuming but also diminished the value of artefacts. Instead they would have chosen to print their representations on days when they achieved their goals. Identifying the correct frequency of feedback is important because existing literature suggests that although frequent feedback on data is considered ideal to support behavioural change (Hermsen et al. 2016), constant or repeated emphasis on achieving health goals can also reduce user's motivation to physical activity (Berry and Latimer-Cheung 2013).

On the other hand, food makes a good case for scheduling feedback on self-monitored data in fixed intervals, for example, around meal times. Structuring interactions in such a way also means that feedback on data is not immediately available but is rather delayed to a certain time of the day, which is also appreciated in supporting slow reflection on data. However, if the material is associated with celebrations such as chocolate and champagne, creating these artefacts can be scheduled on special occasions. As such, scheduling food-based representations could help users in developing better health routines.

10

FREQUENCY

To encourage a health routine



Durable materials afford infrequent longer interactions whereas consumable materials follow a fixed pattern of interaction. Focus on these patterns in design to define the frequency of our interactions with material representations.

11. Material - Necessity

The third card in the *Material* category is *Necessity*. This design theme describes the properties of materials to satisfy certain needs of an individual in relation to their physical activity. For example, electrolytes or sports drinks can help in replenishing loss of bodily fluids from pro-longed physical activity, whereas materials like wool or cotton sportswear can support persistence in physical activity under different weather conditions (hot or cold weather). A representation constructed from a material that the user needs could offer extra motivation to the user in achieving their goals.

The *Necessity* can be utilised in different ways. For example, we can utilise specific materials to initiate certain interactions, whereas we can also design material representations to limit our interaction with certain materials. For example, most participants in the *EdiPulse* study were fond of chocolate. In the beginning of study, they thought using chocolate could be counterproductive to their health goals, and thought it might tempt them to eat more chocolate. But as the study proceeded, they were surprised to see that the use of chocolate helped in moderating their craving for chocolate. Since they knew that they would be eating a small chunk of chocolate in the evening, they were happy to wait for what felt more like a deserving treat, than an "evil" and "unhealthy" temptation. Despite the chocolate being so accessible to them (as they had to temper it themselves,), none of the participants felt tempted to eat the chocolate at other times, choosing only to interact with the chocolate when offering to the *EdiPulse* system. This finding highlights that utilising the favourite materials of users could positively reinforce them in achieving their health goals.

In *TastyBeats*, I found similar traits of behaviour where participants were happy to wait. For example, a couple of participants said that the study nurtured healthy eating habits, where instead of eating something unhealthy as a snack, they were happy to wait until the evening where they got what they considered to be not only a healthy drink, but one tailored to the amount of exercise they did that day. In another example, one participant who felt they were slightly dehydrated from cycling explained how he was happy to wait for the interaction of *TastyBeats* to complete before quenching his thirst with a well-deserved drink.

However, the *Necessity* of certain materials can be negated when considering the question of satiety. With regards to food, particularly, it would be difficult to consume food-based representations once the satiety level is reached (stomach is full). For example, a couple of participants in the *TastyBeats* study mentioned that receiving sports drinks is good when they are thirsty as they "really need it", but when they are not then the value of receiving the drink is diminished. Therefore, the amount of these material representations is an essential factor, such that they appropriately reflect on the user needs. Additionally, it is also important to consider the 'frequency' of our interactions with such materials (discussed earlier) to decide on the amount and time of constructing material representations.

11

NECESSITY

To offer instant gratification

Identify if the material can serve any immediate need of the user. Use consumable materials to provide rewarding post exercise experience. Pay attention to satiety while defining the amount and time of interaction with material representations.

12. Material - Multisensory

The final card in the *Material* category is *Multisensory*. This design theme advocates the use of multi sensory properties of materials to enhance an individual's engagement with material representations. The aim is to include different forms of sensory information in the material representations such that the experience of reliving your physical efforts can be much more cherishing. This theme is important to consider because we use a combination of senses to perceive and experience the world. Using multiple modalities will not only grab user's attention, but will also reduce the cognitive load associated with using only one modality - typically visual (Spence 2002). Additionally, the interplay of different senses together can make the experience long lasting, thereby, creating a greater impact of representations on a user's motivation. For instance, the use of a pleasant fragrance can create pleasurable memories related to physical activity that the user could cherish later.

An essential aspect of the multi-sensory experience is that all the senses should communicate the same message together (Hekkert 2006). In cases when different senses communicate a different message at the same time, the overall experience is not pleasurable since users are not able to focus on the important aspects. For example, in the cosmetic industry, colour, roughness, softness, and smell are all harmonised, (through packaging for example), in order to provide a prospective buyer with a positive multi-sensory experience (Ludden et al. 2006). Hermsen et al. (2016) pointed out the capabilities of different senses in their review of feedback technologies. They highlighted that the visual mode is more disruptive than the auditory medium, while auditory is, in turn, more disruptive than tactile feedback. Moreover, the visual medium offers more capacity for detailed information than auditory, whilst the tactile, physical medium, offers less capacity to accumulate or represent detailed information. Therefore, different senses should be carefully chosen based on what information needs to be communicated.

All three of the systems described in this thesis used different materials and, therefore, offered different sensory characteristics. The appearance of these material representations was the main driving force for participants in all of the respective case studies. For instance, the cute looking *Frog* in *SweatAtoms*, was appreciated mainly because it was always printed well, without any rough edges or extra lumps. Similarly, participants wanted beautiful looking chocolate representations from the *EdiPulse* system, and in cases where the printed representations did not look as good as they expected, participants printed the treats again.

Besides visual alone, other characteristics of material come into play during the construction process. For instance, In SweatAtoms, I utilised biodegradable plastic - PLA, which causes a slightly striking smell during the printing process that participants considered to be unpleasant. The unpleasant smell along with the mechanical sound of the 3D printer did not invite the participants to be engaged in the construction process. In terms of the tangible qualities, the material artefacts had a rigid and firm feel when touched. Participants wanted to use a variety of materials such as rubber, or other materials that had a softer texture. With *TastyBeats*, participants enjoyed the visual fountain interaction of drinks and the sound of water shooting from different tumblers. The interaction was not only considered to be playful, but also provided a good peek into the daily activities of the participants. Finally, the taste of the created drink made the experience cherishing. In *EdiPulse*, the melting chocolate produced a pleasant smell, which kept the participants engaged. The "musical" sound of the chocolate printer further added to the participants' experience. Consequently, participants enjoyed looking at the printing process as it encouraged and helped them in the slow process of reflecting of their data.

As found in the case studies, appealing to multiple senses enhanced the user experience and kept users engaged, even in the process of creating artefacts. Different properties afforded by the technology available (such as a 3D printer) can also add to the experience. However, creating a multi-sensory experience with materials is challenging, since some of the design opportunities are also limited by the available technology. For example, state-of-the-art 3D printers cannot control variables such as temperature or moisture. In addition, the fabrication of material representations with multiple colours is challenging at this time. Similarly, there is only a limited range of food that can be printed using food printers. With increased interest from both academic and industrial communities in digital fabrication, I expect that most of the challenges will eventually become resolved.

12 MULTISENSORY

To create higher impact of feedback

Use materials that offer multi sensory experience of engaging and understanding data. Convey the same information through multiple senses to support greater impact. Avoid confusion by embedding multiple information across senses.

13. Process - Involvement

The first card in the *Process* category is *Involvement*. This design theme describes the method of creating material representations that can either be automatic or manual. Following the advice of Connelly et al. (2006), I argue against automated processes because it reduces the process of critical self-assessment and regulation that happens when an individual is actively involved in the making process. Kahneman (2011) further argues, in his work, that humans are inherently lazy thinkers and often take mental shortcuts - relying on an automatic association created through repeated exposure to an idea rather than taking the time to think about a particular message and its implication. Therefore, by involving users in the creation process of material representations, we can increase the potential value of material representations. This happens because the users feel as though they have created the representation, possibly making the representation more influential than a standard generic form.

Material artefacts become mementos and by virtue of the time and emotion invested in them by their owner. Creating an artefact can be an enjoyable experience, giving individuals the feeling of wonder, agency and satisfaction (Gauntlett 2013). Thus, it is not usually the physical characteristic of the objects that make them biographical, but the meaning imputed to them as significant personal possessions.

Involving user is the creation process gives the user freedom and the possibility to see how the material representation is produced, it also requires that the user has access to a 3D printer and suitable materials at home, as well as the time and necessary skills to 3D print the material representations. Effort is needed on the behalf of the designer to ensure that the process is user-friendly and less prone to error. For example, in *TastyBeats*, spilling was accidental and caused a mess on nearby surfaces. On one hand, participants welcomed this mess as a dramatic outcome of the playful interaction; while on another hand, it also challenged their notion of playing with consumable materials as for some of them food is mostly a forbidden object to play with. This was an interesting finding since I consider playing with consumable materials as an opportunity. However, many participants think the opposite. Therefore, designers need to consider the cultural beliefs of participants when designing certain playful interactions around the use of consumable materials or to offer multiple methods of interactions with the artefacts.

13

INVOLVEMENT

To make artefacts more valuable

Involve participants in the making process of the material artifacts. When people spend time and put in efforts in the making, they also perceive a value in doing so. Make the process visually engaging and fun to be part of.

14. Process - Visibility

The second card in the *Process* category is *Visibility*. This theme highlights the consequences of making the data publicly visible. There is strong evidence that our behaviours are shaped by the behaviours of our family, friends and people we work with (Cialdini 2006). Therefore, by making the process of creating material representations explicitly visible, we can increase the chances of building a sense of commitment which can likely lead to a change in behaviour, relating to the social norm (Ledger and McCaffrey 2014).

Visibility can support two forms of social incentives: Competition — where users can compare their data against others — and Co-operation — where users can work together towards a set goal and motivate each other in doing so. Many tracking devices already allow and encourage social sharing and comparison of the tracked data, and often employ Gamification strategies (Deterding et al. 2011) and the social norm approach (Cialdini and Goldstein et al. 2004). However, the sharing of data is distributed over over the Internet, with little data shared among co-located individuals (who share the same space). Interestingly, physical effort is not good at supporting “kinaesthetic empathy” (Fogtmann 2006), where observers can read and decode the kinaesthetic actions of users, however, the visceral process of creating material artefacts can communicate relative efforts to peripheral participants, and does so in a greater way than observations alone.

In all three case studies, the visibility of material representations played a role of a social catalyst, inviting conversations around their aesthetics and use. The public visibility of the *TastyBeats* and *EdiPulse* systems made it possible for others to easily notice the data and served as a conversation piece between participants and the observers. Participants found watching the drink in *TastyBeats* be prepared as one of the best parts of using the system, and were very keen to also watch the creation of their partners’ drink in order to compare their relative amounts of physical activity that day. Often the drink was made with both participants present and, through watching the making process, each participant became more aware of each other’s physiological state, which in turn triggered discussions and playful social interactions. Participants often competed to get a bigger or more flavoursome drink, and moments of laughter occurred when the prepared drinks were drastically different for each other.

In the *SweatAtoms* study many participants showed their printed artefacts to neighbours and visitors to their home. These artefacts generated a sense of curiosity and sparked conversations among the visitors who did not know what the design actually meant. Participants were enthusiastic to explain the meaning of the artefacts to the inquisitive visitors. Some participants also gave these artefacts to their loved ones as a gift or ‘token of their heart’. Previously sharing of ones inner most self has not been possible with current physical activity trackers, and this opportunity illustrates how material representations of one’s physical activity can extend beyond the self, creating important mementos for not only the individual, but also their loved ones. In much the same way that loving parents collect their child’s baby teeth, handprints, or record their child’s evolving height on the frame of a door, material artefacts create a snapshot in time of an individual’s bodily data, encapsulating their healthy activities in a memorable souvenir. I can imagine in the future someone can view this artefact as a memento of how the individual once was, not just in photos, but also in health and with aspirations and goals and their dreams.

However, the public display of physical activity data can lead to issues of privacy. Within this study, participants did not raise such concerns, as the data was very abstract. Therefore, I believe, one way to address privacy related concerns could be through abstract forms of visualisations, as illustrated through systems like *TastyBeats*, which provide only basic information about one’s physical activity, hiding intrinsic details from the user.

14

VISIBILITY

To support social interactions

Increase visibility of the process to create shared understanding of the data. A visually enticing process of creating representation can attract passerby's attention and it would also encourage individual's participation in the activity.

15. Process - Duration

The third card in the *Process* category is *Duration*. This design theme describes the time span of creating material representations and ways of making that period engaging.

The *Duration* of creating material representations is usually lengthy in comparison to digital representations. It involves, at first, preparing the raw materials, setting up the system and finally printing. Each of these steps takes time and effort from the users. In recent times, investigations are being undertaken to tackle the slowness of 3D printing and make the digital fabrication process more efficient (Mueller et al. 2014). In contrast, I would suggest that there is an opportunity to embrace the slower making process as a useful design resource to support delayed feedback of physical activity. Because just as physical activity has several stages (warm up, activity, cool down) the printing process can exaggerate a similar temporal journey (warming up, printing artefact, letting the artefact cool down).

For instance, in all three case studies, the *Duration* was considered by participants as a time to reflect on their exercise achievements for that day. This process also became a conversation point for the participants where they compared each other's activities in a fun way of guessing who will get a smiling *Emoji*, a bigger *Frog* or a more flavourful drink. In the *TastyBeats* study, participants found the interactive process of creating a sports drink as rewarding as consuming the drink itself. In EdiPulse, all the participants loved the "musical" sound that printer made. The sight and smell of chocolate being slowly overlaid on the printer bed, further added to the temptation of watching the entire process unfold. The randomness in guessing the different parts of the *Slogan*, while it was being printed, also added fun and intrigue to the reveal. Although the preparation, in terms of getting the chocolate ready for printing, was considered as an unnecessary labour and annoyance, participants' interest in the process was sustained throughout the study. Participants expressed that the benefits such as the excitement of seeing their data in a tangible form were bigger than the "duties" they had to perform before hand. I believe that the perceived value of the material representation among the participants also increased with the time they waited for it to finish printing. In future explorations, it could be interesting to examine the relationship between elapsed printing time and the size of the reward (a long time and a small reward, vs., for example, a short time and big reward). To this end, the slow reflection on data in terms of the printing process was considered a valuable part of the overall experience.

I, therefore, draw designers attention to four factors that can make the process of creating material representation engaging: These factors are the: 1) sound of the machine, 2) choice of the representation, 3) surprise element due to the ad-hoc printing of letters, and 4) pleasant smell of the material. As such, I encourage designers to accommodate the characteristics of both the printer and material in their design e.g., choosing a material that produces a pleasant (and safe) smell when printing.

15

DURATION

To make the process engaging

Creating artifacts is a lengthy process. Capitalize on the sound and dynamics of the process to attract participation during the creation process. Make the process playful by keeping representations novel and slowly revealing them one by one.

16. Process - Autonomy

The final card of the deck and the fourth card of the *Process* category is *Autonomy*. This design theme suggests the benefits of giving user the freedom and scope to innovate the design of material representations through the use of their body and movements.

In literature, autonomy refers to the innate desire to take actions out of personal volition and not under external influence or control (Ryan and Deci 2009). According to Self-Determination Theory (ibid) autonomy is experienced when a user is given the freedom and scope to vary the activity within its set boundary. However, existing interactive systems built to support physical activity put more emphasis on doing the physical activity correctly and leave no room for improvisation or physical creativity. For example, most exercise-based digital systems like Dance Central[18] replicate a real world scenario by creating a virtual instructor where the user simply mimics the steps being explained (Segura et al. 2013). I believe that the aesthetics of material representations provide users with opportunities to be self-expressive and autonomous. Additionally, any material representation, if put on display, becomes the public representation of the self and craftsmanship (Goffman 1959). As a result, in order to fabricate different self-expressive material representations, the user might feel inspired to try out new forms of physical activity. Allowing *Autonomy* in data representation and the design of material representations can make the artefacts more meaningful to the user. This is because it enforces the feeling of creativity in a way that allows users to feel as though they have created the artefact. To this end, facilitating ways to influence the design becomes important to support the *Autonomy*.

In all three case studies, I found that participants often altered their pattern of exercise, or increased the amount of physical activity they used to do in order to get a bigger *Frog*, a smiling *Emoji*, a rich flavoured drink, or to achieve a different shaped *Graph* compared to previous days. In the *TastyBeats* study, participants liked how a drink became a celebration of their physical activity along with an opportunity to express themselves in front of a large cheering crowd. As such, the fluidic spectacle of heart rate becomes a public display of self, allowing the participants to be imaginative and creative with their movements.

Although I did not include participants in the design process, most participants in both studies were vocal and enthusiastic about designing representations for themselves. Participants also altered the ways in which they printed and used their representations - not only to improve their understanding, but also to reflect their personality. In the *SweatAtoms* study, participants specifically chose material filaments from the given pool of material filaments to match their favourite colour. Three participants wanted to change the filaments colour everyday so that there are a distinctive feel and order to the representation once assembled together. Looking into the ways in which users can participate in the design of material representations would be a useful research direction when moving forward with this work in the future. Designers, therefore, should allow participants to customise their experience by letting the participants freely choose what, information needs to be printed, and when to print this information. Additionally, there might also exist an opportunity for designers to combine physical activity data from multiple people in order to represent this collected information as one combined object. Designers should therefore allow users to choose their own time period to both exercise, and to print, artefacts. Designers need to be able to make visible changes in the design and printing process in response to user's actions.

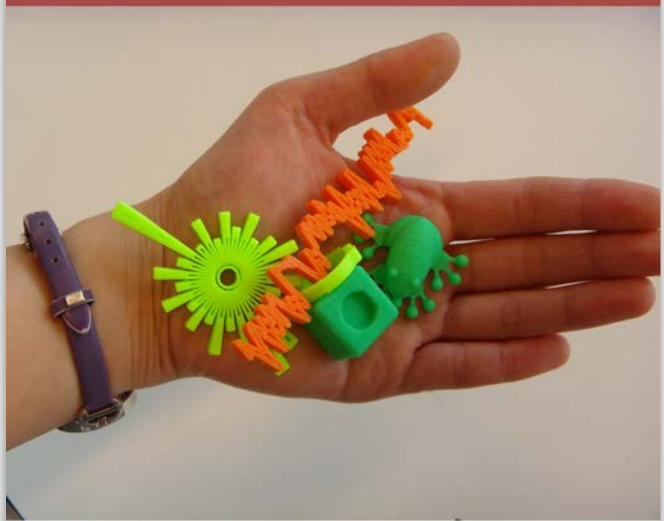
Figure 58 shows all 16 design cards at a glance.

[18] *http://www.dancecentral.com/*

16

AUTONOMY

To support creativity in action and design

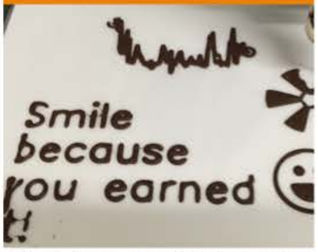


Taking actions out of volition is an innate need. Allow users to schedule their exercise and the process of creating artefacts. Make visible changes in the process and design of material representations in response to user's actions.

1 PURPOSE
To make physical activity pleasurable

Showing data to make actionable changes in one's life should not be the only reason behind creating material artefacts. Create artefacts that make people happy and feel good about their investment in physical activity.

2 FRAMING
To make feedback meaningful



Providing timely and accurate feedback on data is crucial. Strike a balance between positive and negative framing of feedback to support appropriate reflection. Use appealing materials to gloss negative feedback, if required.

3 PERSONALISATION
To support self-expression

An artefact on display is an expressive public representation of the self. People like artefacts that highlight their data and achievements. Identify personal elements and contextual cues from the data and highlight them in the design.

4 TIMING
To provide timely reflection

Feedback during an activity, should be less obstructive yet engaging. To support slow reflection after an activity, focus on appealing materials and novelty in representations.

5 NEWNESS
To create sustained engagement

The look and feel of an artefact often define initial interactions with it. Add surprise and novelty to the representations to make the artefact desirable even after a long time. If possible, offer multiple representations.

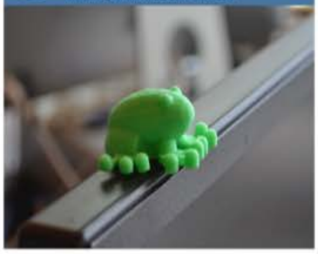
6 READABILITY
To allow reflection at a glance

Embedding too much information within artifacts makes them less readable. Instead focus on key bits of information. Use familiar metaphors that are easy to perceive from a distance and allow exploration through senses.

7 UTILITY
To make artifacts a part of everyday life

Material artefacts can fulfill practical purposes in everyday life. Identify and support different practical needs within the design while keeping the main purpose of representation intact.

8 PAIRING
To design for a specific context



Identify context where material representations will be used. People appreciate material artifacts that match or pair with things that they already have. Think about different contexts of use and design artefacts to match them.

9 LIFETIME
To define moments of interactions

Perishing materials like food become stale with time but people do not like wasting them. Use such materials to bring urgency in interaction. Use permanent materials like plastic for reminiscence and undefined interactions.

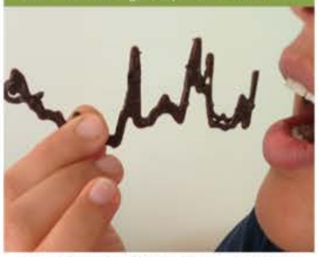
10 FREQUENCY
To encourage a health routine

Durable materials afford infrequent longer interactions whereas consumable materials follow a fixed pattern of interaction. Focus on these patterns in design to define the frequency of our interactions with material representations.

11 NECESSITY
To offer instant gratification

Identify if the material can serve any immediate need of the user. Use consumable materials to provide rewarding post exercise experience. Pay attention to satiety while defining the amount and time of interaction with material representations.

12 MULTISENSORY
To create higher impact of feedback



Use materials that offer multi sensory experience of engaging and understanding data. Convey the same information through multiple senses to support greater impact. Avoid confusion by embedding multiple information across senses.

13 INVOLVEMENT
To make artefacts more valuable

Involve participants in the making process of the material artifacts. When people spend time and put in efforts in the making, they also perceive a value in doing so. Make the process visually engaging and fun to be part of.

14 VISIBILITY
To support social interactions

Increase visibility of the process to create shared understanding of the data. A visually enticing process of creating representation can attract passerby's attention and it would also encourage individual's participation in the activity.

15 DURATION
To make the process engaging

Creating artifacts is a lengthy process. Capitalize on the sound and dynamics of the process to attract participation during the creation process. Make the process playful by keeping representations novel and slowly revealing them one by one.

16 AUTONOMY
To support creativity in action and design

Taking actions out of volition is an innate need. Allow users to schedule their exercise and the process of creating artefacts. Make visible changes in the process and design of material representations in response to user's actions.

Figure 58: All 16 cards of Shelfie.

Using *Shelfie*

The framework can be used to brainstorm within a group as well as to work individually. Although, these cards can be deployed and used in flexible manner, I encourage using these cards in a spread out design based on Lego bricks, especially when working in a group setting.

The intention behind spreading the design cards on Lego board is to make the ideation phase quick and more visible. With traditional design cards, the cards remain mostly hidden throughout the process once a designer has made their choice. For example, a designer draws a card from a deck, uses it in some way to inform their ideation process and then returns the card to the deck. In *Shelfie* framework, however, I instead opt for a visual and spread-out display of cards on the Lego board, where the used cards are visible and quickly accessible at all times. Such an arrangement of cards is partially inspired by a popular board game *Guess Who?*[19]. Allowing all of the cards to be visible in this way also allows the designer to easily view a summary of the chosen design concepts, allowing them to have a broad overview of the design throughout the ideation process. Viewing the overall design concepts in this way also allows designers to quickly change their mind about certain design themes and to move them around until their desired design concept is realised.

Spatial arrangement of Shelfie

The cards are spatially arranged on a Lego board of size 38cm by 38cm in a 4x4 matrix (See Figure 57). The 4 rows denote the four categories of the framework, where each row consists of four columns corresponding to the 4 design themes of the category. The design cards in each row are arranged in the order of their importance, from first to last. These cards are numbered to suggest one possible order of using them. However, this order is not mandatory to follow.

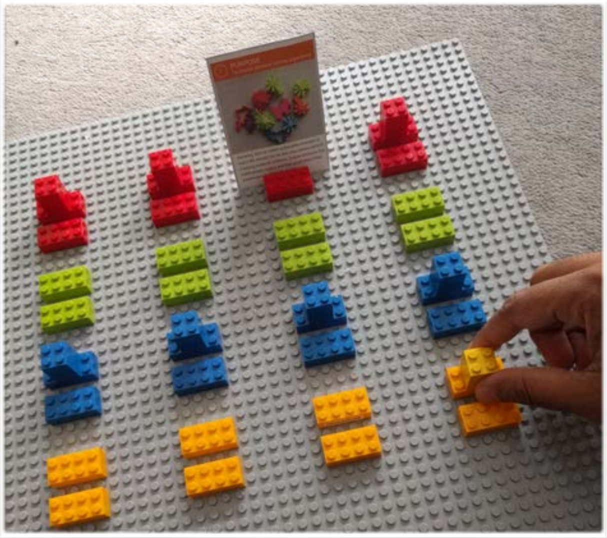


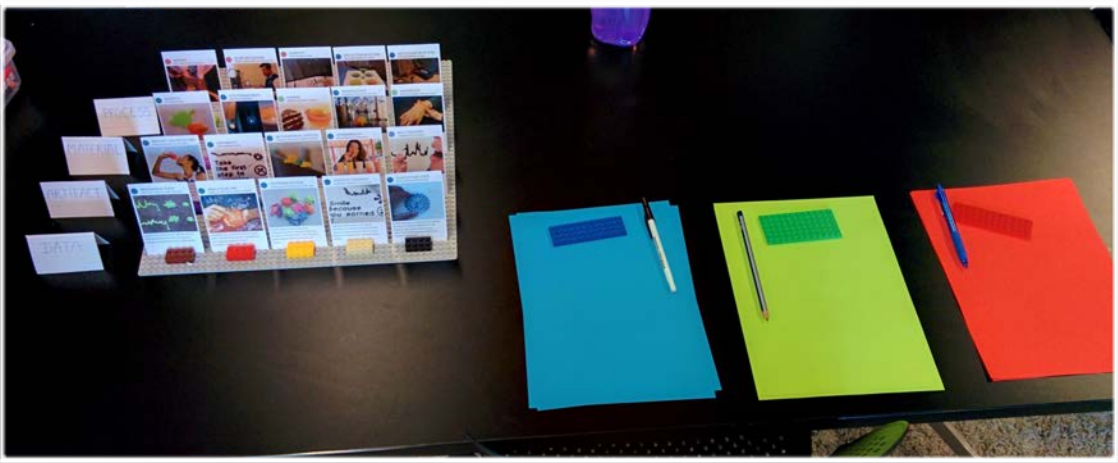
Figure 59: Setting up Shelfie.

Designers can work their way through each of the categories, picking out and combining different cards to formulate their design.

On the Lego board, each design card is arranged between 4-6 Lego bricks with two Lego bricks in front of the design card and the remaining bricks behind the cards. The Lego bricks bear the same colour and label as the category of the design themes. These Lego bricks bear the same label as the design card theme. During the ideation phase, designers can pick one Lego brick from the back of the design card and place it outside of the Lego board - if they decide to use that design theme in their design. As such, the collection of Lego bricks at a specific point of time describes the set of design themes that the designer wants to consider in their design.

The setup and working is explained using the following steps.

Figure 60: Shelfie setup



[19] *http://www.hasbro.com/en-us/product/guess-who-game:8EFEF4A8-6D40-1014-8BF0-9EFBF894F9D4*

Setup

Materials needed: printed design cards, Lego bricks, and n+1 Lego flat sheet with 'n' being the number of participants.

Step 1: Print all the cards individually, each card should be approximately 64mm x 100mm in size.

Step 2: Arrange the cards according to the category names.

Step 3: Arrange a set of 4-6 Lego bricks in 4 colours, each set signifying one category of design themes. However, this number will change depending upon the number of participants. If possible, try to match the colour of these Lego bricks with the category colour for symmetry (refer Figure 59).

Step 4: Label the Lego bricks with the name of the design theme.

Step 5: Create a stack of Lego bricks for each design card. For example, a stack of 3 Lego bricks to place at the back of the card and two in the front.

Step 6: Place the design cards on the Lego sheet in a 4 x 4 matrix. Follow the numbering on the cards to arrange them across different rows such that the first row starts with the number '1' card and ends with the number '4' card. Continue laying out the cards in this way for the other three rows.

Step 7: Now place the stack of Lego bricks in front and at the back of each design card. The final arrangement will look like the one shown in Figure 60.

Step 8: Give one Lego board, called the Selection Board, to each participant for ideation.

Working

Step 1: Place the Shelfie framework in the centre of the ideation space (e.g., table) and ensure that each participant has one selection board.

Step 2: Start with the first card of the first category, i.e., *Purpose* from the *Mapping* category. The first participant may read out the card. Every participant thinks about the relevance of the design theme to the design task at hand. If the design theme is relevant, each participant moves one Lego brick to their selection board. Participants can also use a Notepad to note down some use cases, or to sketch some ideas Refer Figure 61).

Step 3: Participants similarly continue with the next card, and move one Lego brick to their selection board, if they care to use the given theme in their design.

Step 4: Once all the cards are considered, participants then discuss each content of each selection board. They should discuss about what themes each participant has considered on their selection board and why. Finally, participants then create a final set of design themes that they wish to use in the material artefact to be designed.

There could be other possible ways to use the framework. For example, in a group, each participant first works individually on each design theme and selects the Lego bricks corresponding to the design themes they would prefer to have in the final artefact. At the end, participants could have a discussion on what design themes everyone has selected and work out the final design.

Summary

In this chapter I described a design framework *Shelfie* that aims to help further explorations in the context of designing material representations of physical activity data. I took an iterative approach to design the framework where the form and design of the framework evolved through several focus group discussions organised with HCI experts, designers and IT professionals. One of the initial design included 18 design concepts across two broad categories describe as *consumption* lens and *production* lens. I conducted focus group evaluations of the framework to investigate its overall utility. The obtained feedback guided me to design a prescriptive and easy to use framework. The final design of *Shelfie* involves 16 design cards that illustrate key design themes that designers should consider while designing for the given context. I organised multiple focus groups to refine the design cards in terms of its design and content.

The framework has helped in the ideation of the design of sports souvenirs, *Fantibles* (Khot et al. 2016). *Fantibles* is a personalised sports memorabilia that highlights an individual's commentary about sports on Twitter along with the uniqueness of each sports match (Refer Figure 62).

Table 6 shows how the Shelfie cards helped in shaping the design of *Fantibles*.

Figure 61: Using Shelfie during ideation.

	PROPERTY	DESCRIPTION
1	Purpose	To make home-viewing pleasurable through tangible souvenirs.
2	Framing	Inclusion of both positive and negative memories of the match but in an abstract manner.
3	Personalisation	Use of team jersey's colour to match the printed souvenir, focus on individual's tweet along with sports data.
4	Timing	Printing and delivery of the souvenirs after the match.
5	Newness	Use of generative design based on the individual's tweets and sports data, which change with every match.
6	Readability	Distribution of information across multiple artefacts that interlock with each other.
7	Utility	User defined but primarily as a sports memorabilia.
8	Pairing	With magnets so that *Fantibles* can be placed on the fridge door.
9	Lifetime	Focus on durability hence use of plastic.
10	Frequency	User defined and one per match.
11	Necessity	None.
12	Multisensory	Focus on tangibility.
13	Involvement	Not considered.
14	Visibility	Not considered.
15	Duration	Not considered.
16	Autonomy	Freedom to choose when to print and visible changes in the design in response to tweets.

Table 6: Use of Shelfie cards in the design of Fantibles

In future, I aim to explore its utility in different contexts through design workshops. With this framework, I aim to invite designers and researchers - both in academia and industry alike - to challenge their preconceived notion of representing physical activity data to users. As technology evolves, it is important that we as designers harness and explore the exciting opportunities that these technologies offer. In my work, I worked with the vision that in future, every home will have some sort of personal fabrication devices - a food printer or 3D printer. Therefore, there should be any limitation to imagining possible design future. To this end, I would argue that the proposed design framework not only marks the first conceptualised approach to the design, but also paves the way for future explorations of this work.

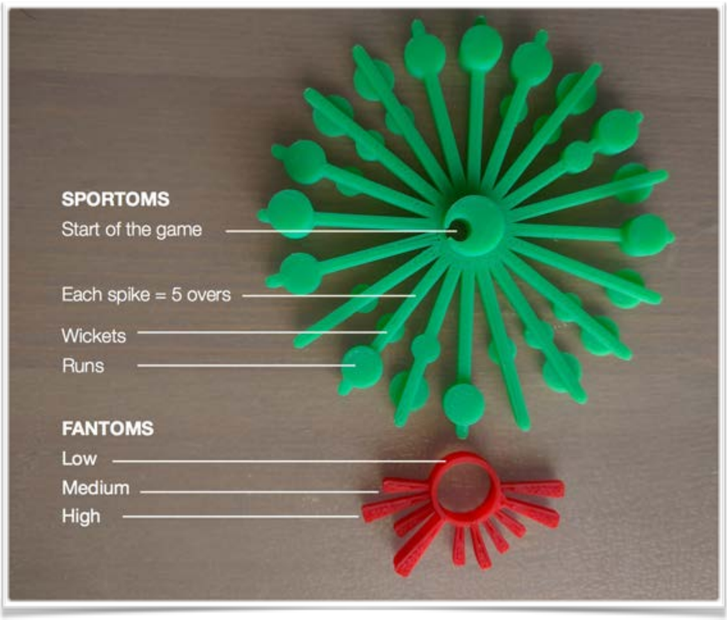
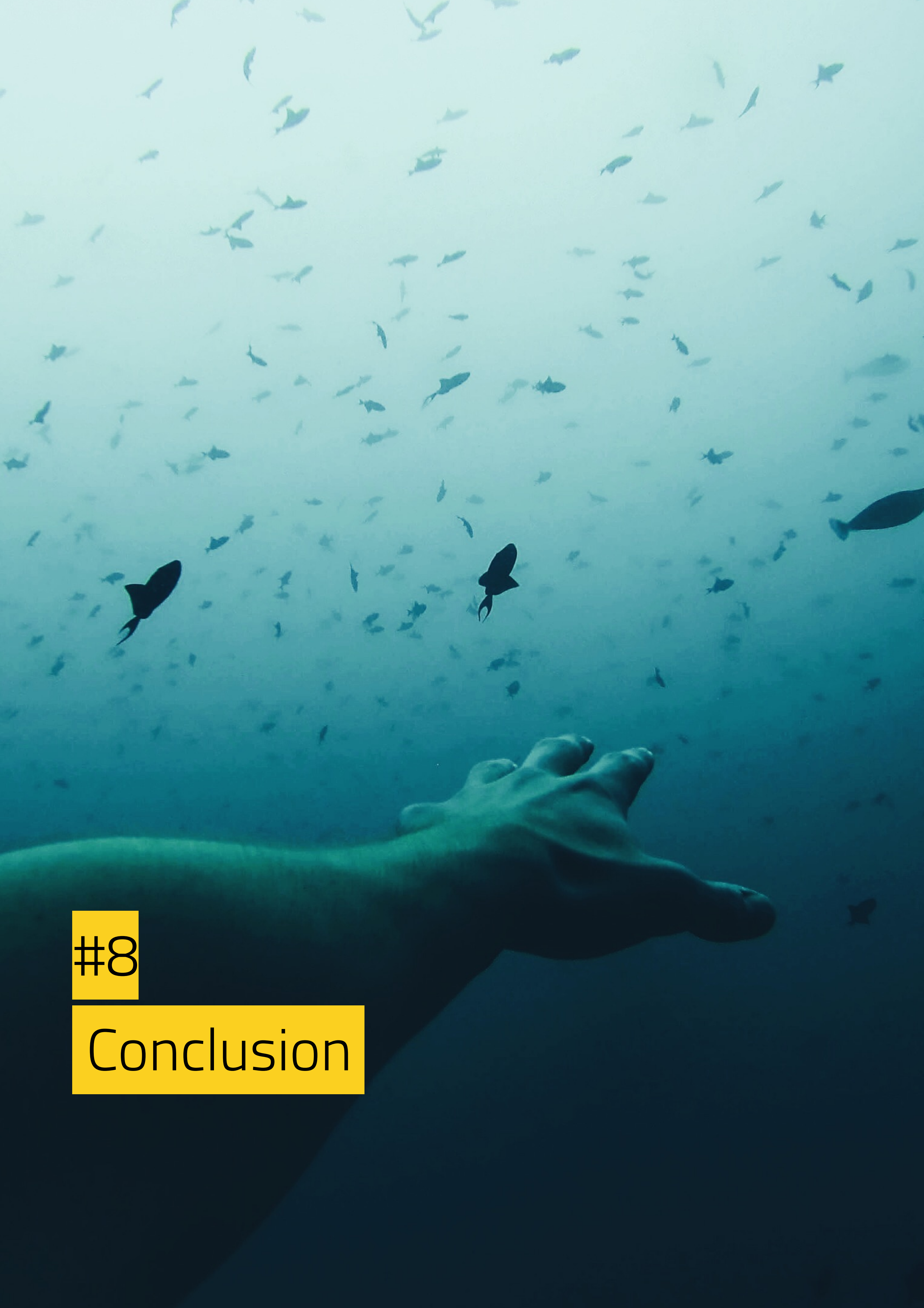


Figure 62: Fantibles



#8 Conclusion

CHAPTER 8

Conclusion

This chapter offers concluding remarks on the entire thesis and suggests future research directions.

“"If the doors of perception were cleansed every thing would appear to man as it is, infinite. For man has closed himself up, till he sees all things through narrow chinks of his cavern."
– William Blake

Introduction

The main research topic investigated in this thesis was how to design material representations of physical activity data that can positively affect the experience of being physically active. In particular, I designed three prototypes that explore different aspects of material representations and tried to accumulate knowledge through in the wild field deployments. I used the study findings to map an emerging design space for enduring and evocative use of physical activity data. The aim of this work was not to pinpoint problems and issues in the existing works, rather it was to offer and explore opportunities associated with a relatively under explored area of material representations. This work does not stand against the existing approaches, instead complements them by offering an alternate means of engagement with one's own data. To this end, I speculate and orchestrate design opportunities and challenges for making data memorable (through *SweatAtoms*), enjoyable (through *TastyBeats*) and fulfilling (through *EdiPulse*).

Research objectives revisited

In the introduction I outlined four research objectives that I aimed to address in my work. Here, I articulate how I addressed these objectives:

Objective 1: Gather an understanding of the existing literature

To meet the first objective, I examined the existing approaches to represent physical activity data and discovered an inclination towards using the screen as a communication medium. I deduced that this is most likely because screens are readily available. In contrast, explorations of using other mediums, such as physical and tangible representations of physical activity, have been relatively sparse. I found that the meaningfulness of data representation has a major impact on engagement and user's behaviour (Hansel et al. 2016 p.1). A poor representation or overload of information can create confusion and discouragement among users (ibid). Although existing methods of data representations are quite successful in increasing awareness about physical activity, their focus has mainly been on quantification and rational self-analysis. Through the use of material representations that involve more than just the visual sense, I put forward a case to look into alternate ways of engaging with one's own physical activity data.

Objective 2: Explore the design space of material representations

To meet the second objective, I looked into existing literature on material culture and physical visualisations, to identify opportunities and strategies for creating material representations of physical activity data. I identified four key aspects, namely, mapping, material, process and outcome that needs attention while designing material representations.

I also found two opportunities with material representations that can complement existing approaches: 1) Using durable materials such as plastic to represent data, 2) Using consumable materials such as food for data representation. I explored these opportunities using three materials, namely, plastic, fluids, and chocolate.

Objective 3: Validate the design space

The third objective was met by designing, prototyping and testing three working systems - *SweatAtoms, TastyBeats,* and *EdiPulse*. These systems translate physical activity data into material, fluid and edible forms by respectively using plastic, drinkable fluids, and chocolate as materials. I conducted field studies of each of the three systems, where the system was deployed in different households for a period of two weeks and participants interacted with the system on a daily basis. Results of the field studies provide empirical evidence of engagement and rekindled interest in physical activity for my participants. Plastic allowed material representations to become long lasting and thus became a tangible souvenir for invested effort in physical activity. Drinkable fluids and chocolate made material representations enjoyable and satisfying, and suggested ways of supporting the body's need to replenish lost fluids and energy from physical activity. The interactive water fountains used in *TastyBeats* also offered a visual vista of seeing one's physical activity in fluid form performed in front of them.

Objective 4: Create and validate a design framework

To address the fourth objective, I used the study findings to derive a design framework called *Shelfie*. The framework offers design guidelines for creating material representations of physical activity data. The framework is realised in the form of 16 design cards. Each card describes an important design consideration, formulated from the study findings and relevant literature on the topic. Through this framework, I believe I present the first conceptual understanding of the relationship between material representations and physical activity data that I also believe will help designers in the design of material representations.

Limitations

All three systems discussed in this research are designed with predefined algorithms that measure heart rate and translate this data into some material form. This designer-oriented view may limit or may not fully support the autonomy in creating the material representations. Therefore, in future work, I am planning to structure these systems as a creative framework that will allow the users to take up the designer's role and express their creativity with interesting designs.

In all the three studies, participants were recruited following a snowball sampling method. As a result, they may not be true representative sample of the population. Moreover, each of the presented systems has been studied with a small sample for a duration of 2 weeks. Longer trials of the systems would have raised other important issues in terms of sustainability and long-term engagement with one's own artefacts. For instance, what would one do with the 450 plastic artefacts generated by the SweatAtoms system over a three-month trial? Would the novelty of individually mixed sports drinks or chocolate treats – pale over that kind of time period? Would it give rise to rebellion and rejection as commonly observed in the use of wearable tracking devices? These are all valid questions and need to be addressed through long term deployments.

Nevertheless, given the lengthy time frame necessary to achieve health benefits as a result of physical activity it is often difficult to judge the efficacy of short design-led study interventions (Klasnja et al. 2011, Purpura et al. 2011). Instead, it has been suggested that such studies should be judged based on: a) their impact on ongoing practices, b) how they bring about changes in people's attitudes rather than changes in their behaviour, c) how they foster mindfulness, and d) create room for stories. The field study of three systems illustrated both 'real' and 'useful' responses from a diverse sample of participants and provides important markers into their attitudes and behaviour towards physical activity. I also received anecdotal evidence of increased physical activity amongst participants with several commenting on how the system helped them to become more active, build a routine and enjoy a more active life. Due to the prevalence of biofeedback tools such as like heart rate monitors and pedometers among youths (Swan et al. 2012), I believe the research outcomes will be able to be applied more broadly.

Future Work

Through investigating the topic of material representations of physical activity I mainly focused on specific examples to help guide my research and allow me to answer my primary research question. This narrow focus often left me wondering about additional explorations and ways in which the work could be further investigated. I consider such investigations to be future work and suggest here how I plan to investigate this topic further.

Using our interaction with food for social reflection

Human Food Interaction (HFI) (Comber et al. 2013) is an emerging field of research within the HCI community. HFI focuses on understanding established food practices such as how we grow, cook and eat food and how these practices relate back to our health and social identity. However, the use of food for purposes other than the established practices has been narrow, which I consider as a missed opportunity. Food, I believe, is an under-explored reservoir of exciting interaction and engagement opportunities offering multi-sensory experiences comprising of touch, taste and smell. Following Rooksby et al. (2014), I believe that there is a need to gain a deeper and systematic understanding of the socio-technical practices at play in order to optimise the opportunities at our disposal. As a starting point, I am interested in understanding food as a design resource for the purposes of communicating personal data and nurturing social interactions. Earlier works by Grimes et al. (2009) highlight the importance of family-based reflection. Supporting this, designers could utilise meal and snack times as opportunities for families to notice changes in each other's health routine and make suggestions for improvement and change. Such edible displays of data, could allow the conversation to be more in person rather than through an electronic medium. Therefore, designing playful technologies around food could be an interesting area to explore for fostering and strengthening family bonding through food.

Personal Informatics in public and home space

Self-monitoring devices collect different aspects of our life and provide us with opportunities to monitor and contemplate on our behaviour. While the term "self" in self-monitoring refers to the individual, there can be benefits of engaging others in the process of self-monitoring through social and collaborative means (Rooksby et al. 2014). Many such devices already allow sharing and comparison of the tracked data with other users. However, this sharing happens over the Internet and little is shared between the people who are co-located (who share the same physical space). However, this research has identified different benefits of making this data public such as encouraging self-expression, creating a shared understanding of data and enjoyment through celebrating each others achievements. Taking this work forward, I propose designing personal informatics in public space that transcend data representations from personal space, such as a mobile screen, to a shared public space such as streets. However, designing for a public social space will require consideration about the overall reception and privacy of the data. Abstract forms of data representation as explored in this thesis could be a way towards tackling these issues.

Creating sustainable material representations

Material artefacts have a longer life and a sustained value in people's life than its digital counterparts as identified by previous literature (Petrelli et al. 2008; Golsteijn et al. 2012; Kirk and Sellen 2010). Additionally, unlike their digital counterparts, material artefacts are more readily available and publicly visible in the surroundings. As a result, it would be interesting to investigate user's engagement over time, looking at how the portrayed representation of personal data can sustain itself over time. There still remain questions on environmental sustainability and food wastage. An interesting research direction to solve this question would be to look into dynamic material representations that augment themselves over time. For example, using shape-changing interfaces (Rasmussen et al. 2011) we can update the shape of an artefact in accordance with the changes on the personal data. Another interesting area of study would be to investigate how people would repurpose these artefacts after a long period of possession, and how they would dispose of these material representations when no longer needed or wanted.

Validating the framework

In this thesis, I presented a design framework *Shelfie* that aimed at helping the designer in the design of material representations. Therefore, the next logical step in this regard would be to validate the framework further to identify its use cases in different contexts. I am planning to evaluate this framework by organising workshops targeted at design researchers in order to demonstrate the frameworks utility in practice. I will invite participants to an ideation workshop where they will use this framework to come up with design ideas for a given design task centred around new ways of visualising physical activity data in material form.

Improving digital fabrication processes

Although I have used a commercially available 3D printer and food printer in my studies, I had to update and modify it significantly to make it work in accordance with my project goals. I improved the extrusion method by exploring an open source printing software, different materials, and 3D models. In the case of EdiPulse, I also experimented with different kinds of chocolates to see which type would print better under varying temperature conditions. Additionally, the study participants were not experts in 3D printing and I had to simplify various steps so that the novice users could use the systems easily at home. As such, this work offers a technical contribution that simplifies 3D and food printing for non-expert use and situates its use within the context of physical activity. Since the main motive of the work was not to present and discuss the 3D or food printing process in general — rather to use them as a medium to represent physical activity data — I focused in this research mainly on the study insights. I point interested readers to exciting works by Mueller et al. (2014) on improving 3D printing in general and to the 3Digital cooks website[20], which is devoted to food printing experimentations.

Final words

Self-monitoring is a persuasive and powerful tool for reflection and increasing awareness of the self. However, state of the art technology still requires a lot of effort, engagement and knowledge to interpret the collected data. As a result, despite the technological improvements and popularity, ensuring long-term user engagement with these devices is still a major challenge (Hansel et al. 2016). For example, Velayanikal (2014) reports a dropout rate of nearly 85% for such devices. Creating new tools and investigating representation strategies could assist in getting past these hurdles and in that way could also provide an active support for self-improvement. The use of different physical materials to represent self-tracking data can create new possibilities and challenges for HCI researchers to push the field forward. In this thesis, I initiated discussion on how material representations can influence the self-tracking practice and, in turn, how the self-tracking practice can contribute to the field of material representations. It is also possible that there are other ways in which multi-sensory media can support the physical activity experience and I invite future explorations in this avenue.

According to Fogg (2013), motivation alone may not be enough to sustain long-term behavioural change. Rooksby et al. (2015), argue that individual's relationship with their data goes beyond persuasion as well as rational self-analysis, rather it ventures into the topics of "how these devices are lived and experienced". Therefore, rather than focusing on motivation alone, designers should allow for the natural processes to emerge from the data and use the data and its representation only as an "anchor" to facilitate the change. Deci aptly said in his TED talk (2012), "*Don't ask how we can motivate people. That's the wrong question. Ask how we can provide the conditions within which people can motivate themselves*". I also quote Fogg (2013), who said, "*plant a seed in the right spot and it will grow without coaxing*". Supporting this notion, I encourage designers to influence the inner abilities of an individual through their design in order to nurture a behavioural change.

For this thesis, I also worked with the vision that in 5 or 10 years time, 3D printing and food printing devices would be commonly found in our homes. At the moment little is known on how and for what purpose people would make use of these exciting new technologies. By contextualising their use in the domain of physical activity and self-monitoring technologies, this research opens up an exciting new design space for researchers and interaction designers to take this field forward. For example, I see the potential for food printing to become an important determinant criterion of future meals and dining experiences. Food printers could provide us with nutrition customised on the macro level, allowing the right level of mapping between the amounts of protein, carbohydrates, and fats in meals for individual consumption. I therefore encourage design researchers to use these technologies, not just to continue to make representations of data we are used to, but to bring to light invisible and internal bodily data (such as heart rate) and explore the novel opportunities that exist in displaying such information in material forms. I hope my work will provoke thinking in this direction and encourages advancement in the area of displaying physical activity with material representations. In doing so, I look forward to exploring and witnessing new ways of connecting the biographies of the material world with the immaterial world.

[20] *http://www.3digitalcooks.com*

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