EXPLORING THE POTENTIAL OF DATA PHYSICALIZATION OF GROUP HEART RATE DATA TO FOSTER SOCIAL INTERACTION AND SHARED REFLECTION IN FAMILIES

MASTER'S THESIS

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ABSTRACT

While tracking for health improvements is usually the focus of personal tracking, the potential of experience-based tracking is often overlooked as a tool for social interaction and shared reflection. The thesis examines the value of data physicalization by visualizing group heart rate data of families as they are engaged in social activities. We explore this through initial formative interviews, followed by focus groups to investigate the qualities of three prototypes, and finally a take-home study of Heart-Tale, our final design proposal. The results of the focus groups prove value in these physicalizations, as participants actively explored and discussed them while creating playful narratives. Furthermore, we establish eight design considerations for designing physicalizations to foster social interaction and shared reflection on group data. Upon these considerations we design Heart-Tale. In the homes of families, Heart-Tale became part of the dining room and was used nearly every day. We saw a reflection on family values and awareness on how families spend time together. We close by presenting future direction for group data physicalizations.

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1 INTRODUCTION

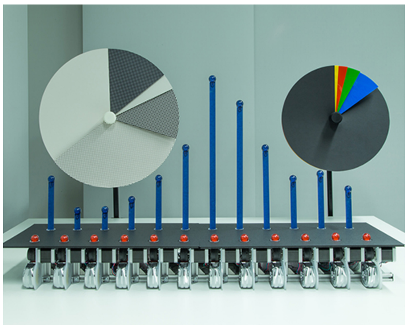
1.1 MOTIVATION

Raw data is found all around us and is being collected at an exponential rate, higher than ever before. In fact, at any point, 90% of the world's data is generated within the last two years (Dragland, 2013). However, due to the sheer volume of data collected, much is left unused. In 1984, John Naisbitt famously stated: "*We are drowning in information but starved for knowledge*" in his book Megatrends (Naisbitt and Cracknell, 1984) which today, more than ever, holds true. The data that gets used to seek insight is often objective data (i.e., representing facts and not personal feelings) used for instance, for companies to develop business strategies, at hospitals in patient care and treatment, or to improve a metric in one's personal life. For this thesis, we suggest a different motivation for the collection and usage of data: to collect data for social and experiential purposes. Specifically, our aim is to foster social interaction and shared reflection using subjective and personal data collected during joint experiences.

Personal tracking has gained traction since the early years of the new millennium (Choe et al., 2014; Swan, 2013; Wolf, 2009), often combined with information visualization tools to create interesting and easily understood visualizations (Ware, 2012) and recently, using data physicalization (Jansen et al., 2015). However, self-tracking for experiential purposes has often been neglected in comparison to tracking for improvement of health or other aspects in one's life (Choe et al., 2014). While research exists that discusses the sociality of tracking (Maitland and Chalmers, 2011; Rooksby et al., 2014), it focuses predominantly on the social aspects of tracking for the sake of motivating each other to improve performance. Instead, in this thesis, we investigate the impact of tracking important moments together and how that affects the overall experience of these co-present activities.

1.1.1 *Data Physicalization*

One approach to visualize data is through *data physicalization*, an emerging research topic in large part due to evolving technologies and increasing accessibility of physicalization tools (e.g., laser cutter, 3D printers). It specifically looks at physical artifacts which encode data via physical shape (Jansen et al., 2015). The artifacts can manifest data in many ways, for example: as physical 3D-bars and charts



(a) Mechanically driven, physical charts to communicate data (Banks et al., 2014).

(b) Data during a year in a company (e.g., computers in use, late night food ordered) translated into a data sculpture (Hush, 2014).

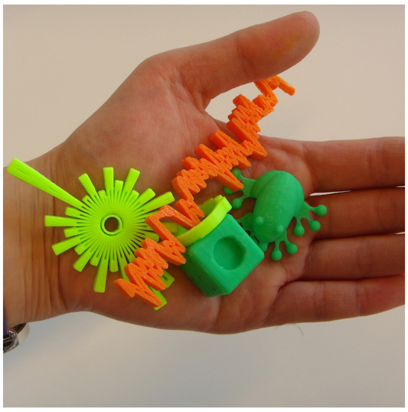
(c) Real-time visualization of comparative rankings of brand performance (ISketchLab & TrackMaven, 2016).

(d) A plant is manipulated by light depending on the distribution of use between trash and recycling containers (Holstius et al., 2004).

Figure 1: Data physicalization examples.

(Figure 1a) (Banks et al., 2014; Tang et al., 2013), or in more artistic and abstract ways often found at exhibitions or museums (Dahley et al., 1998; Lindegaard, 2012). Some artifacts are tailor-made for specific sets of data (Figure 1b) (Domestic Data Streamers, 2014a; Hush, 2014), others can change dynamically when visualizing datasets or as data is continuously provided as input (Figure 1c) (Domestic Data Streamers, 2014b; ISketchLab & TrackMaven, 2016). Physicalizations can vary from static artifacts (Khot et al., 2014) to actuated artifacts (Jafarinaimi et al., 2005), and some researchers even experimented with the use of living organisms in data physicalization (Figure 1d) (Botros et al., 2016; Holstius et al., 2004). There are several benefits to having physical data representations rather than presenting data on a computer screen (Jansen et al., 2015; Thudt et al., 2018), which are presented in Section 2.3.

(a) A figure of eight body parts each representing different measurements of a run (Stusak et al., 2014).

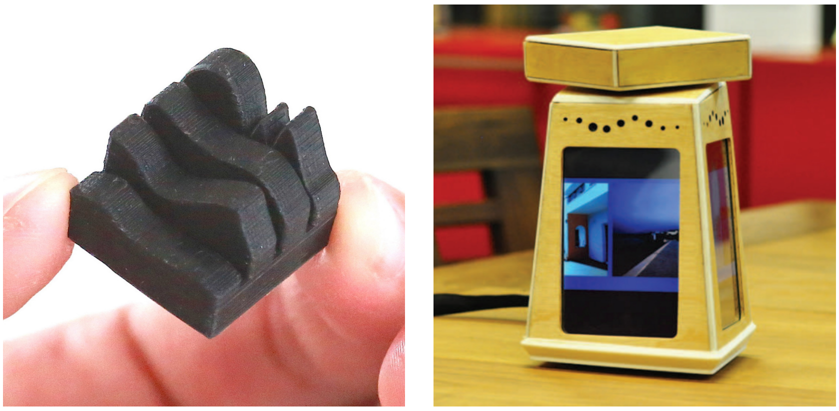


(b) 3D printed sculptures using heart rate patterns during physical activity (Khot et al., 2014).

Figure 2: Personal artifacts based on data.

1.1.2 *Reflection and Sharing of Experience*

A large body of research has applied data physicalization to create subjective and personal artifacts on a user's collected data. These artifacts "*tell stories about personal experiences from the point of view of the narrator*" (Thudt et al., 2017) and allow for focus on the meaningful aspect of an experience, especially those aspects that cannot easily be quantified or simply turned into quantitative numbers (Thudt et al., 2018). Personal artifacts are not always designed to display data in a straightforward manner, but can be rather abstract. Stusak et al. (2014), for instance, created 3D-printed sculptures based on individual running activity. One type of sculpture represents a human figure (Figure 2a), which consist of eight body parts each representing a single run. A body part's different attributes (e.g., length, girth or shape), represent different measurements from the run (e.g., average speed, duration and distance). Figure 2b shows a similar concept of 3D-printed physical artifacts. These artifacts are based on users' heart rate during physical activity, illustrated through five different types of physicalizations (Khot et al., 2014). Khot et al. (2014) found that these physical artifacts can influence how people approach physical activity, while causing reflection and reminiscence on past activities. To our knowledge, current research investigates subjective and personal physicalizations of the individual, but has not explored the qualities and new possibilities of designing similar concepts for group data on families, friends or small communities. One of few examples is a design project by Ryokai et al. (2017) which visualizes laughter in families via 3D printed chocolate, showing how much each family member laughed and when (Figure 3a). The concept embodies many of the qualities of quantifying family experiences that we seek to explore, but as of yet, their research still lacks notable empirical findings.



(a) A piece of chocolate visualizing laughter for each of four family members (Ryokai et al., 2017).

(b) A table centrepiece displaying participants' Facebook photos during shared dining (O'hara et al., 2012).

Figure 3: Concepts designed around family life and togetherness.

Other research areas outside data physicalization have investigated togetherness, the engagement of sharing stories, and participation in social activities in the family. Yet most research deals with families when apart (Brown et al., 2007; Hutchinson et al., 2003; Judge et al., 2010), with less emphasis on examining the family together at home. However, two notable concepts: 4 Photos (O'hara et al., 2012) and Chorus (Ferdous et al., 2017) consider how to support conversations on past experiences in families during mealtime rather than causing distraction through technology. The 4 Photos system collects photos from the Facebook profiles of the people around the table and shares them on a physical device (Figure 3b). By showing photos from the different participants' Facebook albums, 4 Photos presents opportunities for people to showcase themselves, their interest, values and inquire about photos from other participants (O'hara et al., 2012). This research is further built upon through Chorus (Ferdous et al., 2017), a cross-device solution to facilitate interaction between family members using their own smart devices where the shared content is decided by the family members using an app. Chorus provides more freedom to the family to focus on what they want to share and talk about compared to 4 Photos, because the family reflects on what they have experienced today, rather than Facebook photos from years back, chosen at random. However, 4 Photos has serendipitous qualities to make the family reminisce on memories of the past. The previous research on togetherness and reflection of experiences in families, are used to make choices of how to design a concept that aims to create shared, intimate moments in the family.

1.2 RESEARCH QUESTION

By exploring the gap in group data and data collection for social and experiential purposes we hope to shed new light on how data can be used to create meaningful moments and reflection in the family on their time spent together.

The following research questions of group data are explored in the thesis:

RQ1 *How does data physicalization foster social interaction and shared reflection in families?*

RQ2 *Which design considerations are important to foster social interaction and shared reflection?*

RQ3 *How do families appropriate data physicalizations to customize and create memoirs?*

RQ4 *How does heart rate relate to the experience of an activity?*

A short demonstration video of the final design proposal, Heart-Tale, can be viewed here: `https://youtu.be/bHppVfFjCaI`.

1.3 THESIS STRUCTURE

The thesis consist of seven chapters including this introduction. Below is a brief overview of each chapter:

CHAPTER 2 *Related Work* To frame the research area, related work within the fields of personal informatics, information visualization and data physicalization is introduced. Furthermore, research on data-driven reflection is presented as well as the qualities of using heart rate data.

CHAPTER 3 *Methodology* Presentation of the methods utilized for gathering data and analyzing it during the studies of the thesis.

CHAPTER 4: *Formative Interviews to Understand Family Life* The first study of the thesis is presented, where family life, values, interest, and tracking habits are explored.

CHAPTER 5 *Comparative Study of Physicalizations* In a comparative study of physicalizations, we find design qualities in three data physicalizations that visualizes heart rate group data.

CHAPTER 6 *Evaluating Heart-Tale in Take-Home Study* Our prototype, Heart-Tale, is presented and evaluated in a take-home study. The findings of how it is appropriated into the home of families are presented.

Chapter 7 *Reflection and Conclusion* Finally, we reflect upon the future of Heart-Tale, the challenges of the thesis, and new potential research areas. The thesis ends with a summary of main contributions.

2 RELATED WORK

Our work builds upon the foundation of research in personal informatics (Section 2.1), information visualization (Section 2.2), and data physicalization (Section 2.3). Furthermore, we outline what constitutes as data-driven reflection (Section 2.4) by looking at data physicalization and biosensing via heart rate. Finally, this chapter covers the qualities heart rate data has when used for social interaction and shared reflection (Section 2.5).

2.1 PERSONAL INFORMATICS

Personal informatics is the collection of "*[..] personally relevant information for the purpose of self-reflection and gaining self-knowledge*" (Li et al., 2010). Thus, collecting data and providing a platform to reflect on this data are the two key factors when designing personal informatics systems. In 2007, a Wired Magazine article (Wolf, 2009) coined the term *quantified-self* (QS), describing a movement of lifeloggers who take self-tracking and acquiring self-knowledge and turn it into a lifestyle. It is a unified community with tens of thousands of members (so-called quantified selfers) who share their self-tracking habits in regular meetups all around the globe[1]. Tracking of health metrics (e.g., weight, sleep quality, and mood) is the foundation of the QS community but not its exclusive focus: other categories include environmental variables (e.g., weather or location) or situational variables (e.g., context or time of day) (Swan, 2013). Rooksby et al. (2014) established five different styles of personal tracking: 1) *directive tracking*, 2) *documentary tracking*, 3) *diagnostic tracking*, 4) *collecting rewards*, and 5) *fetishized tracking*. Whereas quantified selfers using directive tracking are focused on reaching a specific goal (e.g., an ideal bodyweight), other styles of tracking might seek to document activities or to highlight certain problems, like understanding what caused a stomach ache. Additionally, some merely collect data for the sake of collecting data or because a new device is viewed as fashionable. For extreme users in the QS community, Choe et al. (2014) classifies three main motives for tracking: 1) *to improve health*, 2) *to improve other aspects of life*, and 3) *to find new life experiences*. The latter motive differs from the first two because it is not goal oriented but focuses on new experiences and therefore fosters exploration and curiosity. Instead of using tracking as a tool to improve one's performance, this thesis aims to

1 https://www.meetup.com/topics/quantified-self/

Figure 4: Fitbit Charge 2 is an activity tracker which measures steps, heart rate and sleep.

further investigate experience-based tracking and its possibilities in creating qualitative stories. Although self-tracking consists of large sets of quantitative data, it can be viewed qualitatively through the subjective experience behind the raw data (Swan, 2013). Swan (2013) argues that some of the most effective future products in QS could be those to combine quantitative accuracy and qualitative meaning-making functionality.

Research on existing QS applications, wearables, and automatization of tracking, allows for design and evaluation of how to implement the tracking in our concept in the most engaging and effective way. Currently, assistive apps that uses the smartphone's sensors in data collection have been developed in abundance. Apps like Moves[2], Endomondo[3] and Run Keeper[4] tracks the user's location via the smartphone's GPS receiver. Sleep Cycle[5] uses the built-in accelerometer to detect movement to identify sleep states. Other apps on the smartphone are reliant on the user to track the data manually, for instance, My Fitness Pal[6] or Avatar Nutrition[7], both of which track daily calorie intake. Instead of utilizing the smartphone, physical artifacts have been designed as wearables that often specialize in certain types of sensing. For instance, numerous activity trackers exist on the market that can measure data such as heart rate, steps or location data. An example of this are Fitbit activity trackers[8], designed to be worn

2 https://moves-app.com/
3 https://www.endomondo.com/
4 https://runkeeper.com/
5 https://www.sleepcycle.com/
6 https://www.myfitnesspal.com/
7 https://www.avatarnutrition.com/
8 https://www.fitbit.com/

around the wrist (Figure 4). Another range of applications are stationary and designed as a fixture in the household. A smart weight scale provides an easy and automated way to track body weight and other health metrics. The Wii Fit[9] measures fitness level and allows users to improve their metrics through exergames (digital games combining exercise with gameplay) (Staiano and Calvert, 2011).

In the medical area, an asthma inhaler with GPS receiver and a wireless link to the internet illustrates a specialized way to automate the collection of personal data. By collecting the location and time each time the inhaler is used, the patient and doctor can highlight patterns and problems regarding the disease they were unaware of priorly (The Economist, 2011). Swan mentions automated data collection as possibly the biggest difference maker to making self-tracking a widespread phenomenon (Swan, 2013), but technical challenges emerge with automatized tracking, especially for tracking variables that are already difficult to track (e.g., mood or focus) or requires inconvenient implementations (e.g., eye-tracking outside of a confined area). When the user is responsible for collecting data, the burden can become too high or the data collection too bothersome and complex (Swan, 2013). On the contrary, an automated system might give the user the feeling that they have a loss of control or feel that there are inaccuracies in the data (Li et al., 2010). A possible future for the automatization of tracking is using the data already available through social media (Haddadi et al., 2015). Online bookings, transactions of events, or grocery shopping could also be automatically sampled in the next generation of lifelogging (Petrelli et al., 2009). From this body of work, we gain an understanding of how it is possible to design a concept for families to easily track data without making them lose motivation or making it too complex.

Maitland and Chalmers (2011) investigate supportive and cooperative involvement through social weight management. The paper finds that losing weight, more often than not, is a social endeavor and that it thrives under cooperation rather than competition. Rooksby et al. (2014) found that people used tracking to compete with other users of an app or to compare their metrics against the average for their gender or age group. The study found value not in social features on social media platforms but rather in co-present activities with friends, family, and colleagues. Swan (2013) likewise extends personal informatics beyond the individual, referring to *group data* which she defines as: "*aggregated data from multiple quantified selves as self-trackers share and work collaboratively with their data*". This definition is quite limiting since it does not deal with separate representations of multiple people's data. To encompass our research, in this thesis we redefine the term group data to:

9 http://wiifit.com/

The idea of combining data from multiple people to share information and to collaborate.

Based on this research, our work investigates shared tracking as a family rather than individual tracking—the norm of the QS community. By considering the sociality of tracking we hope to influence a creation of narratives and reflection based on data physicalization.

2.2 INFORMATION VISUALIZATION

When dealing with large datasets, understanding the data can become chaotic and obscure if it is not visualized in an adequate way. Also, the way information is visualized can change its appeal: a table of data divided into rows and columns might be simultaneously difficult to understand and unengaging to view. Ware (2012) presents elemental information visualization approaches that help make the context of data understandable and the visualization as effective as possible. This research is based on a fundamental scientific understanding of the human eye and brain and how we perceive light, color, or movement for example. An important concept is *preattentive processing*: a subconscious processing of information allowing the brain to instantly notice patterns or outliers in data, etc. If ease of search is essential, a visualization should utilize strong preattentive cues (e.g., colors or shapes) (Ware, 2012), so that the user has to make a minimal effort to find the desired information. Ware's research provides effective ways to insure users can locate and distinguish their data from other users.

Nielsen et al. (2016) developed AffinityViz, a concept that helps domain experts who lack knowledge in relation to programming and big data sets to see and predict tendencies and deviators. AffinityViz takes advantages of the spatial structure of a building and changes the color code and size of each room to provide an easy overview of how much is consumed in each apartment (Figure 5). Furthermore, it is easy to get an overview of the sex and age of the inhabitants of each apartment to find any interesting patterns. This illustrates the value of information visualization to make unfamiliar concepts understandable through visual cues that contextualize the information. This is especially relevant to our thesis since the concept of heart rate can be difficult to understand for people who have no prior knowledge about heart rate and its characteristics.

Pousman et al. (2007) investigates the visualization of personally meaningful information which contrast the usual task focus and expert use of the information visualization field. Casual information visualization differs from traditionally information visualization in several ways, most relevant to us are: *data type* and *insights*. The data type in casual information visualization are often of personal impor-

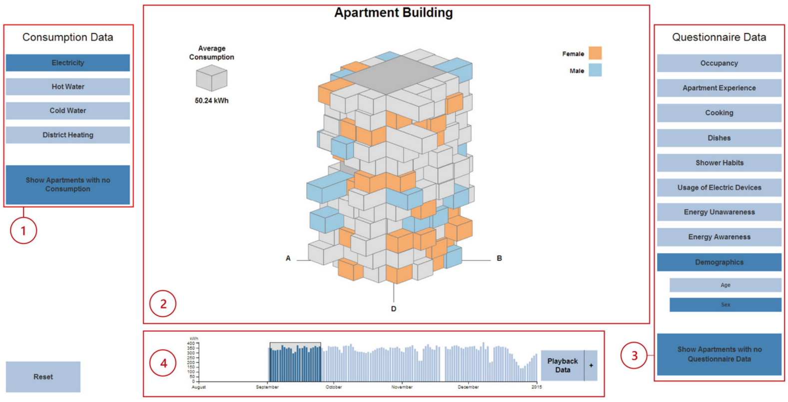


Figure 5: Visualization of consumption data in an apartment complex (Nielsen et al., 2016).

tance. The insights from the data are not analytical due to different design goals in traditional information visualization. An example of an insight is *reflective insights*, which motivate reflections about oneself. It is highly related to the thesis, in terms of working with personally meaningful information and motivating reflective thoughts. Additionally, casual information visualization supports multiple interpretations.

Information visualization is more than just presenting facts, it can also narrate stories. Segel and Heer (2010) outline narrative visualizations by describing techniques for telling stories with data. They analyze 58 visualizations from online journalism, business and visualization research upon which they develop a framework. The techniques are applied to journalism storytelling and educational media, but the framework still provides an idea of tools to consider in any type of visualization. The framework provides techniques to communicate the overall structure to the viewer, directing the viewers' attention and captioning/annotating data among others. Segel and Heer (2010) also highlights that interactive graphs tend to neglect providing sufficient commentary for narrative purposes.

2.3 DATA PHYSICALIZATION

An approach to visualize information is through data physicalization, which has been defined by Jansen et al. (2015) as:

> *A data physicalization (or simply physicalization) is a physical artifact whose geometry or material properties encode data.*

Studies exploring the qualities of information visualization and data physicalization have proved that a physical data representation embodies qualities missing in its digital counterpart (Jansen et al., 2013). Although it is not always favorable to use data physicalization rather than using a classical GUI, it has certain benefits perceptually, cognitively and societally (Jansen et al., 2015). It allows for three-dimensional inspection and depth perception while also supporting the engagement of non-visual senses. Someone with little experience in information visualization and statistical reasoning might not gain much knowledge or insight from viewing certain visualizations that they are not able put into perspective (Huang et al., 2015). Physicalizations have the ability to function as an extension of physical experiences, in contrast to the digital nature of an app (Thudt et al., 2018), which helps create a better cognitive understanding of the dataset (Jansen et al., 2015). According to Zhao and Moere (2008), physicalizations convey messages beyond the data itself and encourage reflection on the meaning of the artifact. These types of physicalizations are often referred to as *data sculptures*, and a dynamically changing data sculpture is referred to as a *kinetic sculpture* (Data Physicalization, 2017).

Another quality of physicalizations is that they can capture the curiosity and interest of its spectators through interesting and thought-provoking visualizations (Jansen et al., 2015; Zhao and Moere, 2008), while their everyday physical presence helps spark social interaction and shared reflection (Thudt et al., 2018). Even though pixel-based visualizations are capable of providing a higher resolution of visualizations, Moere (2008) advocates for physical properties as he believes they embody "*[..] richer, more intriguing and memorable experience that nonetheless communicates complex information and insight*".

2.3.1 *Examples of Data Physicalization*

Figure 6: Visualizing the level of pollution in major cities around the world (left: New York, right: Ottawa) (Kiesl et al., 2007).

A data physicalization that stirs reflection is the exhibition Garden of Eden (Figure 6) by Kiesl et al. (2007) containing eight plants each representing the level of pollution in a major city in real-time. Rather than stating hardcore facts about the level of pollution, a lettuce is placed in each box and the level of pollution for that particular city is represented through the amount of oxygen supplied, affecting the conditions of each lettuce. By utilizing familiar objects people are able to understand the air pollution around the world without using complex numbers.

Hemment (2013) visualized trends and behaviors of tweets for the Paralympic Games and Olympic Games in London 2012 through the concept emoto. The tweets during the Olympics were analyzed using a sentiment analysis and sorted into themes. Afterward, the data was visualized as a data sculpture (Figure 7) which displays the message volume and sentiment score via the shape of the curve and its color. Emoto is designed for visitors to explore the timeline of the Olympics by investigating the data through interaction with a knob. Specific messages and central themes are projected on top of emoto. We see emoto as an interesting design approach to data physicalization, because it provides both the physical visualization and explicit information which the visitors are able to explore via interaction. We see this as especially interesting, if the collected data is difficult to interpret.

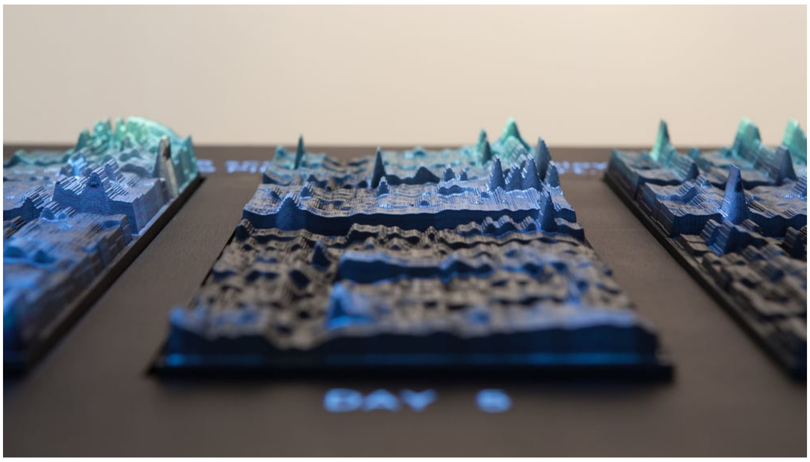
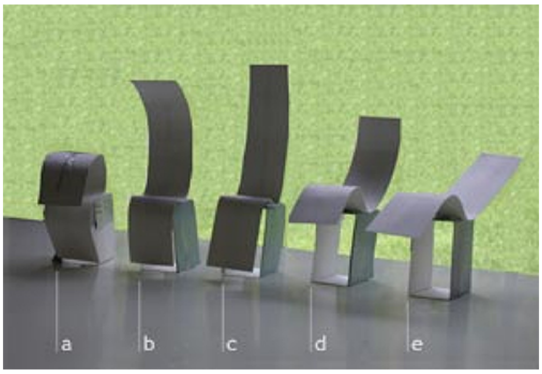


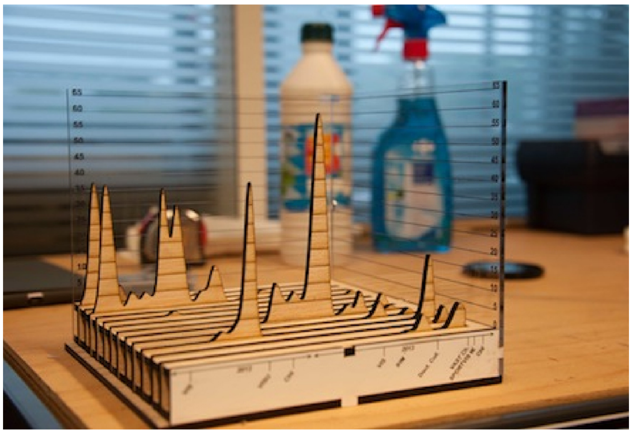
Figure 7: A physicalization overlaid with projections highlighting trending topics from tweets during the 2012 Olympics in London (Hemment, 2013).

When designing Breakaway, Jafarinaimi et al. (2005) sought to explore how to present information in a non-obtrusive way. Breakaway (Figure 8a) is a kinetic sculpture meant to be placed on the desk of the user. Throughout the day it reminds the user to take a break by slowly losing its posture based on the time span since last break. Breakaway aims to inspire going for a walk rather than enforcing a break by revoking access to the computer. LOOP (Sauvé et al., 2017) is another example for representing activity data in an abstract fashion. It is constructed of eight wooden rings, one for each day in a week and the last ring represents the goal to reach for each day (Figure 8b). Rather than revealing the exact step count it rotates a ring each day between 0 and 180 degrees to indicate how close the user came to their daily goal. In contrary to the aforementioned examples others are present-



(a) A small sculpture that gestures to remind the user to go for a short walk after sitting for too long (Jafarinaimi et al., 2005).

(b) A physicalization of step data and progression toward a daily goal (Sauvé et al., 2017).



(c) A Layered bar chart of time-series data on commits in a versioning repository created using MakerVis (Swaminathan et al., 2014b).

Figure 8: Data physicalization examples.

ing the data more explicitly by clearly outlining the values for a given graph. An example hereof is found in a study conducted by Swaminathan et al. (2014b) where a participant tracked his time spent with a versioning repository Figure 8c. The study was centered around lowering the burden for the laymen to create their own data physicalizations through a piece of software called MakerViz (Swaminathan et al., 2014b).

2.3.2 *Background and Emergence*

While the thought of representing data in the physical world is not a new phenomenon (Brinton, 1939), its increase in interest recently can be contributed to technical advances allowing physical representations to enable their properties to change dynamically (e.g., its shape or color) to accommodate the data, previously only made possible in GUIs. In 1997, Ishii and Ulmer revealed their vision about Tangible Bits (Ishii and Ullmer, 1997) where they, besides envisioning *interactive surfaces* and *ambient media*, wanted to couple digital information (bits) with tangible objects (atoms) to ultimately turn physical matter contained within the surroundings of everyday environments into interfaces. A decade later, Ishii et al. (2012) expanded the vision for Tangible Bits by revealing their philosophy for Radical Atoms embedding bidirectional properties, (i.e., changes applied to the digital model affects the corresponding physical structure and vice-versa).

With the democratizing of technology (Tanenbaum et al., 2013), instruments such as 3D printers, laser cutters, and CNC mills have become available for laymen (Mota, 2011) assisting them in producing physical products with high fidelity without the dexterity skills of say a carpenter. A trade-off, however, is that non-expert users need to master the supplied interfaces to utilize these instruments (Swaminathan et al., 2014a). To date, the process for creating physical data representations has been cumbersome as expertise needs to be applied in both the data visualization and the following creation phase (Swaminathan et al., 2014a). Swaminathan et al. (2014b) took upon the challenge to ease the burden associated with fabricating physical visualizations by developing a single piece of software encapsulating the required processes from sorting raw data to producing the physicalization. Although personal machinery cannot follow the pace of industrial machinery, the user benefits by avoiding the criteria for mass production.

We find the above-mentioned areas of particular interest as these are fundamental to our thesis as the research expands on what is possible, while the democratization allow a wider audience to benefit from the instruments effectively giving them powerful tools to create physical objects.

2.4 DATA-DRIVEN REFLECTION

When we actively engage with our experiences, we reflect. A common definition of reflection used in the literature is Dewey's (Dewey, 1997), who defines reflective thought as:

> *Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends, constitutes reflective thought.*

To engage users to reflect, this thesis deals with experienced-based tracking (see Section 2.1), with the *ground that support knowledge* as the personal data that is collected through tracking. This is referred to as *data-driven reflection* by (Howell et al., 2018; Thudt et al., 2018).

A way of creating reflection through data in personal informatics systems is using effective information visualization techniques (Card et al., 1999; Ware, 2012), which the users may reflect on as soon as the data is collected or reflect on more extensively several days or weeks later (Li et al., 2010). Yet, Rooksby et al. (2014) argue for the *temporality of tracker data* since their study found few examples of value in long-term data (data from years or even weeks ago). Users particularly valued their data from the current day or the data collected from a particular recent activity. However, since Rooksby et al. (2014) specifically investigates the tracking of health metrics, we suspect that experience-based data (via interesting physicalizations) can have an impact for longer than a few days.

During a qualitative study on personal physicalization constructions, Thudt et al. (2018) had nine people construct their own physicalizations on data of their choosing. Based on the study, four types of personal reflection tied to physicalization was found: 1) *directly on the data*, 2) *on data in light of one's context and expectations*, 3) *on actions and strategies to improve or achieve goals*, and lastly 4) *on one's values and attitudes regarding the tracked issue.* The different types of reflections have different layers of depth, from simply looking at the data (lowest level of depth), to putting it into the context of one's lived experience, and inevitably, taking a stance on how to act and feel about the issue at hand (highest level of depth). A key finding by Thudt et al. (2018) was the *direct visualization of experience* contextualized in the physical constructions, especially if tracking experiential or qualitative variables. The physicalizations formed a direct association with the participants' qualitative experiences, helping them recall and revisit their activity. Finally, Thudt et al. (2018), highlight the lack of current research in direct visualization of experiences through information visualization and data physicalization–which closely relates to the work presented in this thesis. It is also worth considering the aforementioned four types of personal reflection when studying the effect of personal physicalization for our thesis, even though we investigate group data.

This thesis builds on the findings of Howell et al. (2018) on reflection via biosensing. They explore data-driven reflection through a wearable device that visualizes one's emotional excitement in real-time. The wearable device is a shirt with three pinstripes that can change color (Figure 9). They found participants reflecting upon the feedback of the shirt in regard to their current situation (whether they got a job offer or were watching TV). The participants also reflected about ambiguously displaying emotions to one's surroundings, which some found interesting while others preferred to be able to hide their feelings in certain situations.

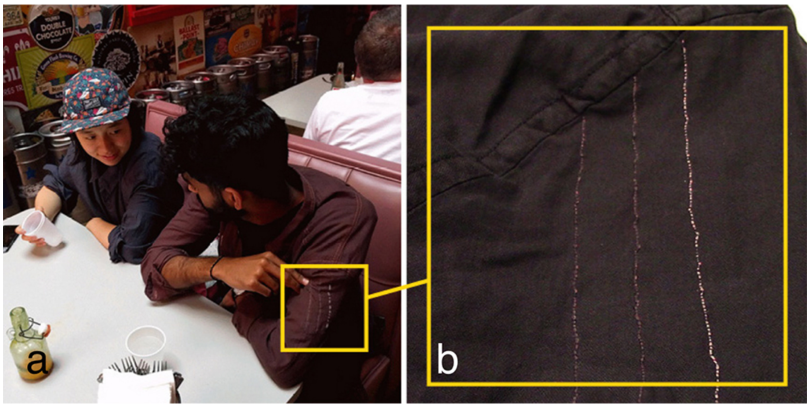


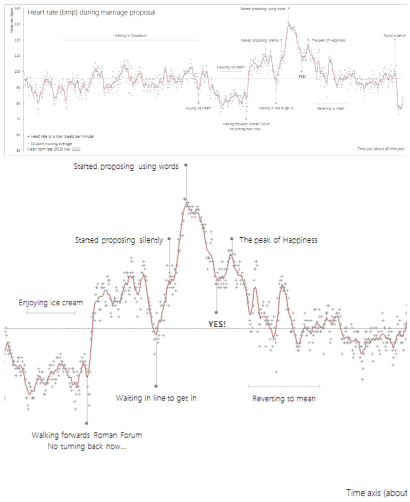
Figure 9: Visualization on emotional excitement via pinstripes on shirt (Howell et al., 2018).

Baumer et al. (2014) suggest that most research on reflection characterize reflection as an individual task, essentially inside a person's head. Baumer et al. (2014) highlight the potential in investigating reflection as a social process, which requires externalization and engagement with others. Khot et al. (2017) mentions: "*in the future, it would be interesting to create artifacts that represent data from multiple people and see how it would facilitate social interactions and shared understanding of each other's data*". Our thesis looks at reflection as something that can happen between people when they engage with activities of the past collaboratively, for example, by verbally discussing it.

2.5 HEART RATE QUALITIES

Heart rate monitors are becoming increasingly integrated in activity trackers and are commonly used by the consumer to gain self-knowledge of their health or physical condition (Pantzar and Ruckenstein, 2015). There are widely different uses for heart rate measurements: for instance, it can be used during workouts to consider a person's activity level or at hospitals to measure the vitals of a patient to ensure their well-being. But, rather than using the heart rate for fitness or health purposes, some designers have found heart rate data to embody narrative and personal qualities, such as Heart Bloom (Studio Rogier Arents, 2015), for instance. It shows the personal attachment to one's own heartbeat by illustrating the variability of a heart rate via symbolic drawings on paper (Figure 10a). The narrative quality of heart rate is illustrated by a visualization of a man's heart rate during his marriage proposal (Sesipikai, 2014). It is visualized by a simple line graph, but the sudden increases and decreases in heart rate (accompanied by annotations of the most important moments), help tell the story in an interesting way (Figure 10b). These designs have not been made for the purpose of research but illustrate some of the qualities that we pursue through the use of heart rate as a tool for narrating personal stories and to support reflection. Research on how emotions influence on heart rate is presented by Kreibig (2010). She created a table illustrating how the autonomic nervous system reacts to emotions, which present a clear outline of how the heart rate respond to a range of different emotions. The table helps us to understand heart rates reaction to emotion, and we can utilize this information when picking which activities to measure heart rate on.

(a) Each heartbeat triggers a line or a dot, the overall heart rate variability is then reflected as a drawing (Studio Rogier Arents, 2015).



(b) Heart rate during marriage proposal with annotations of important moments (Sesipikai, 2014).

Figure 10: Examples that display heart rate's personal and narrative qualities.

A line graph is not the only approach to visualize heart rate. For instance, a project that visualizes heart rate data differently is EdiPulse (Khot et al., 2015a) which examines how a chocolate emoticon can motivate people to engage in physical activity. The median heart rate is represented through the facial expression of the emoticon combined with the thickness of chocolate produced. The product of a high median is a happy emoticon containing multiple layers whereas a low median yields a sad and thin emoticon. TastyBeats (Khot et al., 2015b) represents the heart rate as a drink with mixed flavors. The concept allows participants to explore their own heart rate as different flavors are poured into a glass depending on the heart rate level (Figure 11). Similar to Sweat-Atoms (Khot et al., 2014) (described in Section 1.1.2), participants had a playful attitude towards the prototypes as they altered their running patterns to try to affect the outcome. A challenge for these papers is that the abstract visualization loses granularity of information compared to more traditional visualizations, and therefore does not always tell the complete story. This is fine within the scope of providing a playful physicalization on heart rate data, but if users have to utilize the physicalization for detailed storytelling it is problematic since they are only able to obtain a general overview by looking at aggregated data. Khot et al. (2014) experiment with ambiguous and explicit physicalizations of heart rate and believe that: "*ambiguity in meaning encourages participants to expand their interpretation of physical activity data and thus could facilitate a richer reflection about the self and past activities*" (Khot et al., 2014). However, they also found participants wished for artifacts that were easier to interpret.

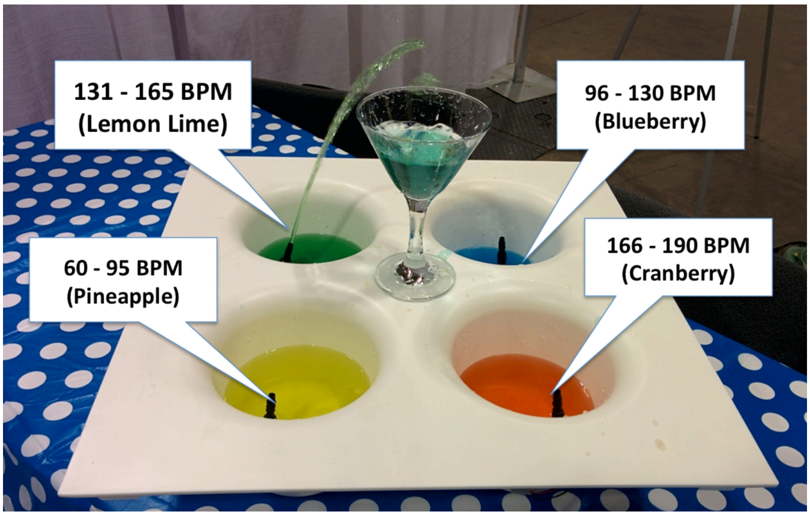


Figure 11: TastyBeats allow users to explore their heart rate by creating a drink of different flavors (Khot et al., 2015b).

Liu et al. (2017) and Slovák et al. (2012) explore social interaction through heart rate. Liu et al. present a mobile application that allows participants to share their beats per minutes (BPM) either through *direct sharing* (a message with their current BPM) or *broadcast* (a live transmission of their BPM). They discovered that sharing this type of information support interpersonal communication and it breeds a variety of different conversations ranging from health and well-being to more intimate and playful messages. In addition, Slovák et al. (2012) suggests the possibility of using heart rate information as *composite signals* (i.e., combining physiological signals between different people together) which might improve social interactions. They conclude the possibility to use heart rate as a tool for communication to facilitate intimacy and complement interactions. The research is relevant since it investigates the sharing of heart rate data between people who have close relationships.

This leads to Jérémy Frey's research (Frey, 2016), which investigates sharing heart rate data while playing a board game. He compares three different conditions: 1) players' heart rate can be viewed by everyone, 2) players' heart rate is visible for everyone but themselves, and 3) heart rate is not shown. Condition 1 and 2 were deemed the most interesting by participants. Frey identified that biosensory feedback can improve the richness of board games and that the participants can interpret their opponents' data to playfully bother them. This research likewise suggests that sharing heart rate data can result in social interaction. Furthermore, the research illustrates the potential for combining competitive activities like board games with heart rate monitors.

To summarize, EdiPulse and TastyBeats allow people to interact with their heart rate and provide a playful visualization. This is a source of inspiration and a strong foundation for the work of the thesis. Our design should likewise be fun, engaging and allow for heart rate interaction. From examining related work, we distinguished two types of heart rate interaction, one which provides *real-time interaction* with heart rate and another which provides *delayed interaction*. In delayed interaction, the heart rate is recorded but the outcome is presented after the end of the activity and all the measurements are gathered (e.g., Sweat-Atoms (Khot et al., 2014) and EdiPulse (Khot et al., 2015a)), whereas in real-time interaction, the user is able to directly see the impact of their changing heart rate (e.g., TastyBeats (Khot et al., 2015b) and Frey's boardgame (Frey, 2016)). A quality of heart rate data is it can enrich social interaction by being shared between people (Frey, 2016; Liu et al., 2017; Slovák et al., 2012). However, none of these articles explicitly explore heart rate in a family context or how it can facilitate storytelling.

3 METHODOLOGY

In this section, we will present methods and techniques applied to data collection and analysis. First, the methods for data collection are presented, followed by the methods for data analysis. In each section, arguments for using the method are accounted for and described in more detail.

The thesis consists of three studies, 1) Formative Interviews to Understand Family Life (Chapter 4), 2) Comparative Study of Physicalizations (Chapter 5), and 3) Evaluating Heart-Tale in Take-Home Study (Chapter 6), each utilized different data collection and analysis techniques.

3.1 DATA COLLECTION

For the thesis, several data collection approaches have been utilized. In general, we have applied triangulation of data collection methods. The advantage of triangulation is that it provides multiple perspectives to increase the credibility and validation of the results (Mackay and Fayard, 1997), to gain a comprehensive understanding.

The data has been gathered in several ways, for instance through audio and video recordings, photography, and written answers. Later, this material has been transcribed or organized digitally to prepare it for data analysis. As studies were conducted in Danish, all quotes included in the thesis have been translated from Danish to English. Video recordings can be analyzed to include gestures during transcription (which could be lost by relying merely on audio) (Rogers et al., 2011), to capture when the participants point to or interact with a prototype.

3.1.1 *Semi-Structured Interview*

Semi-structured interview was utilized in all the studies to collect descriptive information for qualitative analysis. Additionally, they provide an agenda for the interview while still allowing the interviewer to further inquire about interesting answers provided by the interviewee as the interview unfolds. This way, the data collected is highly relevant and ensures that the interview does not miss useful aspects. The questions combine Kvale's (Kvale, 2008) two metaphors of using an interview as a *miner* or a *traveler*. The miner metaphor involves asking specific questions on hard facts. On the contrary, the traveler metaphor attempts to construct knowledge between the interviewer and the interviewee by asking open-ended questions. The traveler metaphor is important because it helps us to understand how the family interact and is one of the key reasons for conducting interviews compared to a questionnaire.

Rogers et al. (2011) argue that the advantages of interviewing participants *in-situ* is that it makes it easier for interviewees to articulate freely about the setting and it can help them remember and reflect on specific moments or values. Furthermore, by having all the family members present they can support and supplement each other to better answer the questions or provide important details. It can also factor into making interviewees feel more comfortable and open during the interview (Rogers et al., 2011). This approach was used in the formative interviews and in the take-home study.

An alternative way of gathering different opinions is through focus groups (Lazar et al., 2017), utilized in the comparative study. Contrary to interviews, interviewees in focus groups are invited to debate the questions among each other. A benefit of having multiple interviewees debating is the interview might unfold in new directions as a statement might spark a thought or disagreement among the others. Additionally, timid interviewees can rely on others to contribute initially, but as the focus group unfolds they tend to gain confidence to speak their mind.

3.1.2 *Questionnaire*

Questionnaires were used as a part of the comparative study to gather a mix of quantitative and qualitative data via both open-ended or closed-ended questions. Closed-ended questions provide countable and quantifiable results that can be answered via checkbox or radio buttons for instance (Nielsen Norman Group, 2016a). On the other hand, open-ended questions provide the opportunity to elaborate and provide detail. A value of the questionnaires is that it is an efficient way to collect the opinion of individuals when doing a focus group study because interviewees can influence each other otherwise (Morgan, 1996).

To provide the participants with a scale of answers for the closed-ended questions, the Likert Scale (Allen and Seaman, 2007) has been used. It is a rating format where participants (commonly) chose whether they 1) strongly agree, 2) agree, 3) are neutral, 4) disagree or 5) strongly disagree with a statement. The Likert Scale is an ordinal scale which only considers the order but not the distance between the values on the scale. However, although heavily criticized, using the Likert Scale on an interval scale for data analysis is rather common in research (Jamieson, 2004).

3.1.3 *Observation*

Observation is an effective tool to understand how participants utilize prototypes and to discover their reactions (Rogers et al., 2011).

3.1.3.1 *Direct Observation*

In *direct observation* (Rogers et al., 2011) participants are observed in an unobtrusive manner. This method is used in the comparative study and the take-home study.

Observations provide knowledge on how participants actually interact with prototypes, contrary to questionnaires and interviews. When interviewing, the participants can feel it necessary to say, what they believe is the "*correct*" answer instead of what the participant really thinks and does (Rogers et al., 2011). To limit this bias, observation can help discover how the participant behaves and see if it correlates with their statements.

3.1.3.2 *Indirect Observation*

In the take-home study, a prototype was evaluated in a *natural setting involving users* (Rogers et al., 2011). Some of the advantages to this are to identify opportunities for new technologies and extract requirements for new designs. This is different to a lab study where no information is collected on a prototype's influence on the natural environment. However, we cannot observe how it impacts the family and their use. To accommodate for this, we use *indirect observation* through diaries and interaction logs.

A diary study provides a way to indirectly observe the behavior of the participants by having them self-report over a period of time (Nielsen Norman Group, 2016b). Diaries do not require many resources as no special equipment or expertise are required to develop and complete them. It is suitable for long-term studies that do not have the means to conduct a field study (Rogers et al., 2011). The diary can contain a template with different questions relevant to the research question that the participant is asked to fill out. Unfortunately, a drawback is that it relies on the participants to fill out the diary, who might lose motivation or forget about it. Therefore, the process of completing the diary has to be straightforward and fast. This is especially relevant to us since the participants are participating without any economic incentive. Therefore, it can also make sense to adjust the rate at which the participants have to fill out a new entry in the diary. An argument for not applying Experience Sampling Method (ESM) (Kubey et al., 1996) is that it asks too much of volunteer participants because they are prompted at random times to answer specific questions. ESM might also disrupt them during their family activities.

The other method as a means of indirect observation is interaction logs (Rogers et al., 2011). This is a tool for logging when participants interact with a system resulting in both quantitative and qualitative data. An advantage is that it is unobtrusive because the logging automatically happens in the background when the user interacts with the system (Rogers et al., 2011). However, it is important to clarify for the participants that their use of the system is tracked, as it otherwise is an unethical act.

3.2 DATA ANALYSIS

To analyze the data collected in the comparative study we utilized *open coding*. Open coding is a subset of *grounded theory* (Muller and Kogan, 2010) and can vary in detail depending on what is needed to produce a viable outcome. The advantage of open coding or emergent coding is that it is suitable for 1) understanding the meaning of the data, 2) captures rich nuances, 3) is purely qualitative, and 4) suitable for open-ended research questions which fits the collected data and research questions (Lazar et al., 2017).

The open codes were developed from a line-by-line basis, which can range from focusing on every single word to codes covering entire answers. Lazar et al. (2017) advocate to read through the dataset (transcripts) to gain a thorough understanding and general idea about the aspects mentioned in the interviews before starting the process of developing codes. Following open coding is *axial coding* which outlines how the categories relate to each other and subcategories. We chose to stop our data processing at this point and abstained from the last part *(selective coding)* which is concerned with *"[...] refining and integrating categories to form a larger theoretical schema. The categories are organized around one central category that forms the backbone of the theory."* (Rogers et al., 2011), as we do not wish to create a new theory but aim to deduce design criteria for future work.

Lastly, the quantitative data from the comparative study was gathered from the questionnaire utilizing the Likert Scale. No statistical analysis is applied to this data due to research arguing against using the Likert Scale on an interval scale (Section 3.1.2), and since the study is not done in a completely controlled environment. Uncontrollable variables include the fact that some heart rate measured activities were more interesting compared to others during the study. Instead, the results are reported graphically to provide an overview and general understanding of the data which is then used to back up findings generated from the open codes from the same study. Lastly, we filtered out the questionnaires filled out by children (from 13 and below), due to them not fully understanding the questions (something we noticed during the study).

4 FORMATIVE INTERVIEWS TO UNDERSTAND FAMILY LIFE

Four semi-structured interviews were conducted to gain an understanding of family life. Additionally, we had a secondary motivation of finding families interested in participating in further studies. The goals for the interviews were to:

1. Understand families' typical week and weekend
2. Investigate the interests of families
3. Explore families' tracking habits

This study does not directly answer any of the thesis' research questions, but it sets the foundation for the design proposal and purpose.

In the following sections, a detailed description of the procedure for the study, results, and analysis are presented along with a discussion on what these results means for the thesis and concepts going forward.

4.1 PROCEDURE

In order to get in touch with potential families, we personally reached out to relevant friends, families, and directly to qualified families suggested to us by friends. Furthermore, a post was shared on social media seeking participants for the study. The ideal participants would be families with at least one child, older than six, living at home. The reason behind the age requirement was to avoid families with infants and rather find families where the children were old enough to actively engage in the planning of activities and have a say in what happens on a day to day basis. Although the research area of the thesis is not confined to Danish families, we focused our search for qualified families living within an hour drive from Aarhus C, Denmark at maximum. This was simply to allow us to visit the families in their homes and to conduct the interview with as many family members present as possible (the reasoning for interviewing in-situ is discussed in Section 3.1.1). Due to cancellations and difficulties in finding families within a desired radius of Aarhus, four interviews were conducted in total. The initial goal was five interviews and we would at least have liked to have interviewed another family living in an urban environment. However, families can be so different that one could argue that even five families would not be enough to get a thorough understanding of the domain. For this reason, we coupled our findings with Envision's research on digital families with children (Envision, 2015). Ideally, interviews should be conducted until *saturation* is reached (Saunders et al., 2017), meaning little to no new knowledge is gained from conducting additional interviews.

4.1.1 *Interview Outline*

Four families participated in the study, which will be referred to as F1, F2, F3 and F4 in the chronological order of the interviews. Prior to each interview, the families were presented with a consent form which the parents had to sign on behalf of their children and themselves. The interviews lasted 40 to 90 minutes and were based on a list of questions meant to foster an organic conversation. The questions of the semi-structured interview are attached in Appendix A.1. The interview focused on getting an in-depth understanding of the family and the individual family members. It also focused on obtaining insight on a normal weekday and weekend in their home, which activities they participate in as a family, and when they choose to socialize or keep to themselves. We wondered if the family planned their activities well ahead of time, or if they were more spontaneous and sporadic. Then, we made them reflect on whether they felt they spend enough time together as a family and which activities are most memorable to them when looking back. To conclude the interview, we asked them if they have any current tracking habits: if they did, we asked them to describe the purpose of their tracking and how they utilize it. If they did not track anything, we tried to have a dialog on tracking to understand their views on the topic. After the interviews, detailed notes were taken and thematically analyzed for patterns and tendencies. One interview was conducted at the workplace of a family member, per their request, while the rest of the interviews were conducted in the respective homes of the families. In some cases, only the parents were present while in others both the parents and their children were included. In Section 4.3.1, we discuss the outcome of interviewing the families in their home. Unfortunately, the audio file of the interview with F2 was lost, but notes were created immediately after the interview.

4.1.2 *Family Overview*

The families who partook in the formative interviews are described below:

F1 consisted of two parents and a 13-year-old child living together. The mother also has two adult children from a previous marriage (18 and 21 years old) who split their time evenly between her place and their father's. Currently, F1 reside in a residential area of a small town of approximately 1.500 inhabitants.

F2 have a four-year-old girl, while the father has two children from a previous marriage (a nine and a 13-year-old) who both stay at their house every other weekend. They reside in a similar residential area in a small town of approximately 3.000 inhabitants.

F3 is a married couple with three children: an elder son of 18, and two 14-year-old twins, one of whom has special needs. They currently reside in a residential area in a city of 7.500 inhabitants.

F4 is an urban family living in the city center of Aarhus (the second biggest city in Denmark) in a central apartment. They are a married couple with two children aged 18 and 22 (one of whom moved out on her own).

All the families were based around central Jutland and we estimated the families to likely belong to the middle class.

4.2 ANALYSIS

4.2.1 *Family Differences*

The interviews emphasized that each family is different – although that statement is somewhat obvious, it became evident during the interviews. Some families were very methodical in how they planned their activities. For instance, F4 were planning a skiing trip 10 months ahead of time and would regularly plan to visit their daughter who lives in Copenhagen. Other families were much more spontaneous and would find a way to work around everyone's schedules on short notice. The mother of F3 mentioned: *"you can drown in too much planning"*, highlighting her view on planning every detail of family life. Rarely would her family (F3) plan their weekends in advance, but they still managed to find time to visit the zoo or their summer cabin on several occasions. The primary difference between the families, it seemed, was that some actively set dates for future family activities whereas others would try to spend time with each other whenever their schedule allowed them to.

Some families had children from previous marriages, which requires additional planning. Two of the families had children alternating between their fathers and mothers home as a result of divorce, a no longer rare occurrence as approximately half of all marriages ends in divorce in Denmark (Danmarks Statistik, 2017). In F1, the children stay with F1 for one week of every fortnight. For F2, the father has his children staying over every other weekend. Being a child from a previous marriage might exclude the child from certain activities or internal understandings in the family, and it makes a big difference whether a child is living with a parent all the time, half the time, or only every other weekend. Usually F2 would fill their weekends with social activities, such as board games, cooking together, or being outside. However, on the weekends that the children of the father were visiting, the father's oldest child would spend too much time on the computer for their liking, something that was much more tolerated at his mother's home. Furthermore, if children rarely visit, it puts more pressure on families to plan activities when the children are present in the household.

Another difference between families was that some families simply have a bigger need to socialize and spend time together compared to others. Sometimes family members wish to have some alone time after a long day at work or in school. The special needs child of F3 often wants some quiet time after a long day at his school and other children wish to play computer with their friends or attend football in the evening. Of course, in all families, the parents and children alike have different hobbies and leisure pursuits that force them to be apart. The way some families are more social than others, as we see it, is manifested not by how much the families are apart but by how they carry out mundane and smaller tasks, such as cooking, walking the dog, or physical activity. Some families manage to turn these activities into social activities between family members, whereas other families do them completely separately. As previously mentioned, we do not judge any right or wrongs, we merely highlight the differences as observed during the interviews.

4.2.2 *Tight Schedules During Weekdays Keep Families Busy*

Having a family with children comes with a lot of responsibility, you need to make money to provide for the children, which in most families means that both parents are working full-time. Additionally, the children need to be raised, educated, and taken care of. All in all, it takes a lot of time, effort, and energy to have a functional family and therefore it can be hard to find room for quality time together. This became evident during the interviews as the participating families mentioned that they would love to spend more time together, but that it was difficult to find time between all their daily routines and responsibilities. During the weekday, dinnertime was generally the first chance during the day the family had a chance to sit down and reflect. Some families would have time for some activities between dinner and work (such as F4 who would go to fitness classes together when the parents came home), but dinnertime would be the first time for a relaxed and meaningful conversation with everyone gathered. A Danish study by Envision (2015) found that between 3-6 PM is the moment during the day that children's families undisputedly struggle the most to do everything they need to do (like buying groceries, picking up children, and making it through rush hour).

All the interviewed families mentioned dinnertime as an important family moment for quality time during the weekday. The father from F4 explains: "*[one of the few activities we still do together is eating dinner as a family*". During dinnertime, we found all families would be seated at the table together and no smartphones or TV were allowed. This was especially evident in F1 where the mother stated: "*[the two oldest children] would like to have a TV in the kitchen, however it was a deliberate choice not to. We had a TV in the previous home and the first thing [the two oldest children] would do was ask if it could be turned on*", and the father joked: "*If anyone uses their phone at the table, it will [be demolished]*". Eating with no TV seems to be something that is valued higher in Denmark as compared to other countries, since research suggest that as many as 60% of US families watch television during mealtimes (Kirkova, 2013) compared to 30% of Danish families (Envision, 2015). Nonetheless, dinnertime is when the family can focus on each other without distractions because after dinner the families tend to split up to either do homework, play sports, or spent some time by themselves in their rooms. If they could find time and motivation, F2 and F4 would occasionally play board games together during the evening and F1 would walk the dog together. F4 discussed that they should start playing more board games in the evening since it was something that they had started doing less than usual in recent times.

4.2.3 *Weekends Allow Quality Time Together*

After a long week of struggling with all the practical aspects of family life, the weekends allowed for some breathing room. The aforementioned study by Envision (2015) found that Friday evenings were when family life seems the easiest and we found a similar sentiment with each of the interviewed families. The weekend provides the families with an opportunity to do activities with each other that they did not have time for during weekdays. Some of these activities could be small and simple like going for a walk together or play board games: F1 would go for long walks in the outdoors every weekend and all families would play board games occasionally. F4 highlighted the competitive aspects of playing games with each other and that the loser would be teased about the results afterward. The weekend also allows for excursion or even an entire weekend trip. We found it to be quite normal for families to have a few weekend trips each year going somewhere interesting: F3 had a summer cabin and F2 a camper they would use regularly for an entire weekend. F4 actively planned to visit their oldest daughter in Copenhagen, because they did not see each other quite as often since she moved out. This made the family quite aware of the importance of a shared interest between parents and children when they part ways. For instance, the father and eldest daughter of F4 found a shared interest in going to concerts together and they would try to influence each other to listen to different artists, thereby widening their musical horizons and simultaneously getting closer to each other. Unfortunately, a problem with the weekend mentioned by F1 is the fact that *"it disappears too fast and then it is back to a hectic work week"*.

4.2.4 *Tracking Habits*

Tracking habits in families are different, but all the interviewed families did or had done some sort of tracking. Many of the families already owned activity tracking devices: F1 all had activity trackers, F2 had multiple activity trackers and heart rate chest straps, and F4 had activity trackers as well. Only F3 did not have specific activity tracking wearables as a part of their everyday life, however the mother stated: *"[...] I think that my son uses [Endomondo] sometimes, but he has also just signed up to do a race"*. The data collected in the families is related to the tracking of health metrics present by Choe et al. (2014) (Section 2.1). F1, F2, and F4 all have at least one person count steps and have a target number of steps to reach each day. In F1 the mother and son were motivated to reach their goal: *"we all walk with a step counter. It is something that we care about and if we have not walked enough by the end of the day then we have to go for a walk"*. This style of tracking is categorized as directive tracking (Rooksby et al., 2014). The aforementioned activity trackers owned by F1, F2 and F4 were all meant for specific directive tracking purposes: in F2 the mother has several heart rate chest straps because she had been training for a half Iron Man race. She also used to count calories, however stopped when the youngest child wanted to do the same. F2 saw this as a problem since young children should not care about how many calories are in their food. In F1, the two oldest children compete against each other by measuring their body weight. Whoever was performing worst or weighed the most would be teased by the other.

All families also utilized documentary tracking (Rooksby et al., 2014), through physical photo albums with pictures of their children. Rooksby et al. (2014) argues that life photography is a part of personal informatics, therefore we view photo albums as documentary tracking, since it documents activities of the past. In F4, the mother created photo albums of the children's lives from birth until moving out. The father mentions: *"[..] the girls are often going through [the photo albums]"*, and that both of the children have multiple books documenting their life. The mom describes the books as a *declaration of love*. Additionally, F3 explains that their son enjoys looking through old photos especially if there are pictures of their now deceased granddad, but it is annoying that the images are not printed and put into a photo album.

However, not all photo albums are enjoyed as much as in F3 and F4. F1 did also have photo albums for their children, but the mother mentions: *"the other day the boys found their photo albums and went through them. [..] if it were up to [the sons] they would have been thrown out, but I told them that is not something you are allowed to do"*. Beside photo albums as documentary tracking, family members from F1 and F3 also used documentary tracking to check the last time they went running. The mother of F1 mentions that: *"sometimes I look back (on the data) to see the last time I was running"*. Diagnostic tracking (Rooksby et al., 2014) was the last style of tracking we encountered. The father of F2 explained that he had trouble sleeping and through tracking of his sleeping patterns, he deduced that his pillow was the problem.

Not all family members see the beauty of tracking data. The mother of F3 mentioned that: *"To be totally honest, it is a waste of time (to track data)"*, she elaborated: *"what can I use it for? [..] I do not know what I can use it for"*. A different perspective is from the father of F4: *"I do not like a Big Brother watching how much I run or walk"*, referring to the fact that smartphones and companies have access to personal information. For this reason, he attempts to turn off or delete applications that collects data. He also argued that quantifying every little detail of one's life is not a value to strive towards in order to live a meaningful life: work can be controlled and measured but one's private life should not be (to the same extent).

4.3 DISCUSSION

Along with research from the related work, these formative interviews function as a preliminary study for us to understand the environment for which we are designing and deploying physicalizations. It also helps us to understand how our design can fit into family life. The ensuing step will be to utilize this knowledge in attempt to design effective prototypes.

Because we only conducted four interviews we realize that the findings by no means can be used as definite conclusions on family life, and that we only have scratched the surface in terms of what can be learned about the complexity of family life. In the end, we argue that we gathered sufficient knowledge to get a glimpse of what life is like in a family with children and that we have gained an understanding valuable to our design process.

4.3.1 *Reflection While Families Are Busy*

A key takeaway from the interviews is our recognition of exactly how busy family life is, considering all the factors involved. Since the weekend clearly provides some breathing room for families to engage with each other and spend quality time together, our concept should be designed around these meaningful and intimate moments. Then during the busy weekdays when families are too busy to engage in deeper and longer family activities, the concept should allow them to reflect and reminisce on the core family moments that happened in the past. We see value in reflection and reminiscing especially during dinnertime when the family is gathered after a long day. Furthermore, since there are many children from previous marriages, these children might be at the other parents' house for long periods of time. When the children are not currently staying in the home, the concept should be designed for the family to remember these moments when they were together and the fun they had. When reminiscing on past activities, the activity does not necessarily have to be a big moment like a family vacation or something life changing like a high school graduation, it can also be a competitive board game, a memorable concert, or a walk in the woods. Some families expressed that these smaller moments in the daily life can be especially important to them; during a take-home study, it is worth investigating which types of activities are best visualized and reflected upon using our prototype.

During the interviews, we noticed a trend: by going to the families' homes and asking them questions about their daily lives, they started to reflect upon it by verbalizing their habits and routines. Some of these habits and routines are only understood between the family members and by having to express the habits and routines it caused them to take a look at themselves and evaluate if they feel like they are happy with their priorities. In F4, both children mentioned that they suddenly started playing less and less card games in the evening. The father mentioned that: *"you need to continuously look at the family and if you are spending enough time together, because sometimes you do not pay enough attention to it and you only realize that when you look back in time"*. Because the reflection between family members is so important, our third interview (just with the mother of F3 at her workplace) did not go as well as the others. We found that visiting the family in the home with all of them present, to be a great factor in conducting an open, relaxed, and informative interview. We hope our concept can have a similar quality as we found when conducting the interviews, where family members are encouraged to talk about their shared moments and reflect on their life together as a family.

4.3.2 *Understanding Why Families Track Data*

From the analysis, we found a lot of the family members actually had specific devices to track their activities. It was a surprise that many of the family members had such devices. This is beneficial because our concept utilizes activity trackers as a part of the prototypes. It is an advantage that families are familiar with activity trackers and collecting data since the integration of the prototype is more natural, compared to families with no experience. If the family does not have any experience, the prototypes might affect the everyday life negatively or not at all. They might forget to wear their activity trackers or they simply forget to track family activities.

All of the families utilized documentary tracking to document their children's first years, additionally these photo albums were sometimes examined to reflect on family moments. But some images do not always leave the computer, which can be annoying as the printed photo albums have a great deal of personal value for the families. This substantiates the importance of the physical aspect of the photos which aligns with some of the qualities in data physicalization, discussed in Section 2.3. Reflection through recalling or revisiting of memories happen when the family looks in their photo albums, which is one of the qualities our concept should aim to support. It does not mean that the concept have the same personal values as photo albums, but that the family should be able to look back and discuss memories. Lastly, it would be an achievement if the families would be motivated to make room for more family activities or use the concept to reflect on fun family moments as a part of their everyday life.

5 COMPARATIVE STUDY OF PHYSICALIZATIONS

The purpose of the comparative study was to test different qualities of data physicalizations to investigate which attributes and techniques are effective in creating visualizations that foster social interaction and shared reflection. This knowledge provides us with design considerations for the design of a final prototype to be evaluated in the homes of the families. These design considerations answer the research question:

RQ2 *Which design considerations are important for fostering social interaction and shared reflection*

The rest of the study provides insight into two other research questions, but these will be investigated in closer details in the take-home study (Chapter 6):

RQ1 *How does data physicalization foster social interaction and shared reflection in families*

RQ4 *How does heart rate relate to the experience of an activity*

To answer the aforementioned research questions, we conducted six focus groups, each with a different family or dormitory, testing three data physicalizations related to an activity carried out during the study (see Section 5.3.4 for the reason to include dormitories). The three prototypes each contain different design elements of data physicalization that we found worth exploring.

In this chapter, we present the three prototypes of the study, and how the study was conducted. Afterward, the findings are presented, analyzed, and discussed.

5.1 PROTOTYPES

Three prototypes were developed which all utilized heart rate data from activity trackers to create physical visualizations. The prototypes visualize the heart rate in different ways in order to evaluate qualities of each design. The three prototypes are called: 1) Annotated Prototype, 2) Laser Cut Prototype, and 3) Interactive Prototype. They are described below along with the design rationale for each of them.

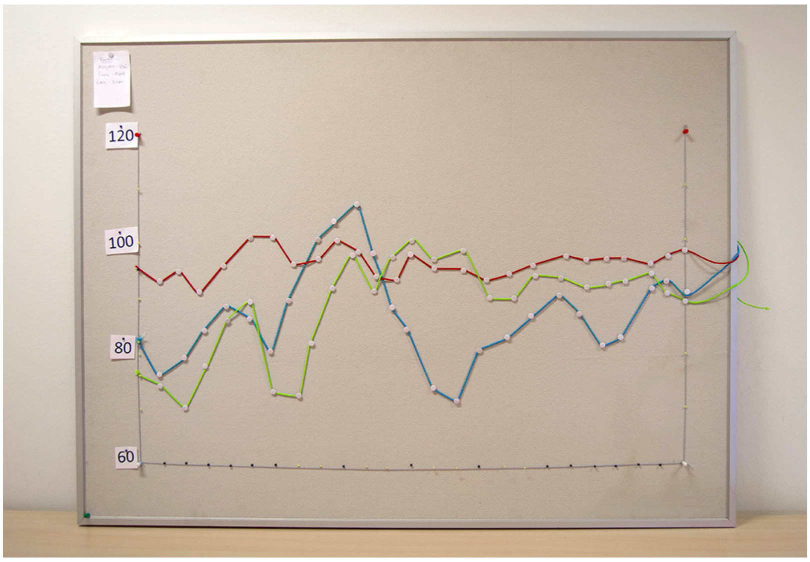


Figure 12: A game of Kubb visualized via the prototype (with annotations removed).

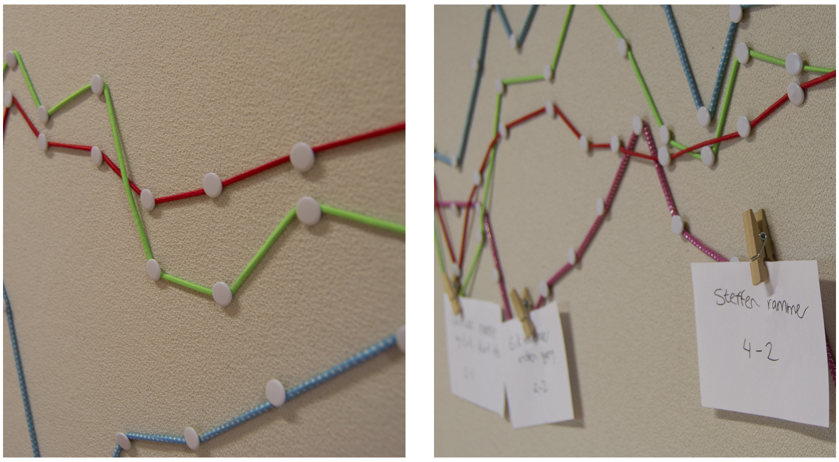
5.1.1 *Annotated Prototype*

5.1.1.1 *Description*

The Annotated Prototype is designed as a large object which can be hung on a wall in the living room of a home. It is a 90 x 120 centimeters pin-up board with lines of different colors each forming a line graph. A line represents the heart rate of a participant and is made from paracord, which is thick and elastic (Figure 13a). The x-axis (the width) of the graph represents time and the y-axis (the height) represents the BPM. Each line has approximately 25 data points on the graph. Using clamps the prototype allows for annotations to be attached to the lines (Figure 13b). In the later focus groups, we would instead pin the annotations below the visualization to avoid having the annotations occlude the lines. The annotations describe anything that happened at that given moment. The entire prototype can be seen in Figure 12. It was based on a fully automatic design proposal, where the lines of each user would be controlled by servos and could dynamical change.

5.1.1.2 *Design Rationale*

Since this prototype is envisioned as a large wall design it is meant to be something that the family is peripherally aware of when they are in the same room as the Annotated Prototype. It could replace a piece of art or a poster, but contrary to most wall pieces this design would have a deeper personal message because it reminds the family of a shared moment between them. By always being there the family can



(a) The pins and paracord. (b) The attached annotations.

Figure 13

reflect and discuss these moments during dinner on weekdays when they otherwise might be too busy to do any activities together (since we found during the formative interviews that dinnertime is the only time the interviewed families consistently spend time together during the weekdays). For this prototype especially, the heart rate data is meant to foster continuous reflection days after the activity has occurred because it is always there and does not require to be put on a table or to be interacted with. These ideas are in line with those of slow technology (Hallnäs and Redström, 2001), in which technology is exposed in a way that aims to create reflection and calm moments by simply being part of the environment.

The Annotated Prototype is the only one to incorporate annotations as part of the visualization. Ideally, the users should be able to talk about the data on their own, however whether they need help to do this is something that needs to be tested. Certain data readings might not make immediate sense to the user and annotations can help with this. Thudt et al. (2017) point out that: *"annotations can add interpretations to the graph as a whole, or point out personally significant points in the visualization"*. Segel and Heer (2010) mention annotations as under-utilized in narrative visualizations. Furthermore, even if the user already understands the context of their data, it can help the other participants to understand each other's data in relation to each other. Sadly, it would be difficult to create automated annotations in a fully dynamic and embedded prototype, first of all because it needs to be context-aware, and secondly because of the physicality of the prototype, which would ideally require physical annotations as well. Alternatively, the users themselves can personalize their physicalizations by creating their own annotations. This provides the families with a physicalization in which they can *self-express* (Khot et al., 2017), which is especially valuable in terms of having the prototype as a piece of design for guests to view as well. Having annotations on the physicalization support users to explain the activity to others. However, for this study, we simply wish to have the participants discuss the different situations and point them out to each other. It is not within the scope of the comparative study to evaluate how the participants can personalize the physicalization via annotations. Instead, the annotations are used for the participants to make sense of each other's data and put it into context. We are interested in their opinions regarding the annotations.

The Annotated Prototype is seemingly the simplest prototype to quickly scan through and make sense of. Furthermore, it is the only prototype that explicitly states the exact value of the heart rate at any given moment. Explicit values are only incorporated into a single prototype because we wish to explore whether people are interested in exact values of heart rate or if they are content to compare the graph without knowing the exact heart rate. The Annotated Prototype does not present as many data points in the graph compared to the Laser Cut Prototype (Section 5.1.2) since each data point requires a pin to be inserted into the pin-up board and for the paracord to be coiled around all the pins. In Section 5.2.3 we discuss initial investigation on how many data points are needed in the visualization. In an embedded version of the prototype, each data point would require an actuator to change the position of the paracord dynamically, which would require a lot of actuators and a creative solution to having several line graphs without the lines obstructing. For this study, we circumvent this by having a handmade physicalization prototype, but for a future dynamic prototype, issues will occur that need to be designed around.

5.1.2 *Laser Cut Prototype*

5.1.2.1 *Description*

Contrary to the Annotated Prototype, the Laser Cut Prototype is designed to be a tangible and movable object. It can be categorized as a data sculpture (Jansen et al., 2013) and is a laser cut plywood box with five slits across its length. The box is 10 centimeters wide, 20 centimeters long and has a height of five centimeters (Figure 14). Area charts[1] of colored see-through acrylic can be inserted into the slits each representing the heart rate over time of a user. We refer to the acrylic charts as graphs. The length of the acrylic displays the time variable and the height displays the BPM. A heart rate of 120 BPM rises 17 centimeters from the box and a heart rate of 40 BPM (or below) is at the same level as the top of the box. The physicalization

1 The area between axis and line is emphasized using color

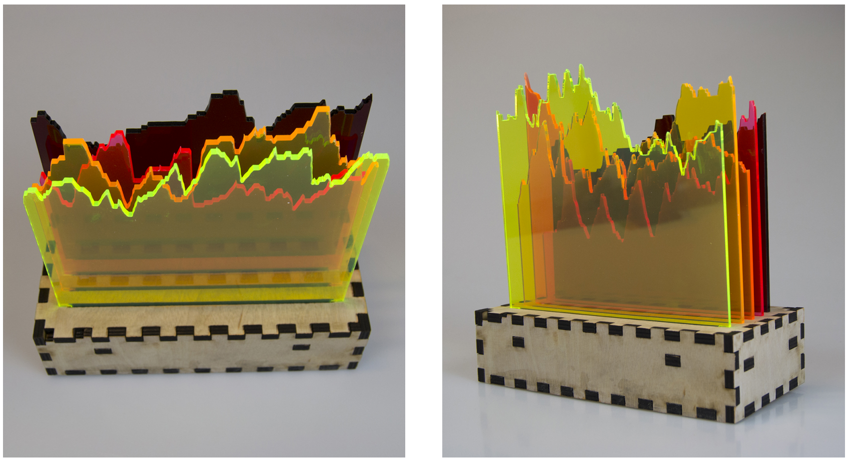


Figure 14: The Laser Cut Prototype representing two different games of Kubb.

has approximately 60 data points for each user since the initial tests demonstrated it was deemed most effective (in terms of comprehending the data) and most aesthetically pleasing.

One physical box (and the associated graphs) represents a specific recorded family activity. The artifact is created after the activity and is meant to be used for reminiscing about the moment it visualizes.

5.1.2.2 *Design Rationale*

The fact that the prototype is laser cut comes with its set of problems: even with the democratization of data physicalization, the technology to laser cut is still not very accessible to the general public (especially not an ordinary family) (Swaminathan et al., 2014b), which means that the concept might not yet be fit as an everyday consumer product. Because of the needed construction phase using a laser cutter, there is a waiting period before the physicalization is finalized.

Of the three prototypes, the Laser Cut Prototype has the most tangible qualities since it allows for a three-dimensional inspection of the graphs due to the size and lack of wired components in the prototype. One of the key advantages of a tangible data sculpture is the use of touch, which is an essential cognitive aid in investigating the data (Jansen et al., 2013). Furthermore, the decision to laser cut the graphs is based on the claim by Wun et al. (2016) that people tend to use more time on the data of a physical chart contrary to digital charts. A common problem for physical graphs is occlusion, which we combat by using see-through acrylic allowing users to look through all the layers of graphs. By having different colored acrylic, we also allow the users to quickly view how they relate to each other. To our knowledge, using colored acrylic in physical charts is a novel concept, yet to be utilized in data physicalization. We only found two other designs that used colorless see-through acrylic in their physicalization (Damião Barbosa, 2017; Huron, 2013).

When designing The Laser Cut Prototype, a focus was to create something aesthetically pleasing. An important element of the thesis is to embed subjectivity and personalization into the artifact, and this is especially relevant for this prototype as one specific object is connected to a shared experience. It is designed to be a presence in their everyday life and something they can place on the shelf, window frame, or take out to investigate like a photo album. The goal is to spark opportunities for social interaction and shared reflection (Thudt et al., 2018) just like when going through a photo album. In the data physicalization community, we have already seen personal and subjective artifact in Sweat Atoms (Khot et al., 2014) and Activity Sculptures (Stusak et al., 2014) but these concepts focus on running activities of an individual rather than social interaction and shared reflection.

5.1.3 *Interactive Prototype*

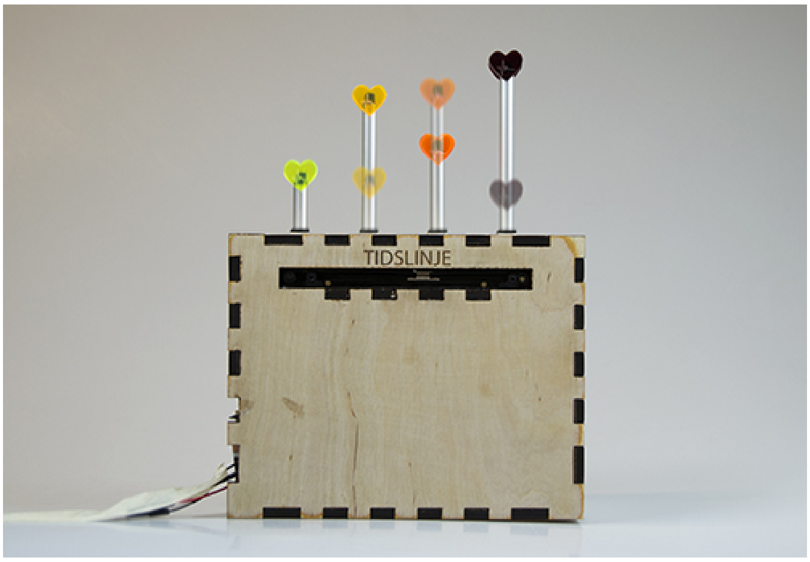
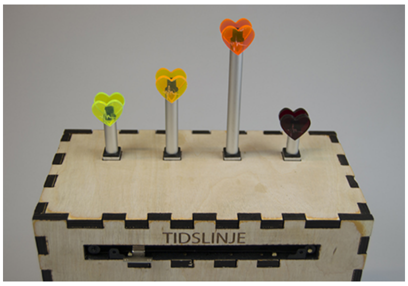


Figure 15: Interactive Prototype with illustration of moving actuators.

5.1.3.1 *Description*

The Interactive Prototype is a kinetic sculpture (Data Physicalization, 2017) and the only interactive prototype of the three. The x-axis (displaying time in the other prototypes) has been removed and replaced with a motorized slide potentiometer (slider) (Figure 16a). The slider represents the progression of time, which the prototype moves through automatically like a progress bar on a video. However, just like in a video, users have the option to go to a specific moment by dragging the knob of the slider. The leftmost position of the slider represents the beginning and the rightmost position represents the end of the activity. Just like the other prototypes, the y-axis displays the BPM. Four linear actuators each represent a user (Figure 16b) and as the slider progresses the actuators move up and down depending on their heart rate at the specific time. This prototype has the lowest detail: due to the speed of the linear actuators, it made sense to only have 15 data points for this particular prototype. In an ideal prototype where the linear actuators would be able to move between two points in milliseconds, as seen in inForm (Follmer et al., 2013), it would be possible to include as many data points as the slider would allow.

(a) The slider representing the timeline.



(b) The linear actuators representing each user's heart rate.

Figure 16: Interactive prototype design

The box is made from plywood and is 17 centimeters tall to fit the linear actuators which can extend 10 centimeters above the box. Each actuator has a laser cut heart on top of it, to allow users to identify each other (these colors match the colors of the Laser Cut Prototype). The box has a length of 21 centimeters and a width of 11 centimeters. The slider is located on the side of the box with the word "*timeline*" (in Danish) engraved above. The entire prototype is illustrated in Figure 15.

Of the three prototypes, the Interactive Prototype is the only prototype which is implemented to dynamically change between different datasets. Because of this, it only takes a short time to prepare this prototype for our study. Unlike the Laser Cut Prototype, The Interactive Prototype can represent several activities.

5.1.3.2 *Design Rationale*

The reason for the removal of the x-axis and using a slider instead was to explore which compromises could be made in order to create a more feasible prototype to develop within the scope of the thesis. The technique is suggested by Segel and Heer (2010) who argue a progress bar communicates the overall structure of the narrative and lets the users understand the current position. By using a slider to display time rather than the x-axis, only one actuator is required to visualize a user, resulting in significantly less hardware compared to the original design proposal for the Annotated Prototype which would require one actuator per data point for each user. Ergo, the goal was to test whether this sort of design was understandable and still fostered social interaction and shared reflection. One interesting aspect to investigate was how the participants would react to not being shown all data at once. Was it sufficient to display the participants' heart rate at a specific moment in time as long as they had a timeline?

As mentioned previously, the Interactive Prototype is the only interactive prototype (hence the name). It is also the only prototype which is not static. Having a moving and interactive prototype was important in order to test if those qualities can make users more engaged in the presented data. In a prior iteration the visualization of the current heart rate was designed as vibration in water, to create a coupling between a fast vibration and a fast heartbeat. Through exploration, we found it hard to distinguish the different levels of vibrations with the hardware available to us. Instead, we opted to use linear actuators to create a moving bar chart. Just like the other prototypes, the Interactive Prototype is not meant to be the perfect concept in terms of visualizing data, instead the prototype is envisioned to help answer interesting questions of design qualities, such as what users value in visualizations, as well as the importance of interactivity and movement.

5.2 IMPLEMENTATION

5.2.1 *Picking Heart Rate Monitor*

Before deciding on the technology for heart rate monitoring, we investigated the type of heart rate monitors available and how to access the data (as some monitors restricted access). We based these criteria on being able to use the same technology for a later study in the home of families. Swan (2013) clarified that the tracking process should be as easy as possible to avoid overloading participants, to not make them lose motivation. Therefore, we quickly decided to narrow our search to wristband activity trackers rather than heart rate monitors strapped around the torso which were more difficult and time consuming to put on. By aiming for activity trackers looking like watches we hoped participants would not feel alienated when wearing them, and would gladly use them in their daily life.

The first activity tracker we explored was a Mio Slice[2]. We choose a product by Mio Technology due to prior research using the same brand (Liu et al., 2017; Vermeulen et al., 2016). We managed to pair

2 https://www.mioglobal.com/en-us/Mio-SLICE-heart-rate-fitness-tracker/Product.aspx

the Mio Slice with an Android smartphone by customizing an open source project found on GitHub[3]. However, the procedure was cumbersome and unstable because we were reliant on a constant connection between smartphone and activity tracker. Therefore, we explored other activity trackers and consulted someone who had experience with several activity trackers. We found Fitbit allowed access to tracked data through their API and required no external application to pair smartphone with the activity tracker. We also found the heart rate measurements to be adequately accurate.

5.2.2 *Fitbit Data Extraction*

To be able to retrieve people's heart rate a Fitbit Charge 2 was worn by every participant. Premade accounts were available as a means to minimize the timespan of the study and lessening the burden for the participants. After every activity, their heart rate data was synchronized through Fitbit's mobile application making it available through Fitbit's API. To access this data a web-application was developed using Node.js[4]. The web-application queries participants' heart rate data during a specific time span, and stores the raw data in a CSV file making it available to be processed. An example of the outcome is shown in Figure 17. The web-application takes six parameters: 1) app filename, 2) port number, 3) date, 4) start time, 5) end time, and 6) output filename.

In general, Fitbit does not allow others beside the users themselves to retrieve intraday data[5] (i.e., unaggregated data). Therefore, all Fitbit users have a unique client ID and a client secret (keys only known by client and server) making it possible to retrieve personal data. This would be a cumbersome process if we were to alternate between pairs of client ID and client secret to retrieve the data from each of our prefigured accounts. To circumvent this cumbersome procedure a request to Fitbit was issued arguing why we needed permission to query for several users data. As a research project, Fitbit approved our web-application, but even though the permission to query the data was granted, users still had to grant us permission as well. After a successful authentication and granted permission the system redirects back to the web-application where a scalable vector graphic graph is shown on a simple webpage. To visualize the heart rate data we have customized the Axis Component example[6] to generate a graph based on the data we obtain from the Fitbit API. This example utilizes the qualities of data-driven documents (D3) allowing for direct manipulation of the *document object model* advocated for by Bostock et al. (2011)

3 https://github.com/mobilars/BLEConnect
4 https://nodejs.org/en/
5 https://dev.fitbit.com/build/reference/web-api/heart-rate/
6 https://bl.ocks.org/mbostock/1166403

as: "*[other visualization toolkits] ignores developers' knowledge of standards, and the tools and resources that augment these standards*".

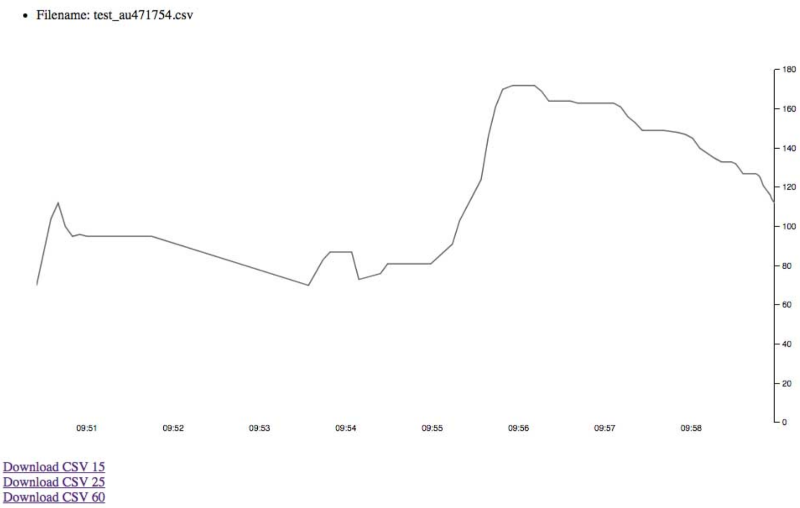


Figure 17: A representative screenshot of the web-application. The heart rate is visualized during the desired timespan. Below the graph are output options for each prototype.

To accommodate the various amount of data points needed for our prototypes the web-application could process the CSV file containing the raw values and average them to either 15, 25, or 60 values. For both the Interactive Prototype and the Annotated Prototype we downloaded the processed CSV file and passed the values to either a small piece of software to actuate the linear actuators or read them through Excel and manually plotted the pins into the pin-up board. To create the Laser Cut Prototype the graphs were exported as SVG files and imported into Adobe Illustrator manually to make them fit the dimensions of the acrylic graphs. The graphs were rearranged before laser cutting them. The y-axis was cut below 40 BPM (50 BPM the take-home study) as measurements lower than that are unlikely while participating in physical activity.

5.2.3 *Investigating Numbers of Measurements in Prototypes*

The Laser Cut Prototype had 60 rows of heart rate data, most of all the prototypes. The Annotated Prototype and Interactive Prototype both had constraints in terms of adding rows of data, either because of the time it would take to construct the prototype or the hardware respectively. In the end, the Annotated Prototype had 25 data points and the Interactive Prototype had 15. The number of data points in each prototype was decided by measuring the heart rate of an activity and determining which number of rows of heart rate data would be able to sufficiently visualize the flow of the heart rate through the activity. As illustrated in Figure 18, when averaging the data too much, all the peaks and dips of the curve blend together.

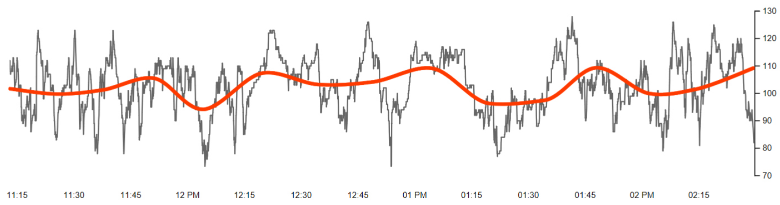


Figure 18: Too few rows of data will flatten the curve excessively, especially if the measurements spans several hours.

Unfortunately, due to slow movement of the linear actuators, the Interactive Prototype only contained 15 data points. Depending on the activity, this could result in the problem stated above where the curve loses its peaks and dips. However, we argue that it still displays the general progression of one's heart rate through the timeline. For the Annotated Prototype, we found that 25 points of data worked quite well for activities between 10-30 minutes. In every tested instance, it would provide a clear overview of the curvature of the graphs. This is illustrated in Figure 19 which shows two graphs, one with the raw data and one with 25 measurements. In this case, the game was nine minutes long, which means each point of data approximately represents 20 seconds worth of time.

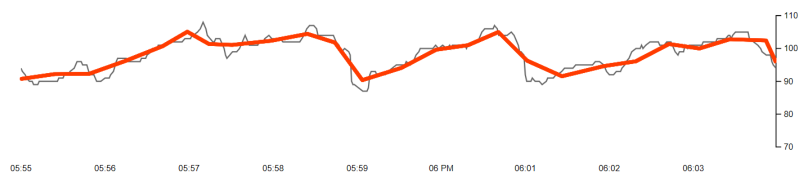


Figure 19: 25 measurements compared to the raw data from a game of Kubb.

In the case of the Laser Cut Prototype, we could include as many rows of data as we wished. However, we found that having too many rows would remove the readability of the graphs because of small sudden changes in the heart rate. This is illustrated in Figure 20, where it is evident that the raw data becomes too detailed compared to the 60 rows of data used in the Laser Cut Prototype. The game lasted 24 minutes, resulting in lots of small peaks and dips which could be influenced by a lot of factors unknown to the user, therefore not containing any narrative value.

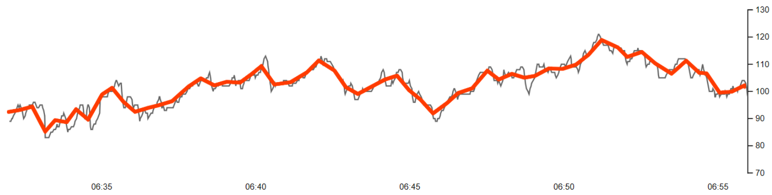


Figure 20: 60 measurements compared to the raw data from a longer game of Kubb.

5.2.4 *System Description of Interactive Prototype*

The Interactive Prototype consists of 1) a Photon[7] (microcontroller), 2) four linear actuators, 3) an H-bridge, 4) a motorized slide potentiometer, and 5) two separate energy sources (to power the linear actuators and the motorized slide potentiometer) besides powering the Photon from a USB. The Photon was chosen because of its similarities to the Arduino platform[8] which we all have experience with. An advantage of the Photon is the integrated Wi-Fi module, since the Arduino requires a separate Wi-Fi shield. The Photon also allows us to update its software over-the-air and to be debugged remotely.

The Photon controls all the components. The heart rate values of each participant are manually plotted into arrays, which are then mapped to values matching the range of the linear actuators. The slider is programmed to progress through the timeline in a predefined pace and the linear actuators adjust accordingly. However, if a user touches the slider the software is programmed to let the user freely drag the slider to a position of interest without interfering with the motorized parts of the slider. This is possible as the slider embeds conductive sensing[9]. When the user lets go of the slider it progresses through the timeline from the new position.

The four linear actuators are connected to the Photon and move every time the slider moves to a new position to match the heart rate at that time. The linear actuators require their own circuit to ensure that the Photon does not get damaged from the ampere required for the linear actuators. The H-bridge ensures that the voltage can act bidirectional, allowing the slider to move both back and forth.

5.3 PROCEDURE

During the study, six focus groups were asked to reflect and talk about the three physicalizations in a controlled setting at Aarhus University. The physicalizations were based on their heart rate while play-

7 https://www.particle.io/products/hardware/photon-wifi/
8 https://www.arduino.cc/
9 A technology that detects conductive materials (e.g., skin)

ing a game of Kubb[10] measured by Fitbit activity trackers. The controlled setting allows us to control the experiment and observe participants while they interacted with and discussed the prototypes. The duration of the focus group sessions ranged from two to three hours, depending on the size of the group and how talkative the participants were. The groups consisted of three to five participants, either from the same family or dormitory (in Section 5.3.4 we argue why we conducted the study with dormitories). To keep the structure of each focus group similar, a script was created to make certain that every participating group were asked the same questions to better compare data between focus groups. The script is attached in Appendix A.3.

(a) The outdoor facilities where the game of Kubb took place.

(b) Environment where we evaluated the different physicalizations.

Figure 21: Comparative study facilities.

As the participants arrived, they were shown the outdoor playing field (Figure 21a). Afterward, when entering the indoor facilities (Figure 21b), they were thanked for coming, offered refreshments, and then presented with consent forms to agree to participate in the study, and a pre-questionnaire inquiring about their age and relation to each other. After signing the forms, a Fitbit was handed to each participant and we introduced its features. To gain more frequent heart rate measurements, participants were instructed to enable workout mode before each game and stop it again at the end. Moving outside, the participants had to play their first game. If they did not know the rules we explained them, but we emphasized that they should make their own teams and enforce their own rules – we were merely spectating from the sideline. While the game was being played, the beginning, the end, and other interesting moments were noted down and timestamped. After the game, the participants were encouraged to note down moments from the game that were interesting or had made an impact on them. While one of us acted as a facilitator the other two developed a physicalization, a process that could take quite

10 https://www.mastersofgames.com/rules/kubb-rules.htm/

a while depending on which prototype was being prepared. While the participants waited, they were free to do as they pleased.

5.3.1 *Preparation of Physicalizations*

Depending on the number of participants, the Annotated Prototype would take 15-20 minutes of preparation time. For each participant, 25 pins were inserted into the pin-up board and the paracord would be coiled around all the pins. Then the most interesting situations from the game of Kubb were written on a piece of paper and attached to the physicalization. For the Laser Cut Prototype, the preparation was simply a matter of laser cutting different graphs onto different colors of acrylics. However, this process was dependent on the speed of the laser cutter and would take between 20-30 minutes. Finally, the Interactive Prototype only required 15 comma separated data points to be inserted into an array in the code. This prototype would take five minutes to prepare at most.

5.3.2 *Presentation of Physicalizations*

When a physicalization was presented, the participants were encouraged to talk about it in any way that made sense to them. These sessions were recorded and observed, and at a later stage, we analyzed if they were able to use the physicalization to pin down interesting situations, or if they felt surprised, amused, or any other feelings toward their heart rate. At first, we let them talk among themselves without interfering, but we occasionally inquired about certain moments in the physicalization to spark a discussion. If some aspects were unclear, we tried to help them out by providing clarification. When a discussion between the participants ended, a questionnaire was handed to the participants. As seen in Appendix A.2, the questionnaire seeks to inquire information about different aspects of the prototype to evaluate their qualities. These aspects are the 1) understandability of visualization, 2) visual appeal of visualization, 3) whether the visualization was used to compare oneself to others, 4) whether the visualization was used to compare one's heart rate over time, 5) did the participant understand which situations affected their heart rate in the visualization, and 6) was the visualization used to discuss what happened during the game (*they are called visualization in the questionnaire due to participants not understanding the concept of a physicalization*). The questions were asked using the Likert Scale to provide us with a quantitative metric to analyze the prototypes. By applying a quantitative analysis of the qualities of each prototype we hope to gain a deeper understanding of the design considerations of data physicalizations using group data.

Finally, the process was repeated two more times, testing all three prototypes. The presented order of the three prototypes were counterbalanced (Bradley, 1958) to ensure each focus group was presented with the prototypes in unique orders to avoid bias or elicit a false response, possibly from fatigue or repetitiveness. Since we conducted a study on three prototypes, by having six focus groups we were able to test all possible orders of prototypes.

5.3.3 *Concluding Interview*

As all three games were completed and each physicalization discussed, the focus group was concluded by a brief semi-structured interview. An outline of the semi-structured interview is included in Appendix A.3. We inquired about their general experiences of having their heart rate data visualized from a game of Kubb. To gain a deeper understanding of how the participants felt about the prototypes, we asked them to compare the prototypes and which aspects they found either positive or negative. They were tasked to pick their favorite physicalization and which they would prefer to bring home. As an end to the interview, we questioned whether the participants could imagine alternative situations or activities which would be interesting to visualize in a similar manner.

5.3.4 *Family Overview*

The six focus groups consisted of three families and three groups of people living together in dormitories. The three families will be referred to as F2, F4, and F5. F2 and F4 are the same families from the formative interviews and F5 is a new family. The three dormitory groups will be referred to as D1, D2, and D3. The new families and dormitories are described below in chronological order of the focus groups:

- D1 was a group of four students living in a dormitory in Aarhus. They were all in their twenties.
- F2 was five in total as they brought all of their children along. The family is already described in the Section 4.1.2.
- F5 consisted of two parents and two children. They brought along their youngest child (13 years of age). The family resides in a suburb of Aarhus.
- D2 was another group of four students from a dormitory (in Aarhus). They were all in their twenties.
- F4 is already described in Section 4.1.2. They brought along their 18-year-old daughter (three in total).

D3 was the last group of four students from a dormitory (in Aarhus). They were all in their twenties.

Ideally, the study would have been conducted with six families (as families are our target group). However, arranging six focus groups with families can be tricky, especially when the focus groups last for a couple of hours. When testing with families we were limited to their busy schedule which often means we only have weekends available. To be able to find participants for more focus groups, we decided to seek out groups from dormitories. We argue, that there are some similarities between dormitories and families that makes it acceptable to include them in the study. For instance, they live together and must coordinate things like chores and cooking etc. People living in dormitories also have conflicts and arguments that can be similar to families such as not cleaning up the common kitchen. Furthermore, since the study focuses on the qualities of the physicalization prototypes, rather than how it affects the family dynamic or how it is appropriated into their home, a choice was made to include dormitory groups.

5.3.5 *Picking an Activity*

Figure 22: A photo of a game of Kubb from the study.

Initially, only board games were considered for our study since the activities had to be carried out at facilities in Aarhus University. By playing potentially interesting board games while wearing heart rate monitors, we experimented with which board games affected the heart rate the most. Games like Ludo, Bezzerwizzer[11] or King of Tokyo[12], while fun to play, did not have many moments that would

11 http://bzw.bezzerwizzer.dk/
12 http://www.iellogames.com/KingOfTokyo.html

make one's heart rate rise or fall. These games can be considered either classical board games (which requires the players to roll a dice) or quiz games (which requires the players to answer questions). Settlers of Catan[13] provided fun and interesting moments that affected one's heart rate, but simply took too long to complete for the study. Due to the already rather lengthy focus groups, time was an important criterion when picking an activity for the families to engage in. From our experimentation we found the two most interesting games to be One Night Ultimate Werewolf[14] and Jenga[15]. One Night Ultimate Werewolf is a 15-minute-long game which requires a player to lie and manipulate others to avoid loosing. Having to lie and make up stories to cover up those lies can result in very sudden increases in heart rate. Similarly, in research of combining board games and heart rate, Frey (2016) chose a game involving lying because of its influence on players heart rate. Jenga would result in big heart rate spikes when a player had to remove a tricky block from the tower. During the later parts of the game the tower would shake even by the slightest touch and players had to keep their hands steady. We found Jenga to be a great family game well suited for all ages, but it lacked a sense of story throughout the game because every game had a similar progression. Heart rate spikes would be clearly visible but lacked any deeper narratives. On the contrary, One Night Ultimate Werewolf was full of interesting stories and situations, but was not a game well suited for children, since they would struggle to lie convincingly and to understand the tactical elements of the game. As a result, we considered having two different games depending on the age group, but unfortunately this would make it difficult to compare the data of each focus group. Consequently, through another ideation phase we found an outdoor game which we believed contained many of the values we were looking for in an activity. The game, called Kubb, is a game of Swedish origin and is quite well known in Denmark. Two teams across of each other compete by throwing sticks at wooden blocks to make them fall over. A team wins when they successfully have hit all of the opponent's wooden blocks before hitting the king in the center (a picture of F5 playing Kubb is shown in Figure 22). The length of the game is approximately between 8 and 16 minutes but can be altered by adjusting the playing field or playing with less wooden blocks. This is a good length for the study, as anything shorter would be too short to contain interesting situations, and anything longer would make the study too lengthy. Through experimentation we found that the gameplay of Kubb affects the heart rate significantly while providing a good sense of storytelling to discuss

13 https://www.catan.com/
14 https://beziergames.com/products/one-night-ultimate-werewolf
15 http://www.jenga.com/about.php

after the game. Lastly, we found the game well suited for all ages and families of different sizes.

5.3.5.1 *Data Analysis Approach*

To analyze our qualitative data, open coding was utilized, as described in Section 3.2. When a code was produced it was put on a board to get an overview and as an inspiration to others. After this session, each code was analyzed and sorted into categories depending on the content (axial coding). Axial coding was an iterative process where categories sometimes were reformulated to encompass multiple codes sharing similarities. This step also focused on eliminating categories which were too similar or to move codes to more fitting categories. Next, we analyzed which of the categories were subcategories and identified how each of these related (illustrated in Figure 23).

Figure 23: Overview of categories found during open coding.

As mentioned in Section 3.2, no statistical analysis was applied to analyze the quantitative data from the questionnaires. Only two questions were included for the analysis: 2) the visual appeal of the visualization, and 5) if the participants understood which situation affected their heart rate in the visualization. Some questions were not included because of little significant difference in results between prototypes, therefore not providing much new knowledge. Another question was removed because its wording was misunderstood by participants, since we asked them if they used the visualization to talk about the game of Kubb, something we explicitly asked them to.

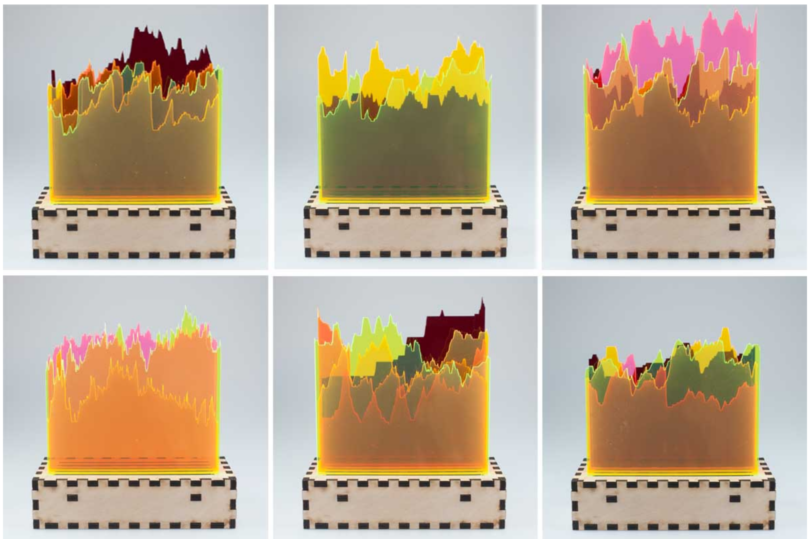


Figure 24: The six Laser Cut Prototypes from the study.

The study provided six different physicalizations of the three different prototypes. Illustrations of four of the Annotated Prototypes are seen in Figure 25 and all of the Laser Cut Prototypes are seen in Figure 24. We chose not to attach any images of the visualizations from the Interactive Prototype due to the nature of the prototype (i.e. since it is ever changing). After the focus groups, the audio and video material were revisited and transcribed for open coding. Each category found during open coding represents an interesting finding. These categories are presented in the following subsections.

In general, the study proved that there is value to be found within the design space of creating physicalizations using group data. All focus groups had fun talking about the visualizations and were eager to create narratives based on the data. Sometimes the interpretations of why participants' heart rate would peak or dip could be inaccurate or merely said to tease them, but the funny interpretations themselves were part of what made the concept entertaining for some. All in all, the participants had plenty to talk about when presented with a prototype. Through observation we found that the following moments created the best elements of storytelling:

1. When two or more participants' heart rate reacted similarly or oppositely of each other
2. When an individual had big peaks or dips in heart rate
3. Looking at the overall trend of participants' heart rates during the entire activity or for a long duration

4. Looking at an annotation and exploring how it impacted participants' heart rate

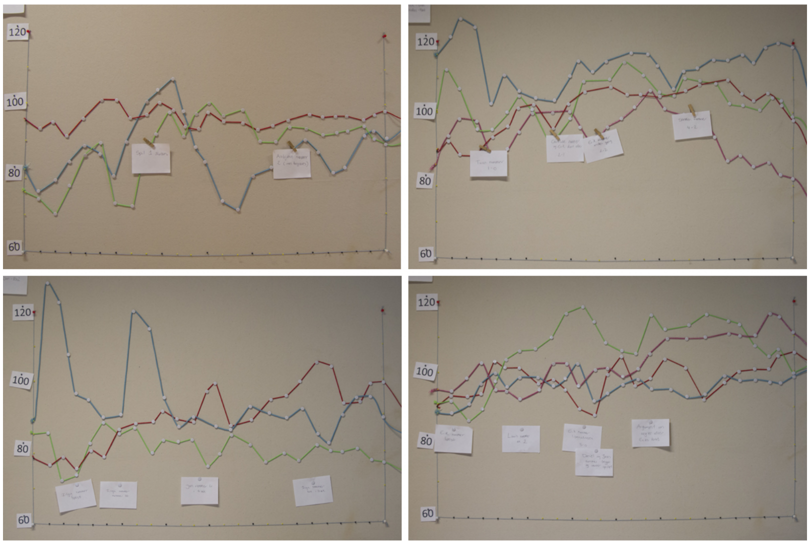


Figure 25: Four of the Annotated Prototypes from the study.

Across the prototypes and focus groups, participants were at first sight interested in figuring out how their own heart rate had progressed during the activity. Sometimes this interest was set aside as some participants paid particular interest to their teammates' heart rate. When revealing the Annotated Prototype and the Laser Cut Prototype we encountered that the participants also turned their initial focus towards extreme peaks, dips or anything striking in the data.

Surprisingly, we found that people have different heart rate *personalities* as some participants would have a highly sensitive heart rate with sudden peaks and dips, whereas other participants would have a steady heart rate throughout the game. Of course, the former personalities resulted in the most interesting visualizations since they were easier to interpret. There was a general curiosity from the participants to investigate and understand their own heart rate in a way similar to the quantified-self communities goal of gaining self-knowledge. Different types of personal reflection (Thudt et al., 2018) occurred during the study. At the lowest level of depth, participants *reflected on data* and insights directly derived from just the data. This was seen when participants noted general trends in their heart rate or big peaks and dips without interpreting why. *Reflection on context*, the second level of personal reflection, happened continuously through the study when participants tried to compare their heart rate to the actual experience. This was seen anytime a participant tried to come up with an explanation to why their heart rate would react the way it did. Sometimes they had a clear explanation as to why, other times they tried to make sense of it by reflecting on the context, like when a participant from D2 tried to figure out whether her heart rate would rise because she performed well during the game or simply because she bent down to pick up a stick. Along those lines, many participants were surprised to see how much their feelings and emotions influenced their heart rate during the game, since its common to think that physical activity is the only influence. Two participants became self-conscious of their high heart rate, while others interpreted a low heart rate as a sign that they were not engaged in the game. A participant of D3 exclaimed: *"It is weird my heart rate is so low, I felt like I was really wound up in the game"*.

During our study, most focus groups found that they reacted differently to the same situation, some would relax after successfully hitting a target while it would make others more excited. An important finding was that participants not only contextualized their own data but others as well, either by comparing heart rates or by simply making fun observations on others heart rate. A participant from D1 mentioned to another: *"I liked that your [...] heart rate is increasing when [a third participant] hit the last wooden block"*. The fact that participants actively used not just their own, but also others' heart rate shows the narrative qualities in group data for shared activities.

Some *reflection on action* was observed when participants developed strategies to improve their performance in the game. A participant from D3 discovered that he performed better when he kept calm. F4 had a discussion regarding elite athletes using heart rate data to know how to stay composed. The father of F4 realized that his heart rate would spike every time he felt like the other team was playing unfair and that it clearly influenced his performance. *Reflection on values*, the highest level of personal reflection according to Thudt et al. (2018), is not something that we observed in this for this study.

5.4.1 *Overview of Data*

Studying the three prototypes, we identified that a key element in terms of visualizing the data was to provide a clear overview of the entire activity. It is essential both in terms of making the data understandable, but even more as a means to embed narrative qualities in the data. The participants had an easier time interpreting their data when they had the complete overview, which was provided in the Annotated Prototype and the Laser Cut Prototype. When the participants could not view their heart rate progression throughout an activity, they had a hard time putting the data into context (i.e., participants were not able to understand episodes that happened during the activity by looking at the physicalization). This was evident in the Interactive Prototype, which did not allow the participants an overview of their data. The following quote from F5 illustrates that participants had a hard time interpreting the timeline: *"[The Interactive Prototype] was confusing to me. The other prototypes allowed me to see* *full progression of the game, but for the [Interactive Prototype] I cannot remember if my heart rate was higher than it was previously"*. The temporal aspect of the prototype made it difficult for participants to remember when their heart rate was high or low at a given moment. The only mode of comparison they had was between each participant which we found was not sufficient. Another challenge was the movement of the linear actuators, which was often modest or completely static, resulting in participants losing track of time (indicated on the slider). Additionally, the participants were not aware of how many steps were on the timeline from start to end which made it increasingly difficult for them to put the data into the context of the activity. As previously mentioned (Section 5.1.3), the prototype in question was a design experiment to see whether the participants acknowledged the timeline and could reflect on their data. We found that the Interactive Prototype did not qualify as a good design solution.

5.4.2 *Comparing Data*

A consensus of the study was that tracking group data during a game of Kubb was interesting and fun. This was a big part of the discussion when the three prototypes were presented, as F4 described: *"I thought it was interesting [to see your own data compared with others]"*. We found this was valid for all three prototypes. Although participants appreciated seeing their own heart rate first, the participant actively commented on each other's heart rate pointing out anything they found interesting. Participants often compared themselves to their teammate to find similarities or different reactions. A participant from D1 mentioned to a teammate that: *"It was here where we hit [one of the wooden blocks]. Both our heart rates decreased a lot afterward"*.

Each prototype facilitated different types of discussion based on how participants compared their data. For the Interactive Prototype, D1 mentioned: *"We have a fight, about who can have the highest or lowest heart rate"*. The other participant supplied: *"Yes, I am in the lead now"*. We saw the prototype could sometimes make the participants compete to see in retrospect who extended the actuator the most or least. The participants saw the actuators acting as their heart rate as a quality especially when there were extreme fluctuations between their heart rates, illustrated by this quote from D3: *"It is exciting to look at you and me. We are both just going up and down"*.

As mentioned in Section 5.4.3, discussion surrounding the Annotated Prototype related to specific occurrences (often via annotations) whereas the Laser Cut Prototype was more about the general progression. We found this to be the same when participants compared data. A quality of the Laser Cut Prototype was the tangible aspect, which allowed the participants to pick up graphs and put them on top of each other (Figure 26). A description from D2 explains how this was utilized: *"Our* *graphs are almost identical. However, I am generally just more enthusiastic compared to you"*.

Figure 26: Some participants put graphs on top of each other to compare them.

5.4.3 *Explicit Cues*

During the study, it became evident that being able to contextualize the data is essential in order to motivate storytelling. Simply put: if the participants are not able to comprehend their data, the physicalizations struggle as a tool for social interaction and shared reflection. Therefore, we tested different ways to aid the participants in contextualizing the data by providing different explicit cues. We utilized the following cues: 1) annotations, 2) indication of explicit heart rate, 3) timestamps, and 4) use of colors. We analyze each of these techniques below.

The Annotated Prototype proved the importance of annotations. They were not only used to find specific situations tied to the annotations but also acted as a point of reference. The son of F5 pointed at an interval between two annotations: *"Here I can see that dad is thinking 'I can take a break now. I have already won the game [..]' which is why you are so relaxed"* illustrating how a participant used the annotations to narrate their own story by putting into context what happened between annotations. With the Laser Cut Prototype the participants mentioned they missed the annotations, for example the father of F2 noted: *"[The Laser Cut Prototype] could be better if it had comments on it like [the Annotated Prototype]"*. The same was observed to be valid for the Interactive Prototype.

When there were annotations on the prototype the conversations tended to focus on the specific events that occurred during the game, compared to the Laser Cut Prototype which was more about general patterns and overview of participants' heart rate, as someone from D2 explained: *"I think that the focus on [the Annotated Prototype] is about the individual occurrence, [..] whereas [the Laser Cut Prototype] is about the general progression, patterns, and overview"*. Participants were curious to figure out what caused big peaks or dips on the graphs when they were unable to put it into context of the activity. A participant from D3 asked the facilitator: *"I am curious, what happened here? Do you have any idea?"*. Furthermore, while pointing at a peak on the Laser Cut Prototype the father of F2 mentioned: *"It can frustrate me endlessly that I do not have an explanation for [the peak]"*. The question from the survey inquiring whether the participants understood which situations during the game influenced their heart rate (Figure 27), gave us an idea of whether the participants felt like they could decipher their data from the game. Out of all 19 participants only one strongly agreed that they understood which situations influenced their heart rate using the Interactive Prototype, whereas 12 participants strongly agreed to the Annotated Prototype. It seems that having a full overview of the game as well as annotations made a considerable difference in how participants used the physicalizations to talk about the activity. This is in line with the observations previously described: the Annotated Prototype sparked conversations on specific situations during the game, whereas the Laser Cut Prototype generally focused on the overview or patterns.

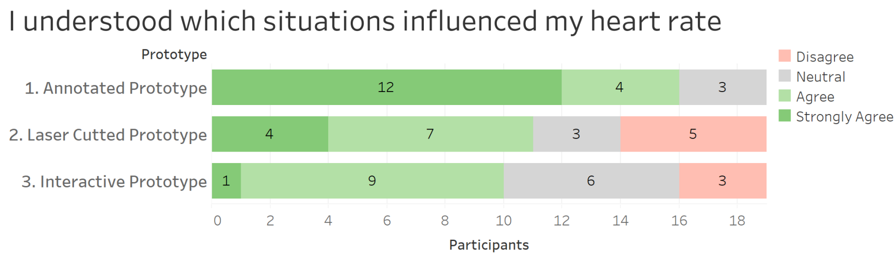


Figure 27: The responses to: "*I understood which situations influenced my heart rate*" for each of the three prototypes.

Another element missing in the Laser Cut Prototype and Interactive Prototype was explicit information on heart rate. The participants could compare the heart rate between each other, but could not estimate their BPM at specific times (which they were able to do using the Annotated Prototype). This issue split participants, as some were interested in knowing specifically how high or low their heart rate were while others were content with seeing the curves of themselves and family or friends. Although not everyone has knowledge about the BPM scale and what constitutes as a high or low heart rate, we found adding explicit heart rate numbers in the visualization to be appreciated. For all of the prototypes, participants requested explicit timestamps in order to understand the duration between each measurement, because they had trouble understanding the time (e.g., how long their heart rate peaked).

Finally, we saw the use of colors as an important visual cue for participants to quickly identify each other. This is based on already established research on information visualization regarding salience (Ware, 2012). The colored acrylic (each representing a participant) functioned as a great way to tell each participant apart. For further clarification, it is worth considering engraving the name of each participant in the acrylic. The participants liked the fact that they had the same colors in both the Laser Cut Prototype and the Interactive Prototype, which made it easier to distinguish between each other.

5.4.4 *Interaction and Movement*

Two of the three prototypes were motionless. The Annotated Prototype comes of rather static as it is intended to be mounted on a wall and viewed from a distance. The Laser Cut Prototype embeds tangible qualities allowing for closer examination by touch, even though the prototype itself is static. For the Interactive Prototype value was found especially in the movement of the prototype. The father of F4 highlighted: *"It would be interesting to have the movement of [the Interactive Prototype] while providing an overview of the data [..] In that case, you would really notice how the heart rate of two people would fall or rise simultaneously on the graph"*. Although we found it essential to provide all of the data at once (Section 5.4.1), the movement through the timeline allowed the participants to focus on specific moments in the data and really notice how their heart rate would differ. For a future iteration, the movement needs to be thoroughly redesigned, as it was too slow and difficult to comprehend. However, movement can make a prototype more exciting, as illustrated in the above-mentioned quote from the father of F4.

Few participants interacted with the Interactive Prototype (like the participant in Figure 28) even when encouraged. We found that the knob on the slider did not afford interaction because of its visual expression. Additionally, since participants had trouble understanding the time aspect they found little reason to interact with the timeline. Still, from observing participants it seemed important to provide some way for them to play around with the data. A number of participants requested explicit heart rate numbers or a timestamp next to the slider to provide context (Section 5.4.3), which could lead to more interaction with the prototype. All in all, the interaction of a physicalization needs to make sense to the users since it is a valuable design element.

Figure 28: A participant interacting with the Interactive Prototype.

5.4.5 *Short Turnaround*

The procedure section (Section 5.3) highlights that the prototypes required different amount of preparation time before being presented. D3 mentioned they wished the physicalization had been revealed instantly after the activity, commenting that: *"When you finished a game, you are very excited, but then you start settling down and you get calmer"*, illustrating that a portion of the excitement is lost while waiting for the physicalization since the participants start distancing themselves from the activity. This was an issue for both the Annotated Prototype and the Laser Cut Prototype. Thus, if the physicalization had been prepared faster it might have influenced the discussion and the participants would potentially have been more enthusiastic. In this case, the Interactive Prototype has an advantage as it required less time to prepare.

5.4.6 *Visual Aesthetics*

During the study the participants delved into the aesthetic qualities when asked about which of the prototypes they would like to have in their homes. In the concluding interview, the Laser Cut Prototype was unanimously picked as the most beautiful and visually appealing. Participants stated: *"I mainly find it beautiful"* and *"[The Laser Cut Prototype] is awesome and beautiful. You want to take it home"* further elaborated on by another participant: *"Yes, and place it on a shelf"*. The choice of material had a great impact as the participants found the colored acrylic aesthetically pleasing, which to some made it look like a sculpture keeping a family secret. The father of F4 commented that it had the look of a great mountain range. Other participants compared the Laser Cut Prototype to a trophy they would bring home to help them reminisce about the experience. The Interactive Prototype was also complimented for its aesthetics, because some participants found it fascinating to observe how it moved (Section 5.4.4). While the participants found the Annotated Prototype useful, several had problems with its visual expression. A participant from D1 complained: *"It seems pretty business-oriented because of the graphs and the fact it is on a pin-up board. I can almost imagine a person explaining it in front of a team"*. Some criticized it for lacking aesthetic qualities, for instance a participant from D1: *"While it is easy to understand I would not want it in my living room"* and elaborated: *"I would like to have it in my [home] office as I am able to close the door [to hide it] when the guest are visiting"*.

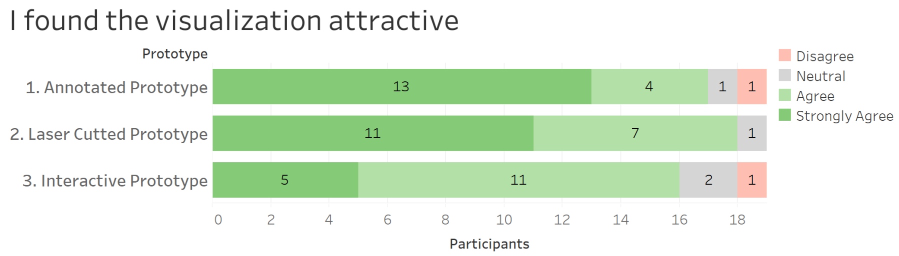


Figure 29: The responses to: *"I found the visualization attractive"* for each of the three prototypes.

Strangely enough, in the survey, the Annotated Prototype had most "Strongly Agree" responses regarding attractiveness (Figure 29) which is directly opposite from the findings of the interview. In this case, we value the result of the interview higher based on all the vocal feedback we received and because the Laser Cut Prototype has more combined participants selecting either "Agree" or "Strongly Agree". The Interactive Prototype had a significantly lower rating than the two other prototypes, which suggests that even though some participants seemed to enjoy certain qualities of the prototype (e.g. the movement), it was too mechanical-looking and motion can be jerky.

5.4.7 *Value for Young Children*

It was evident that children, even young teenagers, did not have the necessary knowledge about heart rate and data visualizations to grasp the physicalizations. When they were asked to comment or elaborate on the physicalizations their brief statements suggested they struggled to understand them. Instead, they were fascinated by the physicalizations themselves. A child from F2 stated: *"I prefer [the Interactive Prototype]. It is a lot of fun because it goes up and down and shows the heart rate [compared to the others]"*. The same child was primarily concerned about finding curvatures that looked like an 'M' on the Annotated Prototype. The child started to wonder about the meaning of the peaks and dips only when the father asked the child to investigate certain things like finding the lowest value. Afterward, the father would explain the context to the child.

5.4.8 *Size of Artifact*

While the opinions on the size of the different prototypes varied, it became clear that the participants were not pleased about the thought of having the Annotated Prototype in their home (also perhaps due to its visual expression). A participant from F2 stated: *"[the Laser Cut Prototype] is easier to have around compared to [The Annotated Prototype] which will become an annoyance given its size"*. The large design nevertheless had some qualities as expressed by a participant from D1: *"[The Annotated Prototype] is possibly preferable because of its size. The points are clearer and not squeezed in on a tiny area"*. Furthermore, people naturally raised themselves from their seats to make comments while pointing to the graph to indicate point of interests. The Interactive Prototype merely made participants turn it towards themselves to distinguish between the four linear actuators. The Laser Cut Prototype, likewise primarily kept the participants seated.

5.5 DISCUSSION

In the analysis we presented findings from the study and eight categories originating from open coding. The findings presented in the following sections are discussed in the perspective of our research questions.

5.5.1 *Social Interaction and Shared Reflection*

The comparative study proved that there is value in the physicalization of group data as the participants in the study actively engaged in fun and investigative conversations on their data and the others. The following section looks at the following research question:

RQ1 How does data physicalization foster social interaction and shared reflection in families?

We saw this happen through the interpretation of the heart rate data (in Section 5.5.2 we account for the advantages and disadvantages of heart rate). From the interpretations, narratives are created: a child teasing his father because of how he reacted to a situation, or mother and daughter talking about when they had a pep talk to turn a competitive game around. These narratives were a necessity and therefore it was important that the physicalizations can be interpreted by the users to create narratives.

Using different types of personal reflection and insights (Thudt et al., 2018), the data physicalizations on group data sparked reflection on the data itself, such as people commenting on observations made directly on the data. We also saw reflection on context, when people interpreted the data. Rather than looking at reflection on action and reflection on values directly derived from the tracked data, we are interested in how it can foster shared reflection in families on topics such as: how families spend their time together and how they can plan to improve the togetherness in the family. The reflection is fostered through the symbolic meaning of the data physicalization and not the heart rate data itself. However, these two levels of reflection are studied more closely in the following study (see Chapter 6). During the comparative study we figured out how data physicalization fosters social interaction and shared reflection, but as it was all tested on a game of Kubb, we did not figure out the best environment or scenarios for fostering these situations. This will be emphasized in the following study as well.

5.5.2 *Exploring Heart Rate*

This section we discuss the qualities of heart rate to answer following research question:

RQ4 How does heart rate relate to the experience of an activity?

The advantages and disadvantages of heart rate data are (in our thesis) linked to the data physicalization since heart rate data is utilized as the tool for families in social interaction and shared reflection. While the visual and physical aspects are important, it is essential that the tracked data type is meaningful to the users. Based on games of Kubb, we found that to be the case for heart rate data. People are generally able to identify themselves and their experiences through their heart rate, however, they occasionally need a helping hand to provide context. As seen in related work, people have a deep personal bond with their heart rate (Khot et al., 2014; Studio Rogier Arents, 2015).

Heart rate data can be ambiguous and people are unsure how their own heart rate reacts to certain situations. We found that whatever caused a heart rate to rise for certain people, would make the heart rate fall for others, which is also illustrated in Kreibig's research (Kreibig, 2010). However, noticing how someone reacted differently to others seemed to be part of the fun. We also found that people had different heart rate personalities, some would fluctuate wildly and others would be calmer. Still, there were also surprising similarities between people as certain situations during the game would notably affect the heart rate for all the involved users at once.

People are naturally curious about their heart rate and how it reacts. They are motivated to interpret their data (even if the interpretations might be wrong) and we observed that people are interested in others' heart rate and actively investigate it as well as their own. This relates closely to the research question of how data physicalization fosters social interaction and shared reflection.

An uncertainty with heart rate is that it is never clear whether someone's heart rate would spike because of an emotional factor or simply from physical reasons. Based on the findings of the comparative study we argue that the emotional factor definitely is relevant. Some people overinterpreted the emotional meaning of heart rate, thinking that a low heart rate means carelessness or not being emotionally invested. This is similar to findings with Ripple (Howell et al., 2018) which called attention to moments of excitement and as a result tended to make participants overlook calmer feelings, causing them to feel less emotional or excitable.

All in all, we found heart rate to be a great, personal and interesting data type to base physicalizations on. As of now, there are no perfect sensors which measure experience, but heart rate does a good job and is widely accessible in terms of *off-the-shelf* monitors. For the following study, we will investigate the advantages and disadvantages closer as we create physicalizations of activities other than a game of Kubb.

5.5.3 *Design Considerations*

The eight categories from the analysis illustrate core components to effectively design physicalizations that fosters reflection and storytelling. These categories are summarized into design considerations to be utilized by others when creating data physicalizations on group data for shared-reflection. Although not tried-and-tested, group data is not necessarily limited to heart rate data but can be data from other types of biosensing or even other types of data as long as it contains narrative qualities (e.g., hours spent together, the average speed of participants in a go-kart race). The design considerations are our contribution to the research question:

RQ2 Which design considerations are important to foster social interaction and shared reflection?

The considerations are shown in Table 1 along with a brief description. The considerations are divided into groups of primary and secondary considerations. The primary considerations significantly influence how the physicalizations foster social interaction and shared reflection, whereas the secondary considerations, while still important, are so to a lesser extent. We advocate to think closely about the primary considerations and carefully contemplate the scope of the project when implementing the secondary considerations. Each consideration is described in detail below.

Design Considerations	Description
Primary Considerations	
Overview of Data	*Present the whole story first, then let users dive into specifics*
Comparing Data	*Users actively investigated not just their own data but also others. The basis of storytelling is often found through the comparison of data.*
Explicit Cues	*Provide explicit cues to help users interpret the context of the data (e.g., heart rate values, timestamps, and annotations)*
Interaction and Movement	*Interaction invites users to investigate data, movement makes physicalizations captivating*
Secondary Considerations	
Short Turnaround	*Visualize data while users are still excited about the data*
Visual Aesthetics	*The data is deeply personal and subjective–the artifact should demonstrate the beauty of the data*
Value for Young Children	*Charts and numbers are often incomprehensible for children–find another way to engage them*
Size of Artifact	*The tangible qualities in smaller artifacts invite discussion in pairs, whereas larger artifacts tend to function as a gathering point including a wider audience*

Table 1: Design considerations–divided into primary and secondary considerations. The primary considerations have a significant influence on the physicalizations narrative qualities. The secondary considerations, while influential, depending on the scope.

Overview of Data: Providing an overview of data is essential for the users to obtain a general understanding of their data. If users are not able to compare their data of the entire measured activity, they struggle to contextualize the data. Therefore, by providing the users with an overview of data, it helps them to embed stories into that data.

Comparing Data: To our knowledge, no prior research has investigated the potential of creating physicalizations using group data for storytelling. We found it contained opportunities for social interaction and shared reflection as users were actively investigated not just their own data but the other users as well. If the goal of a data physicalization is to foster shared reflection it is important to consider how users compare data. The ability to see one's own data in relation to others is essential for users to tell stories. Things that users notice can be similarities or differences in how they react to a certain situation, or who has the highest or lowest heart rate. With physicalizations of Kubb we found participants were especially interested in comparing data with their teammates.

Explicit Cues: Although creating explicit physicalizations is not always the goal of data physicalization research (Khot et al., 2014; Stusak et al., 2014), if the artifact is meant to foster storytelling and shared reflection then participants need be able to comprehend their own data. Therefore, it is important to be aware of how users are able to interpret the data and tell stories when presented with the physicalization. It can really frustrate users if they are not able to interpret a peak. When provided with less explicit information users generally talk about patterns in the data and not specific situations, which result in less interesting narratives. We found effective ways to provide explicit cues to be: 1) annotations, 2) indication of explicit heart rate, 3) timestamps, and 4) use of colors. Annotations were the most appreciated cue by participants of the study. There are likely more approaches to provide explicit cues which are unexplored in the thesis.

Interaction and Movement: Users like to watch moving physicalizations: it catches their attention even when the visualization itself is not the best. Adding movement to a visualization invites users to investigate the data and explore specific parts. To engage users, interactivity can be an interesting element to add. Especially since users are interested in their data, allowing them to explore the data interactively can be effective in immersing them.

Short Turnaround: Users are eager to get the physicalizations immediately after tracking. However, this is not always feasible as data physicalization sometimes requires tools such as a laser cutter or 3D-printer. Designers need to think about the waiting period between tracking and receiving the physicalization. Rooksby et al. (2014) found few cases where people concerned themselves with their data once it was tracked too far back, but this might not be the case when tracking experiences rather than health metrics or physical activity. Still, designers must be aware that the initial excitement of receiving a physicalization will wear off eventually.

Visual Aesthetics: Users tend to value aesthetics higher than explicitness when objects are designed to their homes. The data is deeply personal to the users so the artifact should visualize the data in the most aesthetically pleasing way to display the beauty of their personal data. This can help emphasize the fondness of the memories and ensure that the family proudly displays the physicalizations in their homes. However, it is still crucial to not sacrifice the usefulness for aesthetics. We found using colored see-through acrylic was an interesting, novel way to create data physicalizations. It was deemed beautiful, especially when using colors in order of the color spectrum.

Value for Young Children: Children (including young teenagers) do not always have the necessary skills to comprehend charts and numbers in data visualizations. Uttal and O'Doherty (2008) argue that children focus on what is being displayed but fail to understand what is being communicated: *"The relation between a 'visualization' and its referent is seldom obvious to novice learners"*. However, there are other ways to engage children in physicalizations, for instance via interaction, movement, annotations or interesting visuals. Additionally, as children mature they will be able to utilize the physicalizations to reminisce on the shared experience.

Size of Artifact: Users find the dimensions of the artifact important, especially if it is designed for their homes. Depending on the concept, larger physicalizations have the ability to attract users from a distance while also making it easier to pinpoint details. Smaller physicalizations can embed tangible qualities which allows pairs and smaller groups to use it as a tangible object for discussion.

6 EVALUATING HEART-TALE IN TAKE-HOME STUDY

A final prototype called Heart-Tale has been developed based on the design considerations found in the comparative study of physicalizations (Table 1). The prototype was tested for 17 days in the homes of two families for evaluation of the concept, and to explore which activities are the most meaningful to families in terms of reminiscing and talking about it afterward. Lastly, we were interested to see how Heart-Tale is appropriated. We use the definition of appropriation from Carroll et al. (2002): *"the way that users not only adopt technology but also shape it to their needs and situations of use"*.

Building on the knowledge of the comparative study (Chapter 5) we seek to answer the following research questions during the take-home study:

RQ1 How does data physicalization foster social interaction and shared reflection in families

RQ3 How do families appropriate data physicalizations to customize and create memoirs?

RQ4 How does heart rate relate to the experience of an activity

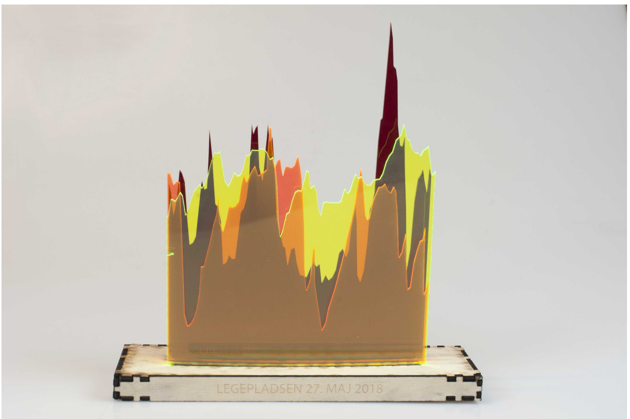
In this chapter, we present Heart-Tale, the design rationale and technical implementation. Then, the procedure of the study is presented, along with the results, and a final discussion on the result.

6.1 PROTOTYPE

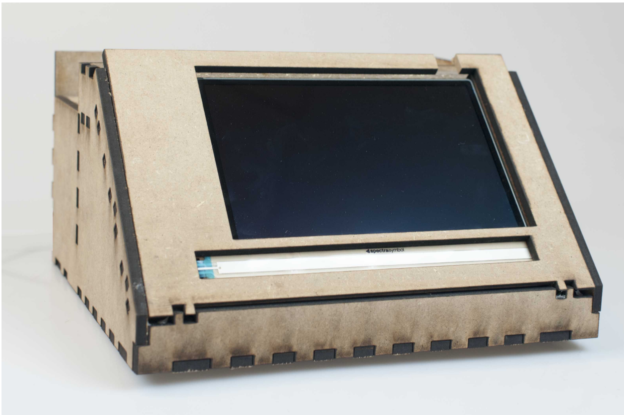
6.1.1 *Description*

Heart-Tale consists of two parts: recorded activities as laser cut physicalizations (Figure 30a) and a dock for further explorations of the physicalizations (Figure 30b). Each activity is represented by different boxes laser cut in plywood with the name of the activity engraved in the front. Each user is represented by a cut-out from colored see-through acrylic with their name engraved near the base of the graph. A component diagram can be seen in Figure 36, which illustrates the different components of the prototype and how they are referred to.

Heart-Tale shows photos, annotations, heart rate and timestamp from the recorded activities on an embedded display (Figure 31) while



(a) A physicalization of an activity.



(b) The dock.

Figure 30: The physical components of Heart-Tale.

also providing a physicalization of the users' heart rate (the aforementioned boxes). When a recorded activity is slid into the dock it fetches the activity and displays it on the screen display (Figure 32a). A slider below the tablet invites the user to navigate through the activity (Figure 32b). The slider is mapped to the acrylic area charts so that the position of the finger responds to a specific position on the acrylic. When a user removes their finger (Figure 32c) from the timeline it stays at the last identified position making it possible to leave Heart-Tale displaying certain moment from the activity. Lights are placed side by side with the acrylic to provide feedback when navigating the slider and further indicate the temporality of the activity. If users would like to add or edit a comment they are provided with the option to do so using the touch features on the display. The tablet, besides showing personal pictures or annotations, indicates the average heart rate of the users in that timespan. Another form of annotations that is not personal, provides facts about whenever a person reached their maximum or minimum heart rate during the activity. When users want to showcase another activity, they do so by replacing the physicalization.

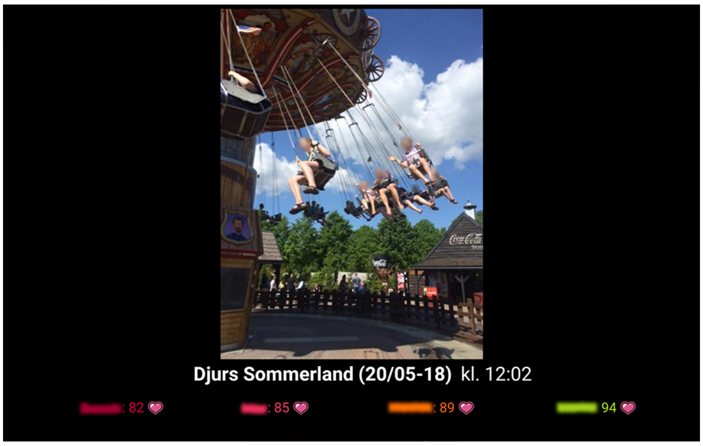


Figure 31: A view on the display of Heart-Tale, showing: a photo, name of the activity, timestamp, and heart rate of each family member.

6.1.2 *Design Rationale*

While Heart-Tale was designed for the take-home study, it also functions as our design proposal to a prototype which best fits with the design considerations established in the comparative study (Table 1).

Heart-Tale builds on the central ideas of the Laser Cut Prototype (Section 5.1.2) in its visualization using area charts laser cut in colored see-through acrylics. Visualizing data this way provide the users with an overview of the data and allow them to easily compare their data with other participants. However, as found during the study, the conversations generally focused on the overview or patterns on the graph because it lacked explicitness such as annotations or timestamps. But even though it was less comprehensible than the Annotated Prototype, participants repeatedly asked if they could bring home the Laser Cut Prototype. This is because the size of the artifact and its visual expression were admired. However, there were still problems related to other design considerations. The design already had some appeal to young children because of its colorful aesthetics but lacked deeper ways to engage them. No movement or interaction were incorporated into the design nor did it provide any explicit cues.

The dock of Heart-Tale was designed to cover these design considerations: interaction was provided by inserting different activities into the dock and using the slider to steer through the activities. The interaction with the slider resembles emoto's (Hemment, 2013) interaction: allowing users to closely investigate the data by navigating through the graph.

Movement is utilized to provide feedback via the LED's and to some extent the changing of annotations on the display. Movement and interaction are also meant to provide value to young children. Furthermore, the LED's and the display provide explicit cues when a

(a) Placing a physicalization in the dock.

(b) Navigating through the timeline.

(c) The selected image is on display.

Figure 32: Interacting with Heart-Tale.

family chooses to insert an activity into the dock of Heart-Tale. An LED illuminating part of the acrylic graph provides a reference for discussion among family members and the display shows the time of the specific moment, the participants BPM and the different types of annotations.

Petrelli and Whittaker (2010) emphasize the importance of the physical mementos in the home as the digital counterpart tend to become invisible, hard to access, and inexpressive compared to physical mementos. Therefore the laser cut physicalizations were altered from the Laser Cut Prototype to better stand on its own. For instance, the height has been decreased to take less attention away form the area charts. The name of the participant has been engraved into the piece of acrylic representing them, and the name and date of the activity engraved into the box. These details add further explicit cues and allow the physicalization itself to have value outside of the dock. The size of the laser cut box is still designed with the same tangible qualities in mind as the Laser Cut Prototype. However, the size of the dock is substantially bigger to afford its stationary placement in the dining area or living room, where the family can gather around to interact with and view the visualization together.

The biggest issue with Heart-Tale, as we see it, is how it deals with the design consideration of instant visualization. Unfortunately, as the physicalizations require a laser cutter and there is no way within the scope of the thesis to automate their construction process. Even if there was, there would still be construction time in laser cutting and material cost of acrylic for every physicalization. During the brainstorming process prior to the take-home study, we found it impossible to fulfill all of the design considerations. This design proposal was deemed the best compromise. Additionally, this allowed us to explore how much of an annoyance it was for participants of the study to have to wait to receive the physicalizations. Perhaps if these activities were more meaningful than a game of Kubb, then it would be less crucial to show the physicalizations right away as it would have a more everlasting effect and sentimental value to the users.

Petrelli et al. (2009) argue that autobiographical tools need to support active user appropriation. The users can appropriate Heart-Tale in many different ways (e.g., picking which activities to track, how they annotate activities, and how it is presented in their homes). Additionally, we added another way to customize the annotations directly via the display allowing users to add or change written annotations via the display embedded in the dock. In this case, we were interested to see if they would add annotations for later use when going through the activity again.

6.1.3 *Alternative Design Proposals*

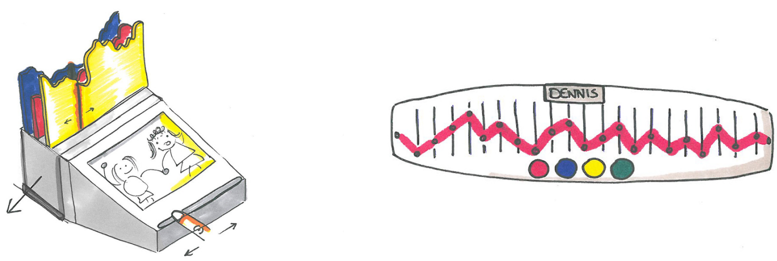


Figure 33: Two sketches from brainstorming the final prototype.

Other design proposals were suggested during brainstorming prior to the take-home study. One such idea was based on the implementation of Pulse (Cargo Collective, 2011), which creates a curve via a line run through needles on servo motors. By having 20 servos, the concept could visualize one user's heart rate at a time (Figure 33). The name of the user is displayed on a small screen, and colored buttons allows to change between users. For this concept we were limited by access to servos which is why only one user could be displayed at a time. The argument to pick this idea was because it was a dynamic prototype that could instantly visualize an activity after its completion. This would likely result in more activities measured by families as they did not have to wait to receive a physicalization. However, the concept was scrapped for different reasons. While it provided an overview of a user's data, it made comparing different users' data difficult as only one users data was visible at a time. It also lacked some explicit qualities like annotations or timestamps. It did provide interaction and movement and aesthetic qualities but in the end, we found Heart-Tale to be the best concept based on the design considerations. A third design proposal was to display all users at the same time, but due to lack of accessible servos only show five data points at once. The servos would then animate through all the data. This concept still had troubles of comparing data, since the curves would not be on the same two axes. Additionally, it did not provide an overview of the data, which we found essential in order to understand it.

6.2 Implementation

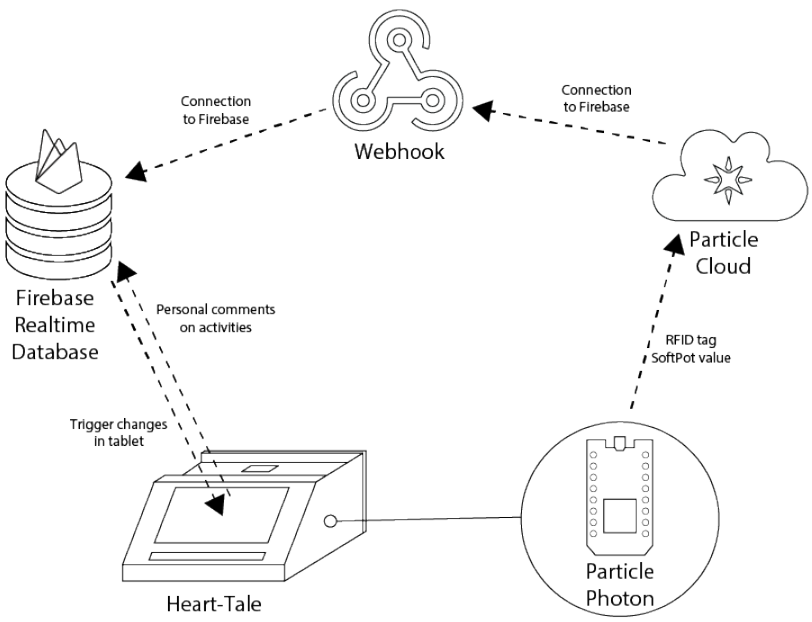
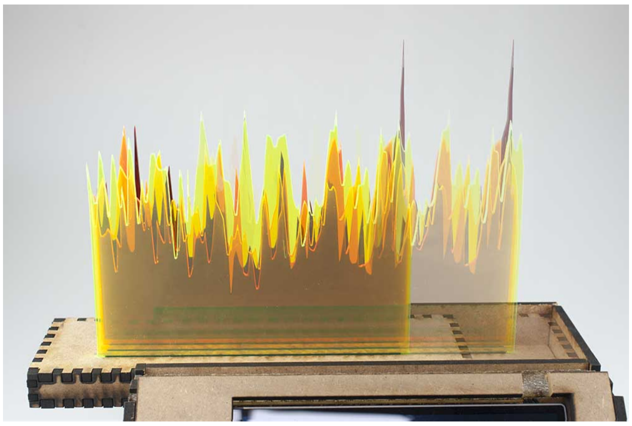


Figure 34: Outline of the communication flow of Heart-Tale.

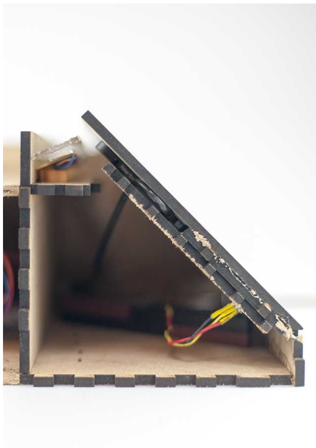
Rather than spending time implementing a technical refined final prototype, we focused on the essentials to be able to conduct a study for as long as possible instead. Nevertheless, we would not be able to implement a prototype with a fully automatic construction process of the physicalizations (as we had to laser cut their activities). We decided the families should provide the information for an activity in an email including date, timestamp (start and end), and a title for the activity. Additionally, they were encouraged to provide annotations and photos. The entire process is described below.

A simplified version of the implementation of Heart-Tale is illustrated in Figure 34. The Photon communicates to Particle cloud, where a Webhook[1] is subscribed to listen for events and communicates changes to the database allowing our application to display the corresponding content.

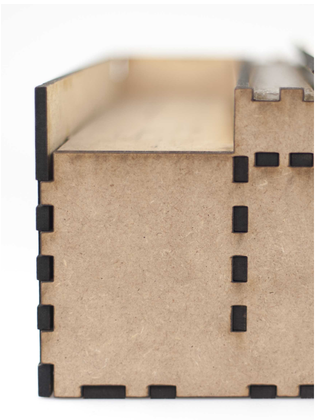
6.2.1 *Physical Artifact*



(a) Sliding an activity in place.



(b) Three layers of plywood keeping the tablet in place.



(c) The walls are intertwined to stabilize the structure.

Figure 35: Construction details for Heart-Tale.

The dock has a width of 28.5 centimeters, a height of 15 centimeters, and a depth of 26 centimeters. The width of the dock originated from

1 https://docs.particle.io/guide/tools-and-features/webhooks/

the length of the Laser Cut Prototype while also accounting for the dimensions of the tablet. The length considers the acrylic physicalization, the timeline, and the angle of the tablet so that it is efficient for the user to view. The height of the dock is likewise primarily based on the angle of the tablet while having space for wires on the inside.

The design of the dock affords that activities can be slid into the top of it. The opposite wall has been extended allowing for a perfect fit (Figure 35a) to keep the physicalization in the right spot making the RFID reader able to read the tag at exactly the right position. Embedded into the front panel is the tablet acting as a display and the slider allowing navigation through the selected activity. To keep the tablet in place three layers of plywood (Figure 35b) were used, the first piece functioning as a base for the tablet. Secondly, a piece of wood surrounds the frame of the tablet keeping it in place, while the third piece covers everything but the tablet and slider. The structure of Heart-Tale is reinforced as the wall separating the physicalization and the LEDs is mounted in the bottom plane and both sides (Figure 35c). In each vertical wall, a square opening allows us to route cables between sensors, microcontroller and a power plug.

6.2.2 *Embedded Hardware*

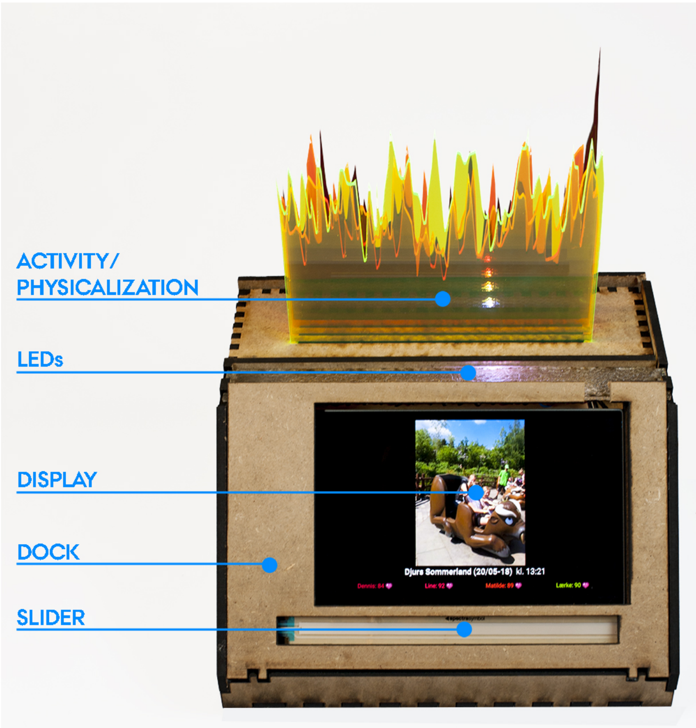


Figure 36: A diagram illustrating the components of Heart-Tale, and how they are referred to.

In the previous study, the Interactive Prototype utilized a Photon as the main controller. Because of the advantages it provides (Section 5.2.4) the same microcontroller was utilized in this prototype. Additional components included in Heart-Tale are: an RFID reader (RFID-RC-522), NeoPixels, and a SoftPot Membrane Potentiometer. Figure 36 illustrates the different components of the prototype and how they are referred to (not the actual name of hardware components).

All physicalizations are equipped with an RFID tag to fetch the corresponding content from the database. The RFID reader reads the tags at a distance within 10 centimeters. This allows us to hide the tags and reader from the users while still being able to read the tags when an activity is placed in the dock. The NeoPixels are controllable LEDs, which enables us to control every single LED on a strip as an array. Adafruit has developed a library for NeoPixels[2] to the Arduino platform easing the burden to manipulate their color and brightness.

The SoftPot is a potentiometer which reads when touching various parts of the strip, allowing the user to either slide their finger across the SoftPot or press at a specific point. We map these values to an interval from 0-19 to match the length of the physical graphs and SoftPot which are both 20 centimeters. The NeoPixels are therefore modified to be on a 20-centimeter strip resulting in one LED per centimeter. The mapped value from the SoftPot acts as a pointer, so when the user moves their finger on the SoftPot the corresponding LED illuminates. When the user removes their finger from the SoftPot, the LED continues to light up while still showing images or comments for that moment. When users shift between the physicalization of activities the first LED lights up to illustrate that the prototype has registered the new activity.

The Photon development platform has integrated functions to publish data to their cloud service and to bridge the Photon cloud with other apps or web services through webhooks. A webhook listens for specific events published by the Photon and triggers a request when the event is published. In our case, the request is a PUT request, which overwrites the old value. In our prototype, the Photon sends the RFID tag and the SoftPot values as a JSON object every second. If the data was published more frequently, we experienced that the Photon would occasionally time out.

6.2.3 *Database*

Firebase[3] is a development platform utilized in our prototype for its real-time database, used to store data from the users' activities and

2 https://github.com/adafruit/Adafruit$_N$eoPixel
3 https://firebase.google.com

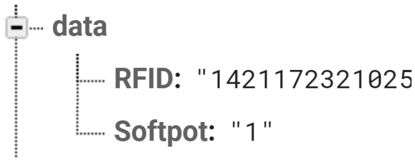


Figure 37: An activity has been read by the RFID reader (1421172321025) and the value of the SoftPot value is 1.

to communicate between the Photon and Android application. Firebase is easy to integrate with Android applications and the real-time aspect is important since the value of the SoftPot decides what will be shown on the display and should therefore update accordingly, in order not to ruin the experience. Figure 37 illustrates that the RFID tag: "1421172321025" is in the dock and that the family has navigated to position "1" on the SoftPot (the initial value is 0). The database contains an entity for each of the families' activities. Each entity consists of 20 rows illustrated in Figure 38. These 20 rows each correspond to a NeoPixel and SoftPot value. The database also stores interaction history with the prototype (Figure 39), however this is handled by the Android Application (Section 6.2.4).

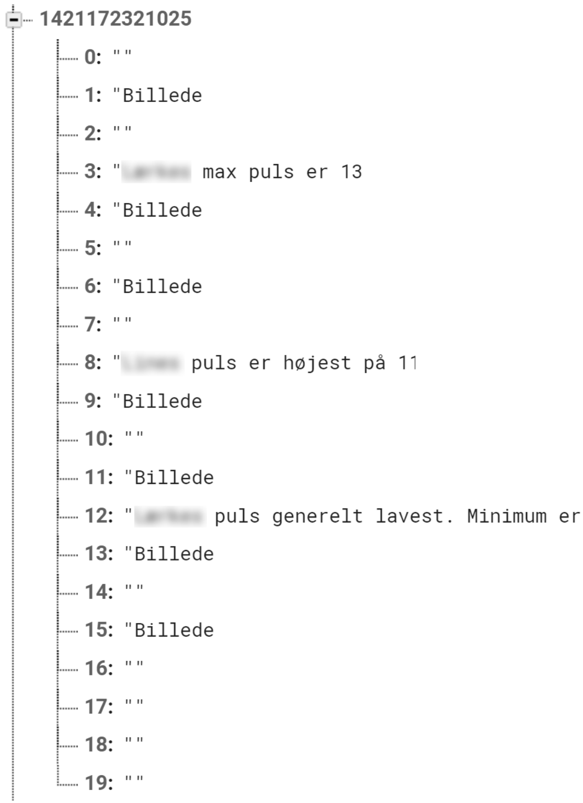


Figure 38: The structure for an event (RFID tag: "1421172321025") including at most 20 annotations.

Figure 39: Interaction log showing how frequent the family used the system and the different activities.

6.2.4 *Android Application*

The display on the prototype is a Dell Venue 8 tablet with a tailor-made Android application installed. To ensure that the users do not view it as a usual tablet, but rather as a display, the application is in fullscreen mode and the screen is always on. However, when an activity is not placed in the dock the display turns dark, looking as if it is turned off.

The application is set up with Firebase (Section 6.2.3), which provides the application with inputs from the embedded hardware. The application listens for two values: 1) the RFID tag and 2) the value from the SoftPot. Whenever the RFID tag on the Heart-Tale dock is changed, the application displays that activity on the tablet. There are 20 different frames in an activity: the first frame is the beginning of the activity, but the application changes between the frames depending on the value of the SoftPot. After reading the value from the database a separate java class is called, which handles displaying the correct information for each physicalization. This class is responsible for inserting all of the information into the application's layout. Each activity has a method which contains the information for all the 20 frames of each activity (i.e., the heart rate value, timestamp, and photos). However, the written annotations are extracted from the database, since these can be changed by users when interacting with the prototype. The users were only able to add or change written annotations through the application as developing a backend capable of handling adding photos was not regarded as a priority.

The process of entering the activities into the application is simple, although tedious. All the heart rate data is averaged out to 20 values (Section 5.2.2) for each user. These values are then manually inserted into each method, along with the timestamp. Afterward, the maximum and minimum heart rate for each participant is noted from the original heart rate files. These values, depending on their appeal, are added as a comment to each activity in the database. Because the new activities (including insertion of pictures) are hard-coded into the application itself, it needs to be updated whenever new physicalizations are provided to them.

There is a button next to the written annotations which allows users to change the annotations or add new ones. This is done in a new view[4] which takes the RFID tag and SoftPot value in its parameters. When the new annotation is submitted it changes the relevant field in the database so that it is updated.

The last feature of the database is to track the usage of the prototype. This information is used for interaction logging during the study (Section 3.1.3.2). The application logs whenever an activity is placed on or taken off the dock, and when the application starts up and shuts down. This was implemented in the Android application because of its simple implementation that required few lines of code to implement. In a future prototype, triggers in the database could be used to log usage.

6.3 PROCEDURE

The take-home study was conducted in the homes of two families for an extended period of time. The duration was intended to include two to three weekends, preferably the latter based on findings from the formative interviews (Section 4.2.2) which said that families are busy during a normal week.

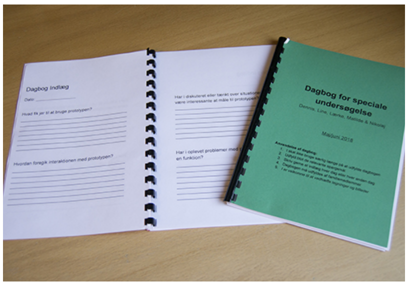
When meeting the families in their homes for the first time they were given a Fitbit Charge 2 activity tracker for each family member. They were instructed on how to use them to measure activities and to synchronize them with the Fitbit application. We planned weekly meetings and informed that we wanted them to record two or more family activities between each meeting. These activities could be anything from playing a game to something spanning several hours, as long as they considered it a family activity. They would then have to send an email or message with the timestamps of the activity. Additionally, they were asked to add written annotations and photos during the activity that could be embedded in the prototype. An instruction manual was provided (Appendix A.4), in case they forgot anything, and they signed the consent forms. For the first iteration, the family was not yet aware of the concept of the final prototype, which was a deliberate choice. We were interested to see how they would change their approach to tracking and annotating throughout the study.

For the second meeting, we brought along Heart-Tale and the activities recorded by the families. We would set up the prototype in their home, preferably on a shelf or something similar in the dining area (as found in Section 4.3.1) as seen in Figure 40a. We let the families interact with the prototype while observing, noting down how they interacted with it and how they utilized the different qualities of Heart-Tale (i.e., the physical graphs versus the digital annotations).

4 https://developer.android.com/reference/android/view/View

Afterward, the families were presented with a diary (Section 3.1.3.2) with four questions to ideally fill out once a day (Figure 40b). Filling out the diary was meant to take little effort: there were only four questions and families only had to fill out the questions they found relevant for that day. The four questions inquired about: 1) what prompted them to use the prototype, 2) describe the interaction with the prototype 3) if they discussed or thought about interesting activities to track, and 4) whether they encountered any problems or missing features. Finally, another instruction manual was provided, this time describing the prototype and how to troubleshoot any potential issues should they arise (Appendix A.4). They were also urged to contact us regarding even the smallest issues. After the second meeting, we would visit them at the end of weekends or the beginning of the following week, until the study concluded.

(a) Heart-Tale set up in F1.



(b) The diary provided to the family.

Figure 40: Heart-Tale and the diary handed out to the family at our first visit.

6.3.1 *Data Collection*

As previously mentioned, we were interested in exploring how the families would appropriate Heart-Tale and how the activities at the beginning of the study would differ from the ones in the end. For instance, would they spent an increasing amount of time taking photos and comment on the events, or would they lose motivation after a while? We gained that information based on how much time it seemed they spent on the preparation of activities as well as the answers in the diary. Additionally, the prototype would also log when it was on or off and if an activity had been placed on the Heart-Tale and for how long.

During the last meeting, an exit interview was scheduled to sum up the families' entire experience (attached in Appendix A.5). The exit interview is divided into three sections. The first part sought to gain knowledge of how the families utilized the prototype, such as the interaction flow and how they use the physical aspects of the prototype in contrast to the digital aspects. We wanted to understand when the physical component was enough by itself and when the digital element added any value. Also, we were interested to hear if there were any features they missed.

The second part of the exit interview was for the family to consider when Heart-Tale was the most effective. For instance, inquiring which types of activities were the most interesting to see as physicalization and which of the activities they used the most with Heart-Tale. We were also interested in figuring out what impact annotations and photos had on the physicalization, and have them compare the personal annotations, the photos and heart rate facts.

For the last part of the exit interview, we were interested in studying the effect of having Heart-Tale in their homes for a few weeks. Did the participants ever go back to look at the physicalizations? Did they change their approach to customizing and creating the physicalizations? We inquired if it impacted their routines and how they would use Heart-Tale if they had it in their home for 6 months. With the family with children from previous marriages, we were also curious to figure out if it impacted the way they did activities together and reflected upon them.

6.3.2 *Family Overview*

We had access to seven Fitbit Charge 2 activity trackers, which allowed us to conduct the take-home study on two families simultaneously. The three families of the comparative study of physicalizations were all contacted for the study but one family declined (no other families were asked for participation due to deadlines and time constraints keeping us from conducting sequential studies). The two families of the take-home study are F2 and F4 from the previous studies (see Section 4.1.2).

6.4 ANALYSIS

For F2, the take-home study lasted for 17 days (three weekends). The nine-year-old daughter was with the family for two of the weekends and the thirteenth-year-old son was with the family for the last weekend of the study. During the first half of the study, the family submitted no entries to the diary but did so for the second half after a reminder. The family made entries in the diary for the last nine days. F2 received eight visualizations in three visits. For the first visit, the family recorded themselves playing games of Ladder golf[5] during a camping weekend. The following day they visited an amusement park. The following week, three activities were recorded, one of which unfortunately had its data corrupted. The activities prepared

5 https://laddergolf.com/

were: a morning of getting ready for school/work, and a walk to the beach with grandparents. During this week, only the youngest daughter was with the family. For the last visit four physicalization were given to F2: a short activity of the mother donating blood, games of Kubb including their cousins, playing at the playgrounds for 50 minutes, and an evening at a school festivity where the whole family participated. A more detailed overview of each activity is outlined in Table 2.

For F4 the take-home study was cut short after the first week due to their busy schedules and not having the time to carry out activities as a family. This meant that F4 only briefly interacted with Heart-Tale and that no exit interview was conducted nor was any data gathered from the diary. F4 had two activities after the first week: a game of Rummikub[6] and a restaurant visit with some of their friends. The data from F4 are gathered from observations from the initial use of the prototype and remarks from an unstructured conversation with the family at the end of the study. These findings are mainly used for evaluations of the physical artifact. The long-term effect and appropriation of Heart-Tale on F4 could not be investigated.

All of the 10 physicalizations are seen together in Figure 41.

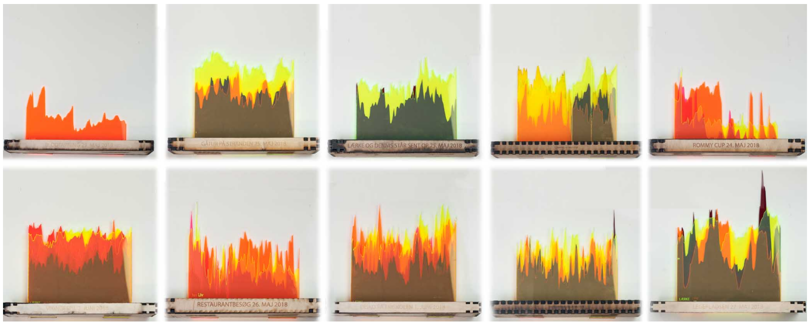


Figure 41: An overview of all physicalizations made during the take-home study.

6 http://rummikub.com

RFID	Event	Number of Photos	Number of Written Annotations	Seen	Views per Day
May 21st - First visit					
253622304314	Camping	3	10	10	0.71
173251250108192	Amusement Park	8	1	16	1.14
May 26th - Second visit					
206992321079	Busy Morning	8	17	6	0.75
1421172321025	The Beach	7	8	17	2.13
June 3rd - Third visit					
1101632271036	Playground	1	0	-	-
1261612321061	Blood Donation	3	3	-	-
25410323210123	School Festivity	10	10	-	-
2817320130102	Kubb	10	10	-	-

Table 2: An overview of F2's activities. The number of times each activity was seen is extracted from the interaction log. Data is hidden for June 3rd as the family only had the physicalizations during our visited them.

6.4.1 *Heart-Tale as an Artifact*

We hoped to see a clear distinction between the value of the laser cut physicalizations and the display, and that both parts would play a role during the interaction. For both families this seemed to be the case, but two different approaches were observed. We saw participants find interesting peaks and dips using the graphs, then using the explicit information on the display (e.g., annotations and timestamp) to investigate what happened so they could contextualize what caused the fluctuation in their heart rate. In the other approach, the participants would find a photo or interesting annotation on the display and look at the graphs to see how each person responded at that moment. It is difficult to say exactly which approach was used the most, however we found that both the graphs and the display had its own role to play. Yet, for young children this was different: the youngest daughter of F2 used Heart-Tale regularly and with great delight, but to her it was more of an interactive photo album. The father explained: "*[She] was the primary reason [the prototype] was used. She wanted to see photos of herself [..] and her two siblings*". Later in the interview he added: "*When she uses it she might become sad because she misses [her half-sister] or happy because she is reminded of something fun they did together*", which is also supported by a diary entry. This means that the prototype successfully provided value to a young child even if she does not understand the heart rate aspect. However, this also caused problems because she used it for different reasons than the parents or older children, so when the family received new physicalizations of activities she would seize control of the prototype and slide through it to find photos. This meant she was in charge of the navigation and the rest of the family could not use it to find the information they wanted. After a while they would tell her to let someone else be in charge, thus allowing the family to investigate the data more closely. Just like the Laser Cut Prototype (Section 5.1.2), the boxes with the laser cut physicalizations could be used on their own. At one point, when the children were playing around with the dock, the mother and father talked about the other activity using just the physicalization (Figure 42).

F2 and F4 used the slider and the LEDs differently. F2 would keep their fingers on the slider while moving it to the desired location, whereas F4 would press on it to find the desired location. Both approaches worked for each family and they both actively used the LED as feedback for navigation. F4 even used the LEDs to create a point of reference for their discussions. Still, both families also actively pointed with their fingers to interesting moments on the graphs (Figure 43). During the interview, when asked to compare the different sorts of annotations, F2 mentioned photos as their favorite type, but elaborated: "*I do not think [any of the annotations types] can be left*

Figure 42: The parents discussing an activity while the children are interacting with Heart-Tale.

out. [With the annotations of maximum and minimum heart rate], I would look on the graph first and then use to slider to find the exact value on the display". In general, F2 deemed the explicit information as an important aspect of the prototype. The mother mentioned that she liked the explicit heart rate values on the bottom of the display, a feature we thought would be rarely used.

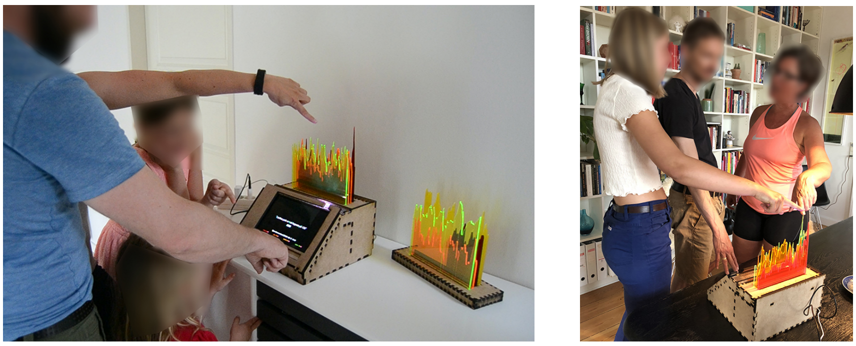


Figure 43: Both families discussing their activities by pointing.

Finding a photo in the activity would often be a nuisance, partly because of the sometime unreliable interaction with the slider, but mainly because the position of each photo was only 1/20th of the length of the slider. This often caused F2 to accidentally skip past the photo having to move their finger to the perfect position to make it reappear on the display. The father suggested always having a photo on the display, that picture being the most recent photo at the current point in the activity. This could be an interesting design solution and would eliminate the empty frames of the activity where there are no photo or text-based annotation. The feature to add or change annotations was not used at all by any families. However, not much can be analyzed from this as the study was rather short. Nevertheless, it would be interesting to explore this functionality in a more refined and future prototype, especially if the study is to be conducted for a longer period of time.

Minor problems occurred during the study. When receiving emails and messages, the photos did not contain any metadata so the family had to add timestamps (increasing the effort to create activities). Nevertheless, the family was engaged in tracking activities and still actively provided photos throughout the study (see Table 2 for an overview of the details). The application gradually became slower and the slider less reliable. During the last few days, F2 mentioned these two problems in the diary. Additionally, a visual concern regarding Heart-Tale occurred. In the physicalizations, the children were always in the front rows. However, since they consistently had a higher heart rate than their parents (especially the youngest), it resulted in those graphs overshadowing those of the parents. The different acrylics can be swapped around afterward, but for a future iteration, having lowest heart rates in the front is worth considering. This issue is illustrated in Figure 44, where the physicalization is better understood from the other side (although the colors do not necessarily match if the graphs were sorted after their height rather than color spectrum).

Figure 44: When the highest general heart rate is in front it tends to overshadow others. on the right side this is fixed but the deep red color overshadows the others due to the order of colors.

6.4.2 *Understanding Activities and Storytelling*

From the study it was discovered that F2 enjoyed the features of annotations combined with explicit heart rate values, and heart rate facts (i.e. lowest and highest BPM) to connect the peaks and dips to the activity, which the mother elaborated on: "*The combination of pictures and heart rate makes you able to connect the story*". The parents felt that pictures primarily were for the children, whereas the heart rate facts were minded the adults. These features support the family to have a social experience including everyone. As a part of the social experience, we asked which physicalization was the most interesting and which one was utilized frequently. F2 answered the amusement park, further elaborated on by the father: "*The longer activities are definitely* *most interesting. The activity at the playground was also fun, but the activities that we have been looking forward to such as the festivity at the school and the amusement park are something that everyone [in the family] were excited to receive*". This is also illustrated in the interaction log where the activity at the playground was the least viewed (on average).

Waiting for the physicalizations was both a blessing and a curse. The family mentioned that receiving the physicalizations was something they looked forward to with excitement, especially after they had tracked something special. As these activities have more sentimental value than others, the less important activities might have suffered because the families had to wait for too long to receive them. This is tied to the design consideration: Instant Visualization. The mother mentioned: "*I tracked myself during a run, but I did not send it to you, because it is less interesting when it is just me*". This is because it is not as interesting for the others to see, but this is not solely due to her tracking alone. Had she tracked a run in a big race, the other family members might be more interested in the physicalization.

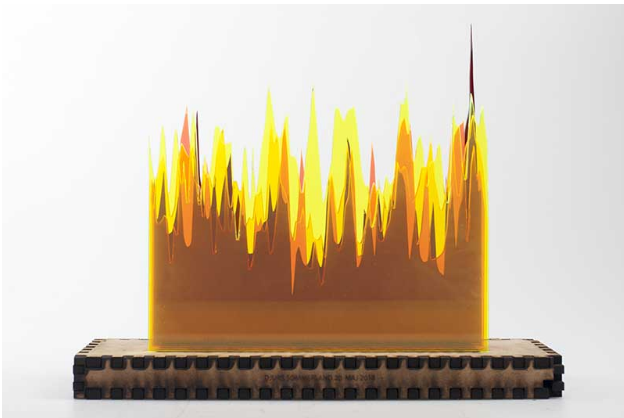


Figure 45: A long activity has to fit within the same boundaries as a short activity resulting in more squeezed physicalizations.

A challenge observed with the longer activities was that some of the emotional changes in heart rate would be overwhelmed by heart rate fluctuations from physical activity. The longer activity also had more information squeezed together resulting in more peaks and dips as illustrated in Figure 45. Therefore, even if a long activity is full of fun narratives the physicalization can adversely influence their ability to interpret and create stories from the data. Likewise, some activities did not suit this type of prototype: F4 tried to track a visit to a restaurant with some friends, but it was hard for them to discuss and interpret the peaks and dips and whether it was due to a fun discussion or just a trip to the bathroom. Some of the challenges were also due to having few pictures or annotation from the visit since it can be socially unacceptable to prioritize to focus heavily on the smartphone when in smaller groups with friends and relatives. From the same physicalization (Figure 45), the daughter had a peak in the beginning of the activity where she mentioned that it was probably where she met a person from a previous school and her mother commented: "*The handsome guy?*", illustrating the importance of context (in this example they know it is in the beginning of the activity before arriving at the restaurant) and the value of interpreting data and creating stories from it, even if the actual reason for the daughters sudden increase in heart rate might actually be something else.

The most valuable physicalization are long-lasting and special activities such as a visit to an amusement park or a school festivity. These activities are worth waiting for. However, one of the challenges for longer activities is that emotions and physical activity can blend together and compromise people's ability to contextualize. A second challenge was that Heart-Tale does not support Instant Visualization. Lastly, the annotations and context help participants to interpret the data and support them in their storytelling.

6.4.3 *Appropriation of Heart-Tale*

Between the first and last visit of the take-home study, we saw changes in F2's behavior towards Heart-Tale. For one, they moved the prototype to account for the height of the of the youngest (and smallest) child. They moved the prototype from a shelf, where she struggled to interact with the slider, to a small table allowing her to utilize the prototype to its full extent (Figure 46 shows the new position of the prototype). The father stated: "*We have told [our daughter] that she is allowed to change [the activity] if she wanted. She is perfectly capable in doing so [...] Sometimes we sit down [in front of the prototype] and ask her different questions.*" The daughter was usually the reason they interacted with Heart-Tale. She was capable of navigating through the activity as she is used to interacting with a tablet on a regular basis. The father also explained that she became gradually better at using the slider in a way where the whole family could participate. The youngest daughter would use Heart-Tale and navigate through an activity as the first thing in the morning on a regular basis, and again once she got back home from kindergarten. This claim was supported by the interaction log (provided in Appendix A.6).

Besides impacting the number of activities done together Heart-Tale also affected their spare time. The father stated: "*It has occurred naturally to us to spontaneously propose to go for a walk*". The daughter had hopefully asked if they could wear the activity trackers, which made him reflect on the fact that they were going for a walk without a purpose. However, to conclude that Heart-Tale encourages families to do activities together based on the results of one family is a bit farfetched. Still, we saw an increase in the amount of time and effort F2 spent on preparing each physicalization, both in terms of capturing

Figure 46: The family (including nephews) are gathered around Heart-Tale.

photos, writing annotations, as well as reflecting and talking about which activities to track. The first iteration of activities contained on average 4.66 pictures and 4 annotations per activity. For the last two iterations this increased to 6.5 pictures and 8 annotations on average per activity. In their process of appropriating Heart-Tale, F2 discussed which qualities an activity should combine to make an interesting physicalization (outlined in Section 6.4.2). This is supported by a diary entry from F2: "*[the youngest daughter] and [the father] are discussing what to track this weekend*", and in a later entry from F2: *[the mother] talked about tracking a shopping trip*.

Even though the family was stressed by everyday routines and chores, they had the time to glance at the physicalizations, as commented on by the father: "*[...] Sadly, we do not have the time [to interact with the prototype every day], but you are glancing at it [...]and you see it all the time*". Additionally, the physicalizations drew attention from visitors, as explained by the father: "*Many have dropped by asking questions [like]: 'What have you got here?'*". After they had explained it, they got positive responses generating further curiosity. This correlates with the finding by Thudt et al. (2018) who highlighted the qualities of physical artifacts compared to a digital alternative as the physicalizations draw attention by being present in the vicinity.

To explore the long-term effect of the prototype, the family was asked how they saw themselves using it after six months. The family explained they would properly put away the dock of Heart-Tale in a cabinet or drawer, but it would be easily accessible when interest to explore the physicalizations occurred. Furthermore, every time they would receive an activity, Heart-Tale would potentially be used for a week before being put away again. The father of F2 elaborated: "*I think the box would be placed in the cabinet but the [physicalizations] would be displayed in the open, at least some of them. Perhaps the activities like at* *the amusement park in hope that guests would inquire about it. Then you could find the box and show it to them*". This illustrates that F2 enjoyed the physicalizations and wanted to showcase them. Similar qualities are found in casual information visualization (Pousman et al., 2007) where a visualization can serve as a resource for informal conversation with social networks.

When inquired about Heart-Tales effect on divorced families the father of F2 responded: "*If it is the case where the parents are still able to communicate I believe it would be beneficial for the children to show the other parent what they had been doing through pictures [and the acrylic physicalization]*". From findings of the formative study, we found it interesting to investigate Heart-Tale's effect on divorced families. However, due to the limited study, not a lot can be said on this topic, unfortunately.

6.5 DISCUSSION

From the analysis of the take-home study, many new interesting perspectives were found. These perspectives are discussed in correlation with our research questions.

6.5.1 *Social Interaction and Shared Reflection in a Natural Setting*

The take-home study provided us with insights that strengthen the findings of the research question:

RQ1 How does data physicalization foster social interaction and shared reflection in families?

While the comparative study provided insight to how people can use data physicalizations of group data for social interaction and shared reflection, the study itself was limited to the game of Kubb. The take-home study provided a deeper understanding of how to best achieve social interaction and shared reflection.

Although difficult to conclude for certainty due to the limited sample size of the study, we found that Heart-Tale fostered reflection on action and values, the two deepest types of personal reflection argued by Thudt et al. (2018). However, the reflection is fostered through the symbolic meaning of the data physicalization and not by the heart rate data itself. We found that Heart-Tale helped F2 become more aware of how they spent their leisure time and how much time they chose to spend together. They also became more aware of their values on spending time with each other face-to-face rather than staying in their rooms.

Not all of the activities measured for Heart-Tale were equal in terms of their value. A day trip to somewhere exciting with the whole family would be reflected on and looked back at more regularly than ordinary activities such as eating at restaurant or visiting a playground. However, based on the findings of the take-home study, we suggest that there are two different design purposes for the physicalization of group data to foster social interaction and shared reflection. The first design purpose leans heavily on the physicalization of significant memories that are of great interest even as time passes. This design purposes is in compliance with the qualities of Heart-Tale. The mother from F2 explained that she tracked an individual running activity but did not ask for its physicalization due to it being boring for her and the rest of the family. This presents a challenge for Heart-Tale, likely caused by how it handles the instant visualization aspect of the design considerations. The temporality of data (Rooksby et al., 2014), makes waiting for the physicalization problematic because users lose their excitement of the data over time. However, it seems that experience-based tracking (Choe et al., 2014) can stay relevant for longer if the experience is noteworthy. Unfortunately, Heart-Tale is less suitable for everyday activities because of the waiting period to receive the physicalizations. Therefore, it can reduce the participants curiosity in tracking certain smaller activities. Other design proposals mentioned in Section 6.1.3, would support the aspect of curiosity by letting the participants track activities and provide instant visualization. These types of instantly changing prototypes could potentially utilize the research area of shape-changing interfaces (Rasmussen et al., 2012) to allow for adapting designs.

We suggest that the quality of instant visualization is worth exploring in our work and related work dealing with data sculptures, such as (Khot et al., 2014; Stusak et al., 2014). With current technology, this cannot always be obtained without sacrifices. Therefore, we see a potential for two design purposes for data physicalization using group data: 1) one which allows instant visualization which affords curiosity and exploration of heart rate or 2) another centered around more meaningful and special activities to be kept as a memory.

6.5.2 *Exploring Heart Rate Revisited*

Many advantages and disadvantages of heart rate were found and discussed in the comparative study (Section 5.5.2). During the take-home study, we investigated the qualities of heart rate more closely as physicalizations were created on activities other than a game of Kubb. This was done in an attempt to further answer the research question:

RQ4 How does heart rate relate to the experience of an activity?

The same curious and ambiguous nature of heart rate was found as in the previous study. However, we saw how different activities by different families gave the physicalizations completely different visual expressions. The activities of one family with older children were much more subdued compared to the family with young children. In general, young children seemed to have a consistently high heart rate matching their high energy level. Some physicalizations better reflected the experience of an activity than others. Competitive games (physical or board games) seemed to best reflect the experience as it had a noticeable progression of heart rate which was easy to contextualize. A visit to a restaurant or a walk would provide less distinguishable features in its physicalization.

Additionally, the activities which were too long would require more careful examination to interpret as the heart rate data would be squeezed together to represent a larger timespan. This would cause more sudden fluctuations in the graph and the emotional factor would sometimes be obfuscated between peaks and dips of physical activity.

6.5.3 *Appropriation of Data Physicalizations*

One of the main purposes of conducting the take-home study was to investigate the research question:

RQ3 How do families appropriate data physicalizations to customize and create memoirs?

Unfortunately, since the take-home study was only conducted with one family in a short amount of time, we are only able to describe tendencies to answer the research question. These tendencies are described from a general perspective but in order to conclude our findings, further research needs to be conducted.

We found that people value the special activities more than regular everyday activities. When families received Heart-Tale their approach to annotating activities either by photos or text changed. The creation of annotations increased and became more personal, as they began to include their feelings and the photos would showcase intimate family moments. The families would excitedly await the arrival of these physicalizations. The family members proposed improvements to Heart-Tale indicating reflection on the future of Heart-Tale by the participants themselves. This suggests that the concept had an impact and that families saw potential in the idea, which they would like to better fit their needs. Additionally, they placed Heart-Tale where everyone could enjoy it hoping friends and other relatives would inquire about it and investigate it. From the exit interview, we found that after some time the dock would likely be placed in a cabinet until a special occasion or upon receiving new physicalization. Lastly, Heart-Tale might have the ability to influence families to spent more time together and make them do new activities.

7 REFLECTION AND CONCLUSION

7.1 FUTURE WORK

Heart-Tale needs to be optimized and have some processes automated. As of now a lot of cumbersome manual work is required for each physicalization and it is dependent on the use of a laser cutter, which unlike a 3D-printer (Khot et al., 2014) is essentially impossible to deploy in the homes of the family. For a future iteration, it would be ideal to develop a smartphone application that handles the tracking for the family and imports photos from the camera taken during tracking. The application would also allow real-time annotation and synchronization directly to a laser cutter which would then begin construction. As technology is democratizing (Tanenbaum et al., 2013), laser cutters might become available to a wider audience, and allow users to cut their own graphs right after an activity. Another challenge is that families are still required to capture pictures and write annotations which might be an obstacle to some families since it removes focus from the activity itself. It would be interesting to experiment with the automatization of annotations through context-awareness and potentially machine learning to infer a context. However, implementing this is no easy feat and there are different contexts to infer depending on an endless range of activities. There is also uncertainty about which type of annotations a family prefers and how many they would like.

Even though one of the families in our take-home study was affected by divorce we did not have the chance to fully explore Heart-Tales potential in regards to this aspect. Nevertheless, we touched upon the topic in our exit interview, and believe it can have a positive effect especially for children of a previous marriage.

For our research, heart rate sensing has been utilized because of its qualities, described in related work (Section 2.5). We find it interesting to investigate how other types of biosensory data (or possibly any sort of data which contains narrative value) can facilitate storytelling (e.g., skin conductance to measure excitement), and if the design considerations can be applied to a broader scale of sensor data. To our knowledge, not much research has focused on creating narratives based on biosensory data, especially not group data, which we see a great unresolved potential for and believe is a research area worth exploring. Similar research such as Khot et al. (2014), while exploring reflection on physical activity, does not investigate detailed storytelling using data.

Our research has focused on using group data as an approach for families to have social interaction and shared reflection. However, group data in data physicalization in general, is an underexplored research area as most research deals with the data of an individual or aggregated group data. We see potential in exploring group data physicalization in athletics, in a work setting, or other areas.

7.2 CHALLENGES

The investigation of families can be challenging due to tight schedules in their daily life. Luckily, through friends and family we were able to find families willing to spend time to participate in every step of the study. But as mentioned in Section 6.4, sometimes things do not go as planned: one of the take-home studies was ended prematurely due to the family's tight schedule. To avoid this in the future, we should either obtain a larger group of participants to choose from or perhaps give them an economic benefit for their participation (besides the physicalizations). This is also applicable for the diaries, which were not filled out by the family for the first week of the study. Nielsen Norman Group (2016b) mentions that participants often are paid to complete the diaries, because of the effort it requires. However, paying participant is not always the right solution as McKeganey (2001) argues: if participants are paid they might not provide authentic answers but instead try to tell the researchers what they want to hear. Still, he argues participants should be paid to cover the time spent on the diary, which might have been a good idea for us, since the take-home study was rather time consuming.

Because of the limited time of the thesis, there was no time to conduct a study for longer than 17 days nor was there time to have sequential studies with more families. We also only had seven Fitbits available limiting the number of parallel studies possible. When evaluating the appropriation of an artifact, 17 days can hardly be considered a long-term study, and two families do not provide sufficient data to make general conclusions. Nevertheless, we conducted a study as academically sound as possible within the scope of time and resources, and we believe we made some interesting findings.

7.3 CONCLUSION

We have investigated how data physicalization can create social interaction and shared reflection using group data, a term which we redefined. Our research started by conducting formative interviews from which we found that families have busy schedules during the weekday and generally used dinner as their quality time together.

The weekend allowed for breathing space and for the family to spend meaningful time together. Family interests and habits would vary greatly, as well as, how each family scheduled activities and how much time they spent together varied greatly as well.

As a next step in the development of Heart-Tale, we conducted a comparative study to explore qualities in physicalizations using group data. The study proved that there is indeed value in creating these physicalizations as the participants of the study actively explored and discussed them, creating fun narratives based on their interpretations. We developed eight design considerations for physicalizations to foster social interaction and shared reflection on group data, divided into primary and secondary qualities, which is illustrated in Table 1.

Heart-Tale was designed based on the design considerations and was evaluated in a the homes of families. Here it became a part of their dining room and used almost every day. Although families had enjoyed physicalizations of their regular everyday activities, they found a deeper emotional attachment with the physicalizations of noteworthy activities. After receiving Heart-Tale, the creation of annotations became increasingly personal and families excitedly awaited the arrival of the physicalizations, which they proudly showcased in their homes. Through Heart-Tale we saw reflections on family values and awareness on how they spent time together.

Heart-Tale used heart rate data to represent the experience of an activity. Emotion impacts heart rate but how it happens can sometimes be ambiguous. Heart rate is also deeply personal and people enjoy interpreting it. For longer activities, the emotional impact on the heart rate can be overshadowed by physical factors.

Finally, we propose two possible design purposes within physicalization of group data for narrative purposes, one which allows instant visualizations and affords curiosity and immediate social interaction, and another which centers around meaningful and special activities to be kept as a memory.

Overall, our study demonstrates the value in the physicalization of group data, and using heart rate as a narrative tool for social interaction and shared reflection.

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Part I

APPENDIX

A APPENDIX

A.1 Script for formative study

Questions

Ask for their written permission prior to the interview to record the session. The purpose of our Master's thesis is to explore the shared social experiences and how families spend their time. The data is only used for our Master's thesis and possibly in an article if we decide to pursue the opportunity to publish our research. Your name(s) will be anonymised and any potential graphic material will be censured.

In this interview, we explore how you as a family spend time together. Some questions will investigate if any family members have experience with tracking data (e.g., counting steps, running, calorie intake, sleep tracking, doing chores) or sharing tracking data with other family members whereas other questions will unfold during the interview.

1. How many family members are in your household?

2. When are you usually spending time together?

3. How do you coordinate social activities in the family?
    a. Is it planned or more sporadic?
        i. Which of these types of activities are most memorable?
    b. Do you feel that you spend enough time together as a family?

4. Which shared social experiences do you have to bond as a family?
    a. What common interest do you have as a family?

5. Have you or another from the household tracked data about yourself and/or other family members?
    a. If yes
        i. What data was collected?

        ii. What service('s) was used to visualize/save the data?

        iii. What was the purpose of tracking the data?
            1. Directive tracking
            2. Documentary
            3. Diagnostic tracking
            4. Collecting rewards
            5. Fetishised tracking
    b. If no
        i. What about who performs the different chores at home or the economy of the household?
        ii. What are your thoughts about tracking data?

6. What would you like to track if you were not constrained by technology and money?

NOTE TO SELF: Ask whether we can contact them for future studies

A.2 QUESTIONNAIRE FOR COMPARATIVE STUDY

Oplevelse af visualiseringen

Her skal du give din mening omkring visualiseringen. Ingen af svarende kan påvirke specialet negativt.

1. Jeg fandt visualisering forståelig
   Markér kun ét felt.
   - Meget enig
   - Enig
   - Neutral
   - Uenig
   - Meget uenig

2. Uddybe gerne dit svar på spørgsmål 1. Ingen svar kan påvirke specialet negativt.

3. Jeg fandt visualiseringen attraktiv
   Markér kun ét felt.
   - Meget enig
   - Enig
   - Neutral
   - Uenig
   - Meget uenig

4. Jeg brugte visualiseringen til at sammenligne mig selv med de andre
   Markér kun ét felt.
   - Meget enig
   - Enig
   - Neutral
   - Uenig
   - Meget uenig

5. Jeg brugte visualiseringen til at sammenligne min puls over tid
   Markér kun ét felt.

   - Meget enig
   - Enig
   - Neutral
   - Uenig
   - Meget uenig

6. Jeg forstod hvilke situationer der påvirkede min puls
   Markér kun ét felt.

   - Meget enig
   - Enig
   - Neutral
   - Uenig
   - Meget uenig

7. Jeg brugte visualiseringen til at snakke om hvad der skete under spillet
   Markér kun ét felt.

   - Meget enig Gå til spørgsmål 8.
   - Enig Gå til spørgsmål 8.
   - Neutral Gå til spørgsmål 8.
   - Uenig Gå til spørgsmål 8.
   - Meget uenig Gå til spørgsmål 8.

8. Uddybe gerne dit svar på spørgsmål 7. Ingen svar kan påvirke specialet negativt.

9. Jeg ville gerne ændre noget på visualisering. Ingen svar kan påvirke specialet negativt.

10. Andre kommentarer til visualiseringen. Ingen svar kan påvirke specialet negativt.

A.3 SCRIPT FOR COMPARATIVE STUDY

Forberedelse til studiet

- Spørgeskema skal printes ud
    - Her skal noteres hvilken gruppe det er, hvilket spørgeskema, samt hvilken visualisering. evt. hvilken person det er
- Aftal hvem der gør hvad under studiet
- Aftal hvem der bliver sammen med dem og hvem der forbedrer visualiseringerne.
- Sørger for at farverne passer til alle visualiseringer.

Før studiet

- Tak fordi I ville deltage, i må gerne beholde jakkerne på da vi skal udenfor. I må meget gerne slukke jeres telefoner, eller sætte dem i silence mode.
- Der er kaffe, kakao og andre snack herover og I skal bare tage.
- Spørg om vi gerne må tage billeder, optage lyd og video, måle puls samt anvende det i vores speciale. Sig at vi sløre ansigterne.
    - Hvis I ikke vil så sige det til os
- I studiet kommer i til at lave en fælles aktivitet, spille et spil sammen. I skal spille det 3 gange. Mens i spiller vil vi gerne måle jeres puls.
    - Vi bruger Fitbits aktivitetsarmbånd og de er sat op for jer.
    - Før vi starter studie har vi et kort spørgeskema der anmoder om jeres alder og jeres personlig forbindelse sammen.
    - Efter hvert spil vil I skulle snakke sammen samt udfylde et spørgeskema.
    - Når evaluering er færdig har vi et fælles interview
- Studiet tager omkring 2 timer og sig til hvis I skal skynde jer, så vi sørger for at I kan nå det
- Giv dem **consent forms**
    - Hvis de har børn under 18 skal forældrene skrive under
- Spørg endelig hvis I er i tvivl om noget.
- **Pointer** i skal ikke være bange for at kommentere på speciale. Vi er interesseret i hvad I mener og <u>ALT</u> kan anvendes
- Giv dem først spørgeskema
    - **NOTER PÅ SPØRGESKEMAET**
        - Der skal noteres at det er spørgeskema 1, det er første test gruppe og at det er person 1.

Studiet

- I studiet undersøger vi hvordan man snakker om oplevelser, i denne situation den fælles aktivitet.
    - Efter hver spil får i lige love til at gå på toilet samt tage forsyninger. Efter det får I en notesblok hvor i skal notere situationer fra spillet ned. I skal helst ikke snakke om spillet her.
    - Efter dette får I en visualiseringen som I kan bruge som en del af jeres snak.
- Introduktion til hvad der skal ske
    - Vi skal spille Kubb/Vikingespil/kongespil og som sagt tidligere skal I spille det 3 gange.
    - Før hvert spil skal I sætte fitbit'ten på run mode
        - Det skal vi nok hjælpe jer med.
    - Spørg om de kender reglerne
        - Hvis alle har prøvet det, forklarer regler kort
        - Ellers gennemgå reglerne
    - Giv dem en kort prøve tur.

Hvad vi gør under spillet

- En tager billeder
- En notere situationer ned, som de evt. kan snakke om eller annotere graferne med
- En sørger for at svare på spørgsmål hvis der kommer nogle.

Når spillet slutter

- Sørg for at aflsutte run mode SAMT sørger for at dataene er blevet synkroniseret
    - 2 personer sørger for at visualisering bliver produceret
    - 1 sørger for at de får snack m.m. samt starter med at notere situationer ned fra spillet (dette skal gøres individuelt)
- Præsenter dem for visualiseringen samt hvilken person er hvilken farve.
    - **En der sætter video i gang**
    - Sig til dem at de skal snakke om spillet
    - En notere hver gang de peger på grafen.
- Når de har snakket giv dem spørgeskema 2
    - Der skal noteres at det er spørgeskema 2, Hvilken test gruppe, hvilken person og hvilken visualisering det er.

Efter de har spillet af spil

- Start interview

Interviewguide

- Hvordan var det at se din data i relations til de andre?
- Vil i prøve at sammenligne de 3 visualiseringer?
  - Hvad for en fandt i mest interessant og hvorfor?
- Hvilken af visualiseringerne ville du helst have stående derhjemme?
  - Hvorfor?
- Kan du forestille dig at visualiseringen kunne bruges til andre aktiviteter
- Har du nogle kommentarer til studiet eller oplevelsen generelt? (Husk igen at ingen svar kan påvirke specialet negativt.)

A.4 GUIDE FOR PARTICIPANTS

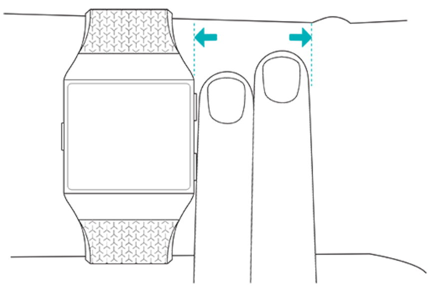
Vejledning til langtidsstudie

Mark Flarup-Jensen, Peter Hallum & Anders Lykkegaard

Fitbits: opsætning

- Alle familiemedlemmer er blevet givet en FitBit Charge 2 til at måle deres puls med.
- Deltagerne bedes downloade Fitbit app'en og parre deres smartphone og Fitbit sammen.
    - I skal lave en profil på Fitbit App'en
    - I skal anvende Jeres egen email men med et password som vi kender.
        - Dette password skal hos alle deltagere være: **F1tB1t2018**
            - *Læg mærke til store og små bogstaver i passwordet*
        - Vi råder jer til at ændre jeres password, når studieter slut eller slette app'en.
- Når Fitbit og smartphone er parret er det muligt at synkronisere data fra Fitbitten over til smartphonen (og til Fitbit's egen server)
    - For at være på den sikre side vil vi gerne have at I aktivt synkroniserer jeres data efter endt tracking. (Se afsnittet "Synkronisering af Fitbit")

Fitbits: brug og gode råd

- For bedst mulige pulsmålinger skal Fitbitten placeres med to fingres bredde under håndleddet (en finger er dog helt fint i de fleste situationer).
    - 
- Fitbitten får bedre målinger hvis den ikke sidder for løst, dog skal den ikke sidde ubehageligt og for stramt på armen.
- Vi ønsker at deltagerne bruger armbåndene så ofte som muligt (specielt) i de tidsrum hvor I ønsker at måle jeres puls. Det er selvfølgelig i orden at tage det i situationer hvor det er i vejen eller føles invaderende.
- Fitbits kræver opladning ca. hver 5 dag. Sæt dem gerne i laderen, hvis I ikke ønsker at gå med dem. Så undgår I også lettere at bruge hinandens.
- Vi gør opmærksom på at Fitbit's **ikke er vandtætte**
- Det er vigtig i altid bruger jeres egne Fitbit og ikke blander rundt på dem

Fremgangmåde for studiet:

- Studiet foregår fra **d. 18. maj til d. 3 juni**
- I vil få besøg af os igen **d. 21 eller d. 22. maj (alt efter aftalt tid)**
- Mellem d. 18 maj og næste gang vi mødes bedes i måle **2** familieaktiviteter.
- Disse aktiviteter må gerne være længere end blot ét spil vikingespil - Det må gerne være flere timer og behøver ikke være bundet op på én specifik aktivitet, så længe familien er sammen.
- Under den målte aktivitet bedes i tage et par billeder med jeres kameraer. Det jeres smartphone eller tablet leverer en fin kvalitet.
- Derudover må I gerne nedskrive en kommentar til et specielt interessant tidspunkt under forløbet (samt tidspunktet).
- En gang hen mod slutningen af weekenden, vil vi gerne have en email med start og stop tidspunkt for jeres to målinger samt vedhæftet billeder og notater.
- Inden mailen sendes, skal jeres data fra Fitbitsene være synkroniseret med jeres smartphone.
- I tidsrummet I ønsker at måle jeres puls bedes I have den i Run-Mode
    - Run-mode skal ydermere stoppes inden I synkroniserer med smartphones.

Synkronisering af Fitbit (Android, iPhone og iPad)

- Gå ind i app'ens dashboard og tryk på dit account ikon →
- Tryk på enhedens titel (charge 2)
- Tryk *"sync now"*. Hvis den ikke vil synkronisere tag telefonen tætter på uret. (Placering, bluetooth og WiFi skal være slået til). Når der står "Synced a moment ago" er synkronisering fuldført

Privathed

- Ingen personlig data eller billeder I deler med os vil ikke blive formidlet videre til andre end os (Mark, Peter Anders og vores to vejledere).
- Dog vil billeder af de endelige visualiseringer vil være en del af vores speciale, men alle jeres indsendte billeder vil blive helt sløret.

Er der det mindste undren, nogle spørgsmål, eller problemer med teknikken, så kontakt os **straks** via. telefon:

- **Mark Flarup-Jensen:** redacted
- **Peter Hallum:** redacted
- **Anders Lykkegaard:** redacted

I skal ikke holde jer tilbage fra at kontakte os. Dette er vores speciale og I hjælper os. Derfor ønsker vi at stå til rådighed, hvis der skulle være det mindste problem. Det er i vores bedste interesse at det foregår så smertefrit som muligt.

Vejledning til fysisk prototype

- *Interaktion med den fysiske prototype bliver vist af Mark, Peter & Anders første gang den bliver fremvist.*
- Den fysiske prototype indeholder elektronik som ledninger, dioder, sensorer, en mikroprocessor og en tablet.
- Den er en smule følsom, så vi håber i vil være forsigtige med den, og være speciel opmærksom når den bliver brugt af mindre børn.
- Både mikroprocessor og tablet kræver WiFi for at fungere.
- Både mikroprocessor og tablet skal være sat i en stikkontakt
- Produktet er ikke et færdig og finpudset produkt, og derfor kan det gå i stykke og der kan forekomme fejl.
    - Nogle af disse fejl kan nemt fikses og mens andre kræver at en tur på værkstedet. ***Nedenunder ses vejledning til opstart af system hvis strømmen har været slået fra eller hvis en fejl er opstået***

Tablet og App

- ***Er der problemer med app'en er det højst sandsynligt tilstrækkeligt at lukke app'en (helt) ned og åbne den igen. Vi forventer dog den kører ret stabilt.***
- Først og fremmest skal tabletten være tilsat strøm og være forbundet til Wifi.
- Derefter åbnes app'en: **ThesisVizApp**
- Knappen på siden af tabletten kan trykkes for at tænde skærmen eller slukke/tænde tabletten.
- Når app'ens skærm er helt sort, så er det ikke nødvendigvis en fejl. Dette betyder også at der ikke er nogen "visualiserings boks" sat oven på prototypen (*eller at læseren der læser de forskellige bokse har problemer med at opfange dens signal (uddybet i et senere afsnit))*

Mikroprocessor

- Mikroprocessoren styrer næsten alt i prototypen. Den sørger for at måle når i rører ved touch sensoren, hvilken visualiserings boks er placeret på prototypen og at få lyset til at blinke. Derudover så er det også den som snakker med vores tablet app via WiFi.
    - Derfor skal den både være tilsat strøm via strømstik, og være forbundet til WiFi.
- Vi forbinder den til WiFi når vi ankommer første gang. Der burde ikke være problemer med WiFi herefter.
- Det er ikke noget problem at starte hele systemet op igen hvis strømmen har været slukket. Så snart strømmen slås til igen så starter systemet op af sig selv og forbinder sig til WiFi. Alt burde køre af sig selv kort tid efter.

Problemer:

Intet signal fra visualiserings bokse

- Hvis i har puttet en visualiserings boks på prototypen og app'en stadig ikke viser nogen information kan de være fordi vi ikke kan læse dens signal.
- Prøv at fjerne boksen og sætte den på igen.
- Der er vigtigt at boksen er placeret på dens rette position for at kunne læses.
- Hvis én specific visualiserings boks ikke virker men de andre virker, så er det højst sandsynligt et problem med det specifikke “kort” som i sidder i boksen.

Intet eller blinkende lys fra dioderne (eller dårlig funktionalitet af touch sensoren)

- Hvis der slet ikke er lys i dioder eller de flakker og er svære at kontrollere via touch sensoren - så er der højst sandsynligt et problem med en løs ledning eller beskadiget hardware.
- Opstår disse symptomer, så kontakt os venligst. Så tyder det på prototypen kræver et tur på vores værksted.

Sort skærm eller app der crasher

- Se Tablet og App sektionen. Crasher den often, og derfor gør brug af prototypen besværlig, så kontakt os venligst.

Vores prototype bruger få ressourcer og burde ikke sætte nogen eller noget i fare. Sker der dog noget som gør jeg utrygge så kan strømmen altid slås fra og tabletten slukkes.

Husk vi altid kan kontaktes!

Exit Interview of Take Home Study

UTILIZATION OF THE PROTOTYPE

- How did you typically use the prototype itself?
- How does the digital component add value?
- When was the physical graph enough alone?
- What did function well about the prototype?
    - What did not?
- What was the feeling of having to wait for the physicalizations?

THE GOOD STORY

- Which of the physicalizations did you use the most?
- Which sort of stories did you find had to most narrative value?
    - Long or short events?
    - Daily routines or special happenings?
- How did person annotations and photos affect the physicalization?
    - Hard facts vs personal annotations vs photos - compare?

APPROPRIATING OF PROTOTYPE

- Did you ever use the physicalizations again?
- If yes, how?
- If no, why not?
- After seeing the prototype how did that change your approach to customizing and creating events?
- Did the physicalizations affect your routines and how you acted as a family?
- Do you feel like the concept has a novelty factor?
    - How would you use this product after 6 months in the home?

{
"history" : {
    // Initial setup in their home
    "Mon May 21 13:21:41 CEST 2018" : "Starting system!",
    "Mon May 21 14:03:35 CEST 2018" : "Found: 173251250108192",
    "Mon May 21 14:03:43 CEST 2018" : "Removed: 173251250108192",
    "Mon May 21 14:08:01 CEST 2018" : "Found: 173251250108192",
    "Mon May 21 14:08:34 CEST 2018" : "Removed: 173251250108192",
    "Mon May 21 14:13:12 CEST 2018" : "Found: 173251250108192",
    "Mon May 21 14:16:18 CEST 2018" : "Removed: 173251250108192",
    "Mon May 21 14:16:34 CEST 2018" : "Found: 253622304314",
    "Mon May 21 14:21:33 CEST 2018" : "Removed: 253622304314",
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    "Mon May 21 14:47:07 CEST 2018" : "Removed: 173251250108192",
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    "Mon May 21 14:47:15 CEST 2018" : "Removed: 173251250108192",
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    "Tue May 22 08:23:04 CEST 2018" : "Starting system!",
    "Tue May 22 10:02:35 CEST 2018" : "Starting system!",
    "Tue May 22 18:15:53 CEST 2018" : "Starting system!",
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    "Tue May 22 18:47:44 CEST 2018" : "Starting system!",
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    "Tue May 22 19:09:27 CEST 2018" : "Starting system!",
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    "Tue May 22 19:34:33 CEST 2018" : "Starting system!",
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    "Tue May 22 21:07:35 CEST 2018" : "Found: 173251250108192",
    "Tue May 22 21:09:40 CEST 2018" : "Removed: 173251250108192",
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    "Wed May 23 07:07:58 CEST 2018" : "Found: 173251250108192",
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"Fri Jun 01 07:10:53 CEST 2018" : "Found: 1421172321025",
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"Fri Jun 01 07:11:02 CEST 2018" : "Found: 1421172321025",
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"Sat Jun 02 21:38:13 CEST 2018" : "Starting system!",
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"Sun Jun 03 10:29:27 CEST 2018" : "Found: 206992321079",
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//End of study.
}
}