

INSTITUT FÜR INFORMATIK  
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# TOWARDS AN INTUITIVE VISUALIZATION OF ACTIVITY, MOVEMENT, AND SLEEP DATA

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## **Bachelorarbeit**

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## Erklärung

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Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst habe und keine anderen als die angegebenen Hilfsmittel verwendet habe.



München, den 30.11.2021

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I further want to thank the participants of my study and the two people who provided me with screenshots of the visualizations from the Fitbit and Samsung smartwatches.



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## Abstract

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This thesis reports on a proof-of-concept novel visualization called *viSleep* of the physiological data collected with the Ōura ring. The visualization approach embedded in a user interface is based on the bubble charts of Hans Rosling. It aims at bringing intuitiveness into the presentation of health data such as activity, movement and sleep data, as these are very complex for human perception. The focus lies on high dimensionality and the parallel presentation of multiple attributes in one view enabling users to interpret and thereby reflect on health data in order to improve health in the long term. Until now, data visualization was often targeted at experts who do not necessarily need to deal intuitively with visualization. The emergence of wearables using physiological data are collected calls for intuitive visualization aimed at non-expert users. Therefore, health data from a wearable was used for implementation and formatting. For the purpose of building an intuitive visualization, the conception and development of the *viSleep* application was derived through a six-step process adapted from Chittaro, during which the definition of and principles for intuitive use were continuously involved. The visualization should be usable through effectively designed interaction and subconscious utilization of prior knowledge. In a study, the resulting interactive visualization was evaluated by considering different intuitiveness indicators. This has yielded successful results in terms of the ability to interpret health data effortless and the simultaneous sensation of joy.



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## Zusammenfassung

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Diese Arbeit berichtet über einen Proof-of-Concept einer neuartigen Visualisierung physiologischer Daten, die mit dem Oura-Ring gesammelt wurden, namens *viSleep*. Der Visualisierungsansatz, der in eine Benutzeroberfläche eingebettet ist, basiert auf den Bubble Charts von Hans Rosling. Er zielt darauf ab, Gesundheitsdaten wie Aktivitäts-, Bewegungs- und Schlafdaten intuitiv darzustellen, da diese für die menschliche Wahrnehmung sehr komplex sind. Der Fokus liegt auf der hohen Dimensionalität und der parallelen Darstellung mehrerer Attribute in einer Ansicht, die es dem Nutzer ermöglicht, Gesundheitsdaten zu interpretieren und dadurch zu reflektieren, um die Gesundheit langfristig zu verbessern. Bisher richtete sich die Datenvisualisierung oft an Experten, die sich nicht unbedingt intuitiv mit der Visualisierung auseinandersetzen müssen. Das Aufkommen von Wearables, mit denen physiologische Daten gesammelt werden, erfordert eine intuitive Visualisierung, die sich an Laien richtet. Daher wurden Gesundheitsdaten von einem Wearable für die Implementierung und Formatierung verwendet. Um eine intuitive Visualisierung zu erstellen, wurde die Konzeption und Entwicklung der *viSleep*-Anwendung in einem sechsstufigen Prozess nach Chittaro hergeleitet, bei dem die Definition und die Prinzipien für eine intuitive Nutzung kontinuierlich einbezogen wurden. Die Visualisierung sollte durch effektiv gestaltete Interaktion und unbewusste Verwendung von Vorwissen nutzbar sein. In einer Studie wurde die entstandene interaktive Visualisierung unter Beachtung verschiedener Indikatoren zur Intuitivität evaluiert. Dies führte zu erfolgreichen Ergebnissen in Bezug auf die mühelose Interpretierbarkeit von Gesundheitsdaten und das gleichzeitige Erleben von Freude.



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# CHAPTER 1

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## Introduction

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In this thesis the problem is addressed that growing data sets and information are difficult to display due to diverse format and restricted space. Further the simultaneous presentation of data and the user's focus on the visualization rather than the design or method needs to be resolved [32]. In conjunction with this, data visualizations are no longer just tools for qualified and practiced data specialists, but now a "broader social communication tool" [10, p. 64]. Especially the possibility of accessing physiological data, measured by wearables, is of interest to non-experts.

Since promoting health is important to everyone, this should be done without regard to technical affinity, therefore it is important to apply design criteria that are not intended for scientific, objective causes [50]. Because such "self-reflection or knowledge-gaining" processes depend on a visualization, how to show the acquired data appropriately, intuitively, and attractively is a crucial success factor [65, p. 3]. Intuitiveness means the subconscious application of prior knowledge as well as interactivity. This must also apply to visualizations of health data, as consumer wearables "can help people own their health and improve their sleep" [66].

Therefore, in this thesis a design solution was developed based on already known biofeedback visualizations and visualizations of common wearables. As such, a prototypical high-fidelity application *viSleep* was created, which visualizes data from a smart ring. This should make the information effortlessly interpretable for users. Through an adapted design process from Chittaro, which contains the steps mapping, selection, presentation, interaction, usability and evaluation and was developed for the correct development of visualizations, the creation of the application is derived. Throughout the process, care is taken to incorporate familiar features and to observe principles drawn from research about the structure of human cognition [27]. Classic methods such as a pop up window to show details were included along with an explanation of their significance. All built-in elements have been reduced to the necessary in order to avoid overwhelming the user.

*ViSleep* enables the visualization of health data in a way that respects and transfers the definition and principles of intuitive use, such as dialogue principles, gestalt principles, affordances and feedback. Additional channels are added to the bubble chart that are often found in other visualization approaches, such as faces or pie charts. In the visualization, not only time is represented, but also data points independent of their date.

A user study evaluates whether the intended principles of intuitive use have contributed to easy understanding and interpreting of *viSleep*'s visualization and how the implemented

application is perceived.

## CHAPTER 2

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### Motivation

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Sleep research has significantly progressed since the detection of rapid eye movement sleep in 1953. Sleep medicine as such has not long been understood as a field of medicine. The advancement of sleep research has built on a growing information base about sleep physiology, circadian biology, and the pathophysiology of sleep disorders. Discoveries of the disadvantages and consequences of sleep disorders are driving forward the research area [61].

The measurement of sleep parameters is a major aspect of sleep research, with technology being developed for this purpose. Among other technologies, wearable devices have moved sleep research out of the sleep laboratories and into the bedrooms. Many non-expert users are using wearables for collecting data since the importance of sleep as a “crucial biological process” related to lifestyle has gained more awareness [49, p. 1]. For wearable users it is essential to recognize information from the data of a wearable because this helps to change the lifestyle and improves long-term health. Therefore, this should be achieved through visualizations as intuitive as possible, so that users easily grasp the meaning of the visualized data and enjoy accessing this data. Data visualization is a wide field and essential to the success of persuasive software applications. The conception of intuitive interfaces is also a large and fast evolving field which can benefit to sleep data visualization. Overall, there are a lot reasons to pay attention to the intuitiveness of visualizations.

### 2.1 Health data

Sleep is an important determinant of a person’s physical state and behaviour [49]. In fact, humans sleep nearly for one third of their lives [33]. Since sleep, nutrition and exercise have a strong relation, the balance between them is relevant. For example, a lot of inactive time has been shown to be associated with health problems and long-term studies have shown that variations in physiological activities result in alterations of the intensity of “sleep-disordered breathing” [4, p. 1][49]. The impact of sleep on many aspects of the day should be taken into account, as sleep loss affects every major system of the body [49].

### 2.1.1 The importance of sleep

Researchers do not yet have a full comprehension of all sleep functions, although a few aspects are known. Through sleep the body can recover its energy, foster recovery, engage biological systems and affect brain activity as well as human behaviour [28]. About 40 percent of the western societies' residents do not reach the National Sleep Foundation's suggested sleep duration of about 7-9 hours [20, 60]. Sleep quality can be influenced by pressure, fear, nutrition, consistency of labour time, activities, other behavioural patterns or diseases [3, 49].

In the short term, sleep loss can lead to a decrease in judgement and cognitive perception. In the long-term, changed behaviour such as mood alterations lead to depression, and imposed control of appetite, to increased weight, obesity and diabetes [49]. Insufficient or excessive sleep over a long period of time contributes to disease formation as well. Sleep duration found to be affiliated with hypertension, cancer and cardiovascular diseases as well as problems with general body functions, the immune system and hormonal release [6, 11, 14, 49]. Furthermore, studies have shown that too short or too long sleep duration correlates with increased mortality [33]. Besides sleep duration, continuity and timing also influence the sleep quality [12].

Overall, sleep is a complex and changing phenomena which reflects a person's overall state of health. Therefore, it is essential for humans to decrease sleep problems and their causes in order to prevent health risks and related consequences [3].

### 2.1.2 Biofeedback measurement and patterns

The National Sleep Foundation has determined low sleep quality by including duration of sleep, "sleep latency", awakenings following the start of sleep, amount of wake intervals longer than five minutes and "sleep efficiency", in addition to behavioural characteristics [48, p. 9]. Therefore, it is necessary to consider some factors that can be interpreted as sleep data in order to determine which parameters could be visualized. In order to do so, different body signals and patterns can be regarded and several indications can be taken into account.

Human sleep is regulated by internal and external signals. There are many larger factors that regulate the time of sleep, the time of awakening, the general structure and depth of sleep. Circadian rhythm and homeostatic sleep drive are two components, as well as cognitive-behavioural influences, which are difficult to measure [2, 49]. Additional significant indicators that can be monitored are the temperature, the heart rate and sleep phases. Information on the measurable values is given here.

- **Circadian rhythm:** The rhythm has a wave-like inner 24-hour cycle, which encourages sleeping during the night and awakes throughout the day. It is synchronized by external timing signals, such as sunlight or the outside temperature [2]. It regulates changes between phases of more or less sleep tendency [9].
- **Homeostatic sleep drive:** The pressure on the brain increases in a linear manner while the body is awake, and falls exponentially as the body sleeps [2]. An increasing sleep inclination while wakefulness and its loss during sleep are the result of the homeostatic process [9]. To compensate for a sleep deprivation, its control relates to the ability to sleep for an extended period of time or more intense sleep [73].
- **Temperature:** To maintain an optimal temperature for the present state, the organism has an internal thermostat. The body can warm up or cool down to stay in an optimal range called core body temperature. Based on the circadian rhythm, the body temperature increases at the beginning of the day and decreases at bedtime, thus making

it possible to draw conclusions about daily routines. In addition, eating, exercise and hormonal changes such as menstruation can influence the temperature. At the beginning of the menstrual cycle the body temperature is lower (follicular phase), whereas in the second half it is higher (luteal phase) [68].

- **Heart rate variability:** The variance of the temporal intervals between heartbeats is regulated by the autonomic nervous system [13]. During stress, severe tiredness and sleepiness phases this system is always changing [72]. These changes can be measured non-invasively by heart rate variability (HRV). In more rested states the HRV is higher, in more stressful states it is lower. After noticing unfavourable HRV values, they can be counteracted by sleep, meditation or physical activity [13].
- **Sleep stages:** Sleep is divided into the “four-stage classification”, defined as “light NREM sleep, deep NREM sleep, REM sleep, and wake”. Different patterns occur in each of these stages, recognized by different body signals [2, p. 1]. In the REM sleep, for instance, the heart rate and respiratory rate rise whereas the temperature of the body decreases and its muscles become more relaxed in order to avoid uncontrolled movement of the body during dreams [66].

## 2.2 The rise of wearables

There has been a rise of interest in assessing sleep features such as the circadian rhythm as further proof of the significance of sleep regarding well-being, its link with illness and mortality has emerged. A major development and usage of multi-modal sensors and technologies to measure activity and sleep has taken place in the last few years [49].

Sensors to explore sleep have been used since the 1960s [61]. The method polysomnography (PSG) together with clinical evaluation is applied in clinical and sleep laboratories. PSG captures “brain wave signals” [2, p. 2], “eye movement signals” [2, p. 2], “cardiac signals” [2, p. 2], “muscle activity” [2, p. 2], “finger photoplethysmography” [2, p. 2], “airflow” [49, p. 2], “blood oxygen levels” [49, p. 2], “body position” [49, p. 2], “heart rate” [49, p. 2]. In this way, various sleep patterns can be obtained from the data in collaboration with experts or algorithms [2]. Because the data collected by PSG is quite complex and multi-channel, it is limited to a brief laboratory setting and observation [3]. As figure 2.1 illustrates, PSG is very elaborate and includes to many devices.

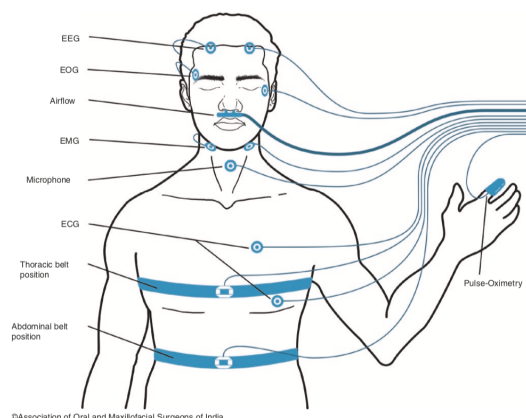


Figure 2.1: “Polysomnography leads and parameters” [36, p.1581]

However, both industry and academia have been working on the advancement of more

compact, less obstructive, stylish and transportable devices for constant sleep and activity tracking [26]. One of the methods used is called actigraphy, which uses a 3D accelerometer to measure human activity, rest cycles and sleep [3, 49]. In a healthy patient group, this technique has been found to be as precise as PSG [3]. Accelerometry, heart rate and heart rate variability provide examples for how wearable devices, such as fitness trackers, smart watches or smart rings, measure bio-signals of users. For research, wearables are helpful to collect long-term data from more people in a natural environment [49]. Regular users, seen as crucial in this context, who want to interpret their data themselves and use it for their own benefit, will benefit greatly from this way of measuring health data. In order to properly target low sleep quality and comprehend the changes and relationship between sleep and health, it is necessary to assess sleep quality [3]. Therefore, wearable technology is being used by a growing number of people to track their health, with sleep as one of the most primary metrics of interest and motivation [2].

In the former method of measuring data, there were experts in charge of interpreting the data, whereas with wearables it is important that users see and understand their data themselves [49]. Measuring sleep and other health metrics through wearables requires data collection and analysis to determine precise sleep patterns [3]. Since the goal of wearables is to provide feedback on a daily basis, to give the user insight into personal health and to encourage a “behavioral change that could contribute to a longer healthspan and lifespan”, it is therefore important that the information is well conveyed [2, p. 1]. For this purpose, the data can be visualized. In order for users who are not experts to be able to use the visualizations in a reasonable way, the choice of the visualization approach should be well considered.

## 2.3 Data visualization

Besides the device as such, the providers of wearable devices in the health sector also offer visualizations that are structured very differently and have various components. This section explains why data is being visualized in the first place and what data visualization refers to.

### 2.3.1 The need for data visualization approaches

Those wearable devices provide constant data gathering of physical activity and important signs in daily surroundings, thus collecting a wide scope of users’ bio-signals [19]. Sleep and health data sets are often multi-modal, multi-dimensional and increasing in volume and dimensions [18]. In general, the size of data with which a person engages has grown exponentially in recent years [10]. So-called big data sets and complex associations among data dimensions complicate the evaluation of data [24]. In order to make such information to be more reachable and comprehensible, the field of visualization addresses these issues. To do this, big data is presented in a way that demonstrates patterns or insights [10]. Efforts to handle big data have been mostly applied to technology, with data scientists working on statistical models, algorithms and visualizations that structure and connect the complex data. The data is calculated, as shown in figure 2.2, and transformed into a visualization that allows exploration.

As Bond has stated, visualizing data is “obviously a key component in the quest for effective sense-making of Big Data” [21, p. 47]. By developing software that enhances people’s ability to see, comprehend, and think about complicated and dynamic data and circumstances, visual analytics aims for an easier way of analytical thinking [70]. The main idea, according to Adriensko et al. is that these software tools process and visualize the data in such a way that a human analyst can recognize the patterns [21].



Figure 2.2: “Conceptualizing Big Data sense-making: a linear model as suggested by industry practices” [21, p.46]

Two purposes of visualization are mentioned, one is to enable researchers to make further use of the data and to recognize concepts that were either not known or previously only hypothesized. The second purpose, which is decisive for this context, is to communicate the results, so visualizations as a tool are able to transmit and convince in a tremendous way [10]. Evergreen claims that “the communication goal of data visualization is to grab audience attention and help them engage with the data such that the resulting product is increased understanding” [22, p. 5].

### 2.3.2 Definition of data visualization

Data visualizations strive to communicate information to people, defined as “computer-supported, interactive, visual representations of abstract data to amplify cognition” [35, p. 13]. Cognition in this context implies the involvement of perception and knowledge [32]. Among other things, perception entails the interpretation of the visual impressions a human is constantly encountering. Newly seen information is continuously sent to the brain and evaluated there. After interpretation, the brain assigns the eyes what to look for next [74]. Thus, in order to discover and comprehend the vast amount of information conveyed by a visualization, the “human eye’s broad bandwidth pathway into the mind” is exploited [32, p. 7]. By providing a visual representation of discrete data, the user is given an insight into the data’s inner construction and shown “causal relationships and dependences” [10][32, p. 7].

There are many different approaches for this, for example diagrams or charts [10]. When considering the type of approach, it is important to look at the number of dimensions, also called attributes. As an example, a two-dimensional dataset means that it consists of data values and associated heart rate values, thus two attributes.

A few of the datatypes are briefly described in order to introduce the terms.

- **1D:** For datasets with only one dimension, one attribute is considered and linear data types are meant. In terms of interface design, this refers to “what fonts, color, size to use and what overview, scrolling, or selection methods can be used” [62, p. 2].
- **2D:** For datasets with two dimensions, two attributes are considered and “planar or map data” is referred to. An example of this would be a table with data arranged in rows and columns [62, p. 2]. Having two attributes is suitable for mapping data onto a display, for example in a coordinate system with horizontal and vertical position [62].
- **3D:** For datasets with three dimensions, three attributes are considered. In classical 3D visualizations with the use of the horizontal position, the vertical position and additionally the position in depth. The challenge is given that users can have problems with spatial thinking and occlusion can occur [62]. However, there are also approaches that deal differently with the additional dimension without going into depth.

- **High-dimensional:** For datasets with more than three dimensions, more than three attributes are considered. As data sets become larger and more attributes are to be considered at the same time, there are already visualization approaches in which “items with  $n$  attributes become points in an  $n$ -dimensional space” [62, p. 3]. According to Shneiderman et al., this is also about “finding patterns, clusters, correlations among pairs of variables, gaps, and outliers” [62, p. 3].
- **Temporal:** The separate viewing of temporal data stems from the fact that their items represent an interval, which means they begin and end and can also include overlaps [62].

## 2.4 Intuitive visualization

Since the target groups of visualizations are shifting further into the wider society due to the increasing amounts of data and the growing number of applications, thinking about the needs and existing knowledge of non-expert users is important. Intuitive design of a visualization does not only concern the visualization approach itself, but also the user interface and the interaction with the tool. According to Schenkman and Jonsson, an application consists of the provision of content, the website’s usability and the effect it has on the viewer [58].

The general perception of aesthetics and approachability of the content has a strong influence on the usability and intuitiveness of a system, therefore the choice of interface signs such as navigation controls, descriptions, command buttons or icons should be well-considered [17]. Interface signs that are intuitive to use act as “communication artifacts” between humans and machines [29, p. 1]. Analyzing and understanding occur not only by observing the actual visualization, but also, for example, by perceiving legends, labels or by operating controls. At present, various concepts, principles and technical design heuristics exist that can be taken into account when designing a visualization and its environment in order to achieve the greatest possible intuitiveness. Therefore, this section first discusses the definition of the term “intuitive” and some implications and guidelines that researchers have already defined for the general design of intuitive applications. Subsequently, it is explained why intuitiveness is important when visualizing data.

### 2.4.1 Intuitiveness and its implications for design

The term “intuitive” is used by companies in various domains for marketing purposes. Intuitive use, according to Hurtienne et al., is becoming a unique selling point when competition is at stake [27]. The growing number of technical systems has also led to the inclusion of the words “intuitive” and “intuitive use” as an assessment criterion for applications or products [43]. The concept of simple, almost self-evident use and interaction forms the core of all these use cases [39]. Hence, it is about the invisibility of an intuitive design, where the user does not have to spend much time thinking about how to operate the system. [40]. In the scientific community, applying the term is avoided because the concept of intuitiveness is perceived as unclear.

However, the IUI research group (Intuitive Use of User Interfaces), a community of psychologists, computer scientists and other professionals, has defined the term “intuitive use” and explored it as a scientific phenomenon that is clearly specified. In relation to an assignment, an application based on technology is “intuitively usable while the particular user is able to interact effectively, not-consciously using previous knowledge” [44, p. 1]. Furthermore, the special term is seen as a property of the interaction between human and machine utilising a user’s intuition [43]. In addition to establishing a theoretical foundation of the idea behind intuitive functioning, the IUI also aimed to develop approaches to



make the implementation of intuitiveness more tangible for an application [40]. According to Mohs et al. it is important to understand that no technical application itself possesses the property of intuitiveness, instead only the information processing procedures of a user can be described as “intuitive” [39].

Designing intuitively usable applications for users means including all the human senses and thus incorporating the area of aesthetics. Many researchers are studying the importance of it for the conception of visualizations [43]. Inspiration for this was also derived from art [27]. The individual sensors of perception are addressed by aesthetics and immediately cause the user to evaluate the operation. Considering aesthetics when creating an intuitive application begins with the user’s first impression. If something is not seen as attractive it will not bring a good experience and thus will not be intuitive to use [43]. But not only the first awareness is important, also in the further use aesthetic assessments are the beginning of a personal perceiving operation. Norman states that good design is hardly noticed by users because the intuition should immediately indicate how the application is to be consumed and read and, as the definition of IUUI group explains, the process of use is supposed to be unconscious [44, 47]. Bad design or one that entails non-intuitive use is immediately recognizable [47]. Moreover, “hindered cognitive fluency disturbs the process and will likely lead to a less favourable evaluation” [44, p. 2].

Intuitive user interfaces require less mental cognitive resources, allowing users to focus on the actual task, such as reading and understanding a visualization [63]. With intuitive design, the user is able to concentrate on the actual content, as it should be the central task.

Intuitive use is a “subconcept” of usability, or according to IUUI an independent concept of it [27, p. 2] [40]. Blackler et al. describe that intuitive interaction meets the demands of effectiveness and satisfaction and also addresses cognitive efficiency [7]. ISO 9241-11, defined by the International Organization for Standardization, declares that these are the components needed for usability. It states that usability is the “extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” [30, p. 6]. In this context, effectiveness is defined as the precision and completion by which users accomplish certain tasks, and efficiency refers to the spent effort compared to the accuracy and completion by which users accomplish their tasks. Satisfaction is defined as being comfortable and maintaining a good mindset regarding the experience of using the device. When designing the intuitive visualization, these three areas were also taken into consideration.

The core of usability is about the actual usage situation and the simplicity of using an application for a specific goal [30]. It follows different concepts and principles that were followed and implemented during the design of the visualization. The application is attempted to be intuitively usable through the use of Gestalt laws, which point to the use of basic perceptual concepts, and through affordances and feedback [7]. These are part of the design guidelines defined by Norman. Affordances describe features of an artifact that give some information how to interact with it [47].

These two concepts, along with Gestalt laws, compatibility and three dialogue principles form the criteria that Mohs et al. found on the basis of a study involving HCI experts [43]. Those criteria are supposed to have an impact on intuitive interaction [39]. The three dialogue principles he included are suitability for the task, self descriptiveness and conformity with user expectations. As defined in ISO 9241-110, the dialogue principles set seven goals for user-centred design in a certain context. In addition to the goals just mentioned, error tolerance, controllability, suitability for learning and suitability for individualisation are also included [1].

The principle of conformity for user expectations states, among other things, that the application should be checked for consistency. This means users should already know certain aspects, since they can then use them intuitively. Whether they do so often depends on their level of prior knowledge acquired in other contexts [7]. The need for intuitive use

is particularly important for starters, infrequent users and diverse user groups [27].

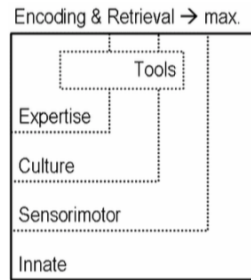


Figure 2.3: “Continuum of knowledge in intuitive interaction” [27, p.2]

This thesis also takes into account that many people with different prior knowledge should use the system subconsciously, as the definition of intuitive use states [39]. For this, it will be noted that there are different knowledge sources incorporated into the design based on different prioritisation. The knowledge continuum states that there are classifications “from innate knowledge, knowledge from embodied interaction with the physical world (sensorimotor), and culture to professional areas of expertise” [43, p. 131]. Keeping this continuum in mind helped in the selection of a visualization approach that should also be intuitively usable for users lacking prior knowledge.

#### 2.4.2 Focus on intuitiveness in visualization

The characteristic users of health data visualizations are no longer very qualified and advanced data specialists. Therefore the new inexperienced users should be enabled to achieve meaningful findings about personal data, which is why it is also important to pay attention to intuitive use in the field of data visualization [38]. Visualization can support users in terms of “what to do with their data and how to take action towards understanding their health and improving it” [51].

Research examining variations in design between designers and non-experts regarding how they value and comprehend visual information has revealed that non-experts consider familiar visualizations appealing, while designers prefer new versions. Thus, the conception of data visualizations may require different criteria for design than the ones intended to meet scientific, analytical requirements [50]. The major distinction of effective and ineffective data visualizations is about conveying information they depict through a simple and obvious manner without overwhelming a user’s working memory capability [22, 57].

This benefit of a visualization does incorporate usability goals, which is why these were considered in the design of an intuitive visualization in this work [57]. Through the use of sophisticated and systematic principles of visual design in data visualization, the viewer is supported in attempts to interpret the insights [22].

According to Firat et al, visualization approaches that are responsive take on a “key role in simplifying and conveying meaningful information” [24, p. 91]. Interactive visualizations give users the opportunity to visually explore the data and thus foster greater understanding and increase readability.

Bennett et al. stated that “researchers associate aesthetics with readability, and readability with understanding” [5, p. 57]. In terms of aesthetics, data visualizations that were classified to be prettier were rejected with less frequency and provided more precise feedback. One study has shown that participants spend more time analyzing and interpreting data visualizations that are well designed. Furthermore, it was found that good visualizations are especially effective at improving the retrieval and storage of knowledge [22].

In order to focus upon intuitive use in visualizations, it is important to achieve appealing information design outcomes not on the basis of facilitating everything, but on the basis of clearing up complex data.

Multiple respondents in interviews and design manuals emphasize further that aiming for clearness doesn't imply that information should be simplified by letting things out. A visual arrangement of information that enables at the same time overview and in-depth reading, and that underlines important things, can help to make a visualization intuitive [50]. In addition, for a non-expert user group, attention should be paid to maintaining a joyous experience [62].

Evergreen stated "The effort we put into making data visualisations more interpretable pays off in more efficient engagement with the products of our [...] endeavors", which is exactly the goal of this thesis [22, p. 18].



There are already many visualization approaches and also user interfaces of visualizations. In order to look at principles of intuitive design and possible elements to use, various visual styles from the field of biofeedback and how they are perceived by users in a study will first be discussed. Subsequently, examples of the data visualizations used by three established smart watches will be analyzed.

### 3.1 Biofeedback visualization approaches

Academic research in the area of visualization has traditionally targeted assisting expert users in conducting complex data exploration and evaluation with methods which are oftentimes interpreted as being scientific because of its origins in “scientific reasoning, computer graphics and algorithmic optimization” [38, p. 356]. In order to achieve an accurate representation and reliable replication of data, they often avoided providing minimal context or advice in addition to what is actually contained in the data [38].

The majority of the commercially existing biofeedback devices also for non experts represents sensory information through analytical visual designs like charts [64, 65]. Using the opportunity to provide visualizations of accessible datasets, many artists and designers have employed visualization principles as a strong and creative way of communication [38]. According to Sun et al. there is a lack of substantial evidence on how users can be engaged through interactive biofeedback visualizations and how data representations can help users to modify their condition.

Sun et al. evaluated different representations of biofeedback training, a technique designed by scientists and health professionals in order to deal with mental stress. It is composed of demonstrating users the physiological alterations of their bodies which are linked to particular brain activities.

In research, it is hypothesized that specific types of design will impact user engagement based on characteristics. They evaluate five different types of design and for each visual style, they determine an appropriate example [65]. These styles of visualizations of biofeedback data which have been applied throughout studies and commercial settings are raw numbers as a numerical style shown in figure 3.1, bar charts as an analytical style visible in figure 3.2, and waves in figure 3.3 provided as an illustrative style, which also includes Chernoff faces [64, 65]. Furthermore, butterfly drawings as an artistic style, where

GSR High  
BPM 8  
IBI 0.19

GSR Low  
BPM 2  
IBI 0.77

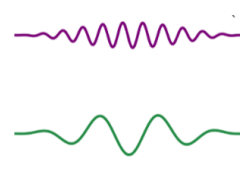
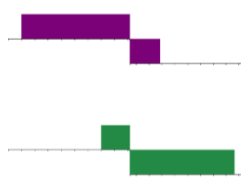


Figure 3.1: Raw data as a numerical style

Figure 3.2: Bar chart as an analytical style

Figure 3.3: Waves as an illustrative style

users' stress levels are depicted by wing animation, shown in figure 3.5, and table lamps as an ambient style, which convert body signals into visual patterns using light, displayed in figure 3.6 [64, 65]. In figure 3.4 a graphical style is given, that is a horizontal graph representing multivariate data over a time series and where it is possible to move the mouse over values to get more detailed information [64].

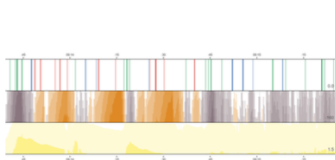


Figure 3.4: Graph as a graphical style

Figure 3.5: Butterfly as an artistic style

Figure 3.6: Table lamps as an ambient style

In a lab experiment conducted with 35 participants, wearable and/or mobile appliances were used “to take stress management practices out of the clinical setting and bring them into people’s daily lives”, similar to the health data that will be visualized in this thesis [65, p. 1]. When compared to a numerical presentation, they discovered that data visualizations boost engagement and so facilitate stress management training. What all participants said about raw data can be summarized by the statement of one participant “The raw values are useful for those who need to do analysis or diagnosis, but they may not be helpful for self-training with general users, like me” [65, p. 8]. Regarding the bar chart, which is representative of the analytical style aimed at in this thesis, all the participants concurred about the helpfulness throughout the process.

Clarity and reduced cognitive load resulted from the apparent visual pattern. They give an overall understanding of the data. One said “[The bar charts design] is intuitive for me to interpret; the directions can easily tell me how I am performing” [65, p. 8]. On the aesthetic engagement scale, bar charts were ranked considerably lower compared to waves, butterfly drawings and table lamps. Some disliked the ordinariness of bar charts, they found the other designs creative and would rather use them. In the development of the visualization of the thesis, this is taken into account by moving a bit away from the definition of intuitive use and introducing more novel things.

The participants have answered many questions positively with regard to the more abstract visualizations such as the butterfly, although this is due to the fact that the experiment design was based on live data representation, i.e. on a specific moment and not on the representation of several data points or points in time, which would require artistic expansion [65].

All in all, it can be deduced from these related works that it is important to think about

user engagement and to mix familiarity and novelty in order to deal with the not intuitive biosensor data that are hard to tamper with [64]. Furthermore, appropriate visualizations of data from self-tracking devices could engage users to further use them [65].

## 3.2 Visualizations of wearable health devices

In visualizations of wearables, different approaches are used to communicate the data to users in a comprehensible way. In order to develop a visualization approach in this area and to design it intuitively, also with regard to its environment, the user interfaces of the evaluations from three smart watches were considered. These are the Fitbit Charge 4, the Samsung Galaxy Watch Active2 and the Apple Watch SE.

### 3.2.1 Fitbit Charge 4

In the following, the dashboard and the app of the Fitbit Charge 4 are briefly analyzed with a focus on their visualizations.



Figure 3.7: Dashboard of Fitbit smart watch

**Dashboard** The dashboard, displayed in figure 3.7, consists of several small visualizations of the data, which are thematically arranged in boxes. A few different methods of

visualization are presented, such as the use of a line diagram for the bpm during walking, whereby axes are omitted, as the focus is presumably on the temporal progression. A lot of data is depicted by a circle and the proportion of the total goal that has been achieved so far. Icons in the middle visually represent what is shown, thus headings are not included. In the three visualizations of standing hours, sleep duration and calorie intake, a semi-circle is used to show the status for these topics. In figure 3.9 a line diagram that is displayed in the dashboard is shown more closely. By hovering over the line, the exact date and the exact bpm value are provided in a speech bubble. Figure 3.8 presents a visualization with the



Figure 3.8: Burned calories visualized as a bar chart- Fitbit dashboard



Figure 3.9: Heart rate visualized as a line diagram  
- Fitbit dashboard

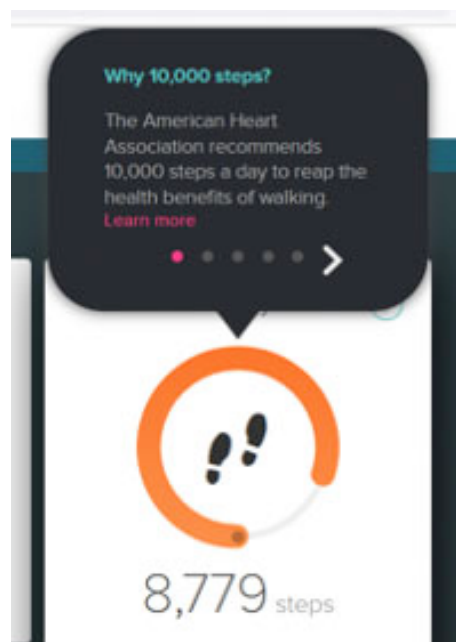


Figure 3.10: Speech bubble containing details above the steps cycle  
- Fitbit dashboard



approach of a bar chart, on the x-axis the attribute time is plotted, on the y-axis the calories burned. By means of two dropdowns in the upper right corner, the attribute for the vertical axis can be changed, a usual way of interacting, as well as the temporal state of a bar can be aggregated from day to week and so forth. This form of aggregation is common in interactive visualizations that show a temporal trend. In addition, the bars are shaded in three different colors, which assign the bars to the three categories “light”, “moderate”, “intense”. In total, three pieces of information are encoded in this diagram. By hovering over the bars, further information is available.

In the upper right corner of the visualization box in figure 3.7, a question mark icon is illustrated grouped with the heading of the visualization “Today”. When the mouse hovers over it, it changes its color and when it clicks on it, a speech bubble appears containing help and explanations about the attribute, shown in figure 3.10. The speech bubble points towards the information it explains, as in the example, why the target of 10000 steps per day was set.

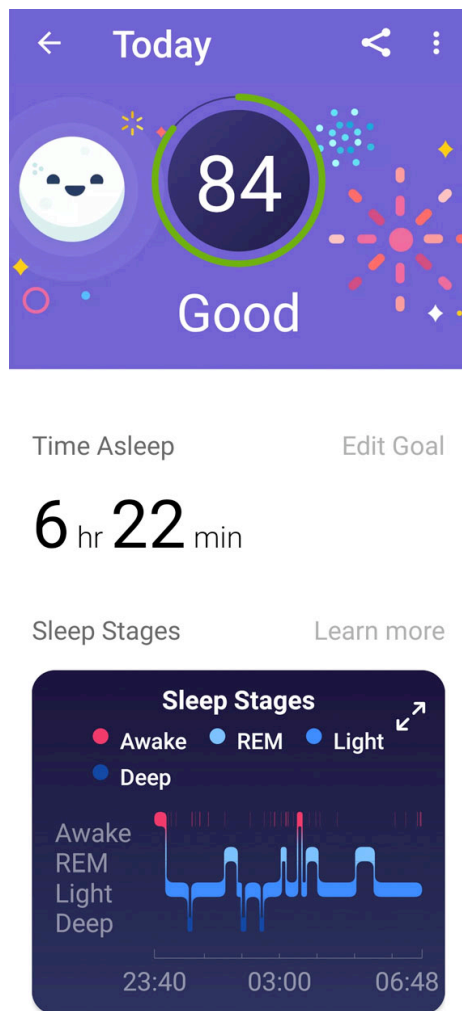


Figure 3.11: Sleep stages visualized in a line diagram - Fitbit app

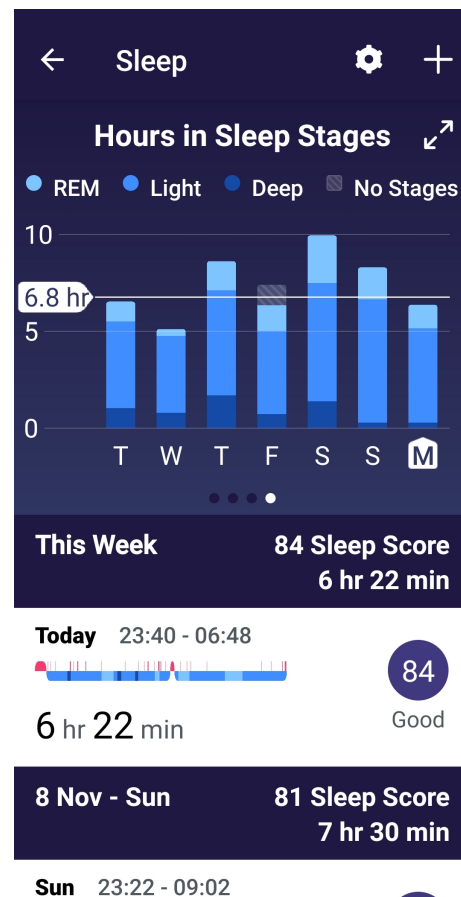


Figure 3.12: Sleep stages visualized in a stacked bar chart

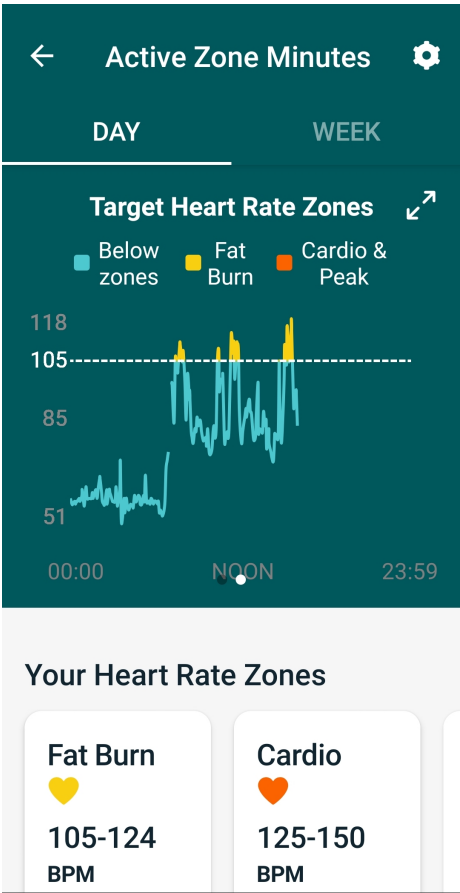


Figure 3.13: Target heart rate zones visualized in a line diagram - Fitbit app



Figure 3.14: Steps visualized in a bar chart - Fitbit app

**App** Figure 3.11 shows a screen from the Fitbit app. It contains a line diagram that depicts the course of the sleep phases during the night. The vertical axis in this case is categorical containing the sleep stages, though these are not ordered according to the socially usual order of Awake, Light, REM, Deep, which could be confusing. Each sleep phase is highlighted by a color and thus, by perceiving the colors of the image, the sleep phase which is predominant can be recognized. Information about the beginning of the night and the end is also conveyed by the x-axis. By displaying the sleep score using the circular percentage of the maximum 100, the color green and the label “good”, an assessment of the quality of sleep is given.

Figure 3.12 presents a weekly view of sleep duration in a bar chart. The bars are divided into the number of individual stages as in a stacked bar chart. In addition, the average sleep duration is shown by a line. In figure 3.14 the same kind of visualization is displayed by a bar chart based on the steps, except that the bars have one color throughout. However, the bars that are particularly good are marked with a star to give the user positive feedback for these days. As all bars start at the same axis, the individual days can be easily distinguished and compared visually.

The active zone minutes are visualized by a line diagram, a common visualization in the area, included in figure 3.13. This shows the target heart rate zones, with colors coding

areas of the line and visually separating the individual heights into “Below zones”, “Fat Burn” and “Cardio Peak”. The colors may be a little confusing here, as in the western world the traffic light color red, for example, is often seen as bad, although in this case it is the target.

### 3.2.2 Samsung Galaxy Watch Active2

In the Samsung Health app, the visualization of sleep, shown in figure 3.15, looks similar to the Fitbit app, except that here the categories of sleep stages are placed in a socially proper order. In addition, the color legend has been dispensed with, in that the labelling of the y-axis already picks up on the colors and explains their meaning. There is a rather unobtrusively displayed sleep score. Similar to the Fitbit app, the duration of sleep is a noticeable number that is the focus of the entire screen. Additionally, the duration of sleep is displayed in a circle proportionate to 12 hours, which gives the user a good impression of the day.

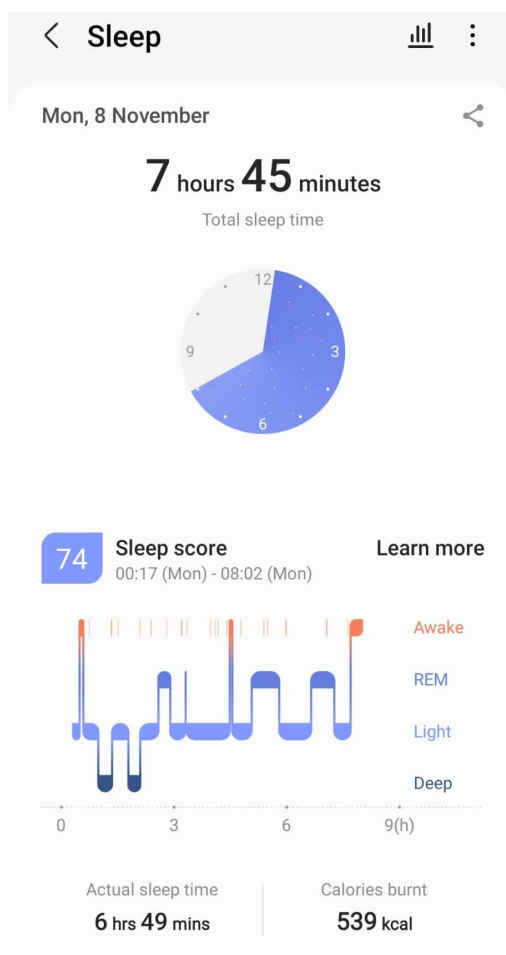


Figure 3.15: Sleep stages visualized in a line diagram  
- Samsung

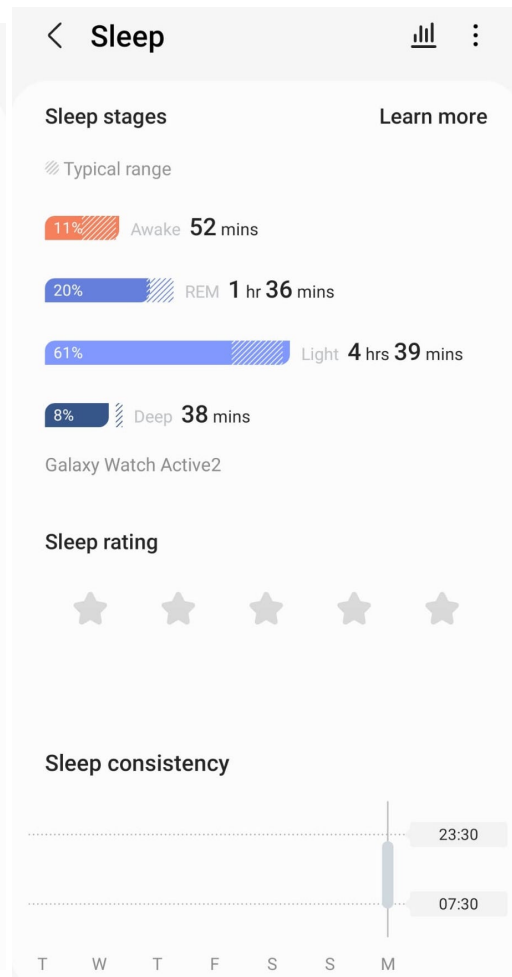


Figure 3.16: Sleep stages visualized with bars  
- Samsung

In the second screenshot in figure 3.16, the duration of the individual sleep phases is shown by the length of four bars, in the same colors as in the line diagram. Due to the length of the bars, the durations of the individual stages can be compared perceptually. In addition, the percentage of the total sleep duration is shown and dotted lines indicate the typical range to enable the user to reflect on it. The activity is represented by the Galaxy



Figure 3.17: Activity visualized with cycles and a bar chart  
- Samsung

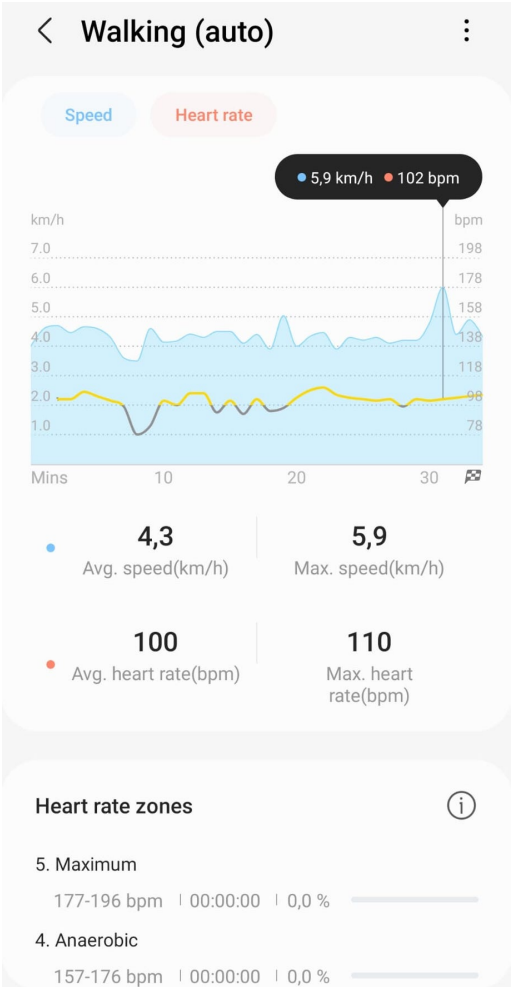


Figure 3.18: Heart rate and speed visualized in a line diagram  
- Samsung

Watch Active2 with three circles in the shape of a heart. This is briefly demonstrated in the screenshot in figure 3.17. Filling those is intended as an incentive for the user. The three circles represent steps, active time and activity calories. In a bar chart below, an x-axis encoding the time shows how the steps were distributed over the day.

The fourth screenshot, shown in figure 3.18, contains a line diagram comparing two different attributes. The blue colored area presents speed. The y-axis on the right represents the heart rate. Confusingly, this is written in red and is also coded red in the speech bubble that appears when hovering and which shows more precise details. The corresponding line is yellow and grey, without the meaning of these colors being indicated. Nevertheless, it demonstrates the connection between these two variables.

### 3.2.3 Apple Watch SE

Another common smart watch is the Apple watch. Its visualizations are briefly analyzed by four screenshots. In the Apple Health app, there is various information on water consumption, the female cycle or health data such as steps, etc. Figure 3.19 shows how sleep is visualized. Instead of bars that start at an axis, bars are shown here that visualize the duration of sleep by their length and the start time or end time of sleep by shifting them up or down. Two very similar shades of turquoise, which may not be easily distinguished, differentiate between “avg time in bed” and “avg time asleep”.

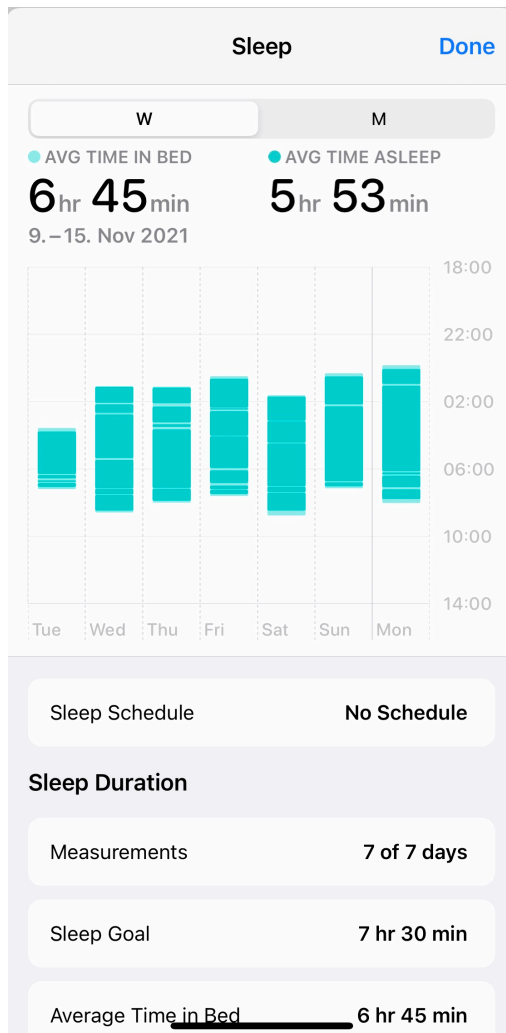


Figure 3.19: Sleep visualized with a bar chart  
- Apple



Figure 3.20: Heart rate visualized with a bar chart  
- Apple

In figure 3.20, the sleep information is augmented by the heart rate, which is also indicated by bars that have been shifted vertically. There is no vertical axis, however, by labelling the maximum and minimum values, it is apparent that it is meant to represent the level of bpm. The length encodes the range the heart rate had within a certain time. In the same figure there is a classical bar chart with one common scale, meaning the x-axis. It

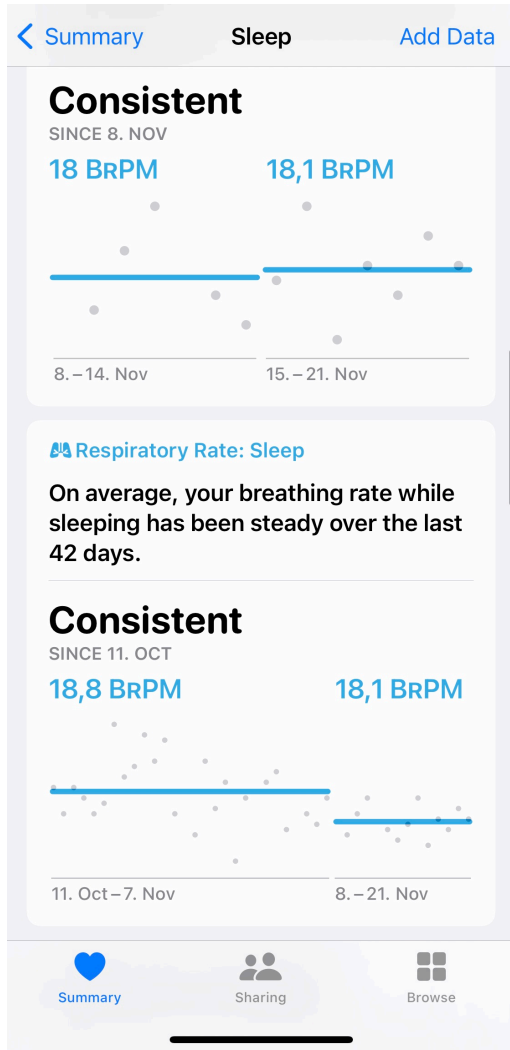


Figure 3.21: Respiratory rate visualized with a scatter plot  
- Apple



Figure 3.22: Fitness app provided especially for Apple watch  
- Apple

shows the sleep duration including a line which represents the average of the whole week.

In figure 3.21 a scatter plot is provided, which is used to show the respiratory rate over time. In addition, there are lines to show the average. The dots are divided into weeks within the visualization, therefore there are two average lines in the screenshot.

The Apple watch also has its own app called Fitness. As shown in figure 3.22, it focuses on three rings, similar to Samsung. On the Apple watch, however, the three rings show the progress of the categories “Move”, “Exercise” and “Stand”.

In general, many things are different in the visualizations of the three watches given as examples, but some things are similar. For example, bar charts are very popular. In addition, Fitbit and Samsung both use a sleep score and pay attention to the sleep phases. In all three, the temporal processes are visualized and in almost every visualization there is the option to hover over/click on the bar, circle or line and have more details on the

respective values displayed. It is also possible in all of them to display a bar/data point as a month instead of a day, i.e. to aggregate it. An abstract common feature, which is also important for this thesis, is that usually more than two pieces of information are displayed in one visualization. In visualizations, the horizontal and vertical position is used to encode attributes along with the length of bars and the use of colors. Furthermore, multiple items of data in one visualization are expressed by using labels such as “min”, displaying the average value by a line, adding dashed areas or shapes such as a star.





Öura Health Ltd., a company from Finland, has developed a smart ring called Öura ring. It is a health tracking tool that uses various bio-signals from users to track and analyze their health [2, 19]. The ring is very unobtrusive, made of ceramic, has a long battery life and is water resistant [19]. This allows the ring to be worn almost continuously [3]. It connects via bluetooth to the Android/iOS Öura mobile app, which then automatically uploads the data to Öura's cloud server [19]. The goal of the Öura ring is to give consumers a new method to get continual, precise health data so they can make better choices and enhance their mental and somatic health [51].

#### 4.1 Technology and measurements of the Öura ring

Unlike smart watches, the Öura Ring takes its measurements directly from the finger's arteries, rather than from the upper surface of the wrist [67]. The ring differs from classic smart watches among other factors by its ring form. Thus all sensors are located inside the ring, lying close to the "underside (palm side) of the finger" [2, p. 3]. Two LEDs are arranged to the right and left of a photodetector. As a result, the measurement is both transmissive and reflecting [2]. These LEDs use infrared light also called "infrared light photoplethysmography" (PPG), accessing a deeper depth than the green lights found in other wearables [3][67]. Besides the 250 Hz PPG signal, Öura applies a 3-D accelerometer that captures data based on a sampling frequency of 50 Hz and a resolution of  $\pm 2$  g [2, 19]. Through these methods, measurements such as heart rate, heart rate variability, respiratory rate and intensity of physical activity can be measured [2, 3, 19]. Furthermore, Öura measures the temperature deviation directly from the skin through the negative temperature coefficient (NTC) thermistor every 10s, so the outside temperature cannot distort this [2]. Öura determines the individual sleep phases or the go-to-bed time based on the measurements. This is possible by connecting physiological signals together with advanced "machine learning based methods" [19, p. 3]. Öura mathematically applies models that integrate existing sleep patterns [2]. It emphasizes nocturnal measures, which are crucial markers of an individual's present physical condition, when calculating ratings. Since day-time readings seem to reflect everyday pressures or lifestyle factors, night is the optimum time to receive an actual depiction of an overall health condition since the body is in a stable condition [67].

Therefore, *Öura* offers the user scores that are simple to interpret on a scale from 0 to 100. These include the three main scores Readiness, Sleep and Activity Score. Other scores are also available, such as the Deep Sleep Score or the Recovery Index Score. The Sleep Score, for example, is calculated using information such as “Total sleep time, Efficiency, Tranquility, amount of REM sleep, amount of Deep sleep, Latency and Timing” [33, p. 2]. Another value based on other values is, for example, “sleep efficiency” which is calculated as the proportion of overall sleep time to total time spent in bed [33, p. 2].

## 4.2 *Öura's* visualization

*Öura* offers users several ways to view their data. The data is always visualized on a daily basis, either a value is shown for one measurement per day, or it is possible to see how the values change throughout the day. The *Öura* app contains various visualization approaches, mainly line plots. Secondly, *Öura* provides a web application, which is divided into a dashboard and a display of trends, which likewise have different visualization approaches integrated. Both, the *Öura* app and the web representation provide functions that are partly the same and partly different.

### 4.2.1 *Öura* app

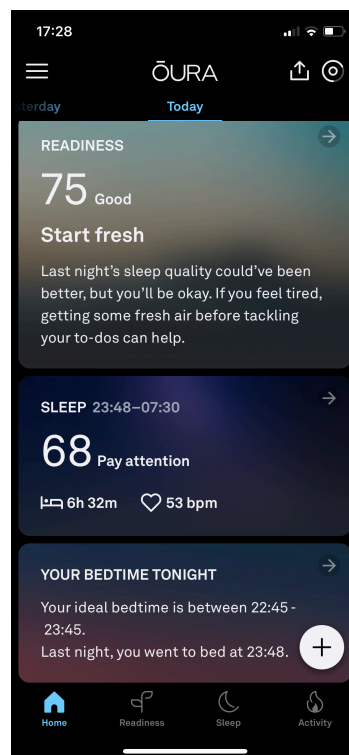


Figure 4.1: Homeside of *Öura* app showing recommendation and feedback

*Öura* offers users an app called *Öura*, through which collected data can be tracked and analyzed on a daily basis. It is structured in four sections containing the home page and the overviews of the various values belonging to the categories readiness, sleep or activity.

There is also the option to “take a moment”, which offers guided meditations or nature sounds in order to give the user some time out.

The home page provides additional information to the otherwise metric data. For instance, it provides background information or recommendations on how to act regarding the current readiness score, such as shown in the first box of figure 4.1. Additionally, the ideal time to go to bed as calculated from recent data is indicated. When Æura automatically detects workouts or naps that have not been entered, the user is asked which type it was and saves it after confirmation. With additional naps, the readiness and sleep score increase.

The three categories readiness, sleep and activity show an overview of the daily associated values. All three use different visualization approaches for two dimensions. In each area, it is possible to swipe left or right to jump back and forth between days to see each day in detail. Each name of a value, such as “Recovery Index”, can be selected and information about the measurement value is displayed. This information also includes what would be considered a good score for that particular reading. Additionally, the main scores of the three categories are marked with a crown if the score is above 90, to provide a reward to the user. All three categories are structured similarly. First, the course of the last days up to the current day is displayed through different types of visualizations. Then four important average values and the score are displayed. Afterwards, the contributors and details follow.

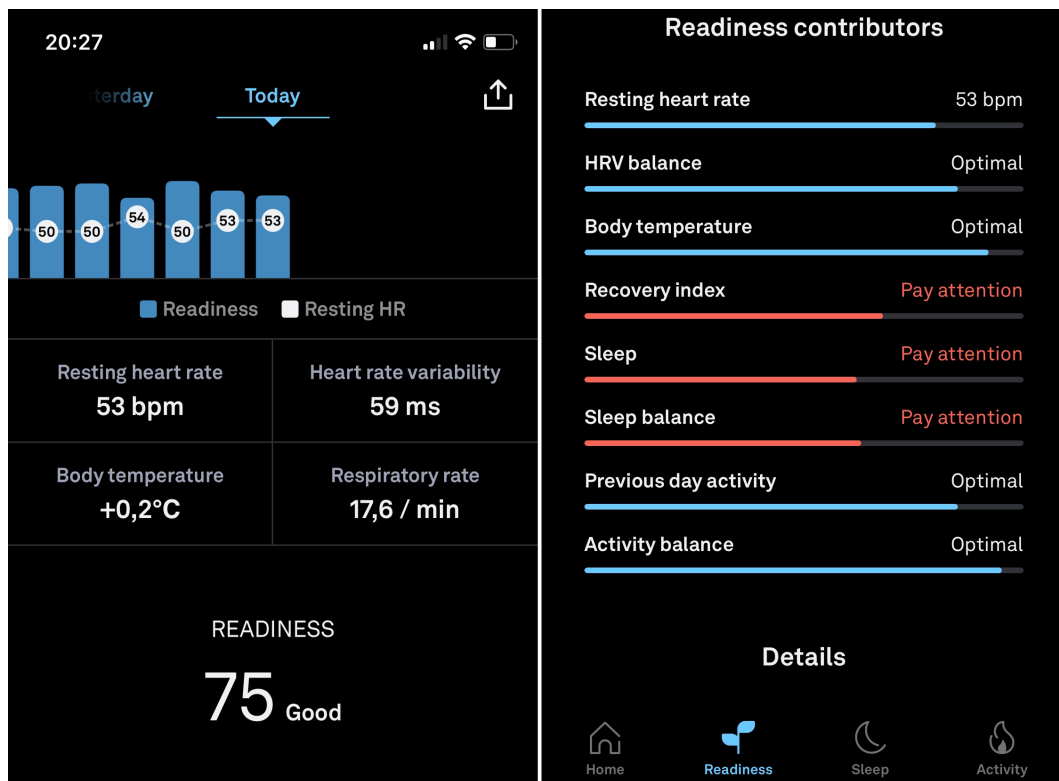


Figure 4.2: Æura visualization of the readiness category on the app

**Readiness** The view of the readiness category, displayed in figure 4.2, contains a bar chart at the very top, which shows the progress of the readiness score over the last few days. In

this diagram, the precise number of Resting Heart Rate is also incorporated by showing the number in white dots, which are connected by an unsolid line, representing a line plot. The line plot is connected to a bar chart which is differentiated by the colors. In general, the perspective of one day is shown. Initially, there is an overview of the resting heart rate, heart rate variability, body temperature and respiratory rate. Below this, the readiness score and the readiness contributors are presented. Contributors include resting heart rate in bpm and the quality of HRV balance, body temperature, recovery index, sleep, sleep balance, previous day activity and activity balance. These displays are visualized by a progress bar, but unlabelled. They are either colored in the classic color of the app, light blue, or in the warning color red, for values with the quality rating “Pay Attention”. It is followed by the lowest and average heart rate under the heading “Details”, and by a line plot showing the progression over the night. The y-axis uses the unit bpm, but does not show all values starting from zero. The lowest heart rate is marked with a dot, the average with a straight line. Then exactly the same structure is repeated with the average HRV, except that the value appears as ms and instead of the lowest value, the maximum value is highlighted by a number.

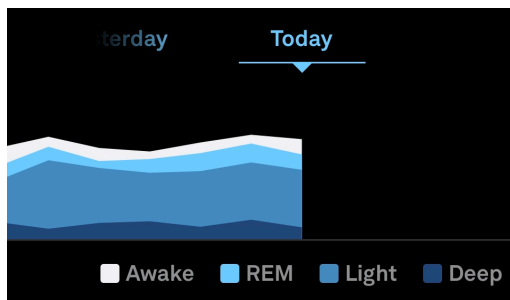


Figure 4.3: Stacked area chart providing overview of sleep for one day

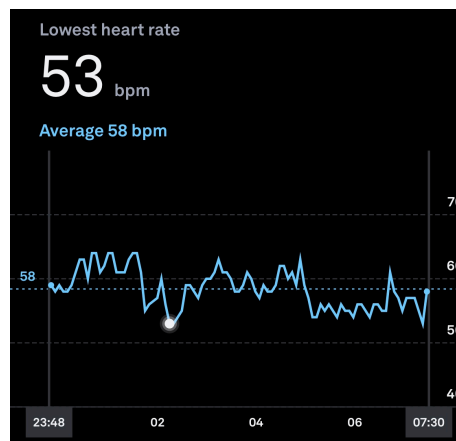


Figure 4.4: Lowest heart rate displayed through a line plot

**Sleep** At the top of the sleep category is a stacked area graph, shown in figure 4.3, in which the values are layered on top of each other. The lengths of the four sleep phases Awake, REM, Light and Deep are displayed and differentiated by color. Through a color legend, the meaning behind the colors is highlighted. The four pieces of information given first are Total Sleep, Time in bed, Sleep efficiency, Resting heart rate. This is followed by the sleep contributors Total sleep in hours, Efficiency in percent, Restfulness indicated as quality. In addition, there are REM sleep and Deep sleep in hours with their percentage of the night, Latency in minutes and Timing with a quality indicator. All of them have a progress bar as in the other categories. Under Details, a specific visualization of the four sleep phases and two numerical values, Time asleep and Total duration, can be found. Underneath, oriented to the x-axis of the previous diagram, the movement of the night is visualized. Furthermore, the exact number of minutes or hours of the sleep phases are displayed. Thereafter, the same two line plots for Lowest heart rate and Average HRV are provided as in the readiness category, the first one is displayed in figure 4.4.

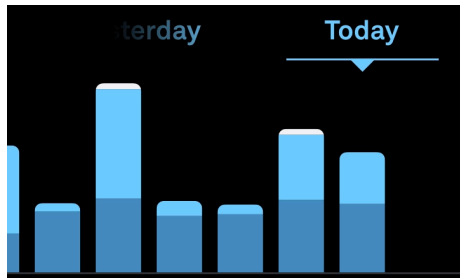


Figure 4.5: Stacked bar chart providing overview of activity for one day

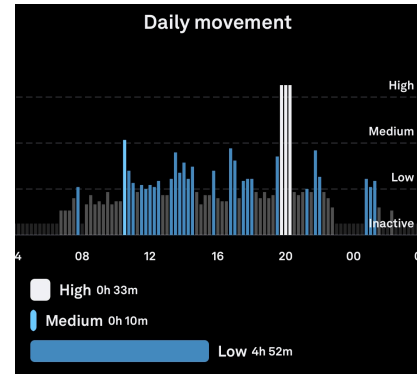


Figure 4.6: Stacked bar chart providing overview of activity for one day

**Activity** For an overview of the last few days, the activity category contains a stacked bar chart with different colors for low, medium and high (activity), presented in figure 4.5. The important values are goal progress in calories, total burn, walking equivalency and steps, followed by the score and the activity contributors. The contributory values include stay active in hours, move every hour in number of alerts and meet daily goals. Next are the training frequency, training volume and recovery time, each with a quality label. This is followed by a bar chart, displayed in figure 4.6, with the various clock times of the day as x-axes, and the four categorical values high, medium, low and inactive as y-axes for the display of Daily Movement. The bars take on a darker and darker blue as they get higher. Moreover, the number of minutes/hours low, medium and high are shown numerically. This is followed by an overview of the workouts that the user has already done on the current day.

**Trends** Besides these views with various visualizations, there is the possibility to edit settings for units, connections to apps such as Apple Health or Google Fit or also to edit goals and body values in a menu. Furthermore, users can view trends of the last days, weeks or months. They can choose between several measured values from all three categories. A chronologically arranged line plot of one dimension is displayed, shown by figure 4.7. By scrolling to the left or right, it is possible to switch to the front or back on the timeline. If the currently viewed measured value present a specific date, the workouts completed there or the tags added by the user on that day are displayed. Figure 4.8 indicates, for example, that in the selected month of July 20 walking workouts were performed. Tags are certain buzzwords that the user can choose from, including details about illnesses or food.

### 4.2.2 Dashboard

This workout overview, as well as the option to add workouts or tags, is missing in the web application. The tags and workouts from the app are not displayed here either. As in the app, the web application of Òura contains a daily view and the display of trends. Although both are structured differently here.

The dashboard shows the daily view of the health data<sup>1</sup>. First, there is a large overview with the dimensions Lowest resting heart rate, total sleep and activity burn, arranged chronologically by day. For each dimension a line is visible, which shows the respective

<sup>1</sup>The evaluation and screenshots provided here are from an outdated version. Òura redesigned its visualizations on the dashboard during October.

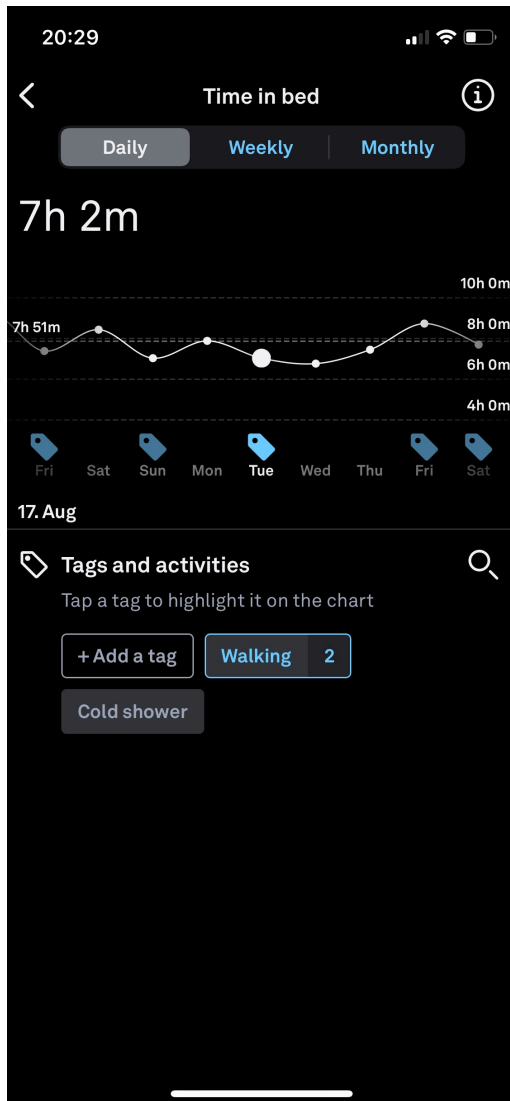


Figure 4.7: Daily trend view of the app

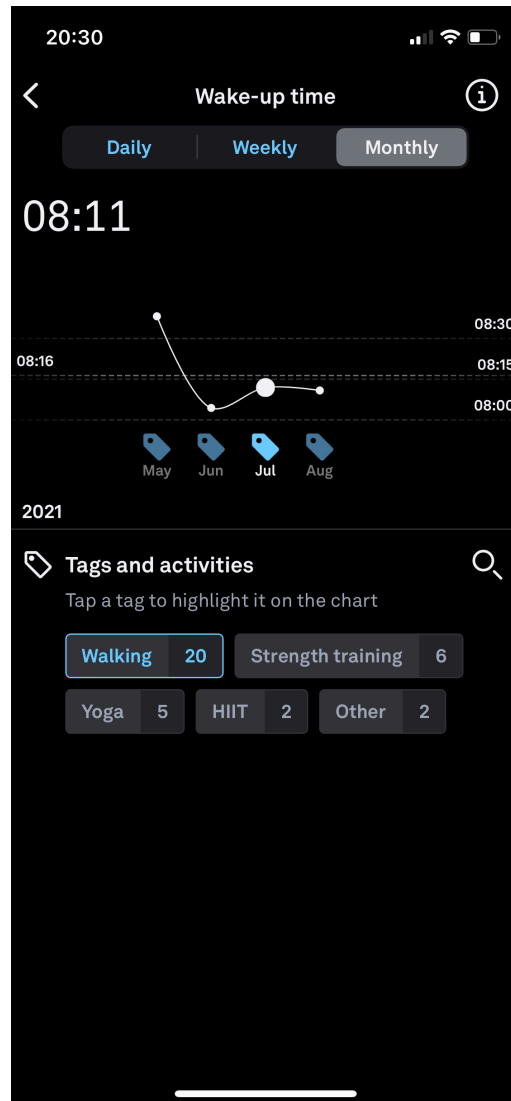


Figure 4.8: Monthly trend view of the app

values, presented at the top of figure 4.9. On the currently selected day, there is a point on the line and the display shows which values this point represents. There is no further y-axis. The user can interactively click through the days. Underneath are the three categories readiness, sleep and activity, which can be chosen among. The values and visualizations are arranged a little differently, but are otherwise the same as those in the app, hence they are not listed again. The difference is that there is a different color scheme. For activity, green indicates good, purple for sleep and light blue for readiness. The warning color is still red.

### 4.2.3 Trends

The trends in the web application are completely different compared to the trends in the app. A time interval can be selected to be displayed. The user can compare two different dimensions in a line plot. The x-axis represents the respective days. There are two y-axes,

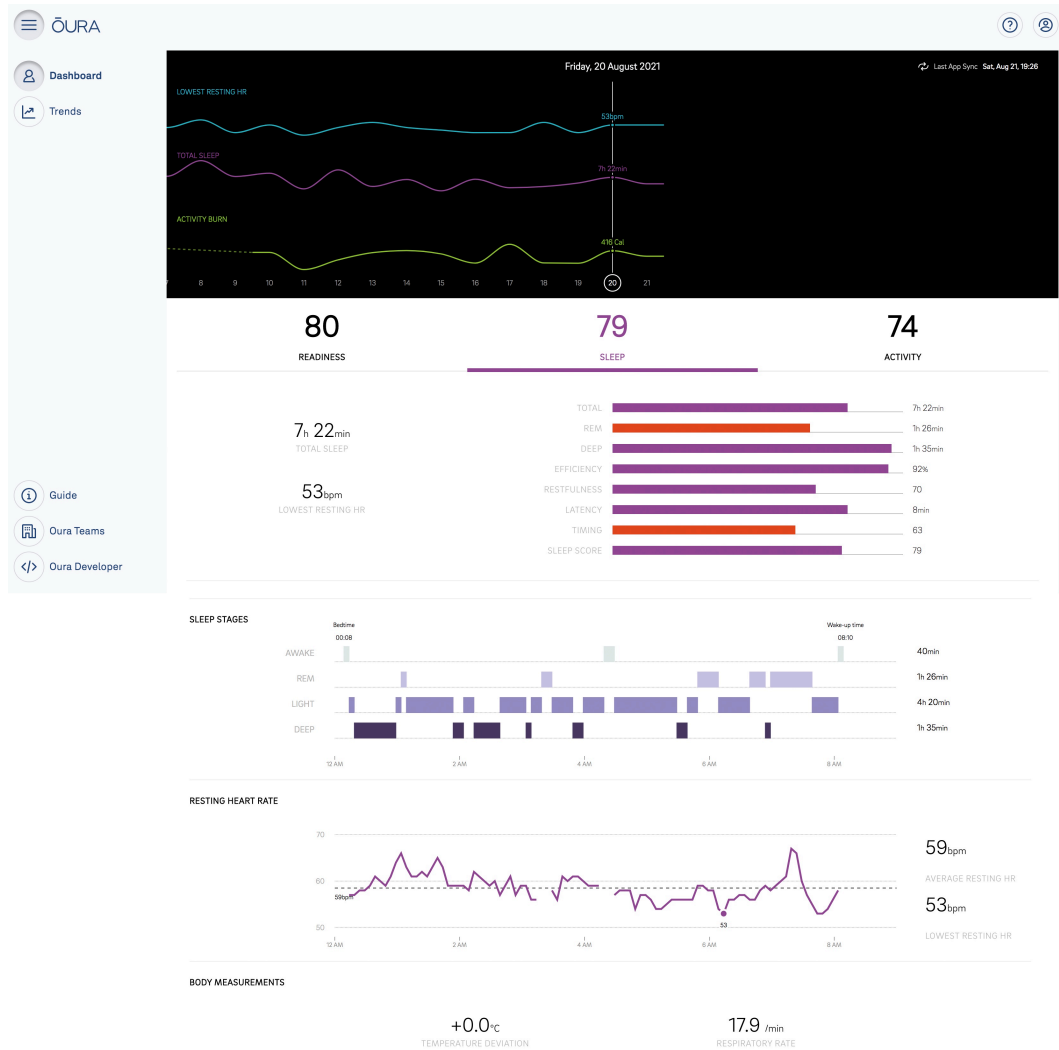


Figure 4.9: Æura visualization of the sleep category on the Dashboard

each labelled with the range of the selected measurement. Interaction is built in, allowing the user to move the mouse over the two differently colored lines and to see the exact value on the respective day. In figure 4.10 this is presented by hovering over Friday the fourth of June. In addition, two straight lines show the two averages. A further important function is the correlation feature. After a certain wearing time, Æura calculates a Pearson correlation between the two values. There is also an explanation of what is meant by a negative/positive correlation, although not customized to the value determined. Above the information about the correlation coefficient, a scatterplot of the two variables is displayed. Several of this type of line plots can be displayed underneath each other.

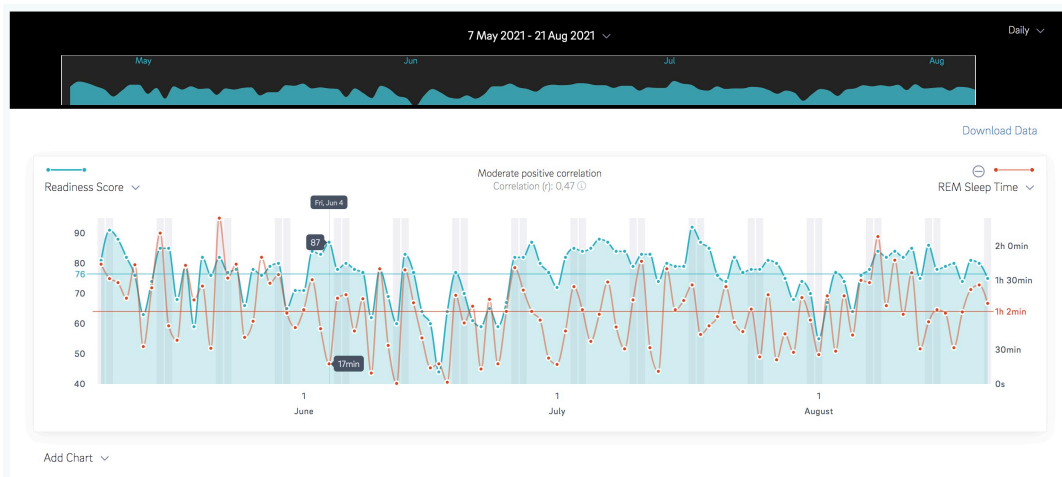


Figure 4.10: Ôura visualization of trends between Readiness Score and REM Sleep Time



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## The application *viSleep*

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A visualization similar to the trends of Ōura’s data visualization was designed for this thesis to show the interrelationships and connections of health data. This developed visualization is applied to data collected by the Ōura ring. Also the user interface, in which the visualization is integrated, was designed with the aim of strengthening health and sleep awareness. The three categories activity, sleep and readiness were adapted from Ōura, but readiness was renamed recovery, as this is a more common term. Through the application, data should be presented and processed in such a way that the given information can be intuitively understood and interpreted by the users. By taking into account prior knowledge and principles from a person’s perception, intuitive use should be made possible.

For this purpose, the general concept and the reasons for a division into four modes are first presented and then, oriented to the “process of designing a visualization”, the procedure and the observed characteristics for the conception of the visualization and the user interface are derived [16, p. 3]. This process is divided into “mapping, selection, presentation, interactivity, usability, and evaluation”, whereby the evaluation will be explained in more detail later [32, p. 2]. First introduced by Chittaro et al., this sequence serves to make the design of visualizations as “precise and error less” as possible [32, p. 2].

### 5.1 General concept

The name of the application *viSleep* is composed of the two terms “visualization” and “sleep” and is based on the proximity to the data of Ōura, whose measurements pay special attention to sleep. In addition, as already explained, sleep can be used to draw conclusions about patterns of the day. The application’s logo, shown in figure 5.1 with white background, writes *vi* and *leep* in small letters and the S forms a curved line. This is intended to represent the connection to the topic of visualization, as lines are often used in diagrams. Although this curved line does not appear in the main visualization of *viSleep*, it does appear in a smaller visualization of a line diagram. The white background of the logo, highlighted by the turquoise background in figure 5.2, was important for the overall effect and for using it in the header.

For displaying the many different data, the application is divided into four modes, the general mode, the activity mode, the recovery mode and the sleep mode. Apart from the use of partly different visualizations and visualization characteristics, as will be explained



Figure 5.1: *ViSleep* Logo with white background



Figure 5.2: *ViSleep* Logo with turkis background

later, the reason for this division is that a lot of choices at once confuses the user, which would argue against intuitive use. The the activity mode, the recovery mode and the sleep mode only offer attributes from their respective subject areas, with some additional information, such as the completed workouts in the activity mode. The general mode, on the other hand, enables the user to compare attributes from different subject areas with each other.

## 5.2 Mapping

Mapping is the first step of a visualization process. In this part of the process, the transformation of information from data, such as numbers, into a visualization is performed by using different visual features such as positions [32, 16]. The creation of visualizations is supported by findings from both cognitive and perceptual research, such as Gestalt rules and “guidelines which determine which representations are most ideal depending on data type” [34, p. 3]. For *viSleep*, a suitable approach was investigated, which entailed a few aspects of consideration. The approach that seemed most suitable, a bubble chart, is then presented and then put into relation with human perception.

### 5.2.1 Choosing an approach

The design of an intuitive visualization starts with finding a suitable visualization approach. These offer “mental models” of often large and complex data and try to make them comprehensible and interpretable for users [32, p. 1]. There are many visualization methods to choose from, and it is not really obvious which one should be used and when. On the one hand, it depends on the number of attributes to be displayed, and on the other hand, which one conveys the most understanding to the user.

*ViSleep* should use a high-dimensional approach, as this allows the various health data and their interrelationships to be presented in greater detail. Through this decision, several insights into the influence of daily routines on the user’s health status can be provided.

Since everyday reality is in 3D, i.e. one horizontal, one vertical and one depth dimension, it could be assumed that using 3D would be a good way to represent multiple dimensions. But many problems exist with displaying the third spatial dimension, depth, especially on a two-dimensional display. Third-dimensional visualizations in a 2D environment favour “occlusion, perspective distortion, shadows” and complicated operation [42, p. 118][15]. Therefore, a high dimensional visualization approach, which is particularly suitable for a two-dimensional environment, was sought for the presentation of health data.

User proximity is supposed to be achieved through visualization approaches “that exploit human’s perceptual and cognitive capabilities of problem solving” [32, p. 1]. This implies that choosing an approach, which requires a lot of consideration, should also take

into account the support of user tasks and the target group. Every person has different prior knowledge and thus understanding. According to Munzner, there are three ways in which users analyze a visualization, named “discover”, “present” and “enjoy”. “Discover” focuses on communicating unknown information, while “present” aims at conveying knowledge and guiding the user. In the last type, “enjoy”, the user should not be “driven by a previously pressing need to verify a hypothesis”, but rather be encouraged. *ViSleep* extracts a bit from all three, which is desired and cannot be prevented. This classification states and draws the conclusion that the different views of the user should be taken into account when choosing the approach [42]. For instance, some really want to look at their health data and draw conclusions from it, others may look at it to get a brief overview. This leads back to the core issue of intuitive use, respecting prior knowledge.

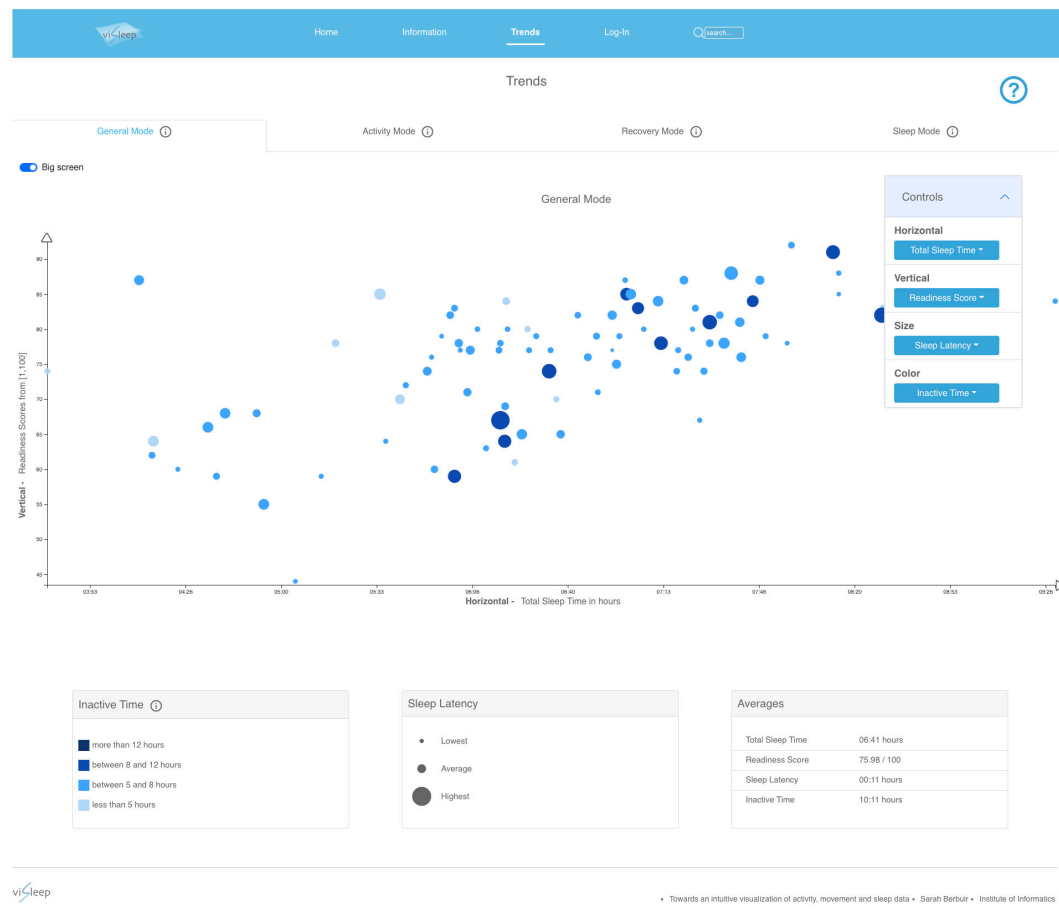


Figure 5.3: Entire *viSleep* user interface (larger version of the figure can be found in figure D.1)

### 5.2.2 Bubble chart

A widely used concept is the cartesian coordinate system, applied by the scatter plot approach. In this method of plotting data, the correlation of two variables is represented. A data point is expressed by a dot with one variable indicating the horizontal position and second variable the vertical position on the coordinate axis. The strength of the correlation

between the values of two attributes is shown by scatter plots [32]. If the correlation is greater, the points are drawn along a diagonal line. A positive correlation results in a rising gradient, a negative correlation in a falling gradient [42]. Furthermore, a scatter plot shows a general overview of the data, for example, whether there occur outliers, general trends or very extreme values. In this context, an outlier is a data point that acts differently from the rest of the data collection.

The representation of two dimensions by spatial positions can be extended by more dimensions to create a high-dimensional visualization approach. The visualization method used for the main visualization is the principle of a bubble chart [32]. In various literature, different terms can be found, such as bubble chart, bubble plot or also bubble graph, which however all describe the same thing [32, 42]. In order to maintain continuity, reference is always made in this context to a bubble chart. This is a “variation of Scatter Plot” with the difference that the point is exchanged for a bubble and in addition to the consideration of the x- and y-axis further attributes are represented [32, p. 7]. These bubbles represent one data point by using different appearances [32].

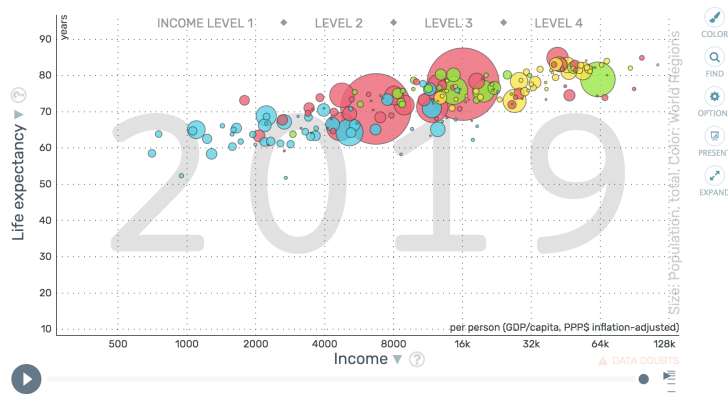


Figure 5.4: Hans Rosling's Gapminder Trendalyzer

The best known application of a bubble chart is the Gapminder Trendalyzer, illustrated in figure 5.4<sup>1</sup>. Developed in 2003 by Hans, Ola, and Anna Rosling, it aims to smoothly animate the size and position of bubbles over time by illustrating trends in high dimensional data. In presentations this seems to be a very useful way of telling the viewer what to look for. However, animation can be a very critical point if it is used without verbal explanation, as the intended message would not be understandable [53]. This is why no animation was used in *visSleep*.

### 5.2.3 Consideration of human perception

When designing a bubble chart, attention must be paid to various constraints. These are divided into user expectations, predetermined conditions like screen size or data consistence, as well as human perception. According to Xenakis et al. human perception and “cognitive capabilities” are the biggest constraints when creating a visualization [75, p. 60]. Visualization is defined as “the use of computer-supported, interactive, visual representations of data to amplify cognition”, where cognition signifies the access or usage of knowledge [32, p. 1]. To communicate modifications, the bubble chart uses visual differences as this is a good way to utilise the human visual system [22, 42]. One reason for this is that a user can quickly detect pictures and perceive differences in appearance immediately [62]. In a

<sup>1</sup><https://www.gapminder.org/tools/>

bubble chart, these visual changes can be made by modifying the bubbles, which are called marks in the following. The creative scope of a visual representation of data is divided into the two elements marks and channel [42]. In the 1967 publication *Semiologie Graphique*, the concept of visual variables was introduced by Jacques Bertin [54]. The approach can be used to describe even complex visualizations and it offers the possibility to consider exactly which information should be encoded how and with which weighting in relation to cognition within the several bubble charts.

Simple geometric entities that represent items are called marks and are “classified according to the number of spatial dimensions they require” [42, p. 95]. If there is no dimension a mark is a dot, if there is one it is a line and if there are two then it is an area. In the case of the bubble chart, a mark is an area, since the size of the bubble is its own dimension.

Channels define how marks appear. They are used to encode information through the properties of a mark, thus of a bubble. Channels are described by combining one of the words visual, perceptual or graphical with one of the words channel, dimension or variable. Therefore, in the bubble chart of *viSleep*, the channels represent the individual attributes. For example, “Total Sleep Time” is encoded with the horizontal position [42].

### 5.3 Selection

To determine which channels encode which attributes, a selection is performed as an answer to the question “Among the data available, what is relevant to the considered task?” [16, p. 3][32]. It is very important to do this carefully, as otherwise huge losses can occur, such as the time needed by users to understand the confusing attributes and thus a lower intuitive use [32]. Therefore, the reasons for the selected channels, their explanation and the selection of attributes will be explained in the following.

Channels: Expressiveness Types and Effectiveness Ranks

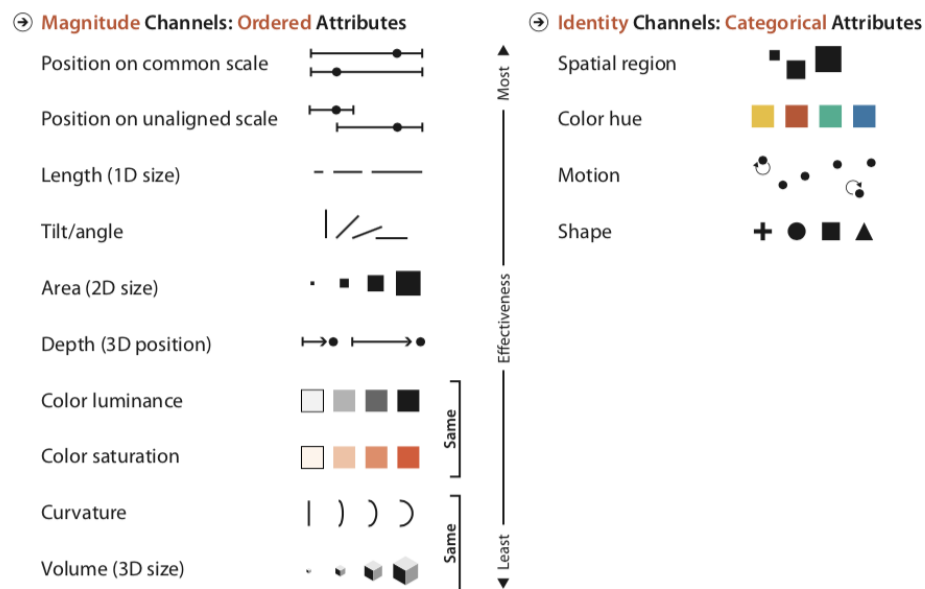


Figure 5.5: “The effectiveness of channels that modify the appearance of marks depends on matching the expressiveness of channels with the attributes being encoded.” [42, p.94]

### 5.3.1 Selection of the channels

Weber's Law states that the "human perceptual system is fundamentally based on relative judgements, not absolute ones" [42, p. 112]. For example the perceived quantity of length difference is a percentage of the length of the object. Those relative judgements have far-ranging consequences.

The human perceptual system can be divided into two sensory modalities, the identity and the magnitude channels. The magnitude channels show the amount of value they express. They encode ordered attributes, including position, length, tilt/angle, area, depth, color luminance/saturation, curvature and volume channels. The identity channels, in contrast, show what information there is regarding the value. They refer to categorical attributes such as spatial region, color hue, motion and shape.

In the following, the channels used and their position in the hierarchy will be discussed. When selecting the channels, attention was paid to discriminability, separability and accuracy between the coded bubbles [42]. They are arranged in descending order of effectiveness. The division of the channels into the two types and the order of these according to a hierarchy can be seen in figure 5.5.

**Position on common scale** A common scale is used in all modes through the axes of the cartesian coordinate system. The attributes encoded with position of the bubble along the axis will occupy the user's mental model the most and thus their selection represents the main choice [42]. The correlation between the two shifts of one point, i.e. the correlation it represents, is a central point of the whole bubble chart.

**Area** A mark can be encoded by several channels. Area or 2D size is a channel used by all four modes, it describes the scope covered by the mark [54, 74]. Size is applied on the one hand to the diameter of a bubble and on the other hand to the width and height of an arrow in the recovery mode.

In case of the arrow, the length channel plays a role in conjunction with size, in which the vertical or horizontal length is extended. So the larger the arrow, the longer it is. Munzner says "Length perception is completely accurate", which is why this channel is prioritised very high up, in *viSleep* directly after the positions [42, p. 104]. In contrast, the judgement of area is notably less precise, therefore the arrow was chosen to encode a channel that is higher up in the hierarchy.

Size interplays with a lot of other channels, for example if marks are small then other channels can not be differentiated well. This is highest with color hue and color saturation [42].

**Color saturation** This channel is used in all modes except sleep mode and means the coloring of a bubble with four different shades of blue, depending on the value of the respective coded attribute. Color is one of the most rapid items to catch interest [22]. Although it can be misleading because sometimes it is treated as a magnitude channel and other times as an identity channel, it can be separated in such a way that color hue has no implicit perceptual order. Since the attributes of *viSleep* are mostly ordered and numeric, they were aggregated into four categories for use in the channel and coded with the color saturation. Color saturation means the quantity of white combined with one color hue, it is also sometimes called intensity. In *viSleep* the saturation is decreasing and the blue tone contains less and less white [42, 54]. The four shades of blue can also be seen in the color legend of *viSleep* in figure 5.28.



Figure 5.6: Mood legend of the activity mode

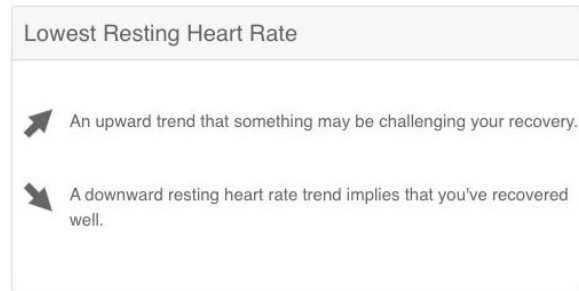


Figure 5.7: Meaning of the arrow orientation from recovery mode

**Shape** Shape refers to the outline of a mark [54]. The general shape in the bubble chart of *viSleep* is a bubble, which can be found in all modes except recovery mode. The shape channel is extended by further channels, only in general mode an empty bubble is used to introduce the user to the concept of multiple bubbles. There is a strong connection between the perception of shape and size, the smaller the bubbles the less distinctive their appearance.

In recovery mode, an arrow is used as the general shape, which is divided into two different pieces of information by the channel angle, i.e. the orientation of a mark, as shown in figure 5.7. Since there are only two versions of the angle in *viSleep*, users can easily distinguish between them. With an arrow, the upper can be distinguished from the lower, and according to Evergreen et al. the “most obvious attention-guiding element is the universal arrow” [22, p.15][42]. Although this is directed at pointing information, this effect is used for *viSleep*, referring back to the prior knowledge thus available and directing attention to the marks [22]. An arrow signals the averages of the values of the vertical attribute from one week. If the trend of the values is upwards, the arrowhead points to the top right, whereas if it is downwards, the arrowhead points to the bottom right. The orientation to the right was chosen here because the arrows are displayed chronologically and time is always advancing, as is the perceived direction of the arrows. Three attributes were given for selection whereby it is possible to say something about the significance of trends. These are Lowest Resting Heart Rate, Average HRV and Temperature Deviation in the Menstruation View. All three assessments of upward or downward trend were adopted from Ōura.

Activity mode has bubbles that show five different moods, as shown in the legend in figure 5.6. These are encoded by faces in which the emotion is indicated by the curvature of the corner of the mouth.

In sleep mode, a pie chart is displayed for the inside of the bubble, showing the individual sleep phases and their percentages of the bed time. Because each of the four stages has a different color effect, differences in the area, i.e. the 2D size of a stage, from bubble to bubble are clearly visible.

### 5.3.2 Selections of the attributes

After going through perceptual and cognitive processes, the identical data attribute which is encoded with two separate channels leads to a varying information in people’s minds. Therefore, when selecting attributes, care was taken not to violate the principles of expressiveness and effectiveness.

The expressiveness principle states “that the visual encoding should express all of, and only, the information in the dataset attributes” [42, p. 100]. Care is taken to display ordered

data in a way that the perception intrinsically perceives it as ordered. This is adhered to in *viSleep*, as all data used has an (implicit) order.

The principle of effectiveness states “that the importance of the attribute should match the salience of the channel”, it alludes to the channel hierarchy [42, p. 101]. To be most apparent, the most significant attributes should be encoded using the most effective channels. In *viSleep*, the strongest correlations found are encoded by the horizontal and vertical position. The correlations between the attributes were obtained from the Ōura web application on the one hand, and on the other hand, in the initial phase of the decision, almost all attributes were implemented and manually evaluated using the visualization of *viSleep* to determine whether a correlation is evident in relation to the data. In further steps, this selection could be extended to the actual logic behind the values.

Besides the logical view of whether it fits the task, effectiveness also relies on its type. For example, the duration of sleep in milliseconds, an ordered value, cannot simply be encoded by color, as it is not possible to distinguish between categories and assign different color values. One way to enable encoding is called aggregation. This involves creating one new component which represents and replaces several others, while still providing the same information. This element can be either an attribute itself or an item of an attribute’s data. *ViSleep* has used this method several times to reduce items of an attribute, for example, the score values of Ōura are given in terms of what the individual gradations imply for health, as shown in figure 5.25.

Another method of eliminating items or attributes is called a filter. It is easy for users to understand because they do not notice it. In *viSleep*, only a subset of the actual attributes was used. The number of attributes users could choose from was minimized to prevent ineffective decisions and overwhelming.

With the exception of the recovery mode, users have the option of selecting time as the horizontal position, which can display counter-trends through the resulting timeline. The given dates per data point also offer the possibility to use the hierarchical structure of temporal attributes. Users have the option of aggregating from day to week, applying the average of the values for the vertical, color and size coded attributes [42].

**General mode** In general mode, the channels horizontal and vertical positions, colors and sizes were selected as shown in figure 5.8.

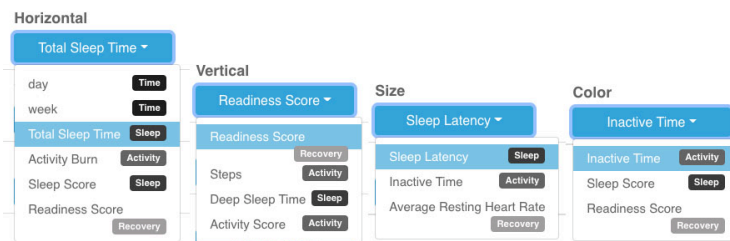


Figure 5.8: Selection options for the channels of the general mode

In figure 5.3, as an example, the attribute Total Sleep Time is selected as a horizontal position, the attribute Readiness Score as a vertical position. Users can immediately recognize the line that is slightly distributed, which shows that the higher the sleep time, the higher the readiness score. Despite the outlier at the top left, it can be seen that no readiness score below 74 appears from a sleep duration of over 7 ½ hours. Consequently, a longer sleep duration is good for recovery. Another correlation can be seen when looking at the color along with the size. Thus, an inactive time between 8 and 12 hours (the darker blue that can be seen) is actually visible in bubbles with a larger size. Since the size encodes sleep



latency, this means in the example that a rather higher inactive time leads to the user taking longer to fall asleep.

**Activity mode** In the activity mode, as in the general mode, the user was given four choices regarding horizontal and vertical positions, colors and sizes, shown in figure 5.9.

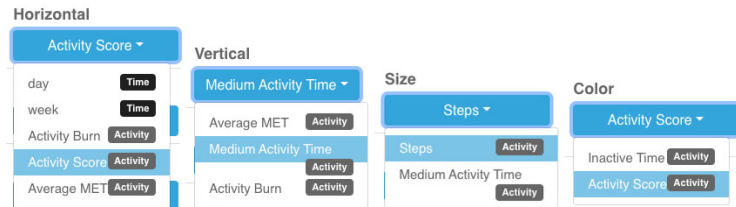


Figure 5.9: Selection options for the channels of the activity mode



Figure 5.10: Activity mode with its visualization and associated legends (larger version of the figure can be found in figure D.2)

In the example illustration in figure 5.10 a diagonal is formed from the bubbles. As the horizontal position is coded with the attribute Activity Burn and the vertical position with the attribute Average MET, it implies that the more calories burnt, the higher the Average MET. Furthermore, it can be seen that the bubble sizes increase towards the right, thus the more steps users have taken, the more they have burnt.

Another example of the recognition of correlations is shown in figure 5.11. If the duration of Medium Activity Time encoded at vertical position increases, then the calorie burn

from the horizontal position is higher. There is no perfect line but the area below the diagonal is filled with bubbles. This is easily recognizable through the channel. Since the emojis are determined prototypically on the basis of the activity score, they show their course as a horizontal value, so the very bad mood is shown on the far left, the very good mood on the far right. With real data, users could, for example, see that the more calories they burned, the happier they were.

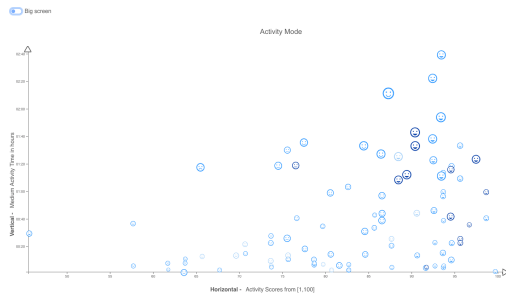


Figure 5.11: Alternative example to show further possibilities of the activity mode

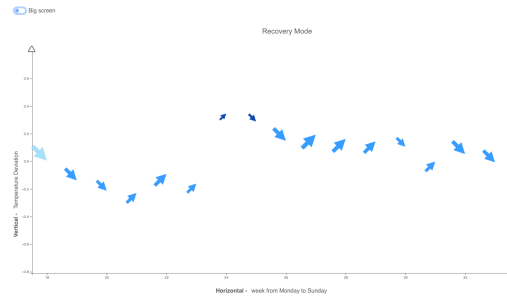


Figure 5.12: Alternative example to show further possibilities of the recovery mode

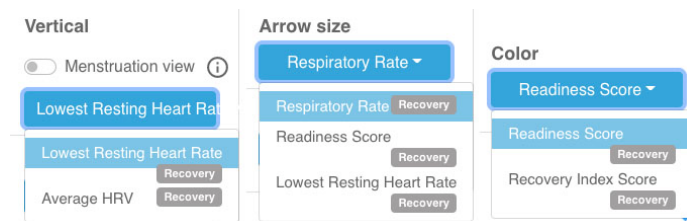


Figure 5.13: Selection options for the channels of the recovery mode

**Recovery mode** The options for vertical positions, sizes and colors, shown in figure 5.13, are selectable in recovery mode. The horizontal position is omitted because a bubble denotes one week. As a result, no normal correlation between x- and y-axis is recognizable, but instead a temporal trend. In the example in figure 5.14, it is immediately recognizable from the beginning that the Lowest Resting Heart Rate in calendar weeks 24 and 25 has two outliers compared to the remaining weeks. This is due to its higher vertical position compared to the others, its larger size and its darker color. In these two weeks, the respiratory rate and the readiness score were particularly good. Users could think about whether something specific happened during those two weeks to reflect themselves. Furthermore, this shows a positive correlation of the two attributes with the Lowest Resting Heart Rate. Figure 5.12 presents a second example selection. The menstruation view is activated and it shows the temperature deviation as vertical position. In the female cycle, monthly patterns are recognizable, which is already slightly evident in this case. Through the arrow orientations, the wave-like shape of the line is emphasized for human eyes.

**Sleep mode** Users can select attributes for the channels of the horizontal and vertical positions and the sizes in sleep mode, shown in figure 5.15.

Through the horizontal position of the values of sleep score, and the vertical position of the values of total sleep time in figure 5.16, it can be seen that the longer the sleep duration,

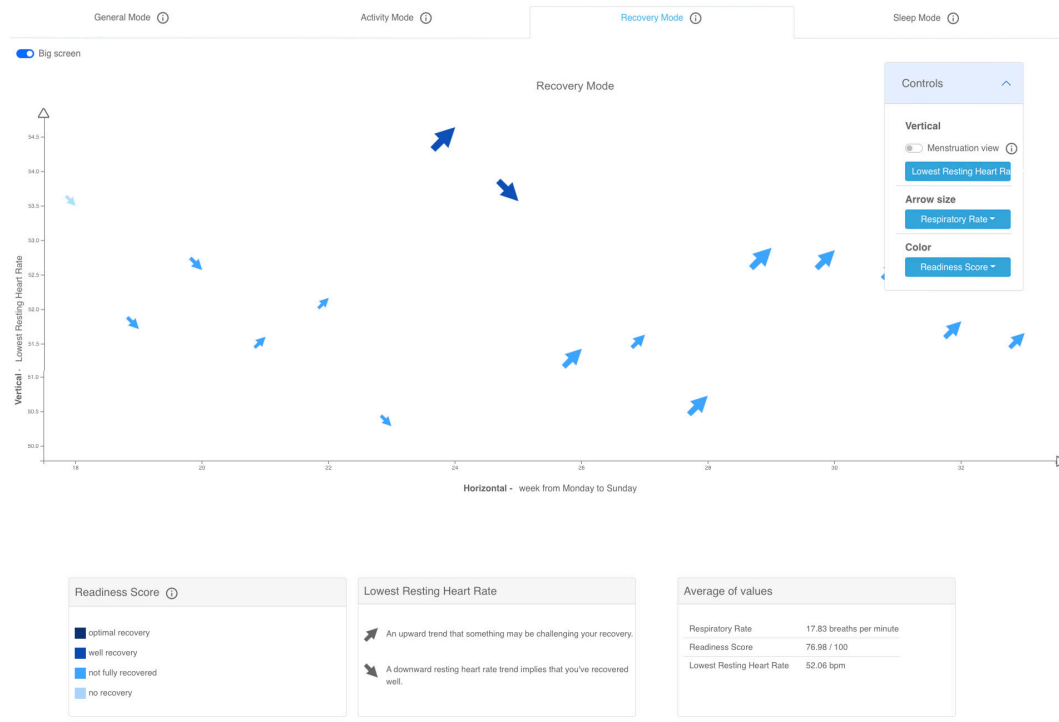


Figure 5.14: Recovery mode with its visualization and associated legends (larger version of the figure can be found in figure D.3)

the higher the sleep score. By adding the size to the observation, it is possible to see how the bubbles indicate higher REM sleep time values as the sleep time and sleep score increase. The more sleep there is, the higher the duration of REM sleep. This is further illustrated by the pie charts, on the far right, which show that the area relating to REM sleep is getting larger and larger.

## 5.4 Presentation

The presentation phase includes the embedding and arrangement of the visualization and its elements. After mapping and the “precise selection of data items”, it is now a matter of effectively using the available space in a way that can be well perceived [32, p. 3].

One danger to an intuitive presentation, also mentioned by Chittaro, is the limitation of screen size. Therefore, for *viSleep*, a regular computer screen was taken as a standard and the visualization was integrated into a web application [16]. Moreover, in order to take the inch size into account and still stick to the prototypical development method, responsive design was not used and instead a switch was built in that enables the user to adapt the visualization to a “big screen”.

*ViSleep* was developed as a prototype and visually adapted to a conventional website, which means that a header and a footer were included. The footer only contains the name and the description of the thesis. Within the header, the logo is positioned on the left margin, as this is always the case by default and thus ties in with the user’s previous knowledge and provides a familiar context. Furthermore, there are links that could lead to other pages and also a search bar. The user gets a message through an overlay as shown in figure 5.17

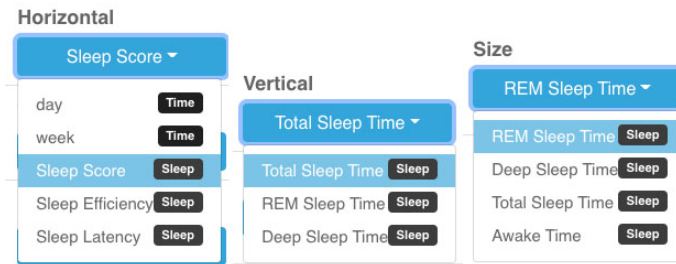


Figure 5.15: Selection options for the channels of the sleep mode

stating that clicking and searching is not possible as it is a prototype.

The remaining space presents the visualization and its elements. Since *viSleep* was divided into four modes, there are four tabs that allow a quick change from mode to mode. General mode was positioned as the first tab, as it contains all other areas and does not contain any extra visualizations. Therefore, users should first get familiar with the general principle of the used visualization approach. The remaining modes are arranged in alphabetical order, as this signals a structure and thus appeals to the user's prior knowledge.

Since the visualization is the essential component, it is placed in the middle of each tab. On the right, the possibility to change the attributes interactively has been placed somewhat overlapping the visualization. This arrangement was chosen because the usual reading direction is from left to right and thus the attention should first be drawn to the visualization and thereafter to the possibility of interacting with it. Also, the designations and their corresponding information icons were placed in such a way that it is more important to know what they refer to first in order to then access the information. The placement of the legends below the visualization follows exactly the same principle, since reading is done in a top-down direction. Both reading directions differ depending on the cultural background. All legends were arranged according to importance for understanding the visualization. The meaning of the bubbles' color is more important than the average values, therefore it is further to the left due to the reading direction. In general, the lower boxes are meant to give a good overview.

## 5.5 Interactivity

The fourth step is to add interactivity, answering the question, "What tools are provided to explore and rearrange the visualization?" [16, p. 3]. In the field of visualization, this is considered essential for developing approaches that display large and complex amounts of data, as only a few pieces of information can be presented in a single static view, for example a maximum of five in *viSleep* [32, 42]. Thus changing visualization dimensions allows for a wider information volume [42].

By interacting with the bubble chart, the user can understand it better, because it increases their engagement and degree of enjoyability [16, 57]. In the context of intuitive use, "interaction is defined as a two-way exchange of energy and information between human and product" [43, p. 133]. Therefore, user convenience should be considered in the selection of controls [32]. Since *viSleep* is limited to a computer, just hover and click methods are applied.

In terms of integrating interactivity into a visualization, Ben Shneiderman's information seeking mantra, "a design guideline that emphasises the interplay between the need for overview and the need to see details", can offer some direction [42, p. 135]. He developed it because he considered that all strong visualizations incorporated it [62]. It is divided



Figure 5.16: Sleep mode with its visualization and associated legends (larger version of the figure can be found in figure D.4)



Figure 5.17: Feedback to the user that links in the header are only displayed prototypically

into “Overview first, zoom and filter, Details on Demand” [42, p. 135]. In addition, it is partly supplemented by several points, such as displaying relations between items, which is already given by the bubble chart [62].

### Overview first

“Overview first” is about giving the user an overview of the total content [62]. Overviews assist users in identifying areas where additional inquiry in more depth would be beneficial [42]. In *viSleep* this is accomplished through the bubble chart and by allowing the user to choose which attribute should encode which channel. Modifying the choice is a “powerful choice for finding patterns in a dataset” [42, p. 246]. An important point is that variations of position are ordered highest and thus it is quickly seen whether the new changes carry new information. A design decision according to Munzner is that the user replaces the old attribute of a channel with a new one and that the bubble chart always requires a selected attribute. Figure 5.27 shows how the selection of attributes is arranged.

The Menstruation View seen in the figure is a special case in *viSleep*. Turning it on or

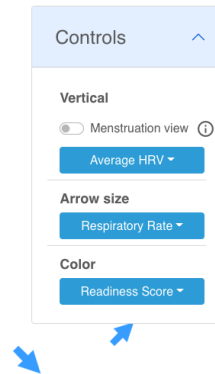


Figure 5.18: Control of recovery mode to pick attributes for encoding a channel

off is presented by a switch that can be activated, which is a form of selection that is very common but limited to only two states. The vertical value is changed either by activating the switch to “Temperature Deviation” or by using the drop-down menu. A mixture of both types of selection has been used here. The various drop-down menus are located in an accordion that can be opened and closed.

Through the overview given by choice, users can explore their health data and thus their health by switching back and forth between different bits of information [42]. Due to the slightly guided recognition of patterns in the bubbles, users are then able to search for more information.

### Zoom and filter

This occurs in “zoom and filter”. Filtering in the context of the mantra is about interactively removing items that are not interesting, although this has not been done in *viSleep*. However, it is possible to zoom in on interesting items by semantically diving into the data through the above mentioned aggregation of time, i.e. from a bubble describing a week to one describing a day [62]. Munzner says that aggregation is a “powerful design choice” when users can interactively modify the desired level of inspection [42, p. 305].

### Details on Demand

“Then details-on-demand” addresses the user’s need to select an item and obtain more detailed information [62, p. 365]. The most common type of element used for interactivity are the data items, i.e. the bubbles [42]. The usual approach to get more detail and attractiveness is to click on an item in order to see a pop-up box, this works in *viSleep* by hovering over a bubble [22, 62]. It presents different types of information depending on the mode. In all modes, as shown in figure 5.19 for general mode, exact values of the respective bubble of the attributes expressed by channel can be seen. In activity score, as illustrated in figure 5.20, a table is displayed showing the activities with type, duration and number of calories. Linking the scores to the activities can provide insights, for example, if a high sleep duration is often related to many activities. A diary entry is displayed to address the user’s memory and eventually recall the day for reflection.

Figure 5.21 depicts the recovery mode pop-up, where an arrow always represents a week. A line diagram is shown that visualizes the individual daily values of the vertical value of the main visualization. Thus it is possible to follow in detail the trend represented

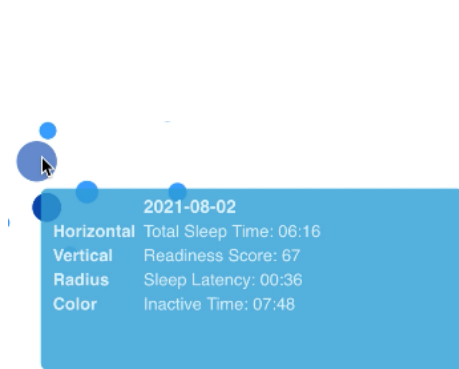


Figure 5.19: Pop up window of general mode

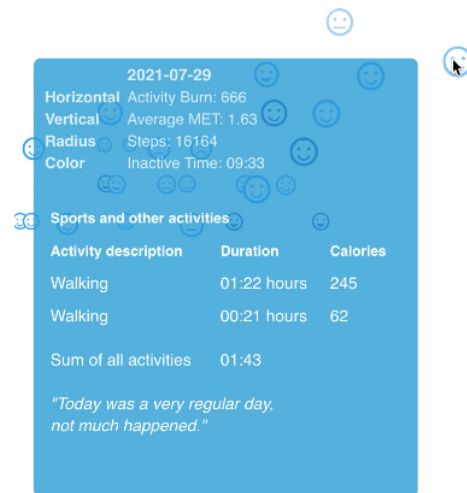


Figure 5.20: Pop up window of activity mode

by the arrow orientation. The pop-up of the sleep mode, shown in figure 5.22, contains the exact percentages of the pie chart and the enlarged pie chart of the respective bubble.

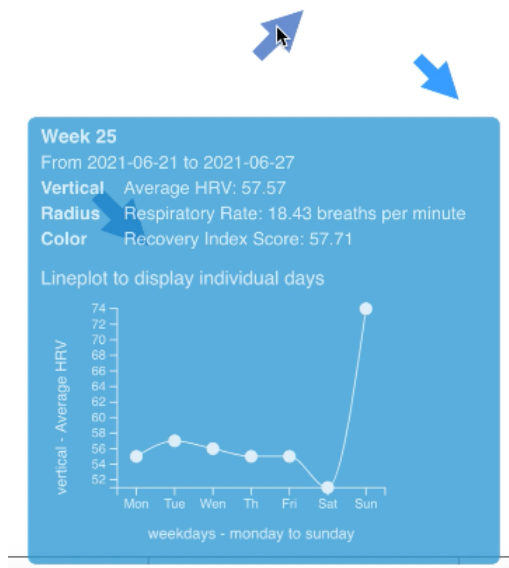


Figure 5.21: Pop up window of recovery mode

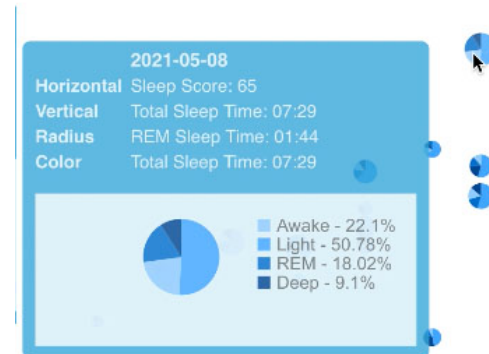


Figure 5.22: Pop up window of sleep mode

Interactivity is also built into the user interface in which the visualization is embedded. Different tabs are available, which change modes by clicking on them. The user can click on the links of the header, but this is answered with an overlay saying that it is only a prototype. Hovering over the info or help button displays a text with information.

These included types of interactivity in *viSleep* are intended to provide the users with the intended information in a way that they can easily explore it and thus use and understand it intuitively.

## 5.6 Usability

The fifth step deals with the question “Are human perception and cognitive capabilities being taken into account?” [16, p. 3]. This is concerned with how users can best perceive and understand a visualization and is aimed at ensuring that they do so willingly and without much effort [16]. It refers to human factors, which, according to Khan et al., are divided into the two areas of “usability, and accessibility factors” in order to design visualizations [32, p. 2]. A good user experience is essential for a visualization, as users should adapt and engage with new information [37]. As already defined, an application is intuitive when users can easily use it subconsciously to accomplish the goal of conveying information [30]. In the following, the principles from the field of perception and usability are explained for the design of the bubble chart in order to achieve the best possible intuitiveness. Then the same is explained for the user interface and the entire application, where even more guidelines were taken into account.

### 5.6.1 Usability in the visualization

In terms of visualization, the area of Human Computer Interaction needs to be considered [32]. Visualizations should be simplified “to the extent possible” to reduce cognitive load, avoid distraction and the impression of complicated and frequent decisions [22, p. 6][31]. Also according to Tufte, the “highest possible data-ink ratio” should be aimed for, which means that the most filled space should be planned for the representation of the bubbles [31, p. 8]. Research indicates that users are more likely to avoid extremely complicated diagrams than to struggle with their interpretation.

According to Evergreen et al. the amount of elements should be minimized because the working memory is incapable of storing large information. Therefore, it is recommended that gridlines and the labelling of items be avoided, as applied to the coordinate system in *viSleep*. In addition, attention was paid to the narrow range of focus that human eyesight has by reducing space between the visualization and its legends, control elements and labelling. Thus no eye movements and scrolling are needed to view the visualization of *viSleep* completely. Although it is recommended not to use legends, the high dimensionality of the bubble chart makes it impossible to do without them, as the coloring, for example, would be incomprehensible. If legends are necessary, they should be close to the visualization in order to achieve efficient mental processing [22].

### 5.6.2 Usability in general

Guidelines and principles exist to create intuitive web user interfaces [29]. User Interface (UI) Design is centred on understanding users’ needs and providing that it has elements that are accessible, comprehensible and used to simplify actions [1]. For this purpose, the seven dialogue principles, a “set of general goals [...] for the design of dialogues” among people and machines, were considered first [52, p. 88]. These principles are suitability for task, self-descriptiveness, conformity with user expectations, error tolerance, suitability for learning, suitability for individualisation and controllability.

#### Suitability for task

Suitability for task means that exclusively features and dialogues are included in the application that assist in the accomplishment of the task [1, 7]. In *viSleep* this is given because the content of the page consists of the visualization and the associated components. To prevent unnecessary interaction steps, the general mode, which is the most universal and the one



with the fewest channels used, is the default mode. From the beginning, default attributes and opening of the accordion with the controls are preset [1].

### Self-descriptiveness

This is also part of self-descriptiveness, whereby it should be precisely conveyed what can be used and in which way, as well as where the user is in the dialogue and which actions can be executed [1]. The expanded accordion with dropdowns makes it apparent how users can interact with the visualization of *viSleep*. This is reinforced by a typical design of the dropdowns as buttons, which was chosen, apart from anything else, to immediately communicate to users what they intend [7]. The active tab is the only one with a turquoise font color, which is a built-in feedback for users regarding their location.

### Conformity with user expectations

The principle states that the user may not intuitively access the design and its content, if no sensation is consistent with prior experience [44]. In case of a “mismatch between perception and world model”, the conscious processor is triggered, which should be prevented by all means [27, p. 3]. Rather than surprising the user with illogical elements or placements, the aim is to provide those that are expected [71]. Technical details should be avoided, which is why the terms “horizontal” and “vertical” were used instead of “x-axis” and “y-axis” [1].

In *viSleep*, internal and external consistency were considered. Internal consistency describes the similarity and regularity within a system that is to be regarded as coherent. For external consistency, the same applies to interaction patterns of different systems in interaction situations that are considered comparable [39].

The three principles of intuitive interaction by Blackler, Popovic and Mahar address this adherence to consistency. They were developed to enable intuitive interaction to be transferred to interface design [43]. *ViSleep* has used the first principle “Use familiar features from the same domain” [8, p. 3] to ensure that “functions, appearance and locations” used are similar to other websites and therefore already familiar to the user [8, p. 4]. Thus, the structure with fixed headers and footers at the top, the use of tabs, dropdowns and the info/help button with familiar symbols of an “i” or a “?” are all common to other websites. The designation of the different visualization views as “mode” picks up on already well-known formulations. This all helps users to quickly and intuitively use *viSleep* the time they first experience it [8].

But even with concepts that are rather new or unfamiliar in the domain, there are ways to reduce complexity, approached by the principle of “transfer familiar things from other domains” [8, p. 3]. In *viSleep*, emojis are used for bubbles in the activity score. Only through transferred experiences from normal life involving recognition of differences in faces users are able to understand the meaning behind the moods. The visualization becomes more familiar to users through the use of mental models, constructs on knowledge which humans evolve in order to understand the world. For example, the color blue is used for the bubbles because this color is used in society for sleep [8].

The third principle “redundancy and internal consistency” is used to make *viSleep* more intuitive. Redundancy helps users, regardless of prior knowledge, to handle the given interface [8, p. 4]. In *viSleep*, the current tab title is turquoise and there is additionally a redundant heading. This principle can also be found in the axes labels. Although in the control units it is already obvious which attribute is selected for which channel, in the axe it is again included as a label. Internal consistency implies that “function, appearance and location of features are consistent between different parts of the design and on every page,

screen, part and/or mode” [8, p. 4]. In *viSleep*, the structure is the same in every mode, with the visualization, the control elements and the legends/average boxes. The pop up is also very similar in each mode, regardless of the content, including that the visualization has the same functions to interact with. Moreover, the info/help icons have the same action and sequence of action throughout the application.

### Error tolerance

A usable application supporting users includes error messages or assistance to help in case of serious errors or illogical input and thus prevent confusion and conscious thinking [1]. In *viSleep*, due to the few interactivity options offered, no serious errors can occur, but it could happen that the user occupies both the horizontal position and the vertical position with the same attribute. Although this is not an error per se, the visualization will return a diagonal, causing users to mistakenly recognize a pattern and thus be distracted from the actual task. In order to prevent this, an error message and an explanation of this appears displayed in figure 5.23. An optional help is suggested.

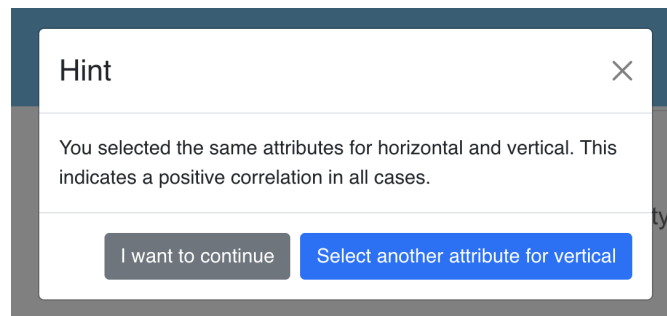


Figure 5.23: Warning in case of the same attribute for horizontal and vertical position

### Suitability for learning

Further assistance to the user is provided by observing the principle of “suitability for learning”. The help button, illustrated in 5.24, briefly explains the visualization in general, how to interact with it and how to recognize patterns. These three categories were chosen because they explain the scope of use.

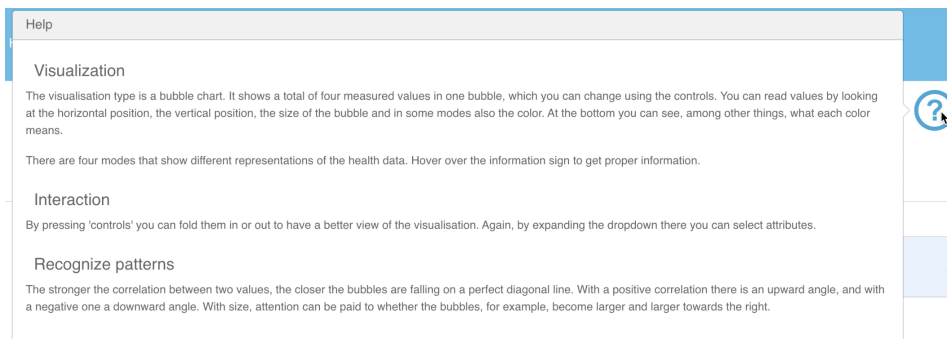


Figure 5.24: Question window, displayed after hovering over question icon

Another support, so that the user can still understand the visualization even if there is some confusion, are the info buttons, which provide information and hints. So-called tooltips are recommended for this purpose [1]. These occur at the modes, the menstruation view, the sleep stages and at color legends to explain the score values. In figure 5.25 an overlay is shown explaining how the readiness values have been categorized to result in the color values and in figure 5.26 an explanation is given of how the menstruation view can be read. Preventive help was therefore built in to not leave users on their own and to achieve a positive and thus more intuitive use. The texts were chosen to be very short in order not to tire the user and to remain time-efficient. The legends, the average boxes and the badges, which divide the attributes for the users in general mode into the three categories, illustrated in figure 5.27, also offer help and further information for visualization.

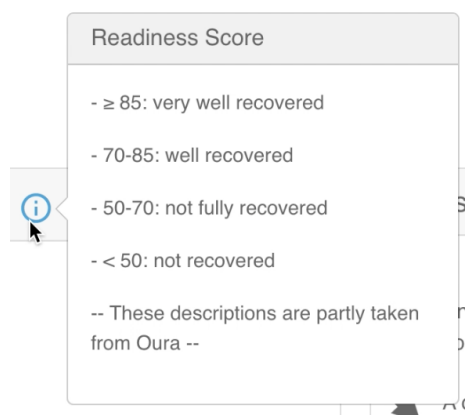


Figure 5.25: Overlay of info icon containing information on readiness score

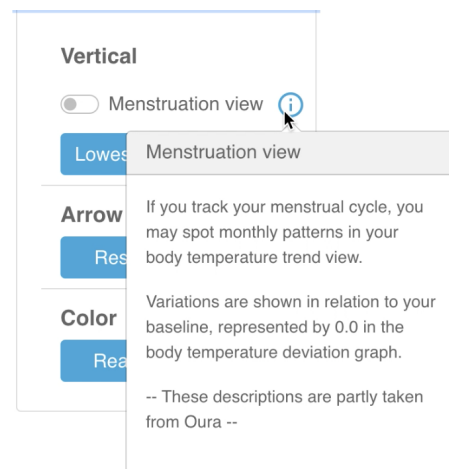


Figure 5.26: Overlay of info icon containing information on menstruation view

### Suitability for individualization and controllability

The dialogue principle “suitability for individualization” aims to make *viSleep* accessible, to accept different prior knowledge of users and to incorporate this perspective into the elements [1]. One way to take this into account is the big screen feature mentioned earlier, which considers different sizes of screens. In order to view the entire visualization, the user can collapse the box with the control elements

“Controllability” means that the user has control over the speed and orientation of the ongoing dialogue, which is given through this box and the general built-in interactivity, like navigating back and forth between modes [1].

Suitability for the task, self-descriptiveness and conformity with user expectations, meaning consistency, are three dialogue principles that were also included by Mohs et al. in the “seven criteria which influence intuitive interaction” [43, p. 130]. The other principles are compatibility, feedback, affordances and gestalt laws [7, 43]. In the following it will be shown how the last three have helped and encouraged *viSleep* to more intuitive use.

## Feedback

Feedback means that the *viSleep* user receives adequate feedback from the controls themselves or the screen after each interaction. This provides reassurance about the success of the user's action and does not disrupt the "intuitive flow of operation" [7, p. 11]. They should not be perceived as feedback in the first place, instead they should be taken for granted [39]. It is considered natural response when users change the tab, change their viewpoint and a new frame is drawn. Additionally the new tab's text becomes turquoise as a feedback. In the dropdowns of the controls, the attribute that currently codes the respective channel is colored blue as shown in figure 5.27 to show users their current status. According to Munzner, highlighting the chosen item is an effective method of confirming that the requested action has been executed correctly [42].

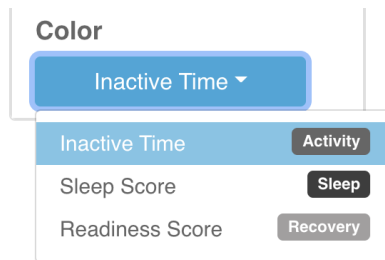


Figure 5.27: Expanded dropdown of the color channel

Further feedback appears when hovering over the header through the "Just prototype" display and through the coloring of the icons of the help and info buttons when the mouse hovers over them. In addition, when hovering over a bubble, the user's operation is made clear by the bubble becoming transparent.

## Affordances

Affordances are characteristics that give an indication of an object's actions. The factors that contribute to affordances are "proportion, structure, size, shape, weight, color (hue, value, saturation)". These parameters can be summarized as appearance, indeed, it can be stated that "nearly every design has some sort of appearance" [55]. For *viSleep*, the font "Open sans" from the sans-serif category was used, because it seems clean and simple and is recommended for computer screens [56]. Subtle headings reinforce the clear impression.



Figure 5.28: Color legend of *viSleep*

The font color and the color of borders is a dark grey. Black is not used anywhere in the visualization, as this would be a strong contrast to the turquoise. In buttons and the header the font color is white, in the active tab it is turquoise. The turquoise is the generally used color of *viSleep*, the two colors on the left of figure 5.28 are the main used. The items in

the legends and average boxes are also grey in order not to distract from the visualization. Other colors are the ones used in the visualization, since this is the central element of the application, these are also included in the color concept of *viSleep* in figure 5.28. The four shades of blue were chosen because it indicates a descending order of value, and Tufte also considers blue to be pleasant for human eyes and for displaying information [15]. The vertical and horizontal labels are written in bold to distinguish them from the attribute labels and to indicate them. A visual distinction is made between the box with the controls and the visualization, in order to highlight the difference. However, the shadows are kept very minimal to avoid deviating from the general cleanliness of the layout. The appearance of functions influences intuitive use significantly [43].

### Gestalt laws

The Gestalt laws were incorporated into the design of *viSleep* to ensure that users can easily navigate through the interface. These laws apply basic perception principles to interface design, and are intended to clarify the overall interface. By grouping minor components together according to the law of similarity, the mind perceives them as a unit [7]. Thus, users are supported in handling complicated information by decreasing everything to a traceable number of elements [41].

In the controls a subheading and its associated dropdown are arranged together with spacing and a separator line from the others. As the others have a similar meaning and the same structure, they are positioned in the same way. The legends and average boxes are also similar and therefore have the same appearance. Nevertheless, they are visually different because they have different content.

The law of proximity is a very important one, elements being nearer to each other seem to be more probable to be grouped. It is the most important for perception. The text is grouped close to its info button, the elements of the header are placed near to each other and the axe label is very close to its corresponding axe. All these choices and spacing were chosen to symbolize the respective togetherness of human unconscious perception. The legends are also close to the visualization and close to each other, as already mentioned. Within the legends, the law of proximity is present, since in each case, for example, the color box with the corresponding description are close to each other. The line within the elements of the average boxes also shows that the content is very similar and is perceived as units through the respective grouping.

In *viSleep*, attention was paid to symmetry because it promises cleanliness and structure [42]. This symmetry is found in the arrangement of the four tabs. In addition, the heading “Trends” is centred, as well as the “Trends” headline within the header. The three legends and average boxes per mode are scaled so that their borders are symmetrical.

In general, attention has been paid to an arrangement that is pleasant to look at and does not cause symmetrical or spacing confusion.



### 6.1 Tools

The visualization as well as the user interface and the interactions were mostly implemented using the programming language JavaScript and partly the languages HTML and CSS. The JavaScript libraries D3.js and React enabled the creation and embedding of the interactive visualizations, both are briefly introduced in the following. In addition, the application was deployed, which will also be described.

The source code is publicly available via the link

<https://github.com/SarahBerbuir/viSleepApplication>.

#### 6.1.1 D3.js

In order to handle the data and dynamically convert it into a visualization, the JavaScript library D3.js was used. D3 originates from “Data-Driven Documents” and is used to manipulate data without, for example, manually calculating their positions. D3.js is based on “functional programming principles” and joins HTML, CSS and SVG to enable the creation of visualizations [69, p. 8].

With D3.js data can be linked to a Document Object Model (DOM) and then conduct data-driven document changes. It adopts a declarative approach that works with groups of nodes, termed selections. This allows for a high degree of flexibility and a good possibility to build in interactivity. For each data point from a csv file, its position, size and more can be calculated by functions. Additionally, the data points and axes can be combined into a visualization. In the application, besides the main visualization and the small visualizations like pie chart or line chart, various labels have also been added using D3.js syntax [69]. Overall, D3.js was helpful in handling the data well and converting them into visualizations.

#### 6.1.2 React

The JavaScript library React and many of the components from the React library React-Bootstrap were used for implementing the user interface and interaction. According to Gackenhimer et al., “React builds large-scale user interfaces with data that changes over

time” [25, p. 3]. Its core elements are components that are assembled into one. In the component ‘App.js’, the components “Header”, “MainComp” and “Footer” were combined to build *viSleep*. “MainComp” contains four components, one for each mode, and several more components were included. In order to prevent redundancy in the code, it is also possible to implement individual elements as one component and then modify the color or text according to their purpose. This feature of React was applied to the info buttons, amongst others. Outsourcing of functions was also used to prevent them from appearing redundantly per mode.

Through CSS, Cascading Style Sheets, the user interface was made visually more attractive, using certain targeted positions, scaling and divisions, as well as colors, fonts and much more. The command `npm run build` properly packages React in a “production mode”, and provides optimization of the build to ensure optimal performance [23]. All this is stored in a build folder, which then contains “deploy-ready HTML files and assets” [45].

### 6.1.3 Deployment

To deploy the *viSleep* web application, Netlify was used, an “all-in-one platform that adds essential power and functionality to React apps”. Through the previously mentioned build folder, after it has been committed to the GitHub repository, a so-called React app can be deployed with Netlify. Thereupon, the application *viSleep* can be accessed through a assigned domain. This domain does not contain any elements that would make it assignable to the project, as the *viSleep* web application is only a prototype and was primarily deployed for the user study [46].

## 6.2 Data preprocessing

The data sets that were used are the central points of the work, as without them the visualization and thus the sense of *viSleep* would not have been viable. Which data sets were used and how they were formatted with the help of JavaScript will be explained in the following.

### 6.2.1 Data sources

The data sets used in the visualization are mostly taken from the measured data of an Ōura ring, downloadable as a csv file in the Ōura web application. A csv file, a “comma separated values format” can be used for interchange and conversion of data, it contains column headings and values, each separated by a comma. These values can be accessed individually, for instance with D3.js. The file contains many different measured values from the three categories sleep, readiness and activity, including those used for the visualization. In addition to this main file, another csv file was created that contains the physical activities of the Ōura app, as these are not exported automatically. Therefore, the date, the type of sport, the number of calories and the duration were transferred manually. The duration was converted from the format “hh:mm” into milliseconds to match the data from the Ōura file. Both the Ōura file and the activity file could be joined by the date value.

Other data that was added manually was the mood and diary entries. Since these were not recorded continuously, their contents were determined directly in the code depending on the activity score of the respective day, thus benefiting the prototypical presentation. The mood is divided into categorical values “very bad mood”, “bad mood”, “neutral”, “good mood”, “very good mood”. Five intervals are calculated to divide the range between the individual minimum value and the maximum value of the activity score, hence it is not



possible to specify exactly in numbers which mood and which diary entry is implied by which value. As an example, the first interval results in “very bad mood” and the last interval in “very good mood” and the diary entry “Today was a really nice day, I had dinner with friends and went to the cinema”. Both the mood, the diary entries and the csv file with the activities were only used for the activity mode.

### 6.2.2 Data formatting

The data from the csv file from Ōura had to be formatted so that it could be used for the visualization. With D3.js it is possible to convert a csv file dynamically. Values describing a score were thus converted into an numerical value and the date was also formatted as such. All decimal numbers are rounded to two decimal places.

The used visualization approach bubble chart uses a cartesian coordinate system, which is why it is important to correctly display the attributes for the x- and y-axis, which each represent an interval. The JavaScript library D3.js offers the possibility to scale data using several functions. For this purpose, a scaling is calculated for the x- and y-axis by specifying a domain that contains the respective minimum value and maximum value and a range, which in this case is the width of the space. Now the position of a bubble can be computed and defined by this scaling, stored in a variable. Exactly the same methodology is used to calculate the size.

Elsewhere, attributes were scaled by setting intervals in color categories through a range. A color value in hexadecimal form like “#0d3471” was determined for each bubble using a numerical value.

For scaling the date on the x-axis, another function was used that was built specifically for dates. Each date was converted into the format “yy-dd-mm” and into a date object so that it can be used as a reference point. Dates that contain a time duration, such as “Total Sleep Time”, have the original unit ms used for their usage in scalings, but are transformed to the format “hh:mm” for the verbatim display, e.g. in the axis labels.

If the user has selected the attribute “week” for the horizontal value, a local csv file is created by an extra function. This contains the calendar weeks, from Monday to Sunday, and their respective average values of the y-, color- and size- attributes. The mean was taken because outliers are not to be neglected in terms of health and have an influence on health. When creating the visualization, a distinction is therefore often made between week and non-week, as both csv files have different column headings. In addition to the averages, the local data structure contains the individual values of the week in order to be able to display the individual values of the respective week, for example in the line diagram of the recovery mode, which is included in the pop-up by hovering over the bubbles.

The arrow orientation is also determined with these values. If the first value is lower than the last, the trend is rising, otherwise falling. This is certainly not the safest way to determine a trend, but it is sufficient for the prototypical structure of *viSleep*. To obtain the percentage values of the sleep phases for the pie charts of the sleep mode, the proportion of the values given for the attributes “Awake Time”, “Light Sleep Time”, “REM Sleep Time”, “Deep Sleep Time” was calculated in comparison to the “Total Bedtime”. These decimal values were used for the creation of the arcs of the pie chart and converted to a presentable percentage value for presentation.

## 6.3 Incorporating interactivity

The React library makes interactivity possible. Every time the user changes something specific, in the case of the dropdown the horizontal, vertical, color or size attributes, the visualization is recalculated and changed dynamically. This is possible through `useState()`

constants, which call React's `useEffect()` method when they are changed. Thereupon, depending on the selected attributes, the visualization and its axis change. In addition, the legends and the display of the calculated averages also adapt.

Another part of the visualizations are the various pop ups that appear when hovering over the bubbles. This is possible by adding functions like `mouseover` and `mouseout` which are provided by D3.js. Thereby, the opacity of the respective bubble is reduced and a window is calculated and displayed. With `mouseout` this is reversed. By hovering, the info buttons can be opened, which is possible through the React bootstrap component `Overlay`. If the same action is performed with the mouse over the links of the header, an overlay "just prototype" appears. In addition, the mouse pointer becomes a prohibition sign. The tabs are also interactive through the React bootstrap component and change to the visualization of the mode. Overall, React has been very helpful in building *viSleep*, especially for the structure of the user interface with its resulting higher usability.

After the application has been successfully conceptualized and implemented, the next step is the evaluation. It is important to make sure that *viSleep* is “appropriate and meets user requirements” [57, p. 1]. In addition to observing the usability goals, it should be checked whether and to what extent the purpose and goal of the visualization has been fulfilled [16, 57]. This is also the sixth and final step of Chittaro’s visualization process that served as a guide for describing the procedure in the development of *viSleep*, here the question asked is “Has the effectiveness of the visualization been tested on users?” [16, p. 4].

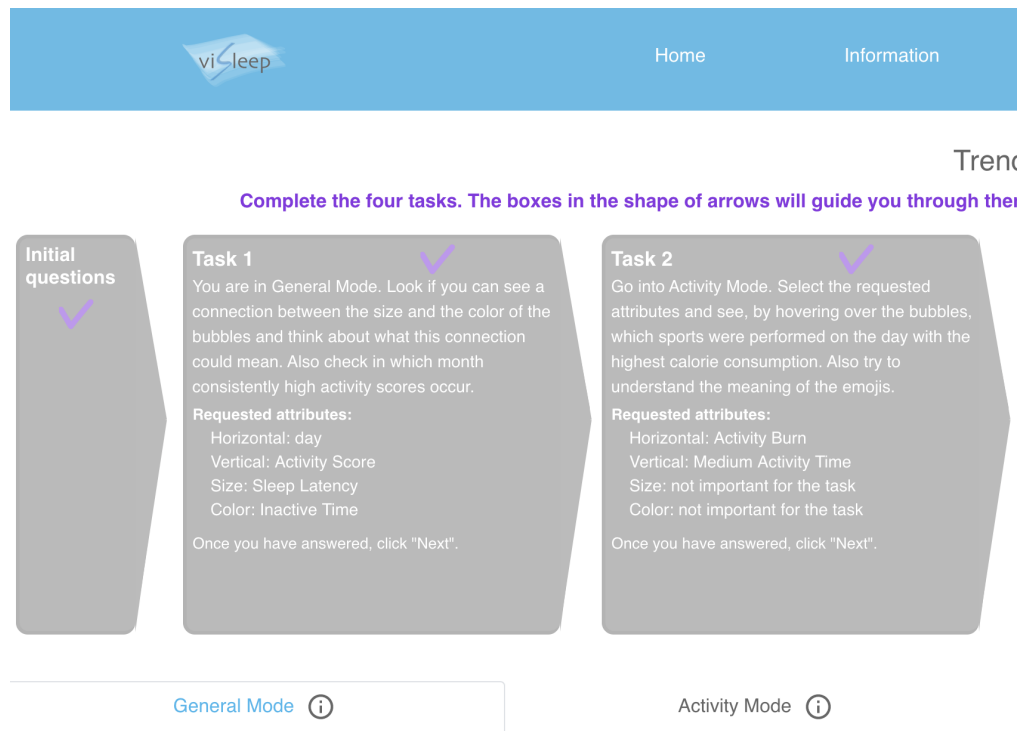
### 7.1 Study design

To evaluate *viSleep*, an online user study was chosen as this can be done with many people and it resembles real-life usage. The participants received a link to the study. Because it aims to detect usability issues and recommendations for improvements, it is an empirical evaluation and because it is conclusive and criterion-referenced it is also a summative survey type [32, 59]. All questions, except one, are quantitative, which means that the answer categories are predefined using mostly Likert-scales.

#### 7.1.1 Questionnaire setting

The actual study that was developed is divided into three sections. First, in a pre-session questionnaire, where, after a short briefing, questions are asked about usage habits and experiences, then the users are given four tasks, one for each mode, which is typical for what users do with the product. At the end, in a post-session questionnaire, questions are asked about the general impression gained from the product.

In *viSleep*, two modals with embedded Google forms are included, one at the beginning and one at the end. Attention was paid to dialogue principles, affordances and gestalt laws in order to avoid distracting the user with an unintuitive study. After answering the questionnaire and reconfirming that all questions have been answered, the user is guided through six boxes as shown in figure 7.2. Arrowheads and numbering highlight the sequence in which the questions are processed, which is from left to right. The boxes were built in between the header and the actual visualization in order to keep the top-down direction and to maintain focus. Already processed tasks turn grey and give an incentive

Figure 7.1: Study embedded in *viSleep* part one

through a check mark, indicating progress. A task that is currently being processed has the most opacity, the others are more transparent. Buttons labelled “next” make it possible to click through the tasks. In the briefing, it was directly pointed out that there is no right and no wrong and that the users should decide according to their feeling when they are finished with completing the task. The exercises, one per mode, were formulated as simply as possible, which is why it is explicitly stated which attributes the user should select. Although this has taken away the great amount of choice, it ensures that the user is not too overwhelmed in the user study. After fulfilling the tasks, the users were again presented with a questionnaire.

The two questionnaires were joined by email addresses in order to be able to draw conclusions between the previous knowledge and the evaluation of *viSleep* in addition to the individual evaluation. These questionnaires and the collected answers can also be consulted in appendices A, B and C starting on page 73.

### 7.1.2 Subjects

A total of 37 persons participated in the study, 19 women and 18 men. The age of the participants ranged from 18 to 56 years, with an average age of 29.62 years and a median of 24 years. The participants can be separated into two age groups. Hence, the first age group with 29 respondents is distributed over an age range of 19 to 28 years, with a variance of 2.99, illustrated in figure 7.3. The respondents in the second smaller group with a variance of 0.3 and eight respondents are aged between 49 and 56 years, which is shown in figure 7.4.

Questions were asked about the participants’ previous knowledge and previous interest. As a first indication of experience and interest, 56.71% have a fitness/health data wear-

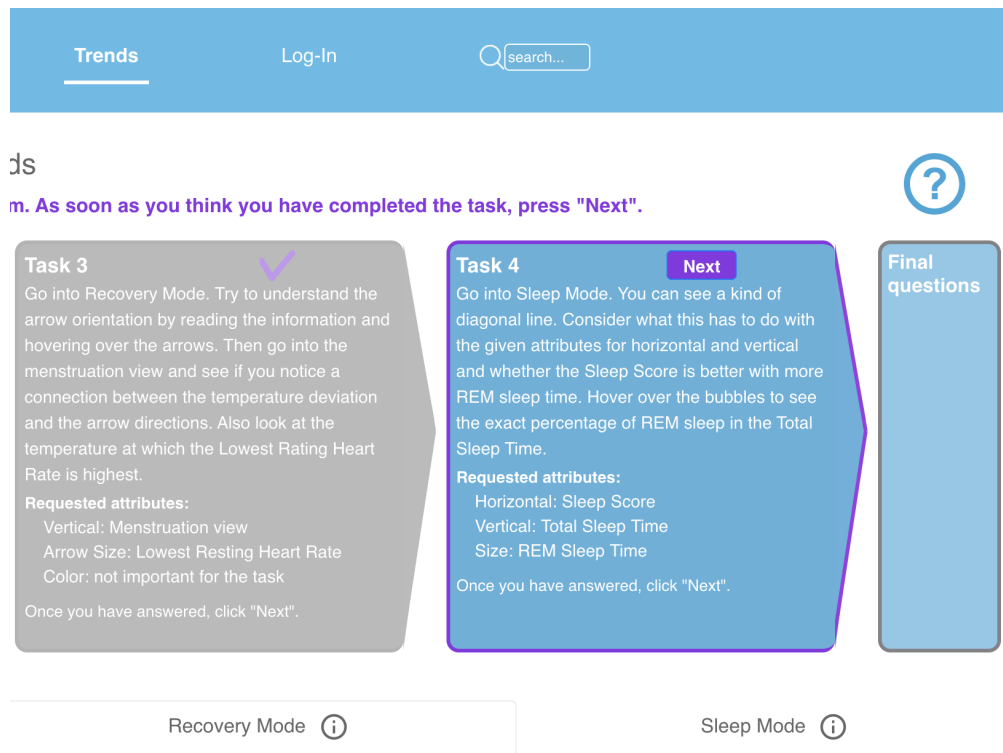


Figure 7.2: Study embedded in *viSleep* part two

able device such as a smart watch/smart ring. Those received questions that the 43.34% of respondents who do not have a device did not get.



Figure 7.3: Age group one

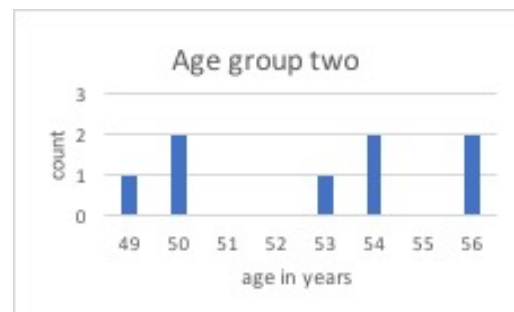


Figure 7.4: Age group two

When asked about previous knowledge with health devices/visualization of own health data, 12 of the respondents had an Apple watch, five a Fitbit, four a Samsung watch and two something else. Two said they had both an Apple watch and a Fitbit. 43.86% of people with a wearable device look at the evaluations of their health data that their device is providing on a daily basis and the same percentage of people do so sometimes, i.e. a few days a week. Only 14.26% use their device infrequently, i.e. a few times a month. This indicates that all owners are frequently in touch with their health data. 35.14% say they draw conclusions from the visualization of their data for their daily life, 16.22% are neutral and 5.41% disagree. Overall, 75.67% say they (totally) agree that they read or recognize patterns from

visualizations. This suggests that there is already a lot of prior knowledge and interest in visualizing their data among the device users.

Of course, all respondents were also asked about their previous knowledge in data visualization. Overall, all had contact with and are familiar with pie charts, all but two with cartesian coordinate systems, 29 with scatter plots. 62.16% already had contact with bubble charts.

In order to find out about previous interest regarding their health data, the questions were asked whether attention is paid in everyday life to the quality of sleep, quality of activity and good balance between both. In all three questions, no one totally disagreed, four or five disagreed. Nevertheless, most of the respondents totally agreed or agreed on all three aspects. The respondents gave very similar answers on all three questions. On average 31.53% agree totally and 40.54% agree, only 11.71% disagree. Interested in more detailed data of their health values and the visualization of these are 24, only two are not interested at all. Two would, if they could recognize patterns from the visualization of their health data not draw conclusions for their everyday life, 37.84% would totally, and 40.54% would. Thus, it can be concluded that there is interest for the field among almost all respondents.

## 7.2 Results

There are different ways to approach an evaluation of a visualization, Merčun et al. says that “user’s perceived hedonic quality (pleasure-producing product qualities), pragmatic quality (user- perceived usability), beauty (aesthetics), and goodness (overall product quality)” are the main constructs of UX [37, p. 103]. These can also be found in the view of criteria of intuitive use defined by Mohs et al. and therefore attention was paid to these aspects in the questions. As shown in figure 7.5, they classified the significance factors for design for intuitive use according to the usability measures. Thus, the assessment of the indicators of effectiveness and efficiency, which were titled “Yes”, brings added value to the assessment of intuitiveness. However, they are omitted from the study due to the difficulty of measuring these objective measures. Ways to do this would be, for example, to measure time or mouse clicks.

Usability measures (ISO 9241-11)	Indicators	Relevance for Design for Intuitive Use
Effectiveness (the accuracy and completeness with which users achieve certain goals)	error rates	Yes (effective interaction is part of the definition of intuitive use)
	quality of goal achievement	
	proportion of users achieving goal	
Efficiency (the relation between the effectiveness and the resources expended in achieving the goals)	users’ mental effort	Yes (points to subconscious use of prior knowledge)
	users’ physical effort	No (no direct correlation with intuitive use according to the above definition) <sup>1</sup>
	task completion time	
	cost	
Satisfaction (the users’ comfort with and positive attitudes towards the use of the system)	attitudes	Yes (users should be satisfied with using technology)
	preferences	
	subjective effectiveness and efficiency	
	experienced stress and strain	

Figure 7.5: “Usability measures and their application to Design for Intuitive Use” [27, p.6]

Several aspects are evaluated to what extent satisfaction, i.e. “the users’ comfort with and positive attitudes towards the use of the system”, is achieved by *viSleep* [27, p. 6]. It is also recommended to determine this by means of questionnaires.

The questions to the users were arranged in individual categories, the first three perceived cognitive load, perceived error rate and goal achievement and perceived learning effort were inspired by evalint. Evalint is the abbreviation for “Evaluate intuitive use” which is a questionnaire for the evaluation of intuitive use developed by the IUUI research group, consisting of the four scales just mentioned [7]. It consists of two parts, the checklist evalint I, which is disregarded here and the user questionnaire evalint II [39]. The questions in these categories deal with the subjective perception of efficiency and effectiveness, two aspects of the indicators for satisfaction. In the further categories modes, usage and perception, further indicators of satisfaction and user experience are considered.

**Perceived cognitive load (ease)** The basic property of intuitive use is processing information effortlessly [7]. The issue is whether the prior knowledge is processed subconsciously in order to reduce the workload on the “conscious cognitive processor” [27, p. 6].

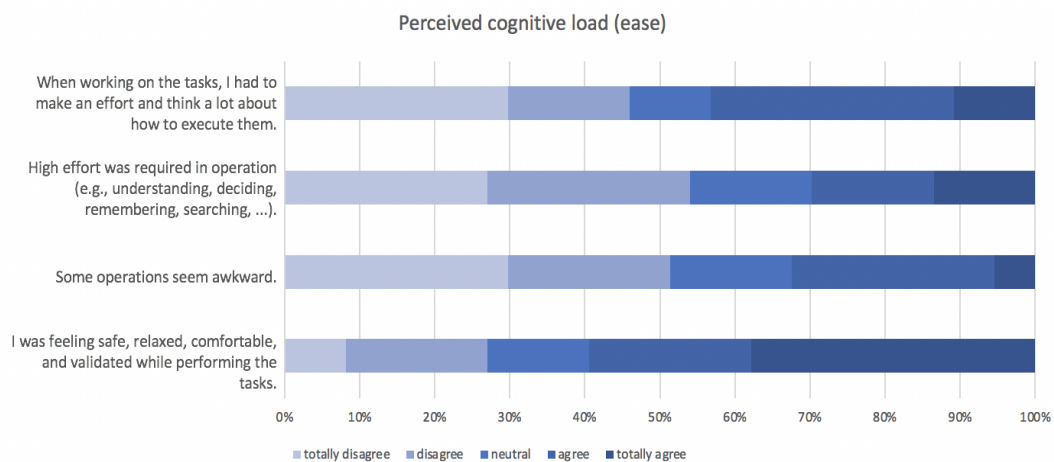


Figure 7.6: Results for the category “Perceived cognitive load (ease)”

According to Hurtienne et al. subjective efficiency is measured by questionnaires that ask people how difficult they find a task [27]. As shown in figure 7.6, 62.16% answered totally agree or agree that they feel safe, relaxed, comfortable and validated while performing the task. 13.51% were neutral, 16.22% totally disagreed and 8.11% disagreed. This may come from the new usage situation that *viSleep* presents to the users, as it is a kind of testing situation on the one hand and also novel due to the different channels.

For 12 people operations seemed awkward, but for 19 they did not, the reason for this could be investigated in a qualitative study, as this must be avoided at all costs for intuitive use.

54.06% answered with disagree or totally disagree to the question whether high effort was required in operation like understanding or deciding, nevertheless 29.73% thought it was. To see if there is a correlation between prior knowledge and the perception of *viSleep*, the relationship between the question whether the user has already used a fitness/health data wearable device such as a smart watch/ring and the question regarding required high effort in operation was calculated. It can be seen that among the 20 who answered the question about high effort with disagree or totally disagree, 57.14% own a device and thus have more experience or are more technologically familiar, while among the 11 who answered

with agree or totally agree, only 50% own a device. The difference is not large, which is good because *viSleep* is supposed to be intuitive for users without previous knowledge, but it still points to a small advantage by the users of devices, which, however, cannot necessarily be circumvented.

In other studies, those who were more experienced with technology were able to utilize much more of the features intuitively at the first time they saw them, and were faster at completing tasks. [7].

In response to the last question about perceived high effort in tasks, 13.51% disagreed completely, 18.92% disagreed and 16.22% were neutral. However, 18.92% totally agreed and 32.43% agreed with the statement. This indicates that the ease of performing the tasks given by the study was perceived as distributed and the reasons should be investigated further.

**Perceived error rate and goal achievement** The two scales from evalint were merged because some questions did not fit the evaluation of *viSleep* and were disregarded. Perceived error rate and the feeling to what extent the user achieved the goals refer to the indicator of subjective effectiveness [7].

Here as presented in figure 7.7, a total of 51.35% answered with totally agree or agree that they did not make any mistake when solving the tasks. 24.32% answered with totally disagree or disagree. For seven people the achievement of the tasks seemed very lengthy, but for 25 it did not.

Overall, 43.24% answered “I have completely fulfilled the tasks.” with totally agree, 27.03% with agree and a total of only 8.11% with totally disagree or disagree. These answers indicate that the tasks themselves were comprehensible and made sense.

However, the last question, whether the respondents knew when the tasks were completed, was distributed. Here 51.35% agreed, but 32.43% disagreed, the number of neutrality is also comparatively high. Perhaps this is due to the fact that respondents themselves were asked to determine when they were completed with the tasks and with *viSleep* the choices can be changed for as long as they want.

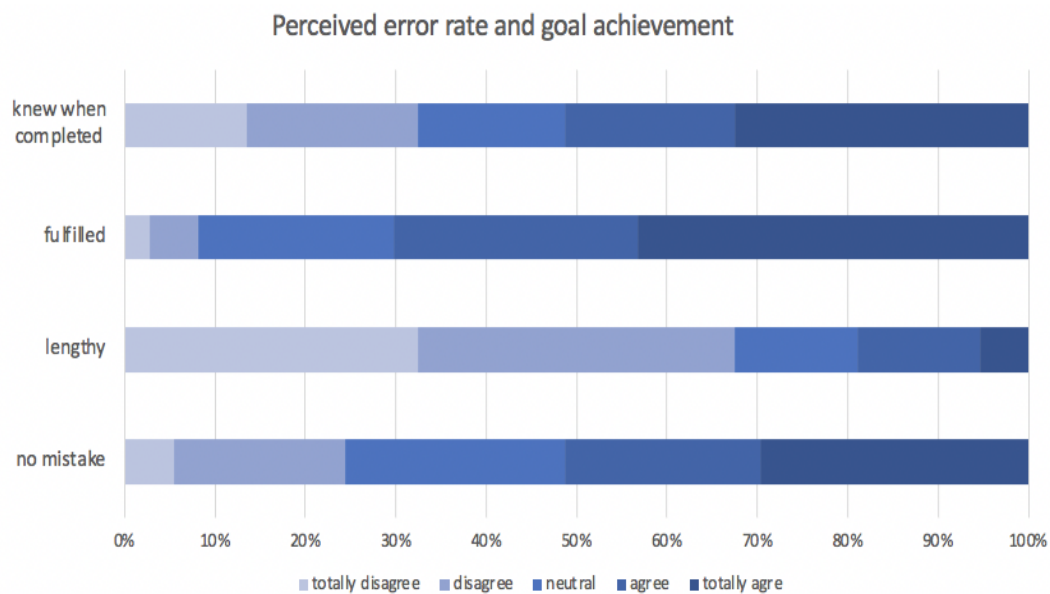


Figure 7.7: Results for the category “Perceived error rate and goal achievement”



**Perceived learning effort** Users should not notice any effort of learning and thus not consciously obtaining interaction knowledge [7]. Several questions were asked when considering this aspect, whose evaluation can be seen in greater detail in figure 7.8.

The first showed that 62.16% of respondents quickly understood how to deal with the individual visualizations, while only 24.32% did not. For 37.84% it was immediately clear and for 27.03% totally clear how to operate with the individual controls. For 21.62%, on the other hand, it is unclear and for 10.81% totally unclear. This could possibly be counteracted in terms of design by placing a little more focus on the controls, as it is very important for intuitive use that users immediately see how they can interact.

When asked whether it was difficult to see some of the possibilities of visualization, the respondents were quite clear. This is the only question in the entire survey where 0% of the respondents were neutral towards the statement. The negation of the statement prevailed here with 59.46%. However, the affirmative answer of 40.54% should not be disregarded and should be investigated.

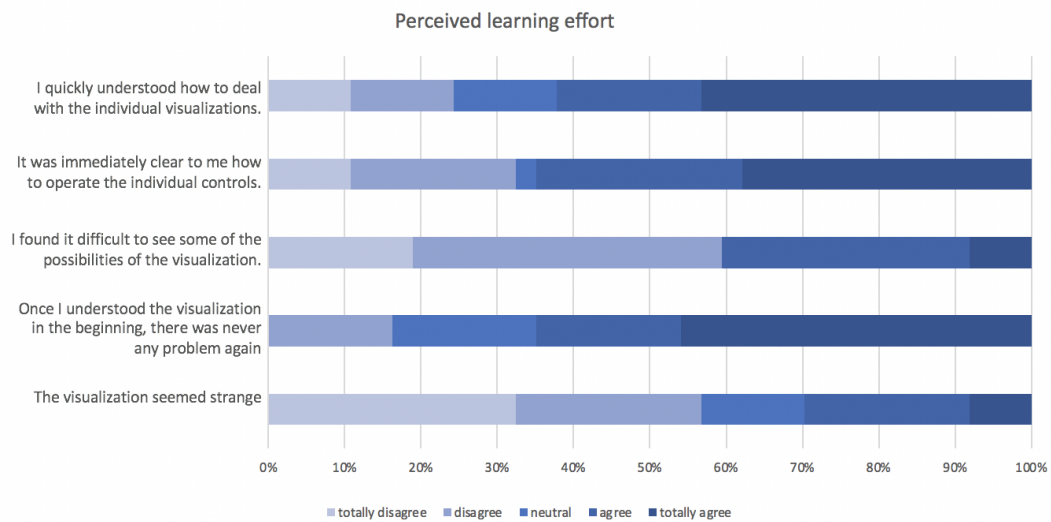


Figure 7.8: Results for the category “Perceived learning effort”

In the next question, whether once the visualization was understood at the beginning, a problem never occurred again, the smallest overall negative proportion of the questions on indicator perceived learning effort can be found. Only 16.22% answered with disagree 0% with totally disagree. Therefore, the users are able to interact better with *viSleep* after a period of familiarisation.

Three respondents think that the visualization seems totally strange, eight that it seems strange. Nine do not think so and twelve do not think so at all. All in all, apart from a few improvement points, there is already a relatively low perceived learning effort, which speaks for an intuitive use of *viSleep*.

In addition to the questions applied from evalint, Mohs et al. defined further success criteria for intuitive use. A few of these are covered in the following questions [40].

The attitude of the user is also relevant since it is the attraction and positive affection towards an object that impact “learnability, preferences, and even performance” [37, p. 103]. Firstly, entering the modes category, users were asked whether the separation into general, activity, recovery and sleep mode makes sense. 0% answered negatively, 16.22%

were neutral and a total of 83.78% agreed with the statement, with the percentage of totally agree being a little higher than that of agree. Therefore, the conception of *viSleep* in four modes is supported and well received by users.

Figure 7.9 shows that users found sleep mode the most interesting, followed by recovery mode and activity mode. On the one hand, this is a satisfactory observation, since sleep is also the central starting point for visualization through the name and coloring of *viSleep*. On the other hand, one criticism regarding *viSleep* is that the general mode is currently the default mode and the first point of contact for the user, which, as already mentioned, is very important for perception and the perceived aesthetic. Eventually it would be better to select the sleep mode as the default mode.

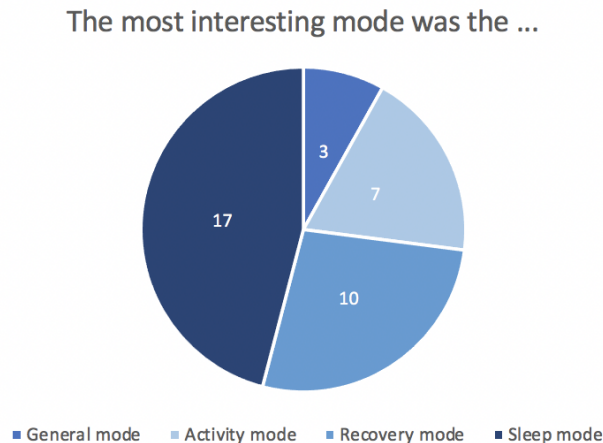


Figure 7.9: Results of the question about the most interesting mode

Another identified success point for intuitive use is whether users needed minimal help and whether they used and recognized the interaction options, for which the users were given four choices from which they selected the choices they performed. The info buttons were used by a total of 18 respondents, i.e. 48.65%. 19 people looked at the averages, 32 people at the legends for the colors/sizes and 35 indicated that they had changed the horizontal, vertical, size and color attributes. The other two probably were unable to understand either the task or the question. Everyone hovered over the bubbles with the mouse and looked at the individual values. All interaction options were used by many. For the info buttons, the aim was to have a low usage. Regarding the averages, their usefulness could be reconsidered.

Usability can be determined by asking user preferences, which are subjective and depend on aesthetics [5]. Aesthetics was briefly scratched by the question whether the color scheme of the application was visually appealing and contributed to understanding. 26 respondents agreed, four disagreed, which suggests a good aesthetic of the chosen colors. 8.11% found the size of the visualization was inappropriate, 86.49% found it appropriate. This was asked to evaluate a matter that came up several times during the implementation.

Further in terms of preferences and to evaluate the pop up windows, users were asked if they found the line chart useful when hovering over the arrows. 21.62% responded with totally agree, 24.32% with agree and 21.62% were neutral. This question category also involved the answer option "I have not paid attention". With regard to the line chart, 10.81% used this option. 21.62% did not find the line chart useful. The highest number of respondents who did not pay attention was seven respondents. They are found in the question whether the sports activities when hovering over the bubbles are useful. A total

of 21 agree with the usefulness, three deny it. Also three negate the usefulness of the exact display of the pie chart percentages when hovering over the pie charts. Actually, 45.95% find them totally useful, 24.32% useful. Thus, a total of 70.27% find them useful, which could come from the criterion of prior knowledge. After all, all respondents stated that they have had contact with and are familiar with pie charts.

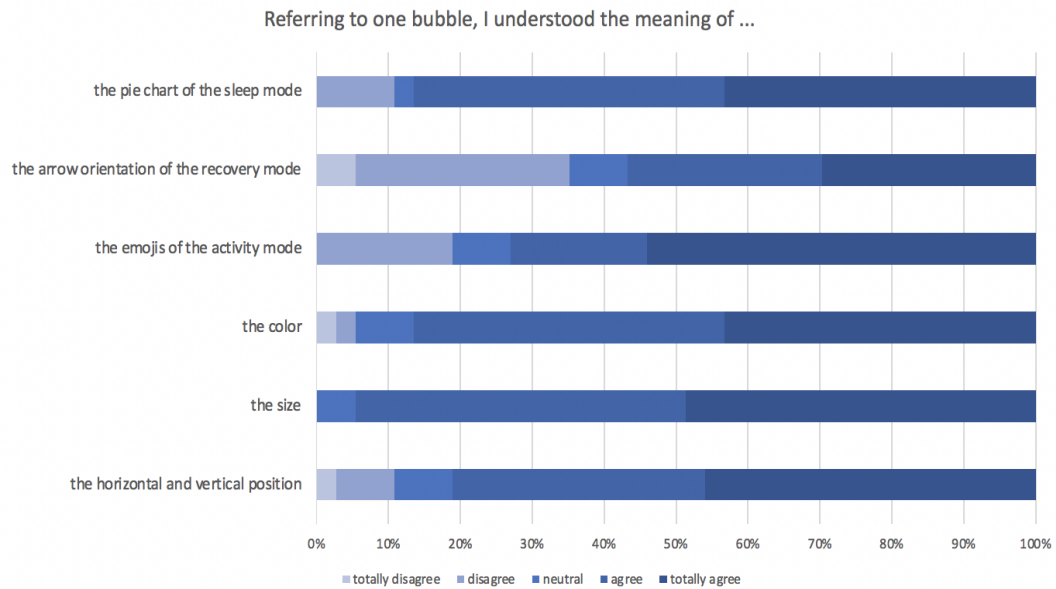


Figure 7.10: Results of the questions about the understanding of individual channels

Several studies in the field of visualization lately got results by exploring user experience goals like memorability and recall, engagement, enjoyment and fun. Saket et al. cite the “level of a user’s understanding of a visualization” as a measurement for engagement [57, p. 137]. When asked about the understanding of the individual channels used in the modes, the pie chart and its shape channel show a high level of understanding. A total of 32 respondents understood it, half of them totally. In addition, no one answered the question about the understanding of the pie chart with totally disagree. The situation is similar for horizontal and vertical position, as can be seen in figure 7.10. For size, nobody did not understand it, only 2% were neutral towards it. This is interesting because the channel horizontal and vertical position is actually higher up in the channel hierarchy. The color also has better values than the position, so only a total of two people answered with disagree or totally disagree when it comes to understanding. The situation is a little different for emojis and arrow orientation. In the case of emojis, 27 people understood them. The channel that caused the least understanding was recovery mode, which was not understood by 35.14%, the worst value in this question category. This may be due to the fact that the use of arrows to show trends in an approach such as the bubble chart is not common and therefore does not tie in with prior knowledge and must therefore be thought of consciously. Since the study is a cross-section, i.e. people are surveyed at one point in time, not over a longer period of use, an understanding could possibly emerge after a longer period of use and survey.

According to the thesis of Saket et al. “if users are surreptitiously given the option to experience either of two visualizations, they will spend longer with the one they enjoy better” the user experience goal enjoyment and fun was also asked, 37.84% of users had totally fun, 21.62% had fun, 27.03% answered neutral, 5.41% answered disagree and 8.11%

answered totally disagree [57, p. 137]. Thus, the visualization brings already joy, or at least not the opposite for many. Engagement, defined as “users’ interest in putting effort to investigate and explore visualizations and gain more insights”, was briefly highlighted in one question, 26 stated they had experimented more than just doing the tasks, seven did not [57, p. 136]. Also, 32.43% would totally like to use the visualization with their own data, 32.43% would like to. Only 10.81% would not like to use it, 25.32% are neutral towards it. This indicates a high level of engagement, which can, however, be further developed.

**Conclusion of the study** The perceived effort should be reduced in further steps in order to approach the definition of intuitive use. Also with regard to *viSleep*, the study shows that some things should be better explained, for example the arrow orientation, which was poorly received due to the unfamiliarity of the users with this kind of visualization. Improvements to the evaluation sketch would be appropriate in some aspects, for example for the tasks. These do not have a natural end and the users had to decide for themselves when they were finished with them. This should be done for them. In addition, it should be noted in all the results just mentioned that the study is not representative due to the number of 37 respondents and that the division of users into the two participant age groups is also not equal.

However, overall, the study indicated that *viSleep* was generally rather positively accepted by users. The general concept, the color scheme and the channels used in the modes made sense and were understood. The sleep mode was the most popular one and the majority would use the visualization with their own data in the future.

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### Perspectives for future work

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The chapter briefly reports on possibilities for extensions for the visualization and its environment developed in *viSleep*, perspectives for future have been collected below. Four categories are considered.

#### Conversion of the prototype into a real application

*ViSleep* was built as a high fidelity prototype. It uses csv files with the data of one user's Ōura ring. By adding a log-in function, which is already drafted in the header, and accessing the API of Ōura, users could display their own data.

Pop up windows can be expanded with more visualizations to provide more details. Access to these windows should be supported by an alternative way such as clicking, as hovering sometimes does not work despite many attempts to fix it.

The selection of intervals would be helpful to compare the data in a certain period of time or even month- or year-wise, in other words an expansion of aggregation. In addition, filtering of values above/below a user-defined threshold could be built into the visualization, for example, to display only days on which the sleep duration is below seven hours. Extended feedback, which values of attributes can scientifically state something specific about health, can be integrated into the visualization. However, care must be taken, as data in the area of health is very individual.

In addition, as seen in the bubble chart of Hans Rosling's Gapminder Trendanalyzer in figure 5.4, the attributes of the horizontal and vertical bubbles could be categorized. But attention should be paid that the amount of elements within the visualization stays low.

A feature to add activities, tags or diary entries could be included in *viSleep*, which would require a database. They could be inserted into the main visualization. Stressful periods, holidays, eating, drinking alcohol, illness or vaccinations could be indicated. The connection of these with the quality of sleep could be displayed and thus offer more individualised findings for the user. An extension would also be to provide users with an area where they can note down their observations about patterns.

#### Connection with other applications

Physical activity or other tag opportunities can be provided through connections to health

apps such as Apple Health, where it is possible to set workouts directly. Linking to apps such as Yazio, where users log their food, calories and nutrients such as sugar/protein, would also create new visualization opportunities. For instance, this could help athletes in their training. Additionally data from apps that track the menstrual cycle could be used in menstruation view to show how the cycle is proceeding as well as to highlight patterns in certain weeks.

### **Application of automated evaluation**

Another extension of *viSleep* can be automation. By calculating correlations before displaying, strong correlations between attributes could be detected and suggested as choices. Attributes with the strongest correlation would then encode the horizontal and vertical channel, for example. This could provide more added benefit to users by offering them combinations that allow them to read trends more intuitively. Recognized patterns could be explained more clearly in order to further support the user, e.g. by providing assistance such as “increasing activity results in greater sleep duration”. However, users should be free to choose whether they want to select themselves or whether they prefer to receive suggestions.

Thinking even further, *viSleep* could recognize patterns itself using methods from the field of machine learning and thus provide the user with good feedback. The application of supervised learning would be conceivable by training with labelled data sets, for example of certain diseases and the resulting health values. In this case, it would be possible to classify the users’ data and incorporate the results into the visualization, for instance by highlighting individual bubbles. But also the application of unsupervised learning could help to find clusters and visualize them in the bubble chart.

Through these found patterns, users could be warned in case of worrying results.

### **Support to improve health**

In this context, the cooperation of doctors and *viSleep* would also be possible, as they may have more background knowledge for understanding the data and the correlations. An extra view for doctors with values authorized by the user would be a good idea here, in order to give the user the freedom not to share all the data.

A connected environment could be created, as is already the case with smart watches and shared activities. With *viSleep*, the user could network with friends and by comparing the visualizations determine who for instance has the best sleep. Critical observations are left out of this. Challenges have the potential to motivate people to live healthier, sleep more, etc. and to engage more with the visualization.

## CHAPTER 9

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### Conclusion

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Since *viSleep* is based on a prototypical design, a few aspects need to be discussed. One of these is, with regard to the visualization approach, that a bubble chart loses a certain intuitiveness to the decreasing clarity as the number of bubbles increases [42]. Alternative visualization approaches, such as the high dimensional approach parallel coordinates, would certainly also have been a good way to visualize health data. Another point that can be critically considered is the selection of attributes, based on the assessment of the author. In the modes different channels were used and different numbers of attributes were offered for selection, some were also filtered out. This is due to the fact that “the designer needs to choose which data are relevant and which patterns and relationships to show in order to convey the intended message” [50, p. 7]. When designing colors, consideration must be given to socio-cultural context or colorblindness [56].

In this bachelor thesis, principles of intuitive use were applied to the development of a visualization of activity, movement and sleep data in response to the problem that with high-dimensionality data sets and increasing numbers of non-expert users, it is important to develop appropriate representations of information that can be well interpreted. Thus, the six steps of the Chittaro design process were followed in a structured way, always with the benefit for the user in mind. To achieve this, the concept *viSleep* was developed with the four modes general, activity, sleep and recovery mode. First, a bubble chart was selected as the visualization approach, then for each mode it was considered which channels could be used for the bubble chart to combine familiarity and novelty and which attributes were available for selection in each channel. Data processing methods such as aggregation were used. The channels position on a common scale, area, color saturation, shape, length, curvature and angle were used in different combinations.

The bubble chart was embedded in a user interface with associated legends and controls. The controls and the overall interactivity was reflected and carefully chosen. More detail is provided to the user through pop up windows. Throughout the design and development, care was taken to adhere to usability principles aligned with Mohs et al’s seven principles for intuitive use, meaning the dialogue principles, the gestalt laws, affordances and feedback.

A short evaluation in this thesis has been performed, the results indicate that the visualization is mostly well understood and can be used without complete familiarity with the topic, which reflects the goal of intuitive use and also the goal of the thesis.





## APPENDIX **A**

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User study - Start questionnaire

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## Initial questions

You will be asked for your email address twice in order to be able to combine your answers in the evaluation. Otherwise, the email address will not be used and will be deleted immediately after the evaluation.

**You will be asked to evaluate a visualization of the Oura ring data. You will be guided through four tasks. At the end, you will be asked questions about your experience with the system. The questions at the end are not about your concrete answers to the tasks, just about how you felt when using the system.**

**This means: There is no right and no wrong!**

(The Oura ring is a smart ring which measures various health data.)

The recommended approach to processing is: Understanding how a data point is read, interacting and changing the data presented, finding trends and then drawing conclusions. It will take you no more than 20min. Thank you for participating!

## Previous knowledge

I already used a fitness/health data wearable device such as a smart watch/smart ring. \*

☐ Yes

☐ No

### Previous knowledge of using a wearable health device

From which company have you used a wearable health device? \*

You can choose more than one

- ☐ Fitbit
- ☐ Apple
- ☐ Oura
- ☐ Samsung
- ☐ Garmin
- ☐ Huawei
- ☐ Sonstiges: \_\_\_\_\_

I look at the evaluations of my health data that my device is providing through an app/website \*

- ☐ never
- ☐ infrequently (a few times a month)
- ☐ sometimes (a few days a week)
- ☐ daily

I draw conclusions from the visualization of my data for my daily life (e.g. more sleep, more exercise, getting up more often). \*

- |                  |                       |                       |                       |                       |                       |               |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|---------------|
|                  | 1                     | 2                     | 3                     | 4                     | 5                     |               |
| totally disagree | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | totally agree |

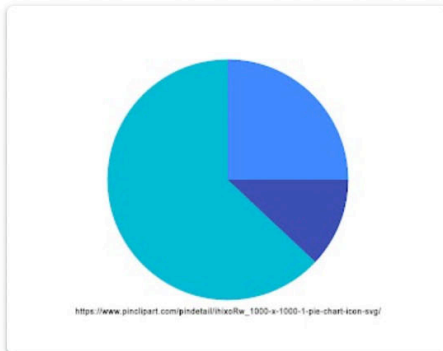
### Previous knowledge of visualizations

I suppose that I can read or recognize patterns from visualizations. \*

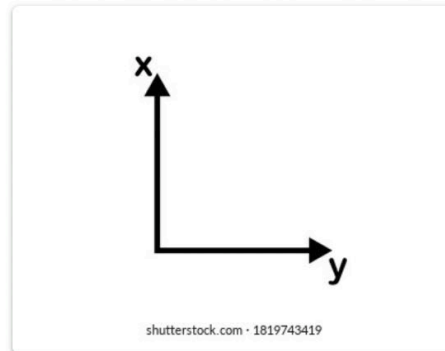
	1	2	3	4	5	
totally disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	totally agree

I have had contact with and am familiar with the following terms. \*

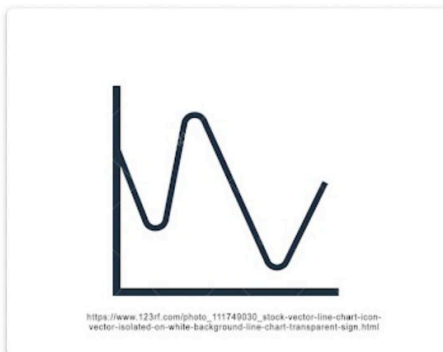
You can select more than one



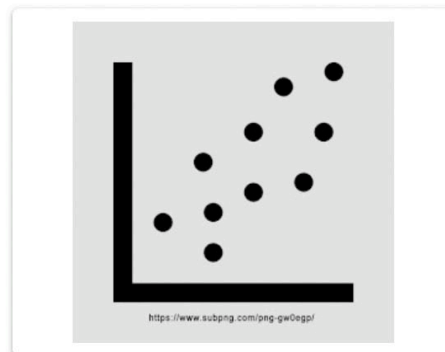
☐ Pie chart



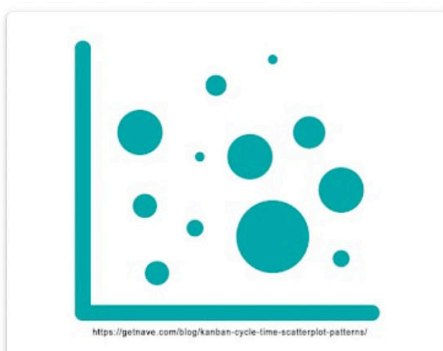
☐ Cartesian coordinate system



☐ Line chart



☐ Scatter plot



☐ Bubble chart

	totally disagree	disagree	neutral	agree	totally agree
the quality of my sleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
enough movement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
a good balance between rest and activity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

1 2 3 4 5

totally disagree ○ ○ ○ ○ ○ totally agree

1 2 3 4 5

totally disagree ○ ○ ○ ○ ○ agree



## APPENDIX B

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### User study - End questionnaire

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## Final questions

You will be asked for your email address twice in order to be able to combine your answers in the evaluation. Otherwise, the email address will not be used and will be deleted immediately after the evaluation.

### Perceived feelings

Perceived cognitive load (ease) \*

	totally disagree	disagree	neutral	agree	totally agree
I was feeling safe, relaxed, comfortable, and validated while performing the tasks.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Some operations seem awkward.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
High effort was required in operation (e.g., understanding, deciding, remembering, searching, ...).	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
When working on the tasks, I had to make an effort and think a lot about how to execute them.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



## Perceived error rate and goal achievement \*

	totally disagree	disagree	neutral	agree	totally agree
I did not make any mistake when solving the tasks.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
To me the achievement of the tasks seemed very lengthy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I have completely fulfilled the tasks.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I knew when the tasks were completed.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## Perceived learning effort \*

	totally disagree	disagree	neutral	agree	totally agree
The visualization seemed strange and unusual for a long time.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Once I understood the visualization in the beginning, there was never any problem again.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I found it difficult to see some of the possibilities of the visualization.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
It was immediately clear to me how to operate the individual controls.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I quickly understood how to deal with the individual visualizations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

### Modes

The separation into general mode, activity, sleep and recovery mode made sense to me. \*

	1	2	3	4	5	
totally disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	totally agree

The most interesting mode was the \*

- ☐ General mode
- ☐ Activity mode
- ☐ Recovery mode
- ☐ Sleep mode

Referring to one bubble, I understood the meaning of \*

	totally disagree	disagree	neutral	agree	totally agree
... the horizontal and vertical position	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... the size	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... the color	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... the emojis of the Activity Mode	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... the arrow orientation of the Recovery Mode	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... the pie chart of the Sleep Mode	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



## Usage

What actions did you perform? \*

You can choose more than one

- ☐ I hovered my mouse over the bubbles and looked at the individual values
- ☐ I changed the horizontal, vertical, size and color attributes
- ☐ I have made use of the info buttons
- ☐ I have looked at the legends for the colors/sizes
- ☐ I have looked at the averages

What do you think about these statements \*

	totally disagree	disagree	neutral	agree	totally agree
The size of the visualisation was appropriate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The colour scheme of the application was visually appealing and contributed to understanding	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I had fun using the application	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I also experimented a bit more than "just" working on the tasks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would like to use the visualization with my own data	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

### Personal questions

How old are you? \*

Meine Antwort \_\_\_\_\_

Which gender do you belong to? \*

☐ Female

☐ Male

☐ Diverse

☐ Prefer not to say

☐ Sonstiges: \_\_\_\_\_

Is there anything else you want to add?

Your answer \_\_\_\_\_





## APPENDIX C

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### User study - Study results

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I already used a fitness/health device such as a smart watch/smart ring.	From which company have you used a wearable health device?	I look at the evaluations of my health data that my device is providing through an app/website	I draw conclusions from the visualization of my data for my daily life (e.g. more sleep, more exercise, getting up more often).	I suppose that I can read or recognize patterns from visualizations.	I have had contact with and am familiar with the following terms.	In my everyday life I pay attention to the quality of my sleep	In my everyday life I pay attention to [a good balance between rest and activity]	I am interested in more detailed data of my health values and the visualization of these.	If I could recognize patterns from the visualization of my health data, I would draw conclusions for my everyday life.
Yes	Apple	daily	4	4	5 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	totally agree	5	5
No					5 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	agree	3	3
No					5 Pie chart; Cartesian coordinate system; Line chart; Scatter plot	agree	agree	1	4
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	agree	4	5
Yes	Apple	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5
Yes	Apple	sometimes (a few days a week)	3	3	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	disagree	agree	4	4
Yes	Apple	sometimes (a few days a week)	3	3	3 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	disagree	agree	2	3
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	neutral	totally agree	4	4
Yes	Fitbit	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot	agree	disagree	2	1
Yes	Fitbit; Apple	daily	5	5	3 Pie chart; Line chart	neutral	totally agree	5	5
Yes	Fitbit; Apple	sometimes (a few days a week)	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5
No					3 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	disagree	agree	2	4
No					5 Pie chart; Cartesian coordinate system; Line chart; Scatter plot	agree	neutral	4	4
Yes	Samsung	sometimes (a few days a week)	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	disagree	4	4
Yes	Apple	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart	agree	neutral	5	4
Yes	Apple	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot	agree	neutral	3	4
Yes	Apple	sometimes (a few days a week)	1	1	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	totally agree	3	3
No					4 Pie chart; Cartesian coordinate system	disagree	disagree	1	1
Yes	Samsung	sometimes (a few days a week)	3	3	3 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	4
Yes	Apple	sometimes (a few days a week)	4	4	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	agree	3	4
Yes	Fitbit	sometimes (a few days a week)	3	3	4 Pie chart; Cartesian coordinate system; Line chart	agree	neutral	5	5
Yes	Fitbit	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5
Yes	Samsung	infrequently (a few times a month)	4	4	5 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	agree	4	3
No					5 Pie chart; Cartesian coordinate system; Line chart; Scatter plot	agree	neutral	5	4
Yes	Apple	sometimes (a few days a week)	3	3	3 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	neutral	totally agree	4	4
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	neutral	2	4
Yes	Samsung	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5
No					3 Pie chart; Cartesian coordinate system; Line chart	totally agree	agree	4	5
Yes	Fossil	infrequently (a few times a month)	3	3	5 Pie chart; Cartesian coordinate system; Line chart; Bubble chart	neutral	agree	4	5
Yes	xiaomi	infrequently (a few times a month)	2	2	4 Pie chart; Line chart; Scatter plot	neutral	totally agree	4	5
No					3 Pie chart; Cartesian coordinate system; Line chart	disagree	neutral	3	3
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	agree	neutral	4	4
No					4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot	agree	disagree	2	4
No					3 Pie chart; Cartesian coordinate system; Line chart	agree	agree	4	3
Yes	Apple	daily	5	5	4 Pie chart; Cartesian coordinate system; Line chart; Scatter plot; Bubble chart	totally agree	totally agree	5	5









What do you think about these statements?					Which gender do you belong to?	Is there anything else you want to add?
(The size of the visualization is appealing and easy to understand)	(The colour scheme of the application was visually appealing and easy to understand)	(I had fun using the application)	(I also experimented a bit more than I did with the application)	(I would like to use the visualization with my own data)		
agree	totally agree	agree	totally agree	agree	22 Female	I feel like the General Mode was a bit hard to understand, since it was so much data and a bit overwhelming not knowing the graphs. But after getting into the application it was easier to understand.
totally agree	agree	neutral	neutral	neutral	21 Female	
agree	totally agree	agree	totally agree	agree	53 Male	
agree	totally agree	totally agree	totally agree	totally agree	22 Female	
agree	agree	totally agree	agree	agree	28 Female	It is fun to work with this kind of visualization and to reflect yourself
totally agree	totally agree	agree	agree	totally agree	22 Female	
agree	totally agree	neutral	neutral	agree	22 Female	
neutral	neutral	disagree	neutral	neutral	19 Female	I would presume using the app with my own data would help me understand it much better and I'm interested in trying so.
totally agree	neutral	neutral	disagree	totally agree	27 Male	No clear Tasks were given. In some visualisation the colour code was inverted to the given Data and therefore showed an inverse correlation
totally agree	totally disagree	totally disagree	agree	agree	27 Female	
totally agree	agree	agree	agree	disagree	56 Female	Die Aufgabenstellungen/Tasks waren unklar, das hovering über den Bubbles funktionierte nicht immer.
agree	neutral	totally disagree	agree	disagree	23 Male	Sometimes the popup window for arrows and dots did not work appropriately or were out of the presented coordinate system/ frame boundary. Other than that really nice!
disagree	totally agree	totally agree	totally agree	totally agree	50 Female	
agree	totally agree	neutral	agree	agree	22 Female	
totally agree	totally agree	totally agree	totally agree	totally agree	26 Male	
agree	totally agree	totally agree	totally agree	totally agree	50 Male	
agree	totally agree	totally agree	totally agree	neutral	54 Female	
agree	disagree	neutral	agree	totally agree	22 Male	
agree	agree	totally agree	agree	neutral	27 Female	
disagree	agree	neutral	disagree	agree	23 Male	
agree	neutral	agree	agree	agree	22 Male	
totally agree	totally agree	neutral	agree	neutral	24 Female	Hovering didn't work for me, so some tasks were very difficult to complete.
totally agree	totally agree	totally agree	totally disagree	totally agree	20 Male	
agree	neutral	disagree	disagree	disagree	28 Female	
agree	disagree	neutral	disagree	agree	21 Male	Wird statt verschiedener Blau- und Grün verschiedene Farben nehmen
totally agree	totally agree	agree	totally agree	totally agree	21 Female	
agree	agree	neutral	totally disagree	disagree	20 Male	
totally agree	totally agree	totally agree	totally agree	totally agree	56 Male	
agree	agree	totally agree	agree	agree	54 Female	
neutral	agree	totally agree	agree	totally agree	49 Male	
agree	disagree	totally disagree	neutral	totally disagree	23 Male	
agree	totally agree	totally agree	totally agree	agree	24 Male	
disagree	agree	neutral	disagree	neutral	23 Female	
agree	neutral	agree	totally agree	neutral	25 Female	I was very confused by having sleep/ awake times displayed in two different dimensions. I could not make sense of how to interpret the relationship between sleep time (last REM?) on x and y axis with
agree	totally agree	totally agree	totally agree	neutral	25 Female	
totally agree	totally agree	totally agree	totally agree	totally agree	25 Female	

## APPENDIX D

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### Overview of modes

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Figure D.1: Overview general mode based on 5.3



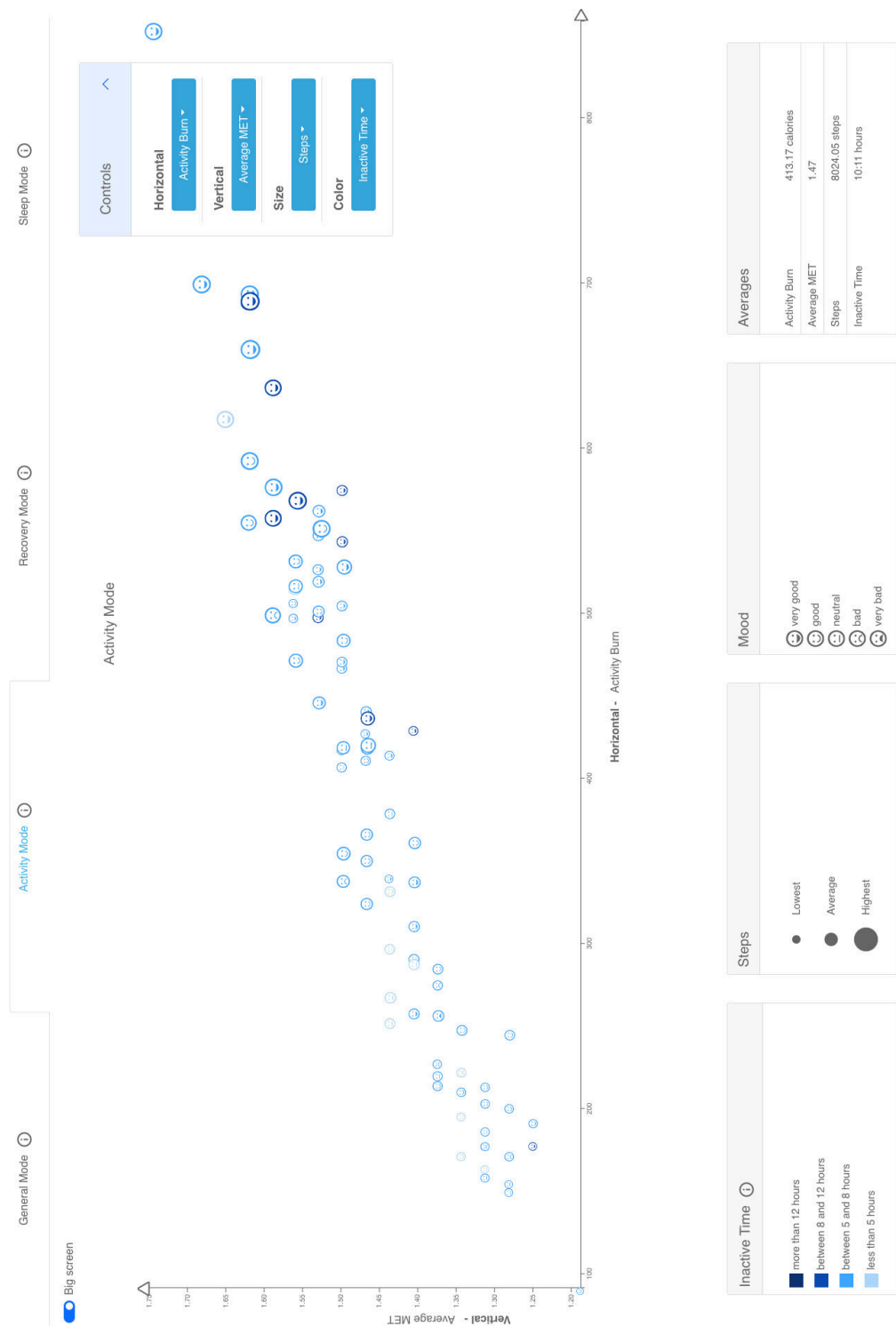


Figure D.2: Overview activity mode based on 5.10



Figure D.3: Overview recovery mode based on 5.14

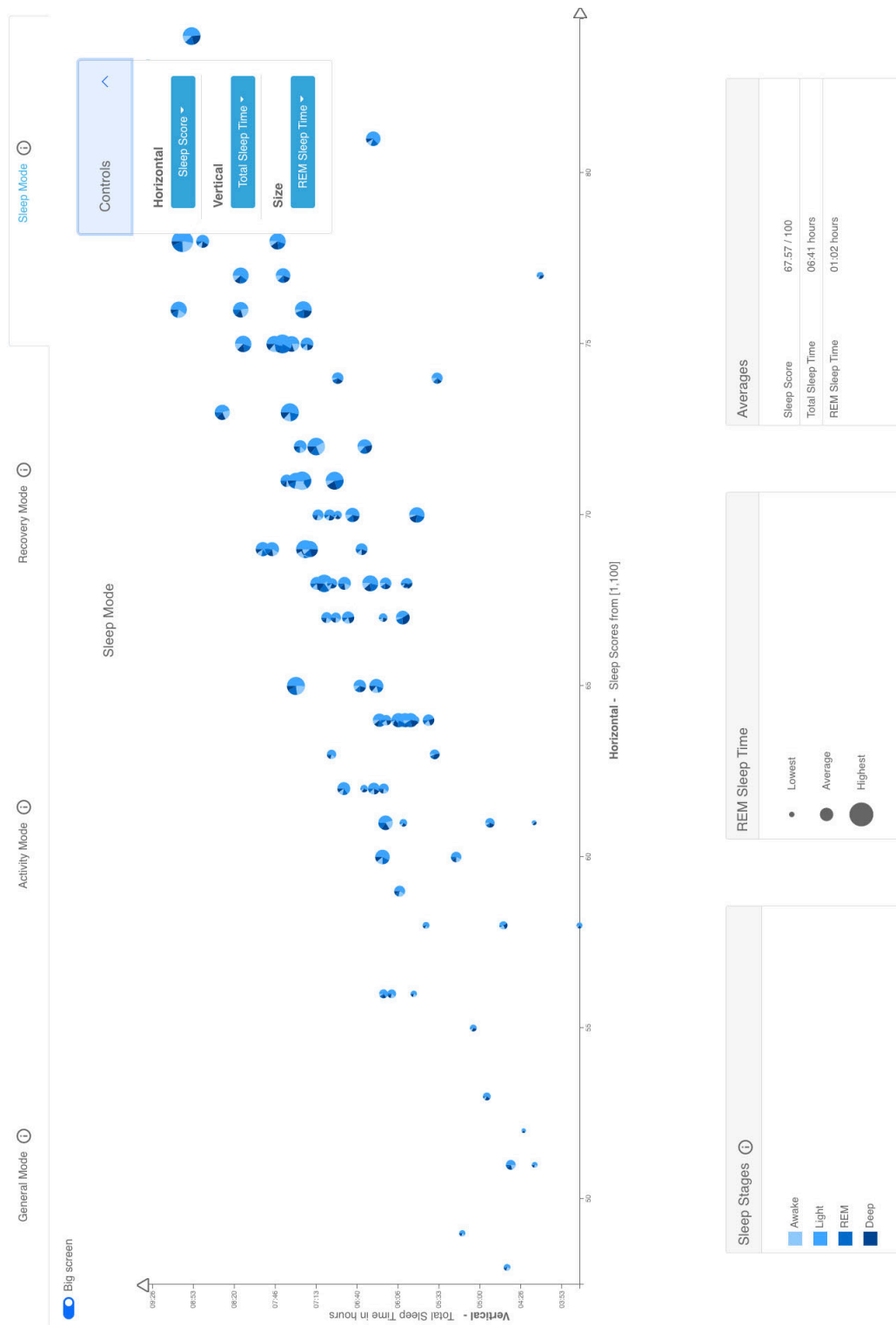


Figure D.4: Overview sleep mode based on 5.16



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## Bibliography

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- [1] ISO 9241-110, *Ergonomics of human-system interaction—part 110: Dialogue principles*, International Organization for Standardization, 2006.
- [2] Marco Altini and Hannu Kinnunen, *The promise of sleep: A multi-sensor approach for accurate sleep stage detection using the oura ring*, vol. 21, Multidisciplinary Digital Publishing Institute, 2021, p. 4302.
- [3] Milad Asgari Mehrabadi, Iman Azimi, Fatemeh Sarhaddi, Anna Axelin, Hannakaisa Niela-Vilen, Saana Myllyntausta, Sari Stenholm, Nikil Dutt, Pasi Liljeberg, and Amir M. Rahmani, *Sleep tracking of a commercially available smart ring and smartwatch against medical-grade actigraphy in everyday settings: Instrument validation study*, JMIR mHealth and uHealth, 11 2020, pp. 1–16.
- [4] Karim Awad, Atul Malhotra, Jodi Barnett, Stuart Quan, and Paul Peppard, *Exercise is associated with a reduced incidence of sleep-disordered breathing*, vol. 125, The American Journal of Medicine, 05 2012, pp. 485–90.
- [5] Chris Bennett, Jody Ryall, Leo Spalteholz, and Amy Gooch, *The Aesthetics of Graph Visualization*, Computational Aesthetics in Graphics, Visualization, and Imaging (Douglas W. Cunningham, Gary Meyer, and Laszlo Neumann, eds.), 06 2007.
- [6] Luciana Besedovsky, Tanja Lange, and Jan Born, *Sleep and immune function*, vol. 463(1), Pflügers Archiv - European Journal of Physiology, 01 2012, p. 121–137.
- [7] Alethea Blackler and Jörn Hurtienne, *Towards a unified view of intuitive interaction: Definitions, models and tools across the world*, MMI Interaktiv - User Experience: Vol. 1, No. 13 (Martin Christof Kindsmüller and Sascha Mahlke, eds.), vol. 13, 08 2007, pp. 36–54.
- [8] Alethea Blackler, Vesna Popovic, and Douglas Mahar, *Towards a design methodology for applying intuitive interaction*, WonderGround: Proceedings of the 2006 Design Research Society International Conference, CEIADE-Centro Editorial do IADE, 2006, pp. 1–17.
- [9] Alexander A Borb and Peter Achermann, *Sleep homeostasis and models of sleep regulation*, vol. 14, Sage Publications Sage CA: Thousand Oaks, CA, 1999, pp. 559–570.
- [10] Anneli Bowie, *Aesthetics versus functionality : challenging dichotomies in information visualisation*, vol. 18, Image & Text : A Journal for Design, 01 2011, pp. 64–81.
- [11] Orfeu M. Buxton and Enrico Marcelli, *Short and long sleep are positively associated with obesity, diabetes, hypertension, and cardiovascular disease among adults in the united states*, vol. 71, Social Science & Medicine, 09 2010, p. 1027–1036.

- [12] Daniel J. Buysse, *Sleep health: Can we define it? does it matter?*, vol. 37, *Sleep*, 01 2014, pp. 9–17.
- [13] Marcelo Campos, *Heart rate variability: A new way to track well-being*, vol. 22, *Blog post*, 11 2017, <https://www.health.harvard.edu/blog/heart-rate-variability-new-way-track-well-2017112212789>.
- [14] Francesco Cappuccio, Lanfranco D’Elia, Pasquale Strazzullo, and Michelle Miller, *Sleep duration and all-cause mortality: A systematic review and meta-analysis of prospective studies*, vol. 33, *Sleep*, 05 2010, pp. 585–92.
- [15] Nick Cawthon and Andrew Vande Moere, *The effect of aesthetic on the usability of data visualization*, IEEE, 2007 11th International Conference Information Visualization (IV’07), 2007, pp. 637–648.
- [16] Luca Chittaro, *Visualizing information on mobile devices*, vol. 39, *Computer*, 2006, pp. 40–45.
- [17] Constantinos Coursaris, *Exploring the relationship between aesthetics and usability*, The Proceedings of International Telecommunication Education and Research Association Conference, Louisville, KY, USA, 06 2007.
- [18] Gerwin de Haan, Michal Koutek, and Frits H. Post, *Towards intuitive exploration tools for data visualization in vr*, Proceedings of the ACM Symposium on Virtual Reality Software and Technology 2002, Association for Computing Machinery, 2002, p. 105–112.
- [19] Massimiliano de Zambotti, Leonardo Rosas, Ian Colrain, and Fiona Baker, *The sleep of the ring: Comparison of the Ōura sleep tracker against polysomnography*, vol. 17, *Behavioral Sleep Medicine*, 03 2017, pp. 1–15.
- [20] Abhinav Dr. Singh, *How much sleep do we really need?*, *Blog post*, 2021, <https://www.sleepfoundation.org/how-sleep-works/how-much-sleep-do-we-really-need>.
- [21] Kim Erwin, Maggee Bond, and Aashika Jain, *Discovering the language of data: Personal pattern languages and the social construction of meaning from big data*, vol. 40, *Interdisciplinary Science Reviews*, 03 2015, pp. 44–60.
- [22] Stephanie Evergreen and Chris Metzner, *Design principles for data visualization in evaluation*, vol. 2013, *New Directions for Evaluation*, 12 2013, pp. 5–20.
- [23] facebook, *Create react app*, README, 2021, <https://github.com/facebook/create-react-app#readme>.
- [24] Elif E. Firat and Robert S. Laramée, *Towards a survey of interactive visualization for education*, Proceedings of the Conference on Computer Graphics and Visual Computing (Goslar, DEU), CGVC ’18, Eurographics Association, 2018, p. 91–101.
- [25] Cory Gackenhimer, *What is react?*, *Introduction to React*, Springer, 2015, pp. 1–20.
- [26] Yang Hao and Robert Foster, *Wireless body sensor networks for health-monitoring applications*, vol. 29, *Physiological Measurement*, 11 2008, pp. 27–56.
- [27] Jörn Hurtienne and Lucienne Blessing, *Design for intuitive use - testing image schema theory for user interface design*, Proceedings of ICED 2007, the 16th International Conference on Engineering Design, 01 2007.

- [28] Luca Imeri and Mark R. Opp, *How (and why) the immune system makes us sleep*, vol. 10, *Nature Reviews Neuroscience*, 03 2009, pp. 199–210.
- [29] Muhammad Nazrul Islam, *Exploring the intuitiveness of iconic, textual and icon with texts signs for designing user-intuitive web interfaces*, 2015 18th International Conference on Computer and Information Technology (ICCIT), 12 2015.
- [30] ISO, *Ergonomic requirements for office work with visual display terminals ( v d t s ) — part 11 : Guidance on usability*, International Organization for Standardization, 03 1998, pp. 1–22.
- [31] Helen Kennedy, Rosemary Lucy Hill, Giorgia Aiello, and William Allen, *The work that visualisation conventions do*, vol. 19, *Information, Communication & Society*, 2016, pp. 715–735.
- [32] Muzammil Khan and Sarwar Shah Khan, *Data and information visualization methods, and interactive mechanisms: A survey*, vol. 34, *International Journal of Computer Applications*, 2011, pp. 1–14.
- [33] Heli Koskimäki, Hannu Kinnunen, Teemu Kurppa, and Juha Röning, *How do we sleep: A case study of sleep duration and quality using data from oura ring*, *Proceedings of the 2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers (New York, NY, USA), UbiComp '18*, Association for Computing Machinery, 2018, p. 714–717.
- [34] Andrea Lau and Andrew Vande Moere, *Towards a model of information aesthetics in information visualization*, 2007 11th International Conference Information Visualization (IV'07), IEEE, 2007, pp. 87–92.
- [35] Isabel Meirelles, *Design for information: an introduction to the histories, theories, and best practices behind effective information visualizations*, Rockport Publishers, 2013, p. 109.
- [36] Suresh Menon, *Obstructive sleep apnea syndrome*, *Oral and Maxillofacial Surgery for the Clinician (Krishnamurthy Bonanthaya, Elavenil Panneerselvam, Suvy Manuel, Vinay V. Kumar, and Anshul Rai, eds.)*, 02 2021, pp. 1577–1589.
- [37] Tanja Merčun, *Evaluation of information visualization techniques: analysing user experience with reaction cards*, *Proceedings of the Fifth Workshop on Beyond Time and Errors: Novel Evaluation Methods for Visualization*, 2014, pp. 103–109.
- [38] Andrew Vande Moere and Helen Purchase, *On the role of design in information visualization*, vol. 10, *Information Visualization*, 09 2011, pp. 356–371.
- [39] Carsten Mohs, Jörn Hurtienne, D. Scholz, and M. Rotting, *Intuitivität: definierbar, beeinflussbar, überprüfbar! [intuitiveness: definable, influenceable, verifiable!]*, vol. 1946, *VDI Berichte*, 01 2006, Original document in German, pp. 215–224.
- [40] Carsten Mohs, Jörn Hurtienne, Martin Christof Kindsmüller, Johann Habakuk Israel, Herbert A. Meyer, and IUUI Research Group, *Iuui intuitive use of user interfaces: Auf dem weg zu einer wissenschaftlichen basis für das schlagwort 'intuitivität' [iuui intuitive use of user interfaces: Towards a scientific basis for the keyword 'intuitiveness']*, *MMI Interaktiv - Aufmerksamkeit und Situationawareness beim Autofahren [MMI Interactive - Attention and Situation Awareness while Driving]* (Sandro Leuchter, Leon Urbas, and Martin R. K. Baumann, eds.), vol. 1, *MMI interaktiv [MMI interactive]*, 01 2006, Original document in German, pp. 75–84.

- [41] Kevin Mullet and Darrell Sano, *Designing visual interfaces*, vol. 28, *Acm Sigchi Bulletin*, 1996, pp. 82–83.
- [42] Tamara Munzner, *Visualization analysis and design*, A K Peters/CRC Press, 12 2014, pp. 1–428.
- [43] Anja Naumann, Jörn Hurtienne, Johann Israel, Carsten Mohs, Martin Kindsmüller, Herbert Meyer, and Steffi Husslein, *Intuitive use of user interfaces: Defining a vague concept*, *Engineering Psychology and Cognitive Ergonomics* (Don Harris, ed.), Springer Berlin Heidelberg, 01 2007, pp. 128–136.
- [44] Anja Naumann, Anna E. Pohlmeier, Steffi Husslein, Martin Christof Kindsmüller, Carsten Mohs, and Johann Habakuk Israel, *Design for intuitive use: Beyond usability*, *CHI '08 Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA), CHI EA '08, Association for Computing Machinery, 2008, p. 2375–2378.
- [45] Netlify, *Get started with build configuration*, 2021, <https://docs.netlify.com/configure-builds/get-started/>.
- [46] ———, *Make react do more.*, 2021, <https://www.netlify.com/with/react/>.
- [47] Donald A. Norman, *The design of everyday things: Revised and expanded edition*, Basic Books, 2013.
- [48] Maurice Ohayon, Emerson M Wickwire, Max Hirshkowitz, Steven M Albert, Alon Avidan, Frank J Daly, Yves Dauvilliers, Raffaele Ferri, Constance Fung, David Gozal, et al., *National sleep foundation's sleep quality recommendations: first report*, vol. 3, *Sleep health*, 2017, pp. 6–19.
- [49] Ignacio Perez-Pozuelo, Bing Zhai, João Palotti, Raghvendra Mall, Michael Aupetit, Juan Garcia-Gomez, Shahradd Taheri, Yu Guan, and Luis Fernandez-Luque, *The future of sleep health: a data-driven revolution in sleep science and medicine*, vol. 3, *NPJ Digital Medicine*, 12 2020, pp. 1–15.
- [50] Annemarie Quispel, Alfons Maes, and Joost Schilperoord, *Aesthetics and clarity in information visualization: The designer's perspective*, *Arts*, vol. 7, Multidisciplinary Digital Publishing Institute, 2018, p. 72.
- [51] Harpreet Singh Rai, *Oura in the age of ownership*, *Ōura blog*, 2021, <https://ouraring.com/blog/series-c-announcement/>.
- [52] Francisco Rebelo and Marcelo Soares, *Advances in ergonomics in design, usability & special populations: Part ii*, *Applied Human Factors and Ergonomics (AHFE) Conference*, 2014.
- [53] George Robertson, Roland Fernandez, Danyel Fisher, Bongshin Lee, and John Stasko, *Effectiveness of animation in trend visualization*, vol. 14, *IEEE Transactions on Visualization and Computer Graphics*, 2008, pp. 1325–1332.
- [54] Robert E Roth, *Visual variables*, *International Encyclopedia of Geography: People, the earth, environment and technology*, 2017, pp. 1–11.
- [55] Dan Saffer, *The elements of interaction design*, *UX matters*, 05 2006, <https://www.uxmatters.com/mt/archives/2006/05/the-elements-of-interaction-design.php>.
- [56] ———, *Designing for interaction: creating innovative applications and devices*, New Riders, 2010.



- [57] Bahador Saket, Alex Endert, and John Stasko, *Beyond usability and performance: A review of user experience-focused evaluations in visualization*, BELIV '16: Proceedings of the Sixth Workshop on Beyond Time and Errors on Novel Evaluation Methods for Visualization, Association for Computing Machinery, 2016, p. 133–142.
- [58] Bo Schenkman and Fredrik Jönsson, *Aesthetics and preferences of web pages*, vol. 19, Behaviour and Information Technology, 01 2000, pp. 367 – 377.
- [59] Michael Scriven, *The methodology of evaluation (vol. 1)*, Washington, DC: American Educational Research Association, 1967.
- [60] Anoop Shankar, Charumathi Sabanayagam, and Sita Kalidindi, *Sleep duration and self-rated health: the national health interview survey 2008*, vol. 34, Sleep, 09 2011, pp. 1173–1177.
- [61] John W Shepard, Daniel J Buysse, Andrew L Chesson, William C Dement, Rochelle Goldberg, Christian Guilleminault, Cameron D Harris, Conrad Iber, Emmanuel Mignot, Merrill M Mitler, et al., *History of the development of sleep medicine in the united states.*, vol. 1, Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine, 01 2005, pp. 61–82.
- [62] Ben Shneiderman, *The eyes have it: A task by data type taxonomy for information visualizations*, The craft of information visualization, Elsevier, 2003, pp. 364–371.
- [63] Norbert Streitz, *Cognitive ergonomics: An approach for the design of user-oriented interactive systems*, seminar of The International Union of Psychological Science (IUPsyS) on Man-computer interaction research (MACINTER-I): Proceedings of the first network, 04 1986, pp. 21–33.
- [64] Zhida Sun, Nan Cao, and Xiaojuan Ma, *Attention, comprehension, execution: effects of different designs of biofeedback display*, Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems, 2017, pp. 2132–2139.
- [65] Zhida Sun, Manuele Reani, Quan Li, and Xiaojuan Ma, *Fostering engagement in technology-mediated stress management: A comparative study of biofeedback designs*, vol. 140, International Journal of Human-Computer Studies, 08 2020.
- [66] Oura Team, *Oura announces results of new sleep staging algorithm*, Òura blog, 2021, <https://ouraring.com/blog/new-sleep-staging-algorithm/>.
- [67] ———, *The oura difference*, Òura blog, 2021, <https://ouraring.com/blog/the-oura-difference/>.
- [68] ———, *Your normal body temperature isn't just 98.6 degrees*, Òura blog, 2021, <https://ouraring.com/blog/natural-body-temperature/>.
- [69] Swizec Teller and Andrew H Hug, *Data visualization with d3.js*, vol. 78, Packt Publishing Birmingham, UK, 2013.
- [70] James J. Thomas and Kristin A. Cook, *A visual analytics agenda*, vol. 26, IEEE Computer Graphics and Applications, 02 2006, pp. 10–13.
- [71] Usability.de, *Usability-glossar*, 2021, <https://www.usability.de/usability-user-experience/glossar/erwartungskonformitaet.html>.
- [72] Jose Vicente, Pablo Laguna, Ariadna Bartra, and Raquel Bailón, *Drowsiness detection using heart rate variability*, vol. 54, Medical Biological Engineering Computing, 01 2016, p. 927–937.

- [73] Vladyslav Vyazovskiy, *Sleep, recovery, and metaregulation: Explaining the benefits of sleep*, vol. 7, *Nature and Science of Sleep*, 12 2015, pp. 171–84.
- [74] Colin Ware, *Visual thinking for design*, Elsevier, 2010.
- [75] Ioannis Xenakis and Argyris Arnellos, *The relation between interaction aesthetics and affordances*, vol. 34, *Design Studies*, 2013, pp. 57–73.