HealthHue: Developing an Artistic Visualization of Health data for Individuals and Informal Caregivers

By

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List of Abbreviations

RMTs	Remote Measurement Technologies
RQ	Research Question
IC1 to IC5	Informal Caregiver Participants in Study 1
I1 to I3:	Individual Participants in Study 1
ATLAS.ti	ATLAS.ti Scientific Software Development GmbH
C1	Design Consideration 1 (Emphasize Aesthetics)
C2	Design Consideration 2 (Comprehensibility)
C3	Design Consideration 3 (Balance of information)
C4	Design Consideration 4 (Seamless integration into daily routines)
SD	Standard Deviation
M	Mean
HQ	Hedonic Quality
HQI	Hedonic Quality Identity
HQS	Hedonic Quality Stimulus
PQ	Pragmatic Quality
AT	Aspect 1 (Attractiveness)
A1	Aspect 2 (Comprehensibility)
A2	Attractiveness
P1 to P12	Participants in Study 2, 1st Iteration
bpm	Beats per Minute
TU/e	Eindhoven University of Technology
E1 to E4	Participants in Study 2, 2nd Iteration

Abstract

The global aging population and the increasing prevalence of multimorbidity among older adults have resulted in a growing demand for elderly care services. To alleviate the burden on formal healthcare systems and promote self-management, providing tools to support independent living is crucial. Remote measurement technologies (RMTs) offer promising solutions for self-monitoring and caregiving support. However, the current visualizations of health data used in RMTs primarily cater to data-savvy experts, with expertise in health or data science. This poses challenges for individuals and informal caregivers with limited knowledge in these areas, leading to difficulties in understanding the data. To tackle this problem, researchers have developed creative visualization approaches, but they have limitations in facilitating data comprehension and often overlook the needs of informal caregivers.

This research aims to bridge this gap by developing a novel artistic visualization. Two studies have been conducted. Study 1 was a survey study investigating the preferences and requirements of individuals and informal caregivers regarding health data visualization in RMTs. It also collected feedback on preliminary design ideas and therefore established four design considerations as the guidance for Study 2. Study 2 proposed HealthHue, an artistic health data visualization, aiming to deliver meaningful cues about the health data of individuals (when they are the users themselves) or care recipients (when the users are informal caregivers) in personal or casual settings, prioritizing an enjoyable and intuitive interaction with health data. Through an iterative design process, HealthHue was implemented as a live clockface on the Samsung smartwatch, visualizing heart rate and activity. The results of the final user study indicated that participants appreciated the appealing appearance and novelty of HealthHue. However, feedback from the perspective of informal caregivers highlighted notable criticisms, indicating the need for further improvements in the visualization.

This study contributes to the advancement of novel unconventional visualization approaches in the field of healthcare. The findings and insights gained from the development and implementation of HealthHue can inform future research and the design of artistic visualizations that effectively support health monitoring and self-management.

1 Introduction

As the global population ages, the number of people aged 65 or older is projected to reach 1.5 billion by 2050 (United Nations Department of Economic and Social Affairs, 2021). This demographic shift increases the demand for elderly care services due to the longer life expectancies and growing prevalence of multimorbidity among older adults (OECD & Organization, 2020; Salive, 2013). The rise in healthcare utilization and associated costs, attributed to this trend, poses significant challenges for the healthcare industry worldwide (de Meijer et al., 2013; Paul et al., 2021). As a result, it is crucial to promote self-management and provide elderly individuals with the necessary tools and support to live independently. In doing so, it will not only reduce the burden on formal healthcare services but also empower older adults to effectively manage their health and improve their overall life well-being (Coventry et al., 2014; Cramm et al., 2013; Hodkinson et al., 2020).

Informal caregivers, usually family members or close friends, who provide uncompensated care for the elderly, play an important role in this development (Roth et al., 2015). They have been involved in care recipients' daily self-management activities by providing emotional support, medication management, and assistance with their physical activities (Bangerter et al., 2019). While the majority of care recipients are older adults, the results of the study presented here are generalizable to a broader range of individuals who need to monitor their health conditions, e.g., those with chronic illnesses, disabilities, or those desiring to improve their health status. Therefore, the individuals referred to in this report are those from diverse health backgrounds who engage in self-management of their health.

One promising set of technologies emerging in the healthcare industry is remote measurement technologies (RMTs), which assist in delivering or facilitating support for both individuals and caretakers (Polhemus et al., 2022). RMTs include various (mobile) health devices and applications that allow for the collection and analysis of self-monitoring health data, such as physical activity, heart rate, and sleep quality (Simblett et al., 2018). To ensure the success of RMTs, it is essential to design visualizations of the health data that not only convey information but also motivate users to continue using the technology and engage with the health data over an extended period (Polhemus et al., 2022).

However, current visualizations of health data used in RMTs are often presented in conventional forms, such as bar charts, pie charts, scatterplots, and tables (Lee et al., 2018; O'Connor et al., 2020), with primarily target data-savvy experts, such as scientists, data analysts, and health researchers (Lee et al., 2020; Pousman et al., 2007). This poses a challenge for individuals and informal caretakers to underly the health information when they use RMTs since they represent a broader range of audiences who may not have expertise in health or data science. For instance, providing heart rate variability data to indicate momentary stress levels is comprehensible and helpful for stress experts, but overwhelming for end users who simply want to know their stress levels (Polack et al., 2017).

To address this issue, visualization researchers and practitioners have developed multiple creative and innovative approaches to visualize health data, such as the oft-cited UbiFit Garden (Consolvo et al., 2008) or Fish'n Steps (Lin et al., 2006). However, the purpose of these systems is to promote specific health behaviors, such as physical activity, without allowing reviewing and understanding of the health data itself (Meyer et al., 2016). Applications like YourWellness (Doyle et al., 2014) are designed to accommodate a larger user base with simpler visualizations but are limited by the types of health data they can present. It is important to note that existing work has mainly focused on personal visualizations for self-reflection or expert-centric visualizations for data analysis, neglecting the needs of informal caregivers (Gabriels & Moerenhout, 2018; Giunti et al., 2018; Polack et al., 2017). As such, there remains a need for further development of novel visualization approaches that can efficiently present the health data to a wider audience, while also motivating them to engage with the health data.

This research aims to bridge this gap by introducing a novel, artistic visualization. Two studies are presented in this thesis, following a user-centered design approach. Study 1 was a survey study, exploring the needs and preferences of individuals and informal caregivers regarding health data visualization in the use of RMTs. It aimed to understand their current situation, collect feedback on preliminary design ideas, and identify potential enhancements to the user experience of health data visualization.

Building upon the insights from Study 1, Study 2 was conducted as an iterative design study driven by user input. In Study 2, HealthHue was proposed, an artistic health data visualization that aims to convey meaningful cues about the health data of individuals (when they are the users themselves) or care recipients (when the users are informal caregivers). An artistic approach is an unconventional and out-of-the-ordinary approach to visualizing data, which goes beyond conventional data visualization techniques of using straightforward metaphors to encode data. This approach aligns with Aseniero et al. (2022) who designed SkyGlyphs. Examples of such unconventional representations include but are not limited to, artistic visualizations (A. Vande Moere et al., 2012; F. B. Viégas & M. Wattenberg, 2007), data sketches (Bremer & Wu, 2021), and data comics (Bach et al., 2017).

Both conventional and unconventional ways of data visualization can lead audiences to form deeper insights about their data (Vande Moere et al., 2012). The former aims to optimize the analytical efficiency and usability of data representation (Card et al., 1999) while the latter focuses on enhancing the aesthetic and enjoyable aspects of data exploration (Aseniero et al., 2020; Romat et al., 2020). However, these two approaches are not mutually exclusive, and there may be situations where combining them can offer benefits for different types of using intents and contexts. Specifically, HealthHue is designed to deliver health data information to individuals and informal caregivers in personal or casual settings where engaging with data in an enjoyable and intuitive manner is a priority. Therefore, it is not intended to replace the current conventional visualizations widely used in current RMTs, but rather work synergistically with them to offer tailored features that fit the goals, preferences, and abilities of individuals and informal caregivers.

As a result, HealthHue was implemented as a live clockface on the Samsung smartwatch, visualizing heart rate and activity. The results of the final user study indicated that participants appreciated the appealing appearance and novelty of HealthHue. However, feedback from the perspective of informal caregivers highlighted notable criticisms, indicating the need for further improvements in the visualization.

Overall, this study contributes to the advancement of novel unconventional visualization approaches in healthcare. The findings and insights gained from the development and implementation of HealthHue can inform future research and the design of artistic visualizations that support health monitoring and self-management.

1.1 Research Objectives and Questions

This study has a twofold objective. Firstly, it aims to explore and define design considerations for an artistic health data visualization intended for individuals and informal caregivers.

In response to the first research objective, the first research question is:

> **RQ1:** *What are the key considerations for designing an artistic visualization of health data that meets the needs and preferences of individuals and informal caregivers?*

To answer the above question, a survey study was administered to investigate the needs and challenges faced by individuals and informal caregivers regarding data visualization in the use of RMTs, also their feedback on initial design ideas. The results were then analyzed and used to answer RQ1.

The second research objective is to examine how individuals and informal caregivers perceive the user experience of an artistic visualization in terms of comprehending the represented health data and assessing its visual appeal.

In response to the second research objective, the second research question is:

> **RQ2:** *What is the user experience of an artistic visualization in terms of comprehension of represented health data and visual appeal, as perceived by individuals and informal caregivers?*

To answer this question, HealthHue was developed based on the design considerations derived in Study 1. Through an iterative design process, HealthHue Clockface has been created, a live clockface on the Samsung smartwatch. A “Co-constructing stories” method has been adopted in the last user study to investigate the user experience from the perspective of individuals and informal caregivers to answer RQ2.

2 Literature Review

2.1 Remote Measurement Technologies

RMTs refer to all digital technologies capable of gathering real-time data from individuals during their daily activities through a remote interface (Walsh et al., 2022), e.g., smartphones, contactless or wearable devices, and associated applications. The data will be shared with various stakeholders including healthcare professionals, caregivers, and the monitored individuals themselves (Czaja et al., 2017). By reviewing the data, these stakeholders can gain insights into the health status and behavior patterns of the individuals being monitored, and provide appropriate feedback and guidance to support health management (Andrews et al., 2020; Simblett et al., 2018). RMTs use two primary data collection methods: active and passive. Active data collection requires intentional user input, such as responding to a sentiment scale, questionnaire, or mood log (de Angel et al., 2023; Matcham et al., 2019). Passive data collection involves the automatic capture of information through sensors embedded in various devices and/or during user-device interactions to gather the data like heart rate, heart rate variation, and skin conductance, as well as activity data such as accelerometry (de Angel et al., 2023; Walsh et al., 2022). This research targets the passive RMT data collection.

There are various factors that influence users' motivation and satisfaction with RMTs, and accessing data and interacting with the data often emerge as the key determinants (Palacholla et al., 2019; Simblett et al., 2018). However, simply providing access to data is inadequate for achieving health management goals; it is essential to organize and present data in a way that addresses awareness and care concerns (Marcengo & Rapp, 2014). Data visualization has been demonstrated to be critical in achieving these goals by enabling efficient processing and interpretation of complex data, enhancing comprehension, and facilitating decision-making (Eberhard, 2023; Mahmoud Sherif, 2021). While previous studies have mainly focused on data visualization in other domains, little attention has been given to its application in healthcare settings. Recently, Polhemus et al. (2022) investigated the experiences and preferences of individuals with chronic neurological and mental health conditions regarding data visualizations derived from RMTs for health management. However, this narrative review lacks quality appraisal and focuses on a limited user group, raising concerns about the generalizability and validity of data visualization for RMTs in healthcare settings. Therefore, further research is required to examine these issues thoroughly.

2.2 Personal Informatics and Health Data

Personal informatics, which refers to the use of RMTs or other methods to enable individuals to collect, manage, and reflect on their personal data (Li et al., 2010), has gained increasing attention in recent years. It is also known as "living by numbers", "quantified self", "self-surveillance", "self-tracking", and "personal analytics" (Lupton, 2014; Yau & Schneider, 2009). The collected health-related data range from physiological measurements like heart rate and sleep patterns to self-reported data on diet and exercise habits. By leveraging personal informatics systems, individuals can gain insights into their health and well-being. This could further improve the act of self-monitoring, potentially facilitating self-reflection and triggering behavior change (Rapp et al., 2018).

However, research shows that there are difficulties with data integration and interpretation (Li et al., 2010). Specifically, Choe et al. (2014) highlighted the difficulty in creating visually accessible representations of personal data, resulting in redundant tracking efforts. Other studies have indicated that a large proportion of people find it difficult to understand statistics (Ancker & Kaufman, 2007) and express discomfort with autonomous analysis of personal informatics data (Mamykina et al., 2008). These findings reveal the limitations and gaps in the current state of personal informatics, calling for further research.

2.2.1 Extension to Personal Informatics

Although health tracking at the individual level is important, many aspects of health or health-related behaviors are affected by other roles, e.g., therapists and caregivers. However, personal informatics is inherently centered on individuals, leading to a lack of support for diverse forms of health-related collaboration. Health informatics researchers have pointed out that current informatics models often fail to adequately represent social context or follow-up tasks for managing chronic diseases (Figueiredo et al., 2017; Valdez & Brennan, 2015). In line with this, Pina et al. (2017) proposed the extension from personal informatics to "family informatics", highlighting the importance of informal caregivers with a focus on family-centered practices. Research on coordination between patients and close caregivers, including spouses, has further highlighted the need to identify and balance values such as mutual support and patient autonomy when designing collaborative self-care systems (Berry et al., 2017; Nunes & Fitzpatrick, 2015), which goes beyond the scope of personal informatics. This body of research provides pointers indicating that health management designs should consider a broader range of stakeholders. To effectively support the dynamic nature of personal data practices in interpersonal contexts, the research and design community focused on personal informatics critically needs to incorporate considerations for social relations and roles (Murnane et al., 2018), extending personal informatics towards more of a collective practice. Therefore, this study aims to further explore this topic by identifying potential opportunities and challenges in providing support for both individuals and informal caregivers in the context of health management.

2.3 Data Visualization Technologies

The historical origins of the term "data visualization" can be traced back to the second century AD (Few & Edge, 2007; Li, 2020). Over time, it has evolved from the earliest hand-drawn methods to more sophisticated approaches such as "photolithography" and computer-based visualization (Friendly et al., 2001), which has made significant contributions to the realms of invention and discovery (Crapo et al., 2000).

Data visualization can be defined in various ways from different perspectives. Most definitions emphasize the role of data and computer technology in creating visual or sonic representations of data. For example, Card et al. (1999) state that data visualization is “the use of computer-supported, interactive, visual representations of data to amplify cognition”. Earnshaw and Wiseman (2012) described that it is “concerned with exploring data and information in such a way as to gain understanding and insight into the data.” These definitions are made in the context of scientific visualization, which is a subfield of data visualization, focusing on representing scientific, physically-based data like spatial or geometrical information (Card et al., 1999; Chen et al., 2014). Information visualization is another subfield of data visualization that specifically deals with abstract non-spatial data (Chen, 2010). Gershon et al. (1994) defined information visualization as “a process of transforming data and information that are not inherently spatial into a visual form, allowing the user to observe and understand the information.”

Interestingly, there is an ongoing debate on the need to define the differences between scientific and information visualization. Li’s research (2020) provided a review of different forms of data visualization and suggested that visual forms of presentation in these two fields often exhibit overlaps, indicating a commonality in their underlying principles. Rhyne (2003) further argued that there is an opportunity for these two fields to share techniques and perspectives, as they can benefit from each other’s approaches. Moreover, Kosare (2007) proposed a thoughtful and analytical way of creating information visualization that integrates ideas from both artistic and pragmatic visualization through the common concepts of critical thinking and criticism.

In this study, a comprehensive definition of data visualization adapted from Bikakis (2018) is employed, which encompasses any act of transforming data into visual forms to provide users with an intuitive way to explore and analyze data, enabling them to effectively gain valuable insights such as inferring correlations and cause-and-effect relationships (Figure 2.1). This inclusive definition allows exploring possible synergies between different subfields of data visualization, without being limited to specific domains or applications.

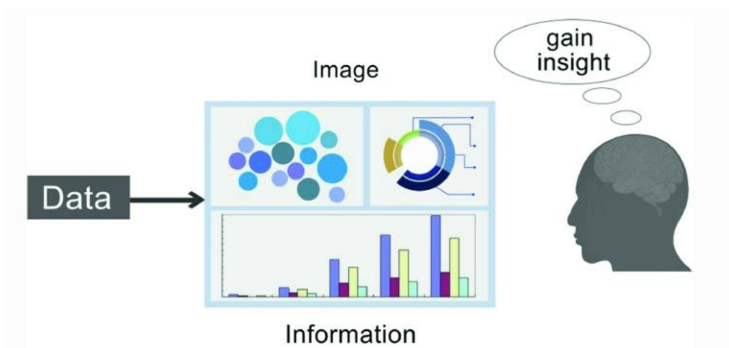


Figure 2.1. Data visualization process, adapted from Li (2020).

2.4 Designing Personal Visualizations: Unconventional Representations

The growing interest in exploring and understanding data that has a significant impact on personal lives has resulted in the increasing popularity of personal data visualization (Perin et al., 2015). This data includes biometric data, such as health-related information, self-monitoring, and sports performance data, as well as personal data, such as energy consumption and web activity. In certain cases, some conventional data visualization techniques can be applied to the visualization of personal data, such as bar charts and line graphs utilized in fitness trackers like Fitbit (Fitbit Inc., 2023) and Garmin Connect (Garmin Ltd., 2023). While these visualizations may be simple enough for most users to understand, they don’t seem to be motivating, as users tend to stop using them quickly (Shih et al., 2015).

In contrast, unconventional or abstract visual representations that do not rely on precise numbers can improve people's awareness of their data (Consolvo et al., 2009). Huang et al. (2015) highlighted the importance of diversifying design perspectives for personal visualizations. This includes incorporating nonconventional metaphors such as flowers or other types of artistic, abstract thematic visualizations, as they are often perceived as enjoyable (Romat et al., 2020) and can facilitate deeper insights (Andrew Vande Moere et al., 2012). These visualizations often prioritize aesthetics, empathy and enjoyability over efficiency and ease of analysis. Vande Moere et al. (2012) suggested that this characteristic can make these visualizations more attractive to the audience, and therefore more suitable for supporting specific needs in more personal or casual settings where end-users tend to be non-experts.

Figure 2.2. Last Clock: BBC 2, Golf (F. Viégas & M. Wattenberg, 2007).

There are several noteworthy examples of visualizations projects that employ unconventional representations. One such example is “Last Clock”, which explores the visual representation of time and space using video footage (F. Viégas & M. Wattenberg, 2007). The clock features three concentric circles representing seconds, minutes, and hours, with each hand made from a slice of live video feed, as shown in Figure 2.2. As the hands rotate, they leave traces of the surrounding environment captured by the camera, resulting in a unique record of time and place.

Another example is “We Feel Fine”, a web-based artwork that collects and analyses data from blogs in real time (Kamvar & Harris, 2011). By identifying emotional expressions in blog posts, “We Feel Fine” creates a dynamic map of human emotions, represented as colored dots on a world map (Figure 2.3). These projects push the boundaries of conventional data visualization to create unique and engaging representations that offer new insights and perspectives to users.

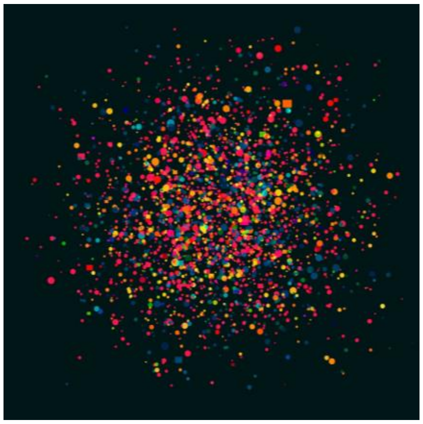


Figure 2.3. We Feel Fine: Madness (Kamvar & Harris, 2011).

3 Study 1: Context Explorations

3.1 Introduction

The design research began with a survey study of target users (individuals and informal caregivers) to investigate their specific needs and preferences regarding health data visualization during the use of RMTs. By doing so, Study 1 sought to understand their current situation when using RMTs, such as challenges and coping strategies with health data and health data visualization, gather feedback on preliminary design ideas, and identify qualities that could potentially enhance the user experience of health data visualization.

This chapter aims to address **RQ1**: "*What are the key considerations for designing an artistic visualization of health data that meets the needs and preferences of individuals and informal caregivers?"*

3.1.1 Collaborative Stakeholder: Hangzhou Bobo

Throughout Study 1, we collaborated with Hangzhou Bobo Technology Limited Company (referred to as Hangzhou Bobo). Hangzhou Bobo is a company specializing in intelligent healthcare solutions, utilizing mobile internet technology to address issues such as communication between care providers and patients, and chronic disease management. One of their products is "Slaap Lekker", a smart sleep and health monitor used to monitor health-related data from the user's vital signs during sleep (Hangzhou Bobo Ltd., 2023). The mobile application of "Slaap Lekker" provides two user roles: primary administrator and follower. This functionality is particularly beneficial for informal caregivers who monitor the health data of elderly parents or family members who may not be proficient in using smartphones. As the primary administrator, users have the highest set-up privileges and can manage not only their own health data but also act as the primary administrator for the people in their care.

3.2 Methods

3.2.1 Inclusion Criteria

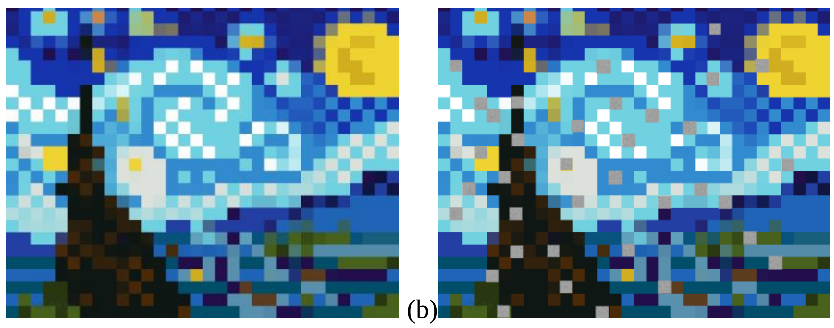
This study comprised two participant groups: individuals and informal caregivers. Eligible participants were adults aged 18 years or older. For individuals, inclusion criteria were current or previous use of at least one of RMTs for health data tracking. For informal caregivers, inclusion criteria included: (1) being a caregiver for a "dependent person" or "care recipient", providing unpaid care, and (2) current or previous use of at least one of the RMTs for tracking the health data of the person under their care.

3.2.2 Sampling and Recruitment

A purposive convenience-based sampling was used to recruit participants who met the aforementioned criteria. Two approaches were used for recruitment: individuals were recruited from the researcher's network of contacts, while informal caregivers were recruited through Hangzhou Bobo. Hangzhou Bobo appointed a coordinator who contacted potential participants from customers of “Slaap Lekker”. Those who provided voluntary informed consent were formally enrolled in the study. This study received ethical approval from the Ethics team of the Eindhoven University of Technology (TU/e). Participation in the study was voluntary.

3.2.3 Preliminary Design

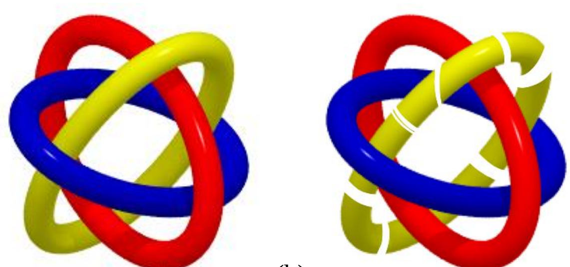
To initiate the design process, two preliminary visualization ideas were presented to participants to stimulate discussion and elicit feedback. Design A utilized pixelated artwork, where the whole image represented the health status through the gradual greying of pixels as the health status deteriorated. The complete pixel artwork indicated optimal health, while the increasing number of gray pixels represented a decline in health (Figures 3.1).



(a) (b)

Figure 3.1. Design A: (a) Complete pixel artwork depicting optimal health status; (b) Pixel artwork with added gray pixels indicating deteriorating health. The artwork is based on Van Gogh’s “Starry Night”.

Design B utilized a more targeted approach by incorporating shapes and colors to visualize specific health indicators. Borromean rings (Figure 3.2) were used as a metaphor for overall health. Each ring represents a different health indicator, such as heart rate, blood oxygen level, and breathing rate. When all the indicators fell within the healthy range, the rings were fully interlocked. If any index exceeded the healthy range, the corresponding ring became disconnected, indicating a suboptimal or bad health status.



(a) (b)

Figure 3.2. Design B: (a) Complete Borromean Rings with all health indices within healthy ranges; (b) Broken Borromean Rings with the yellow ring indicating a health index outside the healthy range.

3.2.4 Survey Study

A survey was developed to collect qualitative data from individuals and informal caregivers. The survey questions were essentially the same for both groups, with minor adjustments to accommodate their different contexts. The data collection methods varied based on the group. For individuals, the survey was administered through face-to-face interviews (in English) conducted by the researcher, who served as the interviewer. For informal caregivers, a paper-based survey was provided in Chinese, allowing them to answer in their native language. The coordinator delivered and collected the surveys from informal caregivers and then sent completed surveys back to the researcher as digital scans.

3.2.4.1 Content of the Survey

The survey was structured into three sections: (1) user experience with RMT(s), (2) user experience with health data visualization and suggestions on improvement, and (3) collection of insights into the initial visualization design ideas. Demographic information was collected from participants at the beginning of the survey.

The first section consisted of six questions, covering the duration of use of RMT(s), frequency of examining health data through RMT(s), potential changes in user behavior over time, perception of the health data, specific information sought during the data review, and whether using RMT(s) helped support the health tracking/management.

The second section comprised nine questions that began with asking about participants' experience with health data visualization tools. It further delved into challenges encountered in tracking health data, the impact of visualization in this process, and how it compared to the guidance or support provided by formal healthcare providers. Participants were also asked about their preferences or requirements for health data visualization, including desired features or functionality.

In the final section, participants were shown the two preliminary design ideas (3.2.4), with an explanation of the difference between conventional form data visualization and unconventional form data visualization. They were then asked to share their thoughts on the design ideas. All terminology mentioned in the survey was clearly explained to participants before or during the survey. The full survey can be found in Appendix A.

3.2.4.2 Paper-based Survey in Chinese

The translation of the face-to-face survey from English to Chinese was conducted by the researcher, a native Chinese speaker. The questions were carefully transformed into a formal and precise paper-based survey format while ensuring that the original content was preserved. To maintain accuracy and quality, the refined questions underwent a thorough review by Jun Hu (the researcher's mentor), who is also a native Chinese speaker. The coordinator forwarded the survey to the participants. The Chinese version of the survey can be found in Appendix B.

3.3 Data Analysis

The characteristics of the participants were summarized using descriptive statistics. Interviews with individuals were transcribed verbatim. A mixture of both inductive and deductive approaches was used to analyze the responses to the survey questions and to identify the major themes that emerged from the data (Bingham & Witkowsky, 2021) by using ATLAS.ti software (ATLAS.ti Scientific Software Development GmbH, 2023). There were multiple codes within each theme, which were subsequently defined as sub-themes. The analysis was structured by predefined themes that corresponded to the three sections of the survey. Responses from informal caregivers, originally in Chinese, were translated into English for analysis alongside individual responses.

3.4 Results

3.4.1 Sample Characteristics

A total of 8 participants attended this study, including 3 individuals (I1 to I3) and 5 informal caregivers (IC1 to IC5). Their characteristics can be found in Table 3.1.

Table 3.1. Background characteristics of the study participants.

Demographic characteristics	**Individuals (n=3)**	**Informal caregivers (n=5)**
Age (years), n (%)		
≤ 30	3 (100)	2 (40)
31- 40		1 (20)
41 - 50		1 (20)
> 50		1 (20)
Gender		
Male: Female	2: 1	2: 3
Residence, n (%)		
the Netherlands	2 (66.7)	
China	1 (33.3)	5 (100)
Highest education completed, n (%)		
High school		2 (40)
Bachelor's degree		3 (60)
Graduate degree	3 (100)	
Duration of using RMTs (years), n (%)		
≤ 1	1 (33.3)	4 (80)
1 - 3	2 (66.7)	1 (20)
Duration of caregiving (years), n (%)	Not applicable	
≤ 1		4 (80)
1 - 3		1 (20)
Type of caregiving	Not applicable	
Parent		5 (100)

3.4.2 Qualitative Results

3.4.2.1 *Overview*

The themes identified for informal caregivers and individuals were merged into a single thematic map, as shown in Figure 3.3.

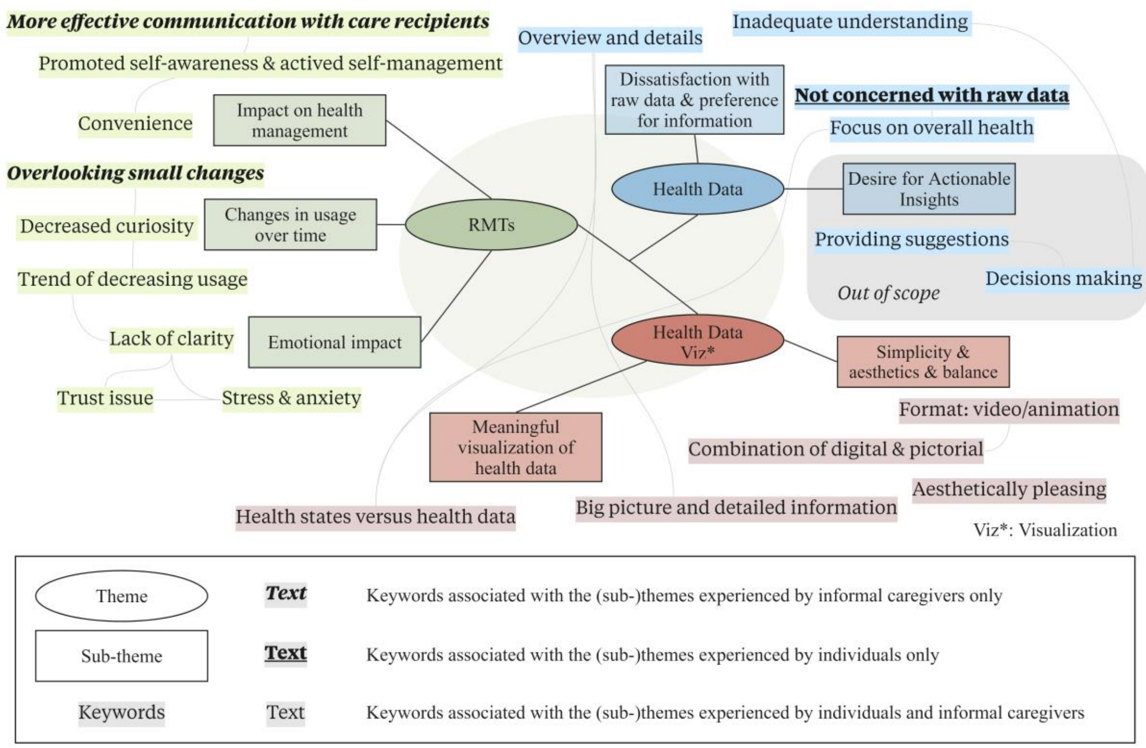


Figure 3.3. Visualization of themes and sub-themes.

The final qualitative results consisted of three core themes and their most relevant sub-themes, further specified by several keywords. It is worth mentioning that the sub-theme "Desire for actionable insights" was considered out of the scope of the study. It was included in the analysis but was not considered as an input to the design considerations.

3.4.2.2 *User Experience with RMTs*

Impact on health management

There was a general view among the participants that RMTs helped them promote self-awareness and support health management by providing them with convenient and timely health data updating. Moreover, informal caregivers reported that RMTs enabled more effective communication with their care recipients since information can be transmitted at any time, which further improved their relationship and emotional well-being. However, participants also expressed an expectation to see more information beyond the data itself, such as information on the overall health condition, which is currently lacking in existing

RMTs. They also suggested that RMTs should be more personalized and interactive, and provide more feedback and guidance on how to improve their health outcomes.

Changes in usage over time

Most participants reported reduced frequency in checking their own health data or that of their care recipients compared to when they initially began using RMTs. This could be attributed to reduced interest, as they did not find the data to be valuable in providing useful insights, as one individual stated:

> *"I don't understand what they mean […] I lost my interest to viewing them without not getting much valuable information."* [I3]

Another factor that contributed to reduced checking frequency related to the informal caregivers was an improved understanding of the data. Some of them who gained a better understanding of the data during the usage period reported a reduced concern for minor fluctuations in the health data over time:

> *"I learned the corresponding explanation of the data later, I would not be too entangled in the small changes in the data."* [IC1]

However, for some individuals, the frequency of using RMTs remained relatively stable over time. Those who relied on RMTs to track their fitness data reported that their continued use was driven by the need to track their physical activities.

Emotional impact

Several participants expressed concerns about the reliability of RMTs, leading to a lack of trust in the health data they provide. Apart from the doubt about the technologies, the lack of clarity between data and user performance was also a major contributor to this concern. One individual reported feeling anxious while using RMTs:

> *"Sometimes it even caused me anxiety since some indexes can be abnormal all the time, which makes me very worried […]"* [I2]

These negative emotional experiences can have a significant impact on the user's mental health. Therefore, it is necessary to consider the emotional impact of RMTs and design them to deliver information in a more user-friendly manner.

3.4.2.3 Health Data

Dissatisfaction with raw data and preference for information

While most participants acknowledged the importance of health data, they expressed their dissatisfaction and uncertainty about raw health data. This was especially reported by informal caregiver participants, who lacked professional training and familiarity with basic health terminologies and analysis. Due to the high demand for health-related knowledge in caregiving tasks, some of them even have resorted to seeking interpretation and meaning of the data online. They, therefore, have expressed a desire for a clear picture of how good or bad the health condition was along with some analysis and explanation, which matches the user experience mentioned earlier with RMTs. Moreover, healthy individuals among the participants have expressed strong disinterest in knowing about specific health data. Instead, they have expressed a preference for general information regarding their health and the option to check specific data only when they want to. As one individual noted:

> *" […] most of the time it can be a general information but if I want to know the specific data I can also find it somewhere."* [I2]

Desire for actionable insights

Participants expressed a desire for specific and understandable recommendations on how to use health data to make better health management decisions. They expressed concern about the actions or steps they should take based on the health information they received.

3.4.2.4 Health Data Visualization

Meaningful visualization of health data

Participants reported that while visualizing health data in a different format (e.g., graphs) seems straightforward, it may not be helpful. Different formats did not add any value if the user did not understand the meaning behind the data. Therefore, participants expressed a desire to see an overview of their overall health status rather than numerous bar charts showing different health data. This opinion was evident in their responses to the question about the missing features in the current health tracking devices and visualization tools.

Simplicity, aesthetics, and balance

Participants emphasized the importance of simplicity in health data visualization as it could contribute to better comprehension. Videos and animations were highly mentioned as potential approaches to visualize health data more engagingly and interactively. While most participants did not provide specific suggestions for making health data more user-friendly, many expressed a desire for visualizations to be beautiful, suggesting that aesthetics play an important role in their preferences for health data visualization. Interestingly, one informal caregiver specifically mentioned the wish for "a combination of digital and abstract, pictorial representations" [IC5], which aligns with the idea of providing a general overview of health status along with specific data as needed. This highlights the importance of striking a balance between the big picture and detailed information.

3.4.2.5 Insights into the Preliminary Design

Participants had mixed opinions on Design A and Design B. Design A was praised for its novelty and creativity, but some participants expressed concerns about the clarity and effectiveness of using pixel art to represent health data. For instance, one participant stated that said that the pixel artwork might be too blurry or low-resolution to convey health information. Another participant questioned whether the pixel variations would be noticeable enough to draw the user's attention. Design B was appreciated for its simplicity and straightforwardness ins using simple shapes and colors to convey the health data effectively. However, it faced criticism regarding its visual appeal, as it was perceived as lacking in aesthetics. Moreover, one participant was puzzled about how the three health data were selected over other health indexes and presented in three rings.

3.5 Findings

The results of Study 1 highlight the need to refine data visualization used in RMTs. While acknowledging the positive aspects of RMTs, the findings reveal shortcomings that require further research.

Current data visualizations in RMTs, such as bar and line graphs, are perceived as lacking meaningful insights by participants, leading to a decline in interest in health data over time. This indicates a clear gap between the value of health data and users' perceived usefulness, where conventional visualizations fail to support users' ability to derive meaningful insights from the data.

Informal caregivers lacking professional training and familiarity with basic health terminologies and analysis expressed incomprehension and uncertainty when faced with raw health data. They sought interpretations, analyses, and explanations accompanying the health data. On the other hand, healthy individuals expressed disinterest in specific health data and preferred general health information as it related to their overall health outcomes and well-being. These findings suggest a need for a flexible design approach that can address the diverse requirements and accommodate the varying needs of different user groups.

Additionally, participants emphasized the importance of aesthetics and suggested the use of dynamic presentations, to engage users. This coincides with the growing recognition of the critical role that aesthetics play in engaging users and facilitating meaningful interactions with health data (Sutcliffe, 2009). However, it is important to strike a balance between artistic expression and conveying meaningful information. A well-executed visualization should harmonize visual appeal with the ability to communicate health knowledge in an understandable manner.

Moreover, the emotional impact caused by RMTs was a significant topic among participants, as concerns about the reliability of the provided health data led to a lack of trust, or the overwhelming focus on health data sometimes led to negative emotional experiences, including feelings of anxiety and annoyance. Such negative emotional responses can potentially diminish one's motivation to seek health information, and therefore lead users to disengage from RMTs during periods of disease relapse or noticeable progression (Lee et al., 2008). Thus, addressing these emotional concerns and designing RMTs to deliver information in a pleasing and user-friendly manner is important to promote positive emotional experiences.

In conclusion, Study 1 emphasizes the need for innovative data visualization strategies for health tracking/management purposes. Although precise design opinions for artistic and abstract data visualization were not extracted in this study, common aspects emerged, including providing a comprehensive overview of health information, addressing emotional implications, incorporating aesthetics, and ensuring consideration of the diverse needs of different stakeholders. These aspects should be prioritized in the development of data visualization for RMTs to enhance user experiences and promote effective health management.

3.6 Design Considerations

Based on the findings of Study 1, we have established four design considerations:

C1 Emphasize Aesthetics: The visualization should prioritize the incorporation of visually appealing elements that captivate users and deliver health information in a user-friendly manner to promote positive emotional experiences. Consider using color, shape, and other artistic elements to evoke interest and convey health information effectively.

C2 Comprehensibility: The visualization should strive to convey health information in an understandable manner. The visualization should not sacrifice clarity for aesthetics, ensuring that users can easily interpret the presented visuals. Avoid the use of complex metaphors.

C3 Balance of information: The visualization should balance general information with specific details, ensuring that users can quickly grasp the key insights while also allowing them to dive deeper into more specific details if needed. Provide visualizations that offer a comprehensive overview of users' overall health status, addressing the preference for collective health data rather than relying solely on conventional forms like bar or line graphs.

C4 Seamless integration into daily routines: The visualization should be designed in a way that seamlessly integrates with users' routines. This can be achieved by considering factors such as simplicity, convenience, and compatibility with existing technologies or devices commonly used in daily activities. By integrating visualizations seamlessly, users can effortlessly access and engage with health information without disruptions, ensuring a harmonious coexistence with their regular routines.

4 Study 2: Design Development and Evaluation

4.1 Introduction

Building upon the design considerations as requirements, Study 2 focused on the development and evaluation of HealthHue, a novel artistic health data visualization. It followed a user-driven iterative approach, consisting of two rounds of design iterations and user studies. As a result, HealthHue was implemented as a real-time clock face on the Samsung smartwatch, visualizing heart rate and activity type. The final user study employed a "Co-constructing stories" method to examine participants' user experience from both an individual and an informal caregiver perspective.

This chapter aims to address **RQ2**: "*What is the user experience of an artistic visualization in terms of comprehension of represented health data and visual appeal, as perceived by individuals and informal caregivers?*"

4.2 First Iteration: Concept Proofing

The goal of the first iteration is concept proofing. Based on C3 and C4, we suggest that incorporating unconventional visualization alongside conventional data visualization can provide greater benefits to users. HealthHue is therefore proposed to work in conjunction with conventional data visualization tools, offering an artistic and abstract representation of health information. This visualization is specially designed for non-expert individuals and informal caregivers in casual settings, where users can gain a general sense of their health information from HealthHue and can refer to more detailed data from RMTs for specific information if necessary. It is worth noting that HealthHue, in the context of this study, specifically refers to the visualization itself, which can be integrated into a variety of digital platforms, including medical devices, desktop screensavers, smartwatch wallpapers, or even presented as a digital painting.

4.2.1 Design Inspiration

Chaos theory is a branch of study in mathematics that is concerned with nonlinear, dynamic systems (Devaney & Keen, 1989; Jørgensen, 2008), where the whole is greater than the sum of its parts due to feedback or multiplicative effects among the components (Boeing, 2016). Chaotic systems are a particular type of nonlinear dynamical system that is deterministic and described by simple differential equations (Biswas et al., 2020). The butterfly effect illustrates their extraordinary sensitivity to the initial conditions, where small actions can have significant consequences (Ghys, 2015; Lorenz, 2000; Shen et al., 2022).

Chaos theory also offers visually appealing concepts like Lorenz Attractors (Peitgen & Richter, 1986) and Julia and Imaginary Numbers (Li et al., 2007), which have potential applications in data visualization. Wright (1996) explored the idea of art in chaos and introduced a cultural practice called the "poetics of knowledge", i.e., the same words, visuals, or rituals when shared across disciplines, undergo changes in their meaning, like poetry. Wright (1996) pointed out that when visualization becomes constrained by predetermined styles or exclusively focuses on complex scientific aspects, it may miss the opportunity to convey meaningful and relevant information. Wright (1996) has encouraged the future to make connections between different disciplines, for example by incorporating elements of scientific visualization into artistic projects, as a means of gaining new insights and knowledge.

Rooted in design considerations (C1 to C3) and inspired by the above context, this study chose to design with the simple mathematical art produced by nonlinear dynamics, which produces visually captivating patterns (C1). These visuals serve as a medium for delivering health information and exploring artistic, abstract visualization. It's important to clarify that the study focuses on the visual itself and is devoted to developing a clear mapping between visuals and health status (C2), rather than diving into the mathematical equations, principles, and complexities of Chaos theory.

4.2.2 Design Mapping

In the context described above, HealthHue utilizes chaotic equations to generate patterns, serving as representations of health information. The visual implementation is based on the work from HackerPoet (2019), which applies random recursive equations to points over time, leading to the emergence of beautiful patterns. We have initially defined a mapping scheme that associates different health statuses with corresponding patterns generated by recursive equations. By utilizing the same set of recursive equations at different time points (t), a variety of patterns will be created representing various health states, see the example provided in Figure 4.1. Specifically, when health is rated as very good, the pattern manifests as complete and intact. However, as health transitions from very good to good and eventually to poor, the visual representation gradually weakens, resulting in a reduced level of detail and an increased level of abstraction compared to the complete pattern.

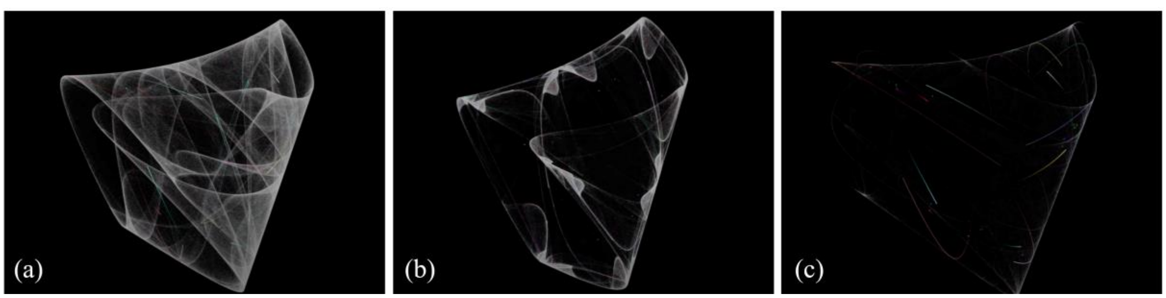


Figure 4.1. Equation: $x^t = -x^2-t^2+xt-yt-x$, $y^t = -x^2+t^2+xt-x-y$: (a)Very Good: t = -0.35; (b) Good: t = -0.30; (c) Poor: t = -0.38.

4.2.3 User Scenarios

To illustrate the practical applications of HealthHue, we present two example user scenarios in which users utilize HealthHue in real-life contexts.

Mobile/Wearable App integration. David is a fitness enthusiast who uses his smartwatch to keep track of his vital signs and fitness goals. One of the features that David loves about his smartwatch is the wallpaper. It is a captivating visual reflecting his current health status, providing instant health data information at a glance. Using this smartwatch for self-tracking keeps him motivated and informed on his fitness journey.

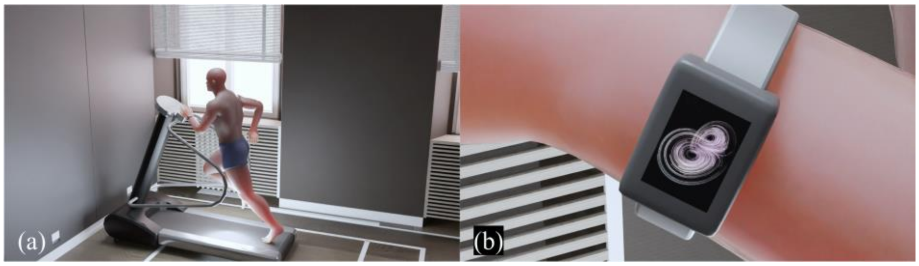


Figure 4.2. Renders of Scenario 1: (a) David is working out (with his smartwatch); (b) close-up details of this smartwatch.

Digital painting. Sarah, an informal caregiver for her father with cardiovascular disease, uses a mobile health tracking application to monitor his symptoms. To stay updated while working, she bought a digital painting that displays visuals based on her father's real-time health data.

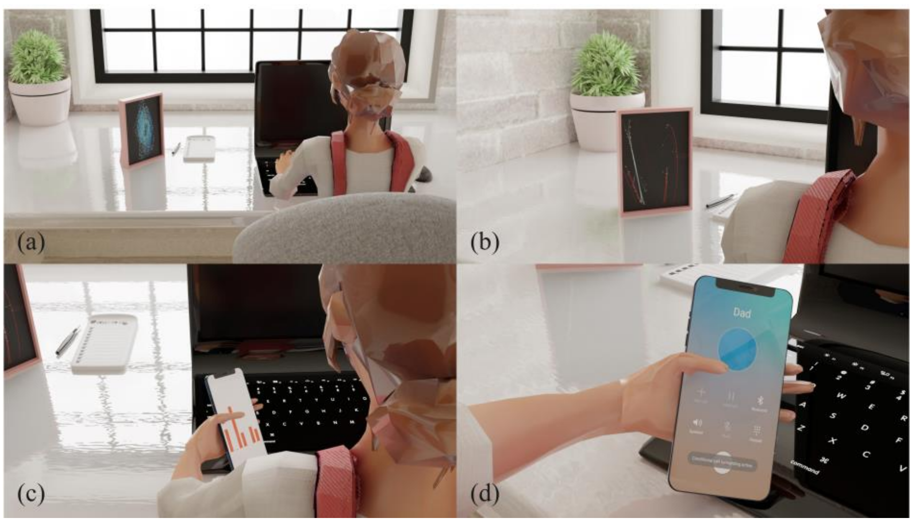


Figure 4.3. Renders of Scenario 2: (a) Sarah is working in the office with the digital painting placed on her desk; (b) the visualization catches Sarah's attention; (c) she opens the mobile app to check the health data; (d) Sarah contacts her father.

Placed on her office desk, Sarah takes occasional breaks to admire the painting, providing her with a moment of relaxation, while also allowing her to keep tabs on her father's health status. One day, while working in the office, Sarah noticed abnormal changes in the painting. She immediately checked the data on her phone and immediately made a phone call to her father.

4.2.4 User study

To test user acceptance of this artistic visualization concept and determine its feasibility, we carried out a user study to assess whether users can comprehend the design and evaluate its visual appeal. Two aspects A1 and A2 were considered:

A1 Comprehensibility: To what extent can users understand and correctly interpret the health states represented by the visualization?

A2 Attractiveness: To what extent do users find the visual design of the health data visualization acceptable and appealing?

4.2.4.1 Participants and Procedure

The user study involved 12 voluntary participants (marked as P1-P12), comprising 5 informal caregivers and 7 individuals between the ages of 22 and 52, with a mean (M) ± standard deviation (SD) age of 30.8 ± 8.99. The inclusion criteria for this study remained the same as in Study 1.

To examine A1, participants were shown four groups of visuals. Each group was generated by the same set of recursive equations and consisted of three visuals, each representing one of the health statuses: very good, good, and poor (See Appendix C for details). The order of the visuals within each group was randomized. Participants were tasked with matching each visual to one of the three health statuses. They were allowed to indicate that they were unsure. After finishing the visual matching task, the researcher informed participants of the intended health status associated with the visuals. A video (https://youtu.be/Lq5dtI-PNAc) was shown to the participants to demonstrate the visual transition process.

Participants were then asked to fill out a survey (Appendix D) consisting of three parts: basic demographic information, the AttrakDiff2 questionnaire (Hassenzahl et al., 2008) and, open-ended questions regarding user expectations and design feedback. The AttrakDiff2 questionnaire was used to assess A2, which is based on a 7-point Likert and semantic differential scale items; high scores indicate positive experiences. It evaluates the overall attractiveness of the visualization to participants from four perspectives: Pragmatic Quality (PQ), Hedonic Quality Identity (HQI), Hedonic Quality Stimulus (HQS), and, Attractiveness (AT) (Hassenzahl et al., 2003). It is worth noting that the Chinese version of the AttrakDiff2 questionnaire used in this study was adapted from Wang et al. (2015).

4.2.4.2 Results

Comprehensibility

The average number of correct answers provided by participants was 6.5 out of the 12 visuals presented (range from 4 to 10 correct answers, SD = 2.09), indicating a low rate of comprehensibility. Participants frequently experienced confusion or exhibited non-response during the task. Even when they answered correctly, it was often based on guessing or comparing with previous visuals. Participants expressed uncertainty about the meaning of the visuals, with one participant associating the visuals from Group 4 with tornadoes and perceiving them as indicating deteriorating health. This feedback highlights the importance of avoiding misleading patterns and the need for clearer visual indicators. Relying solely on a single mapping of health status and pattern complexity is insufficient.

Attractiveness

The mean values presented in Figure 4.4 indicate that participants generally perceive HealthHue as an attractive visualization.

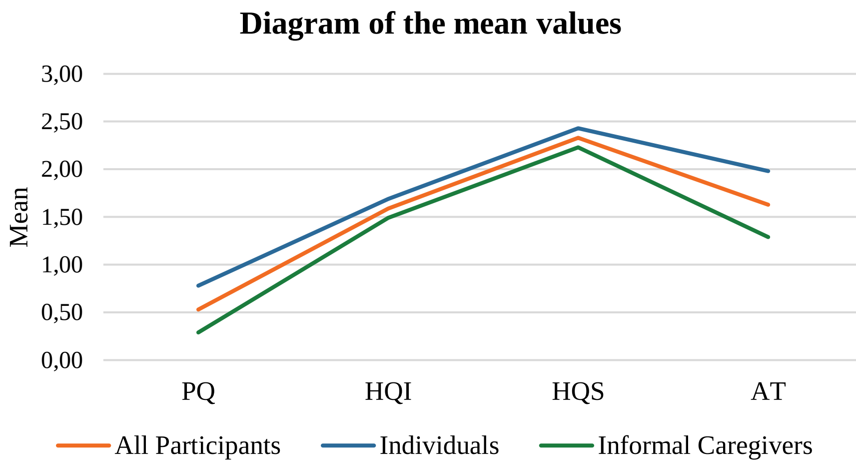


Figure 4.4. AttrakDiff2 questionnaire result: diagram of the mean values.

The overall mean score is 1.51 (SD = 0.99), with particularly high ratings for the perceived hedonic qualities (HQ) of HealthHue, in terms of identity (HQI) and stimulation (HQS). HQS received the highest mean score of 2.29, suggesting that participants find HealthHue visually appealing, and innovative. HQI, obtained a mean score of 1.51, indicating that participant users felt moderately connected or emotionally engaged with the visualization.

While the PQ score of 0.53 is lower than HQI and HQS, it remains in the positive range. This result can be attributed to the fact that HealthHue was evaluated solely based on visual representations, without detailed design specifications or actual application at this stage. To enhance the efficiency and effectiveness of HealthHue, it is crucial to consider practical implementation and address real-world use cases. These three qualities contribute to an overall AT level of 1.63, suggesting that HealthHue is positively received by users.

Furthermore, it is noticed that there is a similarity in the overall scoring trend between individuals and informal caregivers. However, it is observed that individuals assigned higher scores compared to informal caregivers, which indicates a higher level of preference or positive evaluation among individuals compared to informal caregivers. It suggests that individuals may have a stronger inclination towards HealthHue or find it more appealing in terms of its perceived qualities.

Figure 4.5 depicts the mean values of the word pairs, showing a more detailed result beyond the categories of PQ, HQI, HQS and AT. Extreme values provide information about specific characteristics that are particularly crucial or effectively addressed (Hassenzahl et al., 2003).

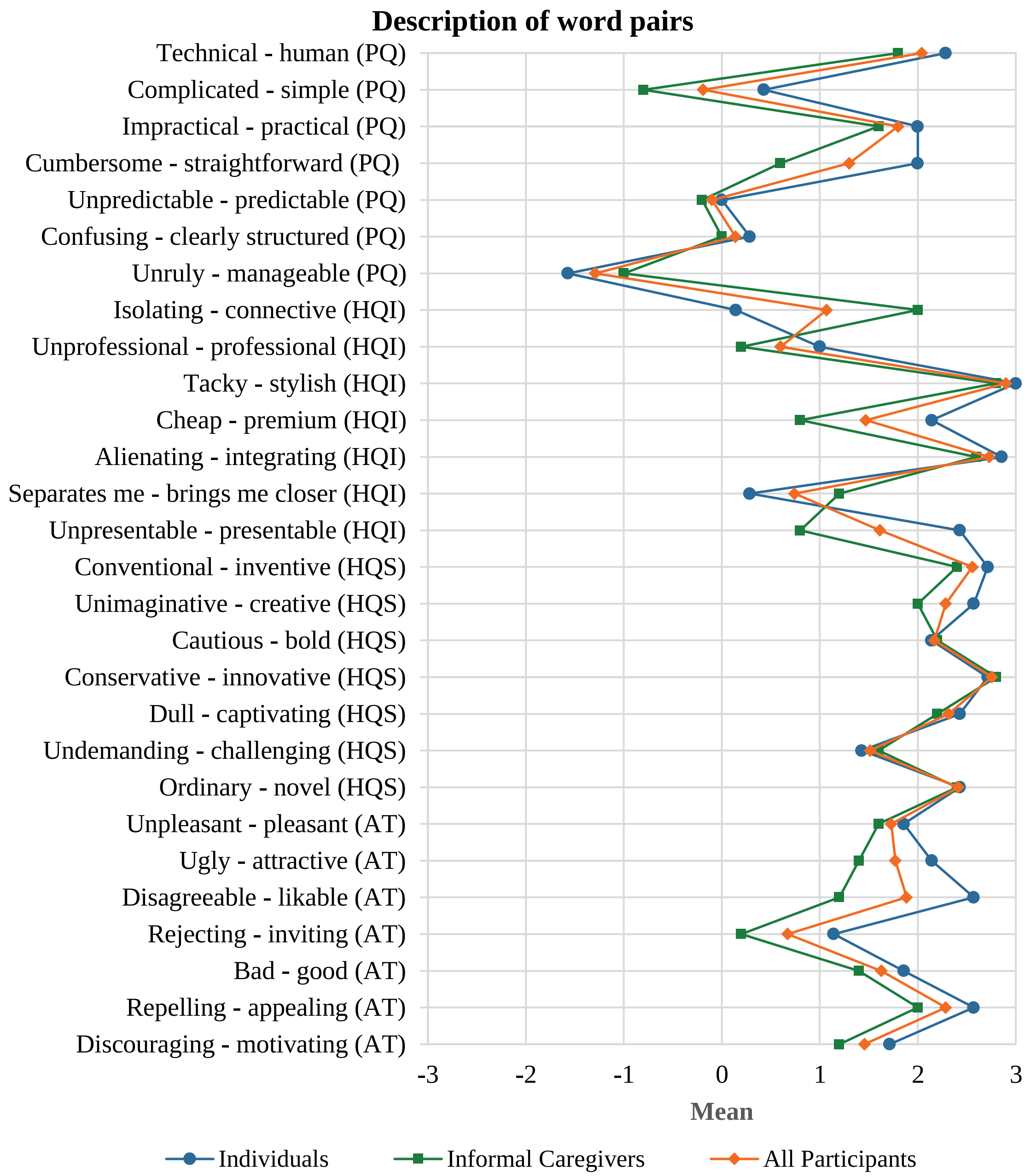


Figure 4.5. AttrakDiff2 questionnaire result: description of the word pairs.

Notably, three parameters show negative scores relative to the neutral line (0), which are the word pairs “Unruly - manageable” (M = -1.33), “Complicated - simple” (M = -0.08), and “Unpredictable - predictable” (M = -0.08), all belonging to the PQ category. These results suggest that participants perceive HealthHue to possess certain complexities or challenges in terms of its practicality or usability. It is worth mentioning that the word pair “Confusing - clearly structured” obtained a mean score of 0.17, which contrasts with the low comprehensibility of the visualizations reported by the participants. This might be caused by that participants received explanations about the visualization before completing the questionnaires, potentially influencing their perception.

Regarding the word-pair “Unprofessional - professional” (M = 0.2), it should be noticed that HealthHue is currently in the concept proofing/development stage and not a finalized product. Therefore, it may not fully meet users’ expectations of professionalism. This result aligns with the ongoing refinement process of HealthHue. The word-pair “Tacky - stylish” receives a score (M = 2.90) that nearly approaches the full score, suggesting a positive evaluation regarding the style. The word pairs “Conservative - innovative” (M = 2.76), and “Conventional - inventive” (M = 2.56) further reinforce the perception that HealthHue is viewed as stylish and innovative by participants. These findings highlight the appealing visual presentation of HealthHue and suggest a positive reception of its aesthetics.

Participants’ feedback and concerns

Some findings emerged from participants’ responses to open-ended questions. Participants questioned how the visuals would maintain a balanced quality between different groups and raised concerns about understanding the switching mechanism between different groups. Participants noted that constantly changing patterns could make it difficult to internalize and recognize the intended representations. They also proposed the function of allowing users to save or identify specific patterns of interest, indicating a desire for personalization. Another noteworthy aspect was participants’ questioning of the classification of health statuses as “very good”, “good”, and “poor”. They sought clearer definitions for these terms and expressed the need for more specific and standardized definitions. Practical concerns were also raised, such as the severity level associated with “poor” health and whether a classification of “very good” meant individuals could skip exercising or informal caregivers could relax their caregiving responsibilities.

4.2.4.3 Discussion

Although the results demonstrate user favor of HealthHue regarding its attractiveness (A2), proofing the feasibility of this artistic health data visualization concept, there is a significant need to enhance the comprehensibility of the visuals. The initial iteration showed a low rate of comprehensibility, primarily attributed to unclear and insufficient design mapping that hindered the effective communication of the intended health data. This resulted in notably low performance on A1 and therefore failed to meet design consideration C2. Furthermore, participant feedback underscores the importance of executing C4 to further evaluate the user experience of HealthHue.

4.3 Second Iteration: Revision and Implementation

The second iteration focuses on two main objectives: (1) improving users' direct comprehensibility of the visualization (C2) by remapping the visual elements and health data, and (2) integrating HealthHue with real-time health data and applying it to the existing RMT seamlessly (C4).

To achieve these goals, the Samsung smartwatch was carefully chosen as the platform for integrating and implementing HealthHue. Consequently, HealthHue was developed and deployed as a real-time clockface, referred to as HealthHue Clockface, visualizing heart rate and activity types. By seamlessly integrating HealthHue into the watch face, users can effortlessly access their own/care recipients' health information without the need for additional applications or menus (C4).

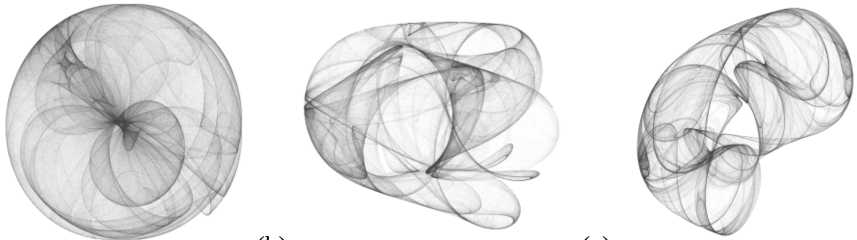
4.3.1 Design Revision

Based on the results of the previous user study, the following changes have been made.

4.3.1.1 Pattern Generation

A different approach was adopted for pattern generation, employing a specific class of recursive equations known as chaotic attractors. Chaotic attractors are characterized by their fractal structure, with each chaotic attractor exhibiting its own unique geometric features (Peitgen et al., 1992). The advantage of using chaos attractors is that they not only produce beautiful, abstract patterns but can also be finely controlled by adjusting certain parameters.

The Peter de Jong Attractor is an example of a chaotic attractor, an iterative system governed by four parameters: a, b, c, and d (Bourke, 1995). The attractor is defined by the equations: $x_{n+1} = \sin(a \times y_n) - \cos(b \times x_n)$, $y_{n+1} = \sin(c \times x_n) - \cos(d \times y_n)$. By iteratively calculating the coordinates using these equations, a set of coordinates is obtained, which can then be plotted in a two-dimensional space. The resulting patterns generated from the attractor can be varied by adjusting the values of the constants a, b, c, and d. Each unique pattern is specific to the particular combination of parameter values chosen, see below.



(a) (b) (c)

Figure 4.6. Example visuals generated by the Peter de Jong Attractor using different parameter values: (a) a = 2.0, b = -2.3, c = 2.4, d = -2.1; (b) a = 2.0, b = -2.0, c = 2.1, d = -0.7; (c) a = 2.0, b = -1.1, c = -0.6, d = -2.4.

4.3.1.2 Parameters Remapping

In the second iteration of HealthHue, the previous mapping was abandoned and two independent parameters were introduced: pattern color and visualization speed, which are related to heart rate and activity intensity, respectively.

Pattern color representation employs a color gradient approach known as color temperature. Color temperature is an attribute of color that universally evokes associations with hot and cold sensations (Ho et al., 2014; Ziat et al., 2016). In HealthHue, the visual patterns transition from cooler colors, such as blue and green, to warmer colors like orange and red, representing different ranges of heart rates from low to high (Figure 4.7). By utilizing this intuitive color gradient, users can easily interpret their heart rate status at a glance. It is important to note that for heart rates exceeding 160 beats per minute (bpm), HealthHue employs random behavior dots as a representation of disorder, aiming to draw attention to the potential danger associated with higher heart rates, serving as a visual alert for users.

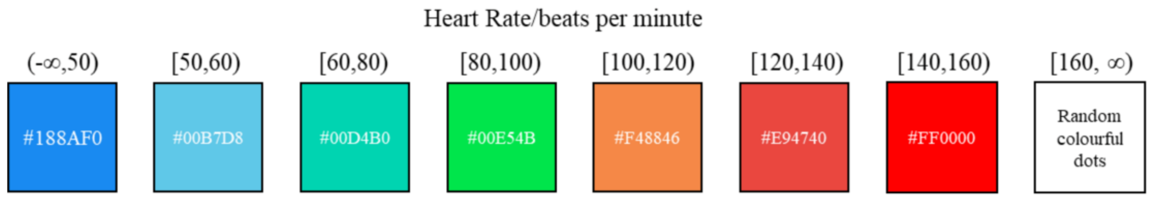


Figure 4.7. Mapping details of heart rate values and corresponding pattern colors.

The speed of generating the visualization is linked to activity intensity. When a user is in a sedentary state, such as sitting, the visualization progresses at a slower speed, gradually building up the patterns over time. During walking, the speed increases, resulting in a faster progression of the patterns. When a user performs a high-intensity activity, like running, the visualization speed reaches its maximum, facilitating nearly instantaneous generation in the patterns. By varying the visualization speed based on different activity levels, it aims to offer users a direct impression of the intensity of their activities.

Under normal circumstances, heart rate and activity intensity exhibit a direct linear relationship (Wiles et al., 2008). For example, higher heart rates are associated with higher-intensity activities. In this situation, the visual patterns displayed on the screen would exhibit warmer colors (e.g., red) and faster progression speeds. This alignment allows users to intuitively perceive the correspondence between the color representation and the speed of visualization, providing a clear indication of their current level of activity. However, if a conflict arises between heart rate data and activity intensity, such as a warmer color being displayed with a low speed, it serves as an indicator that something may not be as expected or optimal. This discrepancy alerts users to potential irregularities in their health or exercise performance.

4.3.2 Implementation

Figure 4.8 illustrates the framework of the HealthHue Clockface system. The smartwatch functions as a multi-sensor device worn on the user's wrist to sense data. This data is collected through the Human Activity Monitor API. The collected data is then processed and visualized in real-time directly on the watch itself, using a visualization program developed within the Tizen Studio programming environment.

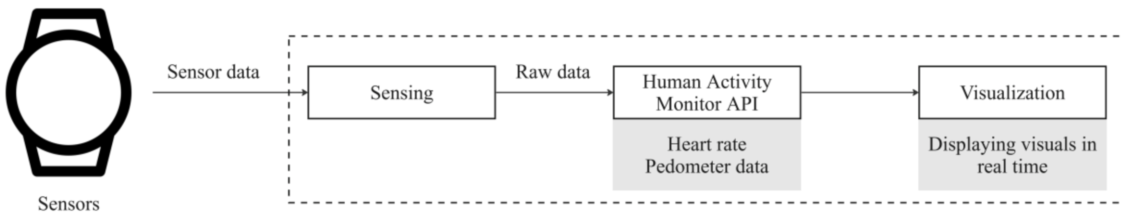


Figure 4.8. The framework of the HealthHue Clockface system.

The complete code for HealthHue Clockface is available on GitHub and can be accessed through the link: https://github.com/TQmsu/HealthHue-Clockface.git.

4.3.2.1 Integration with the Smartwatch

We used Samsung Galaxy Watch Active 2 as the vehicle for HealthHue Clockface, which has a 44mm diameter display with a 360×360 pixel resolution. This smartwatch uses Tizen OS 5.5.0.2 as the operating system. Tizen Studio was used to create a custom watch face, by using Tizen Studio it is easy to integrate with several available application programming interfaces (APIs) (Get Started With Tizen Wearable Applications | Tizen Docs, 2023). The Human Activity Monitor API was used to retrieve heart rate and pedometer data from the device (Human Activity Monitor | Tizen Docs, 2023). The pedometer data was utilized for activity tracking and categorization, encompassing activity types to sitting, walking, and running. Instead of explicitly defining intervals for collecting heart rate and pedometer data, the system sets up callback functions that are triggered whenever new heart rate or movement data becomes available.

Additionally, a user-friendly feature was implemented, allowing HealthHue Clockface to display upon the actions of raising the wrist or tapping the screen of the Samsung smartwatch. This was done by navigating to "Settings", followed by "Advanced" and then selecting "Screen wake-up", where "Wake-up gesture" and "Touch wake-up" were all turned on.

4.3.2.2 HealthHue Clockface

HealthHue Clockface was deployed as a watch face application using JavaScript and HTML5 in Tizen Studio. HTML5 canvas has been used to render the watch layout and content, including the hour, minute, and second needles. By connecting to the internet via Bluetooth or WIFI, precise time synchronization can be established automatically. Additionally, the application sets up an event listener to handle visibility changes and ensure the screen updates immediately when the device wakes up or the screen becomes visible. If the device goes to sleep or the screen is locked, the system performs a cleanup function, which clears the canvas.

The clockface incorporates a chaotic attractor system, which generates intricate patterns based on mathematical equations. We have selected the Peter de Jong Attractor and the Pickover Attractor as the initial attractors in the implementation, which are known for their unique and visually appealing chaotic behavior (Sprott, 1998). A set of predefined parameters has been implemented to ensure consistent quality visual outputs.

Following the parameters remapping, the color of the attractor pattern to be drawn is determined by the heart rate value (initially set to 0). This is achieved by utilizing an array called “heartRateRanges”, which defines different ranges of heart rates and their corresponding colors. Each range object in the array has a min and max property that specifies the minimum and maximum values for that heart rate range, along with a color property that defines the color associated with that range. If the heart rate value is higher than 160 bpm, a set of random dots is generated by using the “Math.random()” to determine the coordinates and size. The layout canvas color was set to black.

Figure 4.9. HealthHue Clockface examples: from left to right, progressively representing increasing heart rates; the last one is over 160 bpm.

The animation speed of the clock face is contingent on the value of the “movementStatus” variable, which denotes the user’s current movement status obtained from the pedometer. There are three categories for movement: “NOT_MOVING”, “WALKING”, and “RUNNING” (initially set to “WALKING”). Each movement status corresponds to a different “timeInterval” value, which controls the animation speed. The time interval determines the delay between each frame update, thus affecting the pace of the visual animation, which allows the animations on the clockface to vary based on the user’s activity type. Specifically, if the movement status is “NOT_MOVING”, the time interval is set to 500 milliseconds. If it is “WALKING”, the time interval is set to 100 milliseconds. And if it is “RUNNING”, the time interval is set to 1 millisecond.

4.3.3 User Study

The primary objective of this user study was to assess the user experience of HealthHue Clockface from two perspectives: individual users and individuals envisioning themselves as informal caregivers. A combination of direct user interaction and the envisioning of caregiving experiences was employed. To facilitate the envisioning process, the study adopted a "Co-constructing story" approach with modifications tailored to the specific context of the study. This approach provided a platform for participants to use their creativity, empathy, and personal experiences (Buskermolen & Terken, 2012), to envision themselves as informal caregivers and share their feedback accordingly.

4.3.3.1 Participants

Participants were recruited through convenience sampling from a private gym located in a residential building, in Eindhoven, the Netherlands. The gym was selected as the recruitment site due to its convenient accessibility and potential to attract people who met the following criteria: (1) good health status, (2) normal color vision without any impairments or deficits, (3) have used a fitness application or comparable RMT devices for more than 2 weeks during the past 6 months, (4) have experience providing care to someone for more than one week (excluding full-time caregiving), and (5) can speak English fluently.

In total, 4 participants (3 males and 1 female, marked as E1-E4) within the age range of 22 to 28 years old (M = 25.0, SD = 2.50) were recruited. Before participation, all participants were briefed on the purpose of this study and asked to provide digital informed consent. This study was conducted with the approval of the TU/e Ethical Review Board. All participation was voluntary.

4.3.3.2 Study Setup

This study was conducted in the aforementioned gym, equipped with a meeting room space and a fitness space. The feedback sessions and preparations took place in the meeting space, which provided a quiet and comfortable space for discussions. The fitness space was used for the interaction with HealthHue Clockface. Throughout the study, the gym was used only by the researcher and participants to ensure privacy and eliminate distractions from other individuals.

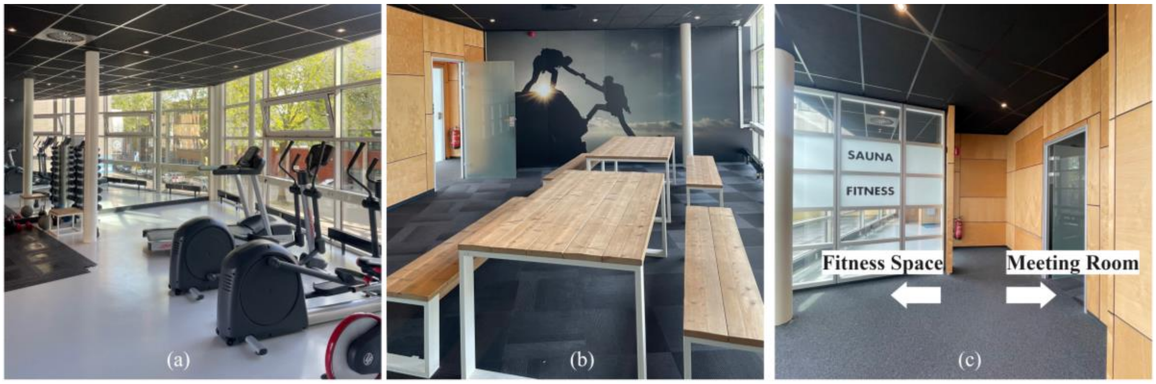


Figure 4.10. (a) Gym area. (b) Meeting room space. (c) The hallway leads to the fitness and meeting room space.

4.3.3.3 Materials

As in the implementation section, we used the same Samsung Galaxy Watch Active 2. To minimize potential distractions, all notifications and the notification panel on the smartwatch were disabled.

We deployed HealthHue Clockface on the smartwatch, offering two modes. In Mode 1, the clockface was adjusted in real time based on the user's heart rate and activity types. In Mode 2, a predetermined sequence of visuals was displayed, independent of real-time data inputs. Two modes could be switched through the settings menu, select "Watch faces", and choose between Mode 1 or 2. Both modes were activated by raising the wrist, tapping the screen, or pressing the Back/Home key.

4.3.3.4 Procedure

The procedure consisted of two sections.

Section 1

Preparation for Section 1 (10 minutes): Participants completed a questionnaire to provide basic demographic information. They were then provided with a Samsung smartwatch set to HealthHue Clockface Mode 1 to wear throughout Section 1, with clear instructions on how to interact with it.

Interaction with HealthHue as Individuals (20 minutes): Participants were asked to perform three different activities: sitting, walking, and running. Walking and running activities were conducted on a treadmill with speeds tailored to each participant's fitness level and ability. The order of activities was randomized, and participants were encouraged to interact with the visualizations.

Feedback Collection as Individuals (10 minutes): After the interaction, participants took part in a semi-structured interview to provide qualitative feedback on usability, aesthetics, comprehension of visual cues, and overall satisfaction. Likert scale ratings from 1 (strongly disagree) to 5 (strongly agree) were used to assess their responses to the following guiding statements:

S1 This visualization effectively represents my health-related data/information.

S2 I prefer this visualization over the established visualization I currently use.

S3 I would like to regularly use such a visualization method in the future.

Section 2

Preparation for Section 2 (10 minutes): Before Section 2 started, participants returned the Samsung smartwatch to the researcher. The researcher then switched the clockface setting to Mode 2.

Envisioning as Informal Caregivers (20 minutes): In the sensitization phase, participants were presented with a fictional story featuring the character Jack, through sketching (Figure 4.11). Jack was portrayed as a full-time employee and an informal caregiver for his father. The story depicted various scenarios: constant attention and monitoring of his father, distractions from work due to checking health data, struggles with understanding professional health terminologies and interpreting the health data, and experiencing fatigue and disinterest from daily health monitoring.

The researcher narrated these scenarios to participants and encouraged them to reflect on relatable situations. The researcher led this process by asking questions such as what the context was, whom he/she was taking care of, what he/she was doing, why he/she was so frustrated, and why he/she was happy.

Figure 4.11. The sketch storyboard.

In the envisioning phase, participants were provided with the Samsung smartwatch again to wear. They were informed that the visualizations on the HealthHue Clockface no longer represented their health information but instead reflected the health information of the person they were caring for. Participants were instructed to view the visuals presented on the HealthHue Clockface in Mode 2. The researcher accompanied this process by providing explanations to aid participants' understanding of the visuals. This process aimed to reinforce their knowledge gained from previous visual explorations and meanwhile ease the transition in perspective in a short period of time.

Participants were asked to retell their stories from the sensitizing phase and imagine how their experiences would have been different if they had used HealthHue Clockface. They were encouraged to consider both HealthHue Clockface and the broader concept of HealthHue.

Feedback Collection as Informal Caregivers (10 minutes): Lastly, participants were asked to share their insights, thoughts, and emotions regarding the experience of using HealthHue Clockface as informal caregivers. Open-ended questions (Appendix E) were used to gather qualitative feedback on the effectiveness, relevance, and impact of HealthHue within the context of caregiving.

4.3.3.5 Data Analysis

The feedback sessions were audio-recorded and transcribed for analysis purposes. Thematic analysis was used to identify recurring themes, patterns, and insights derived from the participants' experiences.

4.3.3.6 Results

Feedback from the perspective of individuals

The interaction of participants with HealthHue Clockface was a positive outcome, as evidenced by the mean scores on the Likert scale (Figure 4.12). Participants expressed a clear preference for HealthHue Clockface and indicated that they would like to use it in the future. They found this visualization interesting, visually appealing and well-integrated into their daily routines.

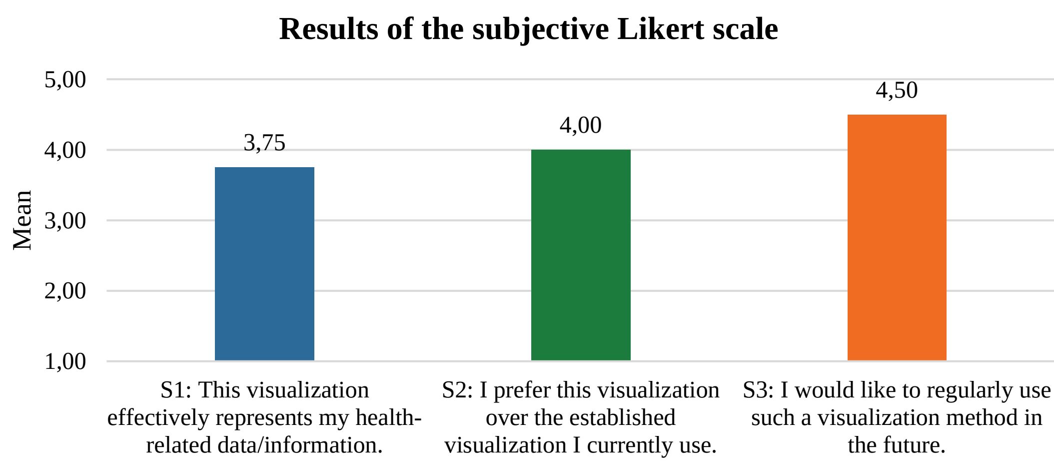


Figure 4.12. The results of the mean scores of subjective feedback.

Clarity and effectiveness. Participants unanimously acknowledged the effectiveness of the visualization in representing heart rate value. They appreciated the clarity of the color scheme. However, there was uncertainty regarding the meaning of the abstract patterns. Although the intention was for the patterns to have no specific information, participants questioned whether they held any significance.

Desires for other health indicators and personalization. Participants expressed a desire for more comprehensive information beyond heart rate and emphasized the importance of user personalization. For example, E4 stated, "Sometimes heart rate is not the only indicator […] I want to know a little bit more information […]". This suggests the inclusion of more health indicators. Some participants mention specific health concerns they would like to monitor, such as blood glucose levels, indicating the importance of customization options to cater to individual needs, as suggested by E4.

Comparison with established visualization and visual appeal. Participants had varied opinions when comparing HealthHue Clockface with the conventional visualization tools they used before. Most participants (n=3) expressed a preference for HealthHue, citing its convenience on the smartwatch and its visually appealing display. However, they also pointed out that this new visualization should not be seen as a replacement for traditional visualization methods, which is in line with our design purpose. They explained that each visualization serves a different purpose depending on the context, as E2 remarked, "I see the benefits of them working together [...] I can choose which one to use in what situation."

Dynamism. Opinions varied among participants regarding dynamism. Some participants found the generation speed to be less significant but appreciated its contribution to the overall aesthetic appeal. Some suggested incorporating additional movement or interactive elements to convey urgency. There was also a suggestion to explore dynamic patterns that that "resemble the fluid motion observed in movies" [E1]. This suggests indicating a shift in focus from visual generation speed to visual movement speed.

Feedback from the perspective of informal caregivers

Speed, efficiency, and relevance. Participants emphasized the importance of quick updates in the caregiving context. They indicated that the current design of pattern generation speed is of little value. As E1 said, "When you want to check on someone, you want it to be fast, not slow." Besides that, They also stressed the significance of practicality and relevance, where the information presented should be clear, meaningful, and actionable. Ambiguity or excessive assumptions were seen as potential drawbacks, as caregivers need accurate and specific insights to make informed decisions.

Abstract, artistic representation versus detailed health data. Participants recognized the visual appeal of HealthHue but questioned its suitability in the caregiving context. They stressed the importance of reliable and precise data visualization to establish trust in the provided insights. Participants expressed concerns about using a single artistic visualization to monitor all the necessary health data for caregiving, highlighting the need for an approach that incorporates more data types into the visual representations. E2 further commented, “Even though I can go and examine specific data, I think I would be more anxious […] it would make me want to check more often about the data”.

Intent to use and desires for personalization. Participants’ opinions on using HealthHue in the future depend on their specific caregiving situations. Some expressed interest in utilizing this tool as its non-intrusive nature and the ability to access information without constant monitoring. This indicates a positive inclination towards using HealthHue as an informal caregiving tool. While other participants felt that it may not be suitable for their particular caregiving situations. Factors like the specific needs of the care recipient, the type of illness or condition, and the required focus areas influenced their perception of HealthHue’s usefulness. These participants emphasized the need for personalized data choices that align with their caregiving responsibilities and the unique health issues of the person they are taking care of. As E2 noted, “different diseases or conditions require us as informal caregivers to focus on different things, different data or aspects.” They suggested that the system should allow them to select and customize the health indicators they wish to monitor. As a result, it was noted that HealthHue Clockface may not be helpful for them.

Potential application opportunities of HealthHue. E1 pointed out an unexpected potential application of HealthHue in monitoring the health of animals as “they can usually not talk, so it’s hard to usually see what’s happening with them.”. E4 expressed a desire to have the visualization displayed as a painting at home, so “me and my mother we can look at it together, I think she will also get benefit from it.” This suggests that HealthHue could serve as a meaningful and engaging decorative piece that promotes well-being within the household. E4 also suggested using the visualization as a lock screen background for the phone, so “[…] if I can know my mom is fine now before I open my phone then I don't have to waste any more time.”

4.3.3.7 Discussion

From the perspective of individuals, the experience of interacting with HealthHue Clockface was very positive. Participants expressed a clear interest in HealthHue Clockface and indicated their willingness to use it in the future. The high mean scores on the Likert scales demonstrate the overall satisfaction of participants with HealthHue Clockface. These findings suggest that artistic visualizations have the potential to enhance user engagement with RMTs and to make the user experience more enjoyable.

The visually appealing display of HealthHue Clockface was a distinguishing factor compared to conventional visualization methods. While most participants preferred HealthHue Clockface over conventional visualizations as individual users, they also mentioned the importance of the coexistence of different visualization methods and the applicability of context. This is consistent with our design intent to develop HealthHue not as a replacement but as a complementary tool that works in tandem with the conventional ones.

The use of color in HealthHue Clockface improved participants' understanding of the visualization compared to the first iteration. However, there was some uncertainty among participants regarding the meaning of the abstract patterns used. Regarding the speed and dynamic elements of the visualization, participants did not perceive significant value in these aspects. Nevertheless, they acknowledged the aesthetic appeal of the generation process, while some suggested that dynamism could be used to represent health information. These findings indicate that there is big room for further design exploration and improvement.

From the perspective of informal caregivers, participants highlighted the importance of quick updates, and data relevance within the caregiving context. They expressed concerns about the applicability of an artistic representation in the caregiving process. Some of them mentioned the need to monitor multiple data, indicating that the abstract visuals may not effectively support caregiving in such cases. These insights raise the need for a differentiated design tailored to the specific needs of different types of informal caregivers. Personalization and customization options were further emphasized as crucial considerations to address the diverse data monitoring requirements.

Overall, the user experience of the artistic visualization, HealthHue Clockface, was perceived positively in terms of visual appeal and integration into daily routines. However, there were desires for more comprehensive information, personalization options, and the inclusion of additional health indicators. The suitability of the visualization in the caregiving context was questioned, with a preference for reliable and precise data visualization. The intent to use HealthHue depended on specific caregiving situations, and potential applications beyond personal health monitoring were identified. These insights will guide the refinement of HealthHue for its next iteration.

5 Limitations and Future Work

Although the findings of this study are overall positive, several important limitations need to be acknowledged. A major limitation of this research was the small sample size, which resulted in the findings not being generalizable to a broader population. The individual participants involved in this study were all healthy adults disinterested in health-related data. This factor influenced our design considerations and the overall design process, potentially making the visualization unsuitable for patient populations with unique needs and valuable insights about specific data. Therefore, we intend to include patient groups in future studies for a more comprehensive investigation.

Moreover, we recognized that informal caregivers have varying needs in terms of the data or aspects they need to monitor. Thus, future studies will necessitate a reassessment and re-screening of target users, which may involve conducting a comprehensive contextual study similar to Study 1. This will also help accommodate the users' visions for customizable visualizations. Although HealthHue Clockface is currently designed to visualize the heart rate and activity type, it has the potential to visualize other data that can be easily achieved on a technical level. This adaptability allows for the expansion of visualization capabilities to accommodate a broader range of relevant data. Meanwhile, it is crucial to explore how artistic, abstract visualizations can establish connections or direct mappings to specific health indicators. Despite undergoing two rounds of iteration, this visualization still causes confusion to some participants. Balancing abstraction and artistic expression with providing straightforward information poses a challenge that deserves further attention in future research efforts.

In terms of connecting Chaos theory to visualization, this study did not establish a direct link between chaotic attractors and health data. However, based on the literature, it was evident that chaotic behavior can reflect human biological rhythms (Biswas et al., 2020; Muhammet et al., 2019). While this aspect was not the primary focus of the study, it presents an intriguing avenue for future exploration of the fields of mathematics and health informatics. Chaos theory, with its complexity and numerous unexplored areas, could potentially offer meaningful connections or explanations between beautiful patterns and health data.

Regarding the findings of the last user study, participant feedback suggests that HealthHue Clockface may be better suited for individual users. However, it could have been influenced by the "Co-constructing story" method employed. Feedback from the informal caregiver perspective relied on the researcher's narrative and participants' imagination, introducing a level of detachment from the actual experience. This discrepancy might have influenced their perceptions. Therefore, for future study, we propose to first implement the feature that visualizes the health data of care recipients and conduct field trials with actual users interacting with HealthHue Clockface in a natural environment. Additionally, it is crucial to continue developing other potential applications, such as the digital painting mentioned in the previous user scenarios. By doing so, we can assess the feasibility and potential benefits of HealthHue in various contexts.

Lastly, it is important to note that this study is still in the preliminary stages of developing a new artistic visualization. While participants were asked to compare HealthHue to traditional visualizations to tell preferences, there are no standardized criteria or definitive answers to assess accuracy in this context. Future research should incorporate more rigorous controlled evaluations that allow users to compare and provide feedback on various visualization methods in the same context. Additionally, the impact of such visualizations on specific user attitude changes, behavioral changes, and outcomes is unclear at this stage. Therefore, it is suggested for extensive long-term research in real-life settings to observe and study the specific impact of such artistic visualizations. By doing so, we can build a more comprehensive understanding of the value of this artistic visualization.

6 Conclusion

This thesis reports the ongoing user-centered research design and implementation process of an artistic health data visualization, providing early insights. It consisted of two studies, each with distinct objectives. Study 1 aimed to explore the preferences and requirements of individuals and informal caregivers regarding health data visualization in RMTs. Through surveying our target user groups, invaluable feedback was obtained, shedding light on their needs and providing insights for preliminary design ideas. These findings led us to establish fundamental design considerations that served as the cornerstone for Study 2.

Study 2 introduced HealthHue, an artistic health data visualization that utilizes the beautiful patterns generated through chaotic attractors for the aim of use in personal or casual settings prioritizing an enjoyable and intuitive interaction with health data. Specifically, it delivers health-related information to individuals (when they are the users themselves) or care recipients (when the users are informal caregivers) in personal or casual settings. HealthHue was implemented as a live clockface on the Samsung smartwatch (HealthHue Clockface), visualizing real-time heart rate and activity type. While participants appreciated the appealing appearance and novelty of HealthHue, feedback from the informal caregiver perspective raised notable criticisms, indicating the need for further improvements.

Moving forward, the next steps encompass two main directions: firstly, further refining the visualization and conducting validation tests on HealthHue Clockface within patients and informal caregiver populations over an extended period to evaluate its long-term influence in a real-life context. Secondly, we intend to explore other applications of HealthHue in different scenarios based on the specific needs of individual users/patients and informal caregivers.

Overall, this study contributes significantly to the advancement of novel artistic visualization approaches in the field of healthcare. By addressing the crucial need for visualizations that convey health data in a more meaningful way to a broader audience, this research project fills a critical gap. The insights and findings gained from the development and implementation of HealthHue can inform future research and guide the design of visualizations that support self-management and health monitoring.

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A Survey for Study 1 (English Version)

Data visualization refers to the use of charts, graphs, and other visual tools to present data in a way that is easier to understand and analyze. In the context of health, data visualization is often used to display health metrics such as blood sugar levels, weight, and step count to help individuals better manage their health.

Health tracking refers to the use of applications, devices, and other tools to record and analyze health data such as step count, heart rate, and sleep patterns. These tools can help people better understand their health status and provide personalized recommendations and advice to help them manage their health.

Self-management refers to the measures people take to control and improve their health. These measures may include regular exercise, healthy eating, monitoring blood pressure or blood sugar levels, and more. By taking these measures, people can better manage their health, reduce the risk of disease, and improve their quality of life.

Before starting the questionnaire, please provide some basic information about yourself:

Gender: ☐ Male ☐ Female

Age: ☐ Under 20 years old ☐ 21-30 years old ☐ 31-40 years old ☐ 41-50 years old ☐ 51-60 years old ☐ 60 years old and above

Education level: ☐ High school/vocational school ☐ Associate's/Bachelor's degree ☐ Graduate degree ☐ Doctorate or higher ☐ Other ____________

Theme 1: User experience with RMT(s)

1. Can you tell me about how long have you been using RMT(s)?
2. How often you typically check your health data via the mobile app?
3. Has your use of RMT(s) changed over time, for example, have you checked your/your care recipient’s health data more or less frequently, or do you understand or react to this data differently than you did at the beginning of your use? If so, can you describe these changes specifically and why?
4. Do you think you can understand what the health data you view on the mobile app means? For example, heart rate of 75, a heart rate variability of 135, and a ventilation index of 21, what does this mean to you?
5. What specific information or explanations are you looking for when viewing the health data?
6. Do you think the RMT and its mobile app that you are using/used helps you to better understand your/your care recipient’s health status? If yes, can you describe a specific moment in your use that stood out to you and the reasoning behind it? If not, can you share your thoughts and reasons?

Theme 2: Experiences with health data visualization and suggestions on improvement

7. Have do you think about health data visualization? Does it help you in your/your care recipient's health management? If so, how?
8. (For informal caregivers: Have you used any other data visualization tools besides Slaap Lekker? How is your experience with them? Does it help you in your/your care recipient's health management? If so, how?)
9. What difficulties have you encountered when trying to track your/your care recipient's health data? (e.g., difficulty understanding the information or not knowing what specific actions to take in response)
10. Have you ever received guidance or support from a professional healthcare provider or other source to help you manage your/your care recipient's health? How does this compare to the experience of using data visualization tools?
11. What features or functions do you think are missing from current health tracking devices and visualization tools, or what improvements would you like to see? And why?
12. What impact has using health tracking and visualization tools had on the process to your/your care recipient's health management? Has it helped improve your/your care recipient's health and overall well-being?
13. What do you think are the most important factors for successful health management? And how can health tracking and data visualization tools help you address these factors?
14. Do you have any suggestions or expectations for presenting health data in a more understandable way? If so, please talk specifically about it.
15. Do you have any suggestions or expectations for presenting health data in a more user-friendly, emphatical, and warm way? If so, please talk specifically about it.
16. What features or functions would you like to see in health tracking and visualization tools in the future?

Section 3: Design preferences and feedback

17. Please describe what your first impressions of the above designs.
18. Do you think them easy to understand? And why?
19. Do you think they are user-friendly, empathetic, and warm? And why?
20. Are there any design elements that make you feel confused or dissatisfied? If so, how would you like to improve it?
21. If you have any idea about the design, please feel free to make a simple sketch. Even if it's just a simple line drawing, we welcome it! We will seriously consider your comments and continue to improve our design.

B Survey for Study 1 (Chinese Version)

注意：以下问题旨在了解用户对健康追踪和可视化工具的使用和改进的看法。如果您对术语不熟悉，请不要担心，在答案中使用简单的语言并尽可能提供实例。

数据可视化指的是使用图表、图形和其他可视化工具来呈现数据，以便更好地理解和分析数据。在健康领域中，数据可视化通常用于展示健康指标，如血糖水平、体重、步数等，以帮助个人更好地管理自己的健康（此处指传统形式的数据可视化）。

健康追踪是指使用应用程序、设备和其他工具来记录和分析健康数据，例如步数、心率、睡眠模式等。这些工具可以帮助人们更好地了解自己的健康状况，并提供个性化的建议和建议，以帮助他们更好地管理自己的健康。

自我管理是指人们采取措施来控制和改善自己的健康。这些措施可以包括定期锻炼、健康饮食、监控血压或血糖水平等。通过采取这些措施，人们可以更好地管理自己的健康，降低疾病风险，并提高生活质量。

非正式护理人员是指家人、朋友或其他无报酬为某个健康状况的人提供援助和支持的个人。

问卷开始之前，请您填写一些您自己的基本信息：

性别：☐男性 ☐女性

年龄：☒小于 20 岁 ☐21-30 岁 ☐31-40 岁 ☐41-50 岁 ☐51-60 岁 ☐60 岁以上

受教育程度：☐高中/中专/技校 ☐大学专科/本科 ☐研究生 ☐博士及以上 ☐其他 ___________

护理类型：☐照顾孩子 ☐照顾配偶 ☐照顾父母

护理时长：☐少于 1 年 ☐1-3 年 ☐3-5 年 ☐5 年以上

护理专业知识：☐专业医疗人员 ☐有相关护理知识或培训经验 ☐没有相关护理知识或培训经验

请简单描述您在支持/帮助您家人健康管理的角色（作用）：

____

____

____

主题 **1**：使用睡客智能智能睡眠与健康监护仪（睡客智能设备）及其移动应用的用户经验

1. 请问您(的家人)使用睡客智能设备有多长时间了？
2. 平均而言，您通过睡客智能手机应用程序检查您家庭成员的健康数据的频率是多少？
3. 随着时间的推移，您对这种健康追踪技术的使用是否发生了变化，例如您查看健康数据的频率增加或减少了，或者您对这些数据的理解或反应与使用初期不同了？如果有，您可以具体描述一下这些变化以及原因吗？
4. 您觉得您能理解在睡客智能手机应用程序上所查看到的健康数据意味着什么吗？您可以举具体的例子说明，比如心率为 75，心率变异性 135，通气指数为 21，意味着什么呢？
5. 您在查看这些健康数据时通常在寻找哪些具体信息或者解释？
6. 使用睡客智能设备和其手机应用程序是否有助于您更好地了解您的家人的整体健康状况？如果是的话，您可以具体描述一个使用期间让您记忆深刻的时刻以及背后的原因吗？ 如果不能，您可以分享以下您的想法以及原因吗？

主题 **2**：使用可视化工具的经验及相关的改进建议

7. 您是否使用过其他数据可视化工具来帮助您或您的家人追踪健康数据？如果有，它们是什么，您如何评价它们？(它们是否在某种程度上帮助了您？)
8. 当您尝试追踪您或您的家人的健康数据时，您遇到了哪些困难？(例如:难以理解这些信息或不知道该采取什么具体行动来应对)
9. 您是否曾经从专业的医疗保健提供者或其他来源获得过指导或支持，以帮助您管理您或您家人的健康状况？这与使用数据可视化工具的体验相比如何？
10. 您认为目前的健康追踪设备和可视化工具缺少哪些功能或特性，或者您希望看到哪些改进？为什么？
11. 使用健康追踪和可视化工具对您支持您家人的健康管理产生了什么影响？这对您的家人整体健康和福祉的改善有没有什么帮助？
12. 在您看来，成功管理健康的最重要因素是什么？健康追踪和数据可视化工具如何帮助您应对这些因素？
13. 您是否有任何关于以更易于理解的方式呈现您的健康数据的建议或期望？如果是的话，请具体谈论一下。
14. 您是否有任何关于以更人性化、更有人情味、更有温度的方式呈现您的健康数据的建议或期望？如果是的话，请具体谈论一下。
15. 您希望未来在健康追踪和可视化工具中看到哪些功能或特性，以便更轻松地管理健康？

主题 **3**：设计意见收集

亲爱的参与者，我们正在开发一款健康数据可视化工具，可以与移动应用程序集成或独立使用。**您可以将其用作手机或笔记本电脑的壁纸，甚至作为您家中展示的数字绘画**。不同于常规传统的数据可视化工具（图 2），该设计旨在用艺术化的抽象形式（图 2）呈现健康（数据）状态以提高个人和他们的非正式护理人员日常生活中对健康状况的意识和理解。它并不旨在取代现有的健康数据呈现方式，而是与其结合使用，为个人及其非正式护理者在自我管理方面提供更有效的支持手段。

下面是对与不同类型数据可视化的简单介绍，本设计侧重于第二类艺术抽象形式的数据可视化：

传统类数据可视化

传统数据可视化是将数据以图形或视觉格式表示的过程，例如图表、图形或地图。目标是使复杂的信息更易于理解，并突出数据中的模式、趋势和关系。传统数据可视化通常用于商业、经济和科学领域。

示例图片：

图 1： 传统类数据可视化，摘于睡客智能。

艺术抽象类数据可视化

抽象数据可视化是一种较新的方法，使用更具创意和艺术性的技术以视觉上吸引人的方式呈现数据。抽象数据可视化的目标不一定是传达特定的信息或见解，而是创建独特而引人入胜的视觉体验，让用户以更沉浸和互动的方式探索数据。

示例图片：

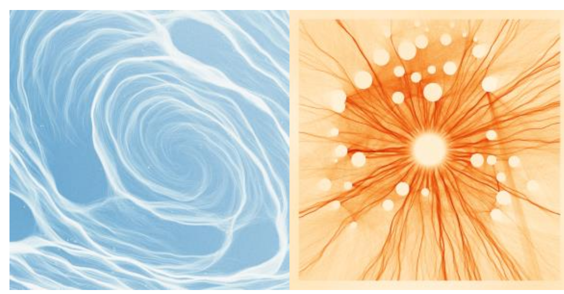


图 2： 艺术抽象类数据可视化，摘于 https://www.visualcinnamon.com/art/elemental-flows/

以下是一些初步的设计构思。

请注意，所提供的示例图片仅旨在让您大致了解设计可能的外观。最终设计在形式、颜色和其他细节方面可能会有显著的差异。因此，我们诚挚地请求您专注于所呈现的设计理念和概念，而非图片的具体细节。

设计 A：像素艺术表现

当健康状态最佳时，像素绘画将是完整的（图 3），但随着健康状态下降，一些像素将逐渐变为灰色（图 4）。变为灰色的像素数量取决于当前健康状态。因此，健康水平在下降，变为灰色的像素就越多，从而创建了健康状况的视觉表示。

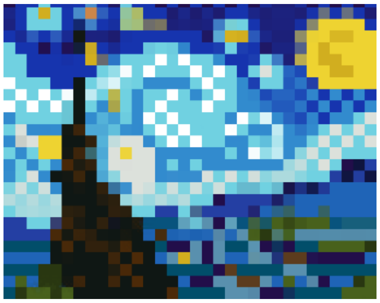


图 3： 完整的像素画（原型为梵高的星夜）。

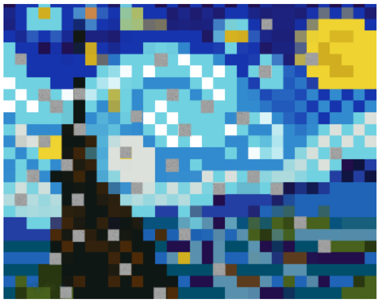


图 4：添加了灰色像素之后的呈现。

设计 B：健康环

使用 Borromean 环作为整体健康的比喻。每个环将代表不同的健康指标，例如心率、血氧和呼吸率。当所有指标都在健康范围内时，这些环将完全相互交错（图 5），形成完整 Borromean 环。如果任何一个指标超出健康范围，相应的环将变得不连续 (图 6)，表示亚健康状态.

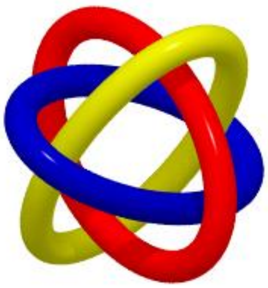


图 5：完整的 Borromean 环。

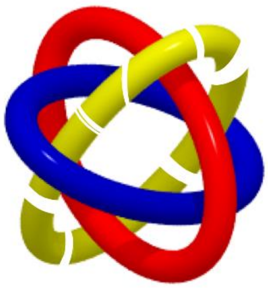
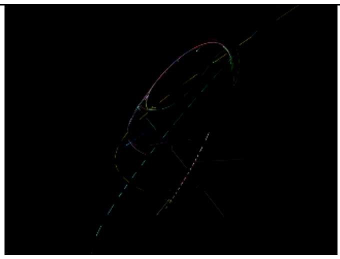
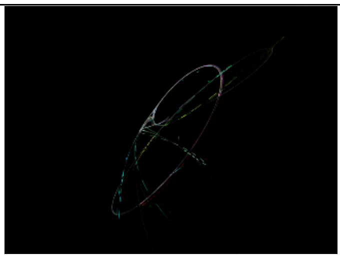
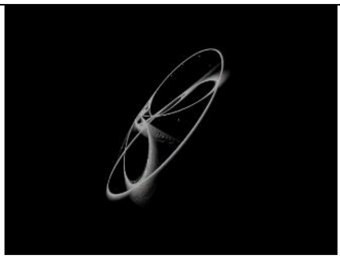
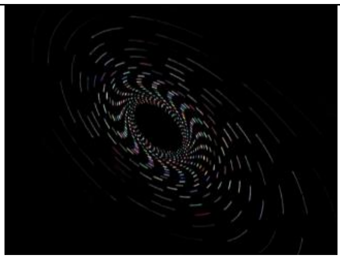


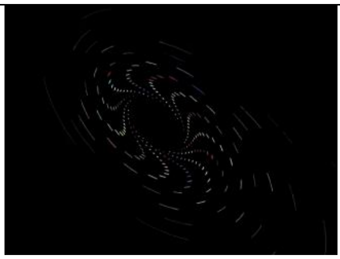
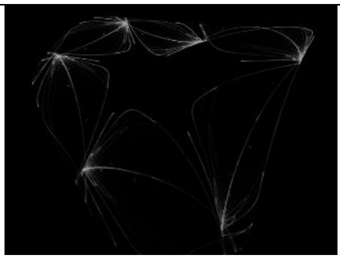
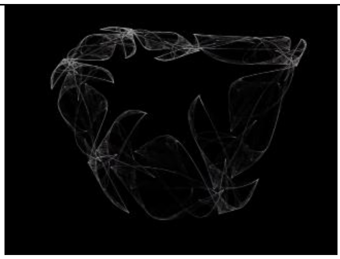
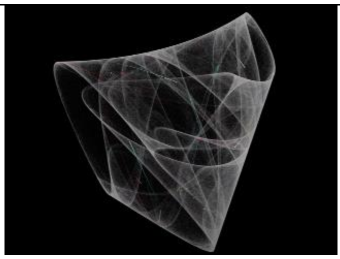
图 6：黄色环不连续，预示着某项指标不合格。

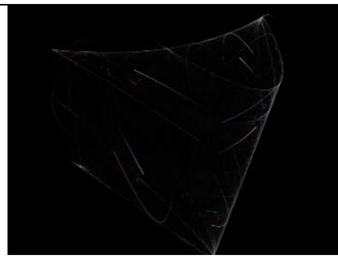
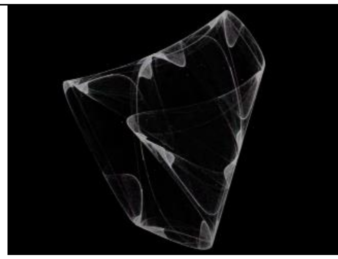
16. 请分别描述您对以上设计的第一印象是什么？
17. 您觉得它们易于理解吗？为什么？
18. 您觉得它们更人性化、更有人情味、更有温度吗？为什么？
19. 是否有任何设计元素令您感到困惑或不满意？您希望它(们)如何被改进呢？
20. 如果您有任何有关工具设计方面的想法，欢迎在下面进行简单的绘图并附上文字描述。即使只是简单的线条图，我们也非常欢迎！我们将会仔细考虑您的意见并不断改进我们的设计。
21. 如果您对本研究有任何期望或想法未在以上问题中得到涵盖，请与我分享。再次感谢您的参与。

C Example Visuals (1st Iteration)

Table C.1. The example visuals of the first iteration for the Study 1.

Item Number	Visual	Represented Health Status	Group Number
V1		Poor	1
V2		Good	1
V3		Very Good	1
V4		Very Good	2
V5		Poor	2

V6		Good	2
V7		Poor	3
V8		Very Good	3
V9		Good	3
V10		Very good	4

V11		Poor	4
V12		Good	4

D Survey for Study 2 (1st Iteration)

HealthHue: An Artistic and Abstract Data Visualization that Depicts Your Health Status

Hello, my name is Tianqin Lu. Welcome to my project about developing an artistic and abstract form of health data visualization. In this project, I am developing HealthHue, a unique, unconventional visualization that uses patterns from Chaos theory to represent different health statuses. Currently, I am testing the effectiveness of the proposed rules and gathering additional insights from users.

The information collected will be anonymous and only seen by myself.

This survey will take approximately 5 minutes to complete. Your participation is very much appreciated, thank you!

In the following, you will find word pairs that are intended to aid you in assessing the health visualization design that you have just viewed. The word pairs represent extreme opposites, with seven graduations between them.

Here is an example:

Bad ☐ ☐ ☐ ☐ ☐ ☒ ☐ Good

The above example shows that the design appears satisfactory to you but with room for enhancement.

Tip:
Your initial response is sufficient; there is no need to dwell on it. Perhaps some of the evaluation terms are not fully correspond to the design, please checkmark at least one option on the scale. Please remember that there are no right or wrong answers, and only your personal opinion matters.

Please indicate your impressions on the viewed visualization by marking on the scale from -3 to 3 between the given terms in each line.

Table D.1. AttrakDiff2 questionnaire.

	-3	-2	-1	0	1	2	3	
Unpredictable	☐	☐	☐	☐	☐	☐	☐	Predictable
Complicated	☐	☐	☐	☐	☐	☐	☐	Simple
Cheap	☐	☐	☐	☐	☐	☐	☐	Premium
Dull	☐	☐	☐	☐	☐	☐	☐	Captivating
Unruly	☐	☐	☐	☐	☐	☐	☐	Manageable
Isolating	☐	☐	☐	☐	☐	☐	☐	Connective
Bad	☐	☐	☐	☐	☐	☐	☐	Good
Rejecting	☐	☐	☐	☐	☐	☐	☐	Inviting
Cautious	☐	☐	☐	☐	☐	☐	☐	Bold
Unprofessional	☐	☐	☐	☐	☐	☐	☐	Professional
Impractical	☐	☐	☐	☐	☐	☐	☐	Practical
Ordinary	☐	☐	☐	☐	☐	☐	☐	Novel
Ugly	☐	☐	☐	☐	☐	☐	☐	Attractive
Separates me	☐	☐	☐	☐	☐	☐	☐	Brings me closer
Conventional	☐	☐	☐	☐	☐	☐	☐	Inventive
Technical	☐	☐	☐	☐	☐	☐	☐	Human
Unimaginative	☐	☐	☐	☐	☐	☐	☐	Creative
Tacky	☐	☐	☐	☐	☐	☐	☐	Stylish
Repelling	☐	☐	☐	☐	☐	☐	☐	Appealing
Confusing	☐	☐	☐	☐	☐	☐	☐	Clearly structured
Cumbersome	☐	☐	☐	☐	☐	☐	☐	Straightforward

Discouraging	☐	☐	☐	☐	☐	☐	☐	Motivating
Disagreeable	☐	☐	☐	☐	☐	☐	☐	Likable
Conservative	☐	☐	☐	☐	☐	☐	☐	Innovative
Undemanding	☐	☐	☐	☐	☐	☐	☐	Challenging
Alienating	☐	☐	☐	☐	☐	☐	☐	Integrating
Unpresentable	☐	☐	☐	☐	☐	☐	☐	Presentable
Unpleasant	☐	☐	☐	☐	☐	☐	☐	Pleasant

Open-ended questions:

- Please discuss your most and least favorite points about this design and why.
- What are your overall thoughts on the design of the visual mapping of health status to the visuals?
- Since this isn't finished, what would you like to see in the final version?

E Open-ended Questions used in Study 2 (2nd Iteration)

1. Based on your understanding of caregiving, what are the specific things you think you would appreciate or dislike in this informal caregiver role with HealthHue?
2. Reflecting on the envisioned experiences, what do you see as the potential added value of using HealthHue in an informal caregiver role?
3. Conversely, what are the potential downsides or concerns you can envision with using HealthHue as an informal caregiver?
4. Overall, in the context of being an informal caregiver, do you think you will use HealthHue in the future? Why or why not?
5. In what specific caregiving situations or scenarios do you believe HealthHue could provide the most value and support?
6. On the other hand, are there any situations or contexts in which you believe HealthHue would have limited or no value as a caregiving tool?

F Raw data

Study 1:
https://drive.google.com/drive/folders/1d0qhSAMoh_pksBciKV4LIxR14Voz941e?usp=sharing

Table F.1. Raw data from Study 2 (1st iteration).

Word pairs	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**C1**	**C2**	**C3**	**C4**	**C5**
Technical - human	3	2	3	2	1	2	3	1	1	2	3	2
Complicated - simple	0	-1	2	0	-3	3	2	-1	0	-2	-1	0
Impractical - practical	1	0	2	3	3	3	2	2	3	0	2	1
Cumbersome - straightforward	2	0	2	3	3	2	2	0	2	0	2	-1
Unpredictable - predictable	0	-3	-2	3	0	0	2	1	0	-3	0	1
Confusing - clearly structured	1	0	0	0	-1	2	0	0	0	0	0	0
Unruly - manageable	-3	-3	0	-3	0	0	-2	0	0	-2	-3	0
Isolating - connective	0	0	0	1	0	0	0	2	3	2	2	3
Unprofessional - professional	1	2	0	2	0	2	0	1	0	-2	0	2
Tacky - stylish	3	3	3	3	3	3	3	2	3	3	3	3
Cheap - premium	3	2	2	0	3	3	2	0	0	2	2	0
Alienating - integrating	2	3	3	2	3	3	3	2	3	2	3	3
Separates me - brings me closer	1	0	0	0	0	0	2	2	2	1	2	2
Unpresentable - presentable	3	2	2	3	3	2	2	0	2	0	2	0
Conventional - inventive	3	3	2	3	3	2	3	3	2	3	3	1
Unimaginative - creative	3	3	3	3	2	1	3	3	2	3	2	0
Cautious - bold	2	3	2	2	3	1	2	3	2	3	2	1
Conservative - innovative	3	3	2	3	2	3	3	3	3	3	3	2
Dull - captivating	3	3	3	3	1	2	2	2	3	2	3	1
Undemanding - challenging	2	2	2	3	2	1	2	0	3	1	2	2
Ordinary - novel	3	2	3	3	2	2	2	3	2	2	3	2
Unpleasant - pleasant	3	2	2	0	3	3	0	2	2	3	1	0
Ugly - attractive	3	2	2	3	2	1	2	2	1	2	2	0
Disagreeable - likable	3	3	2	3	3	1	3	3	0	3	1	-1
Rejecting - inviting	3	1	0	0	0	1	3	1	-2	2	0	0
Bad - good	2	2	1	2	1	2	3	2	0	3	2	0
Repelling - appealing	3	3	2	3	3	2	2	3	2	3	1	1
Discouraging - motivating	2	3	0	2	3	0	2	3	0	2	1	0

Table F.2. Raw data from Study 2 (2st iteration)..

	S1: This visualization effectively represents my health-related data/information.	**S2: I prefer this visualization over the established visualization I currently use.**	**S3: I would like to regularly use such a visualization method in the future.**
P1	4	5	5
P2	3	4	4
P3	3	3	4
P4	5	4	5

Study 2: https://drive.google.com/drive/folders/1sSZDKeoIAXqPAP4M9O2s-JqOVMwqGm1C?usp=sharing