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Bachelorarbeit

Interactive Visualizations for Multivariate Weather Data on Smartwatches

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Abstract

Smartwatches are a rapidly growing market with big potential. However, the small screen of the device also poses new challenges when it comes to visualizations. Especially with more complex representations. Weather data offers many possible visualizations, which are on the more complex side. Whether it is the temperature course being displayed as a chart, or the humidity represented as a progress bar. In this work, the new weather application for smartwatches *WeDaVis* is introduced, using new ways of visualizing weather information. As the results of our user study revealed, did participants not prefer a specific type of data representation, but instead, the preferences depended on the type of weather information. Participants preferred the visualizations of *WeDaVis* for more unfamiliar data, as for example wind, and air pressure. Textual representations are preferred, when it comes to common information, like temperature. Additional results showed, that possibilities of interaction should be visualized, otherwise some participants had problems to identify them. As participants had diverse interests in weather information, applications should be customizable in the best case, and should show around six data representations on the main screen. The field of weather data on smartwatches is fairly new, and this project aims to contribute to this research by making an attempt to develop an efficient weather application, suitable for the use case of a smartwatch.

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1 Introduction

Smartwatches are in many daily situations more accessible than smartphones. They are worn on the wrist, therefore no hand is needed to hold the device, and often times easier to look at, than smartphones, which usually are carried in a pocket or a bag. If the watch comes with LTE, it does not even need a smartphone connected to it, to be able to surf the internet. Smartwatches come in handy in many occasions. Taking calls, reading messages, track fitness data and even paying groceries. And of course, smartwatches can tell the weather. Many watch faces even have the temperature or the weather condition integrated. But what is the state of the art of weather applications for smartwatches?

The research field of smartwatches and visualizations for them is fairly new, and until now, there exists almost no research with respect to weather data visualizations on smartwatches, besides some analysis in the context of watch faces by Islam et al. [IBL+20]. As our analysis of weather apps for smartwatches showed, a majority of weather apps only use text, or text in combination with an icon to represent weather information. But as proven by applications on the smartphone or computer, weather data representations do not have to be restricted to these kinds of representation, but can be illustrating, like an image, or complex, like a chart. As the spread of smartwatches moves forward [Sta22b], the need for proper design and usability considerations rises.

This thesis aims to provide to the research field of weather data on smartwatches, by introducing and evaluating a new weather application called *WeDaVis* (Weather Data Visualization). The main goal of this application is not only to provide the plain data to the user, but to support them by helping fully comprehend the information. The user should be able to classify the information, even though they might not have domain knowledge about the data. In order to do so, *WeDaVis* does not just simply display the value as a text, but for example shows it in a min- and max- range.

To evaluate the efficiency and usability of *WeDaVis*, also in contrast to ordinary weather applications on the market, a user study was conducted. As the results indicated, did participants prefer not a single type of visualization, but rather preferred the type of visualization, based on the type of weather information displayed. If participants were more familiar with the information, they preferred a more simple textual visualization, while for more uncommon data, they appreciated the more complex designs of *WeDaVis*. When it comes to interaction, the study revealed, that possibilities of interaction should be marked, as otherwise, they might get overlooked by participants. The study also showed, that participants do not prefer nine elements on the main screen, but rather a smaller number of data representations, which then could be displayed bigger and more clear.

Outline

This thesis is structured into the following sections.

Chapter 2 explains basic knowledge about weather data and visualizations in general, which is required to follow this thesis.

Chapter 3 summarizes the work connected to this thesis and which limitations in research leaded to this thesis.

Chapter 4 describes the applied methods, with which the weather app was created.

Chapter 5 notes the approach and design of the user study.

Chapter 6 summarizes the results of the user study.

Chapter 7 discusses the general findings of the thesis.

Chapter 8 concludes the thesis and provides an outlook on future works.

2 Background

In this chapter, we will describe some background information that is required to follow the remaining work. First, we explain what kind of weather data exists and what kind of data we used for our application. Afterwards, we expound the term micro visualizations and the current state of visualization of weather data on smartwatches in contrast to smartphones. Ultimately, we present the current state of interaction with micro visualizations and weather applications.

2.1 Weather Data

The field of weather data is wide and multi-layered. Depending on the end-user, the complexity of weather information really differs. This project focuses on the type of user, that is interested in weather data, that has direct impact on them, as for example the precipitation for the current day, or the current temperature, in order to decide, what clothes they should wear outside. This kind of information can be found in various ways. There exists countless websites, from weather services themselves or third parties, applications for pc's, smartphones, smartwatches, and nearly every other device with an internet connection. The presentation and scope of weather data is directly influenced by the device. Pc's and laptops, for example, offer, because of the bigger screen, a more extensive overview of the weather, more suitable for an expert analysis, than smartphones or smartwatches would do. In this sense, the Windows weather application offers also historical weather data, which is not available in most applications for smartphones and smartwatches. This also affects the visualization, as a bigger screen offers more options for graphs, maps, and charts. As part of this project, we collected data about existing weather applications on smartwatches, as smartwatches are the focus of this project. To be able to make some comparisons, we also looked into visualizations of weather information on smartphones. The outcome of this research is described in the following sections.

We discovered, the most used weather data on smartphones and smartwatches is the weather condition, precipitation, and the temperature. The weather condition describes, for example, the weather in the form of a text or a picture. Temperature is either given in Celsius or Fahrenheit, and usually includes values for the current temperature, the temperature forecast for the next hours and days, min- and max- temperature of the day and the felt temperature. Precipitation information can be given either in a probability, for example on 50% of the days with similar weather condition, it rained, or it can be given in the amount of precipitation expected. There also exist rain radars in form of maps, where the area it rains is marked. Other weather information, that appeared frequently are wind information, humidity, sun and moon information, UV index, air pressure, air quality, sight, cloud cover and allergy information. Wind data often includes the wind strength, in form of speed, and the wind direction. Humidity is given as percentage. For example, 20% humidity means very dry air, which harms the skin and makes the body more vulnerable [Hah07]. When the humidity is too high, it is more difficult for the body to give off heat, which makes the body less powerful and efficient [Kra]. Sun information can include the time of sunrise and sunset and the sun strength in kWh. Moon information also includes the moon rise and set, and often times the moon phase. UV index indicates, how strong the ultraviolet radiation is, on a scale from 1 to 11, where 1 signals harmless radiation, where no protection is needed, and 11 is extreme radiation, where it is better to stay inside [Str]. Air pressure indicates the pressure of the air on the human body. The higher a place is, the less air pressure is on the place, but the exact value varies [Weta]. Air quality measures the pollution of the air. The quality can be influenced by traffic and industry, but also by natural factors, like dust from a dessert or forest fires [Bun]. Sight indicates, how far a human can see, influenced by dust or fog. The Cloud cover measures how much of the sky is currently covered by clouds in percentage. Allergy info indicates the amount and type of pollen in the air.

2.2 Micro Visualizations

Because the purpose of this project is to develop a smartwatch weather application, the visualizations must be designed for the small screen of a watch. To display information at this size is not a simple task, because the amount of space, and therefore the amount of information, that can be shown, is very restricted. So the selection of information and the design of the visualizations become more important. Those very small visualizations, which will be used in this project, are also called micro visualizations, and there already exists some research in this field, which will be discussed in this section.

There exist multiple definitions of the term *micro visualization*, for example Parnow and Dörk [PD15] define *micro visualizations* as physically small and only representing a few dimensions or data points. In their definition, micro visualizations are used to add information to a text to make it easier to understand. As such, more complex data displayed on small spaces is excluded, as well as data, which is not accompanied by text. In this research project, the definition by Isenberg [Ise21] describes better, what we intend by micro visualizations. She expands the term to visualizations on physically small display spaces which are not restricted by the number of dimensions or data points and can also stand alone without text.

As the field of micro visualizations is fairly new, many data types were not explored yet, such is the case for weather data. Therefore, we decided to conduct our own analysis on the current use of visualizations for weather data on smartwatches. Because we assume that the potential of visualizations on the small screen of wrist worn devices is not fully exploited, we also looked at the state of the art of visualizations on smartphones.

2.2.1 State of the Art Of Weather Data Visualizations on Smartwatches and Smartphones

To get an impression of the current state of weather data visualizations, we analysed in total 45 weather applications, twelve for smartwatches and 33 for smartphones. Because smartphones are with 4.7 billion users worldwide [Sta22a] far more used than smartwatches with 212 million users worldwide [Sta22b], as for 2022, we expected weather applications for smartphones more evolved with respect to visualizations. Additionally, the smaller screen size of smartwatches makes visualizing and inspecting complex data more challenging.

To find weather applications for smartwatches, we searched for the keyword “weather” in the Google Play Store and excluded all results, that did not have weather data as the main topic, for example, watch faces, because we are interested in how multiple data types of the same category, the weather, are visualized. We also excluded applications that were not available for free or had a 0.0 rating. We installed and tested all Android weather applications on the Fossil Gen 5 smartwatch. The weather app from Apple was inspected on the Apple Watch Series 4. The search was carried out on 16.11.2023 and resulted in ten applications. Additionally, we included the already installed Google weather app and the Apple weather application. We only included the Apple weather application for iOS because we had time- and authorization -wise restricted access to the Apple Watch. In total, we tested twelve apps. Their names with their rating from 0 over 5, in the descending order they were rated, are listed in Table 2.1.

In Figure 2.1 is an overview of the type and the representation of the weather data. To keep the graph simple, data types are summarized, for example, general precipitation for the day and precipitation for now are combined into “precipitation”, so the total number does not always sum up to twelve. Furthermore, we only counted text + icon and text + chart, when they are connected, for example precipitation next to a drop

Application Name	Rating
Wetter (Apple)	4.6
How is the Weather? - Wear OS	4.2
Windy.com - Weather Forecast	4.1
Yr	4.1
Simple Weather	4.0
Weather XL Pro	4.0
Accu Weather: Weather Radar	3.8
Weather for Wear OS	3.7
Weather XS Pro	3.7
MyRadar Weather Radar	3.5
Weather Radar	3.1
Weather (Google)	2.8

Table 2.1: Names and ratings of inspected weather applications for smartwatches.

icon, but not, if they just appear both in the application, for example when there is a picture of clouds in the background and a text which says "cloudy", they are counted separately.

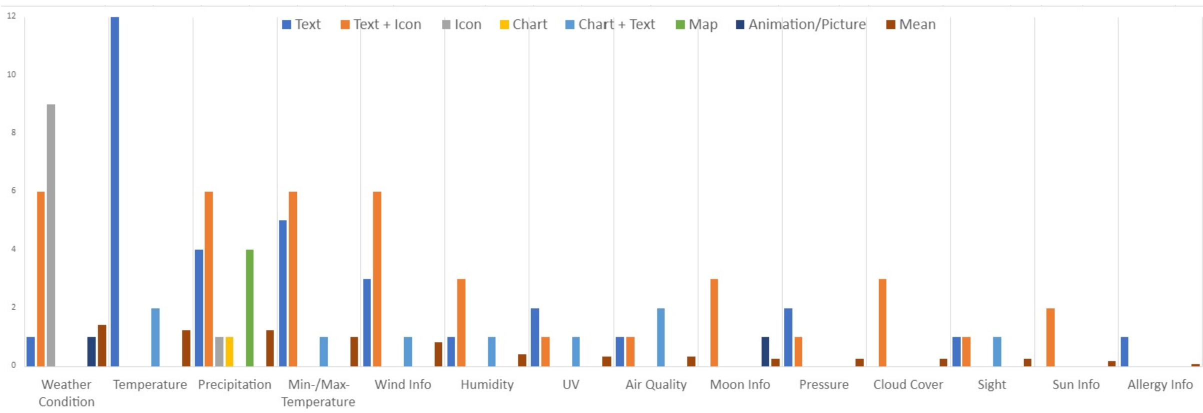


Figure 2.1: Weather data visualization types on smartwatches.

The weather data that appeared the most on the smartwatch was weather condition, with an average of 1.4 appearances per application. The second most used information was the temperature. All twelve applications represented the temperature as text, only one additionally showed the minimum and maximum temperature as a combination of text and icon. All applications that were inspected showed information about precipitation. The least used data, that appeared in only 17 % of the applications, was information about the sun and only 8 % showed information about allergies, while on smartphones this information appeared in 27 % of apps.

The most popular visualization style for smartwatches was a combination of text and icon with an average of 3.3 appearances, followed by plain text, with an average of 2.7 appearances. Only seven applications used charts or charts and text to visualize data, and only three types of charts were used in total. Figure 2.2 provides an overview of the different kinds of charts used on the inspected weather applications. Radial bar charts were the most used type of chart and appeared in four of the applications, depicting for example precipitation probability, followed by bar charts, used in two applications. Four apps provided a rain radar in the form of a map. Only one app used line charts to depict the temperature progression over time, and no app used a pie chart or an area chart, opposed to applications on smartphones. The most used data representation of weather data was a table or a list, which appeared in every application. The weather app by Apple was the only one that used an animation to illustrate the weather condition.

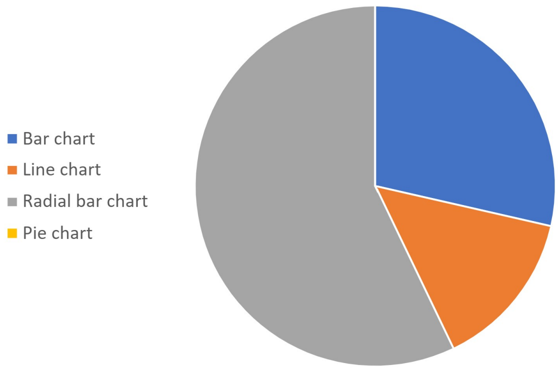


Figure 2.2: Chart types used for weather data on smartwatches.

Because the offer of weather applications on smartphones is larger than for smartwatches, we had to restrict our search more. Again, we conducted a search of the term “weather” on the 16.11.2023 in the Google Play Store. We excluded all applications with less than 10 million downloads, because otherwise, too many applications would have fulfilled the criteria. This leaded to a total of 34 weather applications. The titles of the apps, ordered by their ranking in descending order, are listed in Table 2.2.

One of the apps, called *weather by Xiaomi*, could not be started, therefore it was taken out of the analysis. We analysed the apps on a Google Pixel 3a smartphone. In Figure 2.3 is a summary of the most common data types and how they are depicted on a smartphone.

Similarly to smartwatches, weather condition was the most popular weather data for smartphones, with 2.4 appearances per app, followed by the precipitation, and the temperature with an average appearance of 2. Different to smartwatches, sun

Application Name	Rating
Weather: Live Radar & Widgets	4.8
Local Weather: Weather Forecast	4.8
YoWindow Weather and Wallpaper	4.7
Weather Radar - Meteored News	4.7
Weather24: Forecast & Radar	4.7
Weather Forecast: Live Weather	4.7
Weather App	4.6
Weather XL Pro	4.5
Weather Radar by WeatherBug	4.5
Windy.com - Weather Forecast	4.5
Weather (Saevio)	4.5
Weather Data & Microclimate	4.5
Weather (Quark Ltd)	4.5
The Weather Channel - Radar	4.4
Weather (MacroPinch)	4.4.
Yahoo Weather	4.3
Weather Live°	4.3
Weather & Radar	4.3
Yandex Weather	4.3
1Weather: Forecast & Radar	4.2
Daily Weather (Transsion Holdings)	4.2
Daily Weather (P & L Studio)	4.1
Amber Weather	4.1
Weather Home - Live Radar	4.1
Rain Alarm	4.1
My Weather App	4.1
Weather & Clock Widget	4.1
Weather (Weather Radar Team)	4.1
ilMeteo: weather forecast	4.0
Weather & Radar	3.9
Accu Weather: Weather Radar	3.7
Clime: NOAA Weather Radar Live	3.7
MyRadar Weather Radar	3.3

Table 2.2: Names and ratings of inspected weather applications for smartphones.

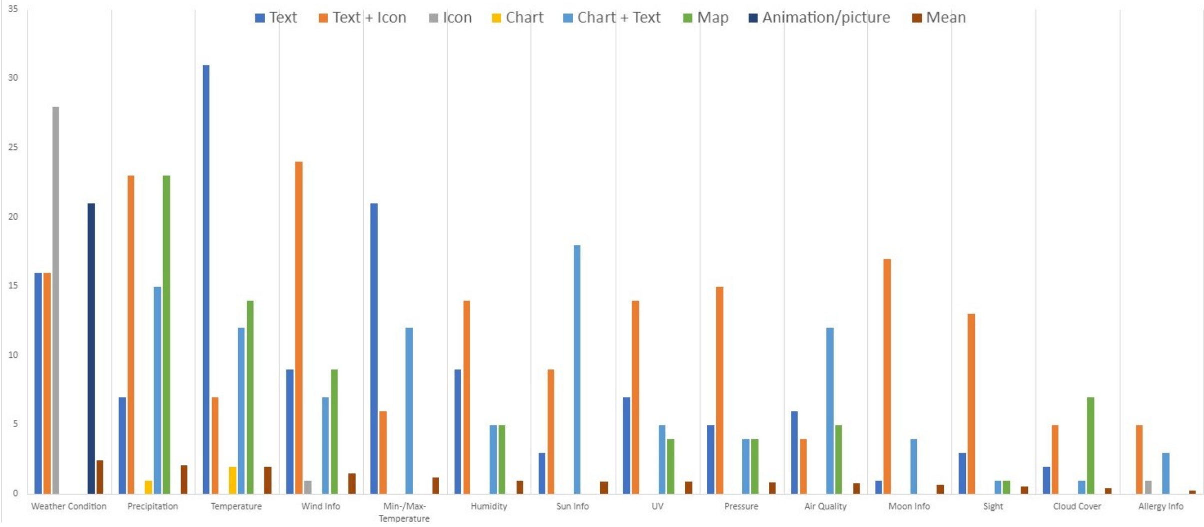


Figure 2.3: Weather data visualization types on smartphones.

information appeared more on the smartphone apps, with 0.9 times, while cloud cover and allergy information were also the least used data types.

Similar to smartwatches, the most used visualization types for weather data on smartphones were text with an icon with an average of 5.2 appearances and text with 3.6 appearances. But different to smartwatches, the use of charts with or without text is, with an average of 3.1, clearly more used. As Figure 2.4 shows, the most used chart types are bar- and line-charts, with appearances in nearly 60 % of all applications each. Followed by radial bar charts and area charts, which 40 % of the apps used. The least used type of charts were pie charts, with only 6 %. Nearly all applications also used a table to depict some weather data, for example, the temperature and precipitation probability for the next hours. Also, on average 2.2 maps were provided, which is also noticeably more than for smartwatches.

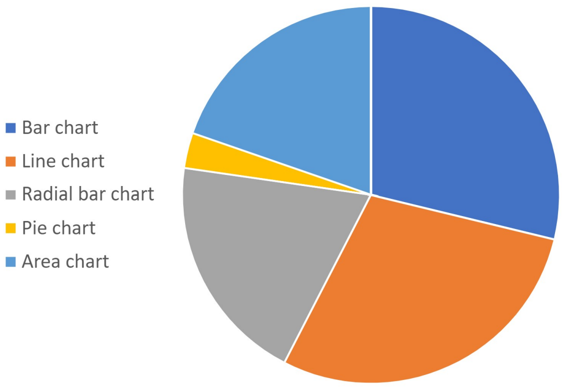


Figure 2.4: Chart types used for weather data on smartphones.

2.2.2 Interaction with Weather Apps on Smartwatches

Interaction techniques with smartwatches are often simply transferred from smartphones. For example, the zooming technique with two fingers is also applied to some maps on smartwatches. But as the use of smartwatches differs from phones, as they are more often used in more difficult angels and in movement, and the screen size is smaller, these interaction methods are not the best option of interaction [SDI18]. Often times, interaction with smartwatches causes the fat finger problem [NRM+21]. That means that the finger covers a big part of the screen. Figure 2.5 shows an overview of the interaction techniques that the weather apps used and for which functions they were applied. The only interaction the weather applications used, that prevents the fat finger problem, is the control wheel, with which a wearer can scroll or zoom without covering the screen. This was also the most used interaction technique in the twelve applications that we analysed. It is noticeable that none of the provided charts were interactive. Also, out of the four rain radars, one map allowed no interaction, and two used the 2-Finger pan, which Singh et al. [SDI18] proved to not be optimal for smartwatches. This shows, that for more complex data representations, there was often no convincing interaction technique provided, which could be an explanation, on why they are used so sparely.

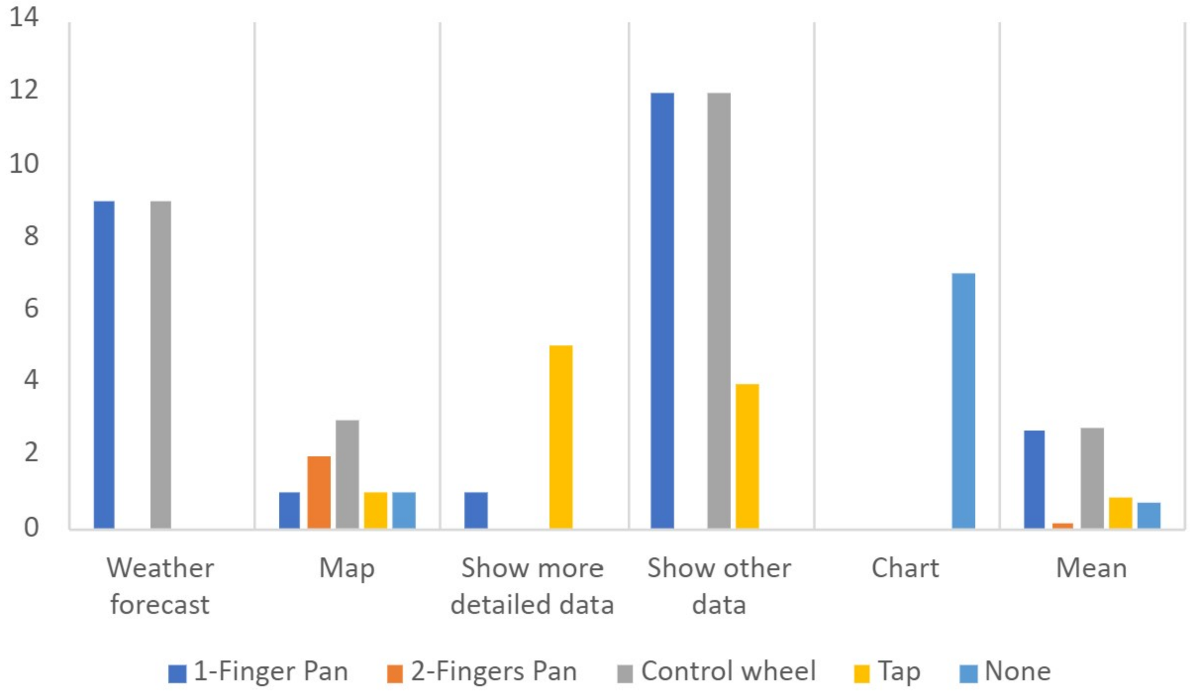


Figure 2.5: Interaction techniques for weather applications on smartwatches.

3 Related Works

In the following, we discuss the related work for this thesis. Different perspectives on weather data and smartwatch applications are possible. So we looked into the kind of data people usually see on their smartwatch, how this data is depicted, and how the user can interact with the data representations provided.

3.1 Data Visualizations on Smartwatches

In this section, we will discuss, how data is represented on smartwatches. We will first provide an overview of research on data representation on smartwatches in general, and later go more into detail on weather data on its own.

3.1.1 Visualization of Weather Data on Smartwatches

In a survey, Islam et al. [IBL+20] examined what kind of data people see on their watch face and how the data is visualized. They found that the majority of smartwatch wearers have three different categories of data, with an average of five different data types on their watch face. With battery level being the most common one, followed by temperature. They aggregated the different data types into categories, and the category of weather data is the second most displayed one. This shows the high demand and the importance to inspect, how to properly display this kind of information. Most of the data on smartwatches is shown as a combination of icon and text, while visualizations like charts and text or charts are used only sparely. However, one must notice, that the study only focused on data being displayed on watch faces. But this also refers to weather apps, as we found out in the research about weather applications for smartwatches. The second most used technique to display data is only text, which might not be the most efficient kind of data representation. Islam et al. [IBL+20] emphasize the need for further research on how detailed the information should be displayed, and also that it might be possible to combine multiple items into one representation to reduce the total number of visualizations.

3.1.2 Common Data Representations on Smartwatches

There are multiple approaches, researchers follow, when they are trying to inspect the usability and efficiency of data representations on smartwatches. One approach would be, to focus on a single data representation itself. How different types of visualizations influence the way, the user perceives them. Another attempt is, to focus more on the overall design of smartwatch applications and watch faces. This opens the door for ideas, like unifying visualizations of different data types to one, with always the purpose of the data representations in mind. We will provide insights in some research from both approaches in the next sections.

Simple Data Representations

Blascheck et al. [BBB+23] inspected how quickly and precisely participants can process data shown on their smartwatch. The researchers conducted three studies during which participants had to detect how many of three values were above 66 %. The authors investigated three different types of depiction: bar charts, radial bar charts and text. Blascheck et al. came to the conclusion, that bar charts are the most effective form, when it comes to time threshold and accuracy, followed by radial bar charts with text having the worst performance. Adding an analogue time representation above the data visualizations had no significant impact on performance, and looking at the data from more extreme angles only had a small impact on the time threshold. Even though the participants performed best and most confidence with a bar chart, radial bar charts were perceived as more aesthetically pleasing. Therefore, when designing GUI's for smartwatches, one has to balance a more effective depiction versus a slightly worse performance with a nicer design. Grioui and Blascheck [GB23] come to the same results, that providing additional visualizations in the form of a bar chart or a radial bar chart noticeably increases reading performance, and the more preferred way was the radial bar chart for smartwatches. These results indicate, that the type of visualization has a significant impact on the performance and experience. Therefore, we tried to produce data representations that give an impression of the current weather condition and not only provide the values in a plain text form. For example, a precipitation chart, that shows, how much it is going to rain for the next hours, so that the users know exactly if they have to take an umbrella with them or not.

Multi-Data Representations

Neshati et al. [NAR+21] developed the Space-Filling Line Graph (SF-LG), which aims to simplify time-series graphs while making not occupied space on the screen available for additional information. The authors found that most current smartwatch interfaces have 40 %-60 % free space available, and that the majority of charts only use 30 %-4 0% of the screen. To use the small display more efficient, the researchers could verify in a study that the response times were quicker for the simplified graphs. The participants preferred multiple correlated visualizations on the free space on one screen instead of switching between the charts. What they did not take into account, is, how the amount of data affects the usability. We want to test, whether a high number of different data can be handled or if it overwhelms the smartwatch wearer. Because the average interaction time with a smartwatch is quite short, the information the wearer is interested in should be glanceable in less than five seconds [BBC+21].

To provide complex data in a glanceable manner, Neshati et al. [NSL+19] introduce the G-Sparks technique, a compression for charts, to make them fit in a tiny space, up to one data point using only one pixel. The authors got some promising results, because the smartwatch wearers were able to quickly perceive the minimum and maximum of the data points represented in a line chart. This emphasizes, that visualizations should be designed for a specific purpose, which is for smartwatches often times not to inspect the charts point after point, but rather looking at a chart for a quick overview, and detecting a span, in which the data points are high or low. Because of those results, we do not want to provide the user with as many values and data representations as possible, but focus on the information, the wearer really needs, not only by thinking about the type of information, but also on reflecting about how this information can be the easiest to understand.

To get an idea, which kind of data representation watch wearers prefer, Islam et al. [IAB+22] conducted four studies about visualizations of sleep data. Even though the studies were about preferences and performance of sleep visualizations, some findings can also be applied to weather data. Visualizations are, for example, more popular than only textual representations, which is contrary to the fact, that text is still the second most used technique to display data [IBL+20]. The authors distinguished between a square, a tall and a wide design and could only find a few exceptions, in which the larger square design performed better than the two more narrow designs. The researchers recommend to use vertical charts for more simple tasks, as they require less movement of the wrist to be read, and horizontal bars for a weekly overview of data. To incorporate those results, we used a vertical bar chart for the precipitation in the next hours and for the more detailed overview a horizontal bar chart.

Some design guidelines for glanceable visualizations are given by Blascheck et al. [BBC+21]. For example, the visualization should be easily accessible, as simple as possible, and especially designed for a purpose. What the authors did not discuss is, how the amount and complexity of the data influences the efficiency and understandability. Therefore, we wanted to contribute to this field, by implementing a complex visualization with a high amount of data, and inspect, if it is still possible to use these visualizations efficiently.

Huth et al. [HBKE23] argue for the use of animated transitions between data visualizations on small screens to help the user understand complex data. The researchers compared performance of normal-scaled and small-scaled visualizations. While the error rate for the small-scaled visualizations was higher, for the completion time and number of times the animation replays, the small size showed no disadvantage.The authors could verify their results in two studies. We included animation, where it was possible, to highlight the change of the values depicted.

3.2 Interaction with Data Representations on Smartwatches.

In this section, we are going to summarize some research of the field of interaction with smartwatches. Because the small display size of these devices poses new challenges, when it comes to efficient interaction, new techniques have been developed.

Interaction techniques, like panning or zooming, are often directly transferred from smartphones to smartwatches. Singh et al. [SDI18] found a decrease in performance on smartwatches, when mobility increases and hands are less available. They propose two new zooming and two new panning techniques, which only use one finger. The researchers could verify that their new techniques surpass standard ones.

The BezelGlide, proposed by Neshati et al. [NRM+21], is a new interaction technique for smartwatches. The goal was to minimize the screen occlusion when interacting with graphs, because on the small screen, fingers are covering a large part. To achieve this, the authors proposed two techniques, one, in which the participant can use the full bezel, and one, in which only 40 % of the bezel is used. This way, 90 % of the screen stays visible during interaction. In a study, the authors could verify their results. While both techniques surpassed the common shift technique, the partial BezelGlide could stand out with being even faster than the full BezelGlide, due to reduced distance travelled.

Guo and Paek [GP16] proposed another interesting interaction technique, focusing simply on gestures. With their two techniques, ObjectPoint and AnglePoint, smartwatch wearers can select menu items or adjust the volume without having to use their fingers. One advantage of smartwatches opposed to smartphones is, that they are worn on the wrist, so both hands are free. However, almost all interactions require using fingers, except a quick tilt of the watch to turn on the display. So, when designing interactions, the researchers took advantage of the fact that the watch was already on the wrist. With the newly proposed techniques, the smartwatch wearers could quickly and precisely solve tasks like item selection when the screen was divided into four sections at most. If the division was more narrow, the interaction techniques faced some problems with increasing completion time and error rate.

Similar to the work of Guo and Paek, Heo et al. [HAL+17] also proposed handless interaction techniques, including to slightly bang the hand on a hard surface, blow on the device or to tap the feet. The preference for these techniques varied because of different body parts being used in different scenarios and social constraints. For example, the tap of the feet was one of the favoured interaction methods, because it was unobtrusive and the foots were not busy in many scenarios, but was more dangerous, when driving a car. The researches came to the conclusion, that there is not a single interaction method, that surpasses all the others, but that it depends on the situation, which method is the most convenient.

To include and implement these new interaction techniques would go beyond the scope of this bachelor thesis. But to provide some interactivity with the data representations, we, for example, display values selected from a chart as a text above the chart, so that the finger, which selects the point in the chart, does not occupy the value, which is selected.

4 Methodology of Weather Application

In this chapter, we will describe the methodology with which we developed our weather app. First, we will go into the approach in Section 4.1, followed by the design in Section 4.2. Afterwards, we will explain, how we implemented the concept in Section 4.3.

4.1 Approach

To develop a weather application for smartwatches with a new concept, we first looked into the Deutsche Wetterdienst (DWD) API, which was recommended by our supervisor and which we used to request the weather data we wanted to display. The API documentation is available under https://dwd.api.bund.dev/. However, because the API is not officially maintained by the DWD, the documentation is not detailed and lacks several explanations. For example, only very few of the returned values are listed with their units.

There are eleven request methods provided, which include several warnings and a station overview. Because we wanted to display current weather information, we mainly focused on the *StationOverviewExtended* method. You pass along a station ID, which stands for a specific weather station in Germany, and the response contains various weather data measured by this station. Because not all listed station ID's worked and the focus on this project is on the visualizations and not the functionality, we only used the station ID 10738, which we statically encoded, which stands for the location Stuttgart Leinfelden-Echterdingen. The information retrieved by the weather station is listed in Table 4.1.

Unfortunately for other data information, as, for example, the precipitation probability, the station always returned a null value, and therefore we were restricted in the options of data we wanted to display in the application.

In order to provide a detailed overview of current weather conditions at one glance, we decided to display nine different data values at once on the main screen of the application. With the weather information available, we decided to display the current temperature, together with the minimum and maximum value, the wind direction, wind

Weather Data	Unit
Hourly temperature	Celsius
Hourly precipitation	Millimetre
Hourly sun strength	Watt-hour per square meter
Hourly dew point	Celsius
Hourly surface pressure	Hectopascal
Hourly humidity	Percent
Hourly information if sun has risen	Boolean
Hourly temperature STD	Celsius
Hourly weather condition Icon	Integer
Daily minimum temperature	Celsius
Daily maximum temperature	Celsius
Daily precipitation	Millimetre
Daily wind speed	Kilometre per hour
Daily wind gust speed	Kilometre per hour
Daily wind direction	Degree
Daily sun strength	Watt-hour per square meter
Daily sunrise	Unix timestamp
Daily sunset	Unix timestamp
Daily moonrise	Unix timestamp
Daily moonset	Unix timestamp
Moon phase	Integer
Daily weather condition	Integer
Warnings	String

Table 4.1: Weather information available from station 10738 Leinfelden-Echterdingen.

speed, humidity, the precipitation amount for the next five hours, sun strength, sunrise or sunset, and the air pressure.

On two additional screens, we decided to display the temperature and precipitation forecast for the next hours and days.

If we had all weather information available, we would have chosen to display the UV index instead of the sun strength and the rain probability instead of the air pressure, because we think that most weather application users find this information more relevant.

4.2 Design

This section describes the design of the weather application. First we describe the design process steps to the final idea, afterwards we describe the final design of the application.

4.2.1 Design Process

After obtaining the weather information, we started to sketch ideas on how the application could look like. Together with our supervisors, we went through two iterations of a draft. In the first sketch, we were focusing on transferring design ideas for smartphones over to smartwatches, because many of them were not available yet on smartwatches, especially for the android applications.

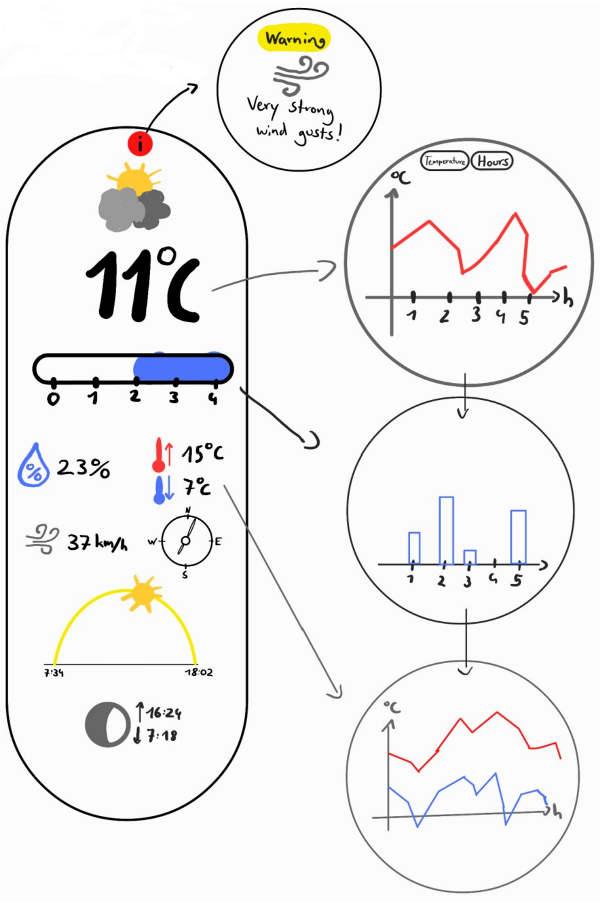


Figure 4.1: First draft for smartwatch weather application with visualizations inspired from smartphone weather apps.

Figure 4.1 shows the main screen of the application. It is scrollable and displays an overview of weather information. If the smartwatch wearer wants to know more about a specific detail, they would be able to click on the element and a new screen would open and show a detailed view of the selected information represented with a chart. On this second screen, the application users can switch between an hourly- or a daily forecast and can also switch between the weather information displayed. That, for example, would allow them to switch directly from temperature to precipitation.

While discussing the design with our supervisors, we came to the conclusion, that the visualizations should be adjusted to the use case of smartwatches. That means, that the application should provide the most important weather information at one quick glance. Ideally, the application would be customizable to the users' preference. So they should be able to pick, which type of weather data information should be displayed and for which data they want to get notifications. Because not all weather information is available, the users are restricted to the information received by the request.

With this in mind, the second draft 4.2 was designed. The basic idea is, that the application should provide one clear overview of the most relevant weather information for the user. However, the goal of the application was not only, to show much information at once, but also to illustrate and visualize the information. The user should get a feeling of the current values and weather situation. In order to achieve this, the data should not be given as plain text, but with visualizations, helping to comprehend the information. For example, a progress bar for wind strength, to indicate light or strong wind.

4.2.2 Final Design

The final design turned out slightly different to the sketch for some visualizations, due to some new ideas and technical reasons. First, we will discuss the design of the main screen of the application, followed by the detailed view of the temperature and precipitation forecast. we decided to name the application *WeDaVis* short for "Weather Data Visualization".

Design of Main Screen

The main screen brings together the different kind of weather information. As initially planned in the second draft, the data representations are arranged around an icon of the weather condition. Figure 4.3 shows the main screen with the chosen weather data.

In the following, we will present the different data representations on their own.

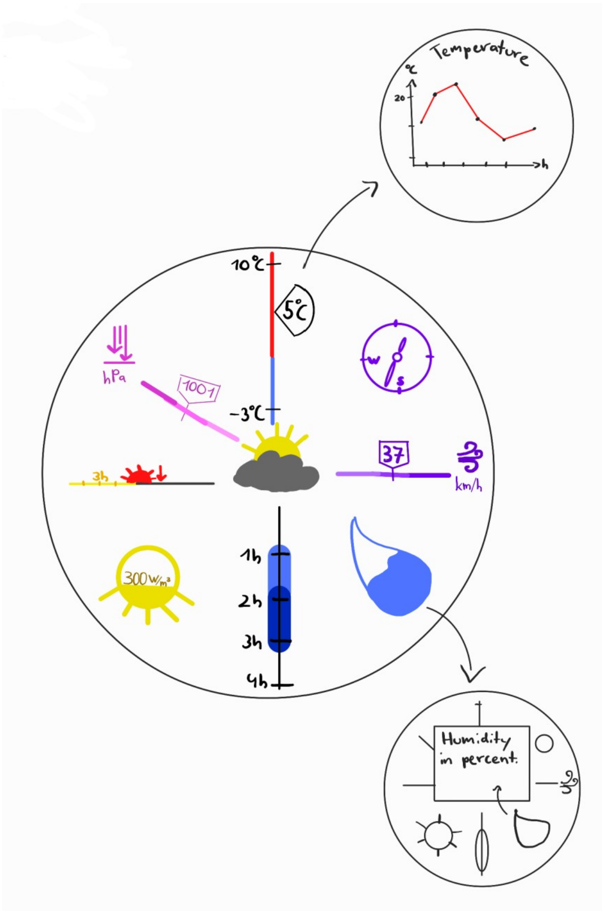


Figure 4.2: Second draft for the smartwatch weather application, showing all the information at a glance.

Temperature Visualization: To display current temperature, we used a vertical progress bar. The progress bar has the minimum temperature as the lowest point, and the maximum temperature as the highest point. The progress bar is filled up to the current temperature. Figure 4.4 shows examples of the temperature visualization, in which the current temperature would vary between minimum temperature 7 °C and maximum temperature 13 °C.

The idea of the temperature visualization is, that we want to visualize if it is rather warm or cold with respect to the minimum and maximum temperature on that day. That way, the user can directly see, if he can expect the temperature to get much warmer or colder at that day. For example, if the user sees the temperature representation (a) of Figure 4.4, they would immediately know, the temperature is getting warmer during that day, and they can dress accordingly. Instead of having the blue colour at the bottom and the red colour at the top, as we initially planned, because cold temperature is associated with blue, we switched colours. If the temperature is filled up all the way up, it would

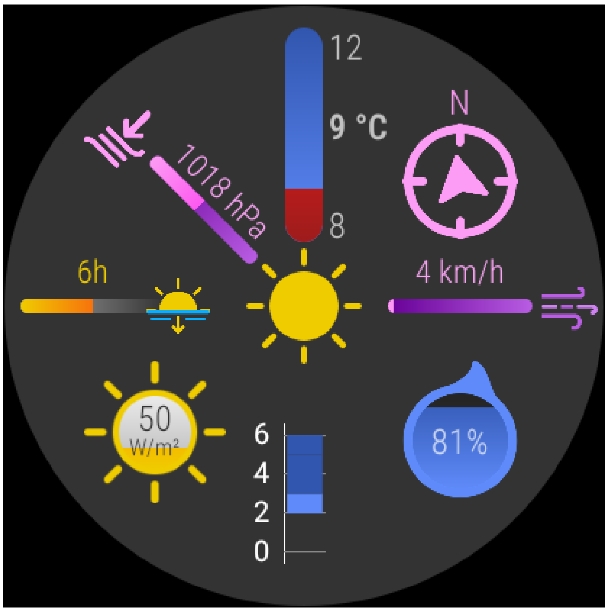
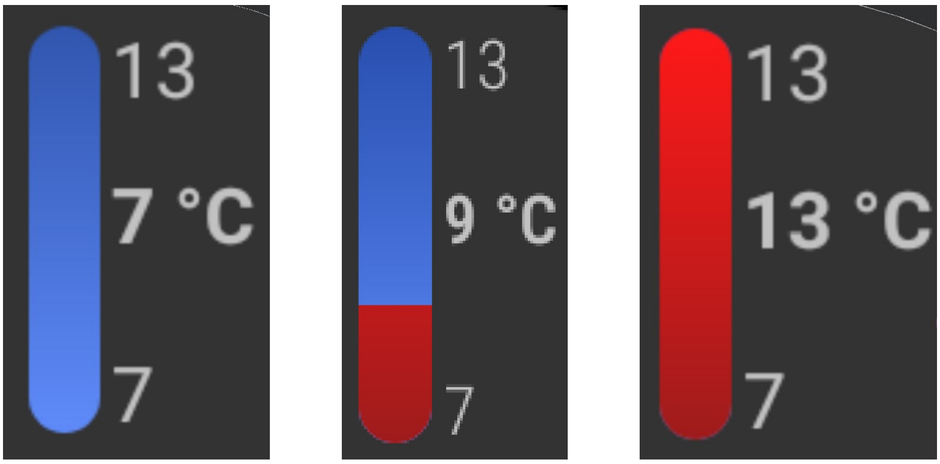


Figure 4.3: Main screen of the weather application.

look weird, because the progress bar would be completely blue, being contradictory to warmer temperature being associated with red.



(a) Current temperature is minimum temperature.

(b) Current temperature is between min- and max-temperature.

(c) Current temperature is maximum temperature.

Figure 4.4: Examples of the temperature visualization.

Wind Direction Visualization: The wind direction is indicated with a compass, in which the needle is an arrow, pointing in the direction, towards which the wind blows. To indicate the alignment of the compass, there is an “N” at the top, to indicate north. The examples in Figure 4.5 show the visualization of different wind directions.

(a) Wind direction north. **(b)** Wind direction east. **(c)** Wind direction south west.

Figure 4.5: Examples of the wind direction visualization.

Wind Strength Visualization: The wind strength is displayed with a horizontal progress bar. The idea is to not only show the user raw values, but to visualize, what these values mean. For example, a filled up progress bar signals very high wind, while just the value of 80 km/h is not that easily classifiable. The exact wind strength is shown above the progress bar. In order to show, that this data represents the wind, a wind icon is placed on the right of the progress bar. In Figure 4.6 different wind strength data is shown. The progress bar covers speeds from 0 to 118 km/h. We decided to take 118 km/h as a maximum value, because speeds above this value are classified as storm, and it is the highest category of the Beaufort scale [Wetb].

(a) Low wind strength. **(b)** Medium wind strength. **(c)** High wind strength.

Figure 4.6: Examples of the wind strength visualization.

Humidity Visualization: Humidity is given in percent, so the natural minimum and maximum limit suggests that it is visualized as a progress bar from 0 to 100. The exact humidity value is displayed in the centre of the progress bar. To indicate, that the value refers to humidity, the progress bar is in the form of a water drop. Figure 4.7 shows, how different values for humidity change the data representations.

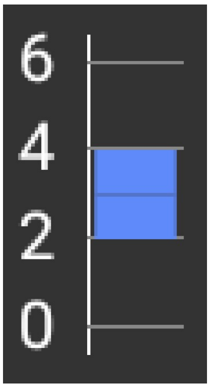
(a) Low humidity. **(b)** Moderate humidity. **(c)** High humidity.

Figure 4.7: Examples of the humidity visualization.

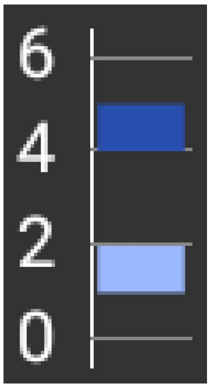
Precipitation Visualization: The precipitation visualization, represented with a stacked bar chart, shows the expectations for rain within the next 6 hours. If there is precipitation, the section of the bar is coloured in blue. The darker the blue shade is, the higher is the precipitation amount. The DWD classifies rain as light, if precipitation amount is less than 2.5 mm per hour. If precipitation amount is between 2.5 and 10 mm per hour, it is considered moderate rain, and if precipitation amount is more than 10 mm per hour, it is classified as heavy rain [Wetc]. We took on this classification for the colour coding of the precipitation representation. As the visualization might seem confusing, when there is no precipitation expected for the next 6 hours, the Icon in Figure 4.8 (a) for no rain is shown and replaces the bar chart visualization. Figure 4.8 (b) and (c) shows the precipitation visualization when precipitation is anticipated.

Sun Strength Visualization: The sun strength is displayed as a progress bar. Because we did not find a scale to classify sun strength, we searched for the highest value of sun strength per hour in 2023, and took this value as the upper limit of the progress bar. The month with the most sun radiation in 2023 was June, with a total of 215 kilowatt-hours per square meter in the region of Stuttgart [Wet23]. Because this value is the sum of sun radiation in June, we divided the sum by the 305 hours of sun in June [Sta23], to get an average value of sun strength per hour. This leaded to an upper limit of 705 watt-hours

(a) No rain the next 6 hours.



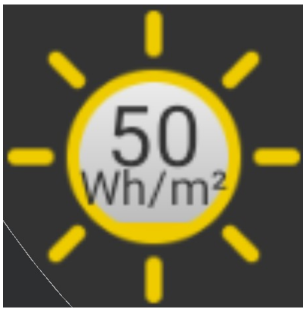
(b) Moderate Rain in 3 hours for 2 hours.



(c) Light rain in 2 hours, heavy rain in 5 hours.

Figure 4.8: Examples of the precipitation visualization.

per square meter. The exact sun strength value is displayed in the centre of the progress bar. To emphasize that this data representation is the sun strength, the progress bar is in the form of a sun. Figure 4.9 shows the data representation with different sun strength data.



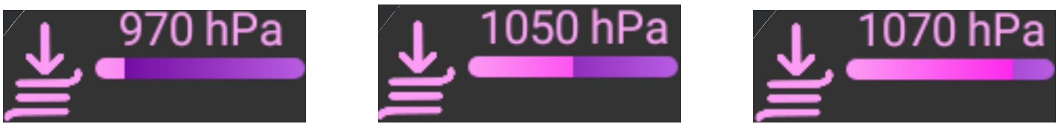
(a) Low sun strength.

(b) Moderate sun strength.

(c) High sun strength.

Figure 4.9: Examples of the sun strength visualization.

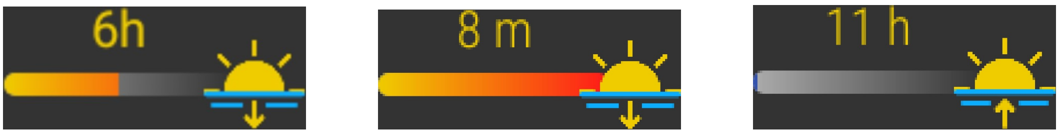
Air Pressure Visualization: The Air pressure is also shown on a progress bar on a scale from 950 to 1100 hPa. Because in Germany the air pressure varies between 950 and 1060 hPa at sea level [Weta], and Leinfelden-Echterdingen is at around 400 meters above sea level [Lei], we decided to round up to 1100 hPa. The exact air pressure value is displayed above the progress bar. In order to clarify, that this visualization represents the air pressure, we added an air pressure icon. Figure 4.10 shows different states of the air pressure representation.



(a) Low air pressure. **(b)** Moderate air pressure. **(c)** High air pressure.

Figure 4.10: Examples of the air pressure visualization.

Sunrise and Sunset Visualization: The sunrise and sunset visualization also consists of a progress bar with some additional text information. The progress bar shows, the progress towards the next event, sunrise or sunset. The text information additionally provides the number of hours till the next event occurs. If the remaining time falls below one hour, the remaining minutes are given, as shown in Figure 4.11 (b). Which event is going to happen next, is visualized with an icon, a sun with an arrow up for sunrise and a sun with an arrow down for the sunset.

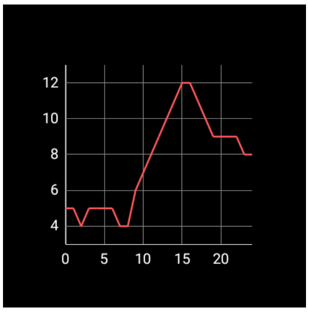


(a) Sunset in 6 hours. **(b)** Sunset in 8 minutes. **(c)** Sunrise in 11 hours.

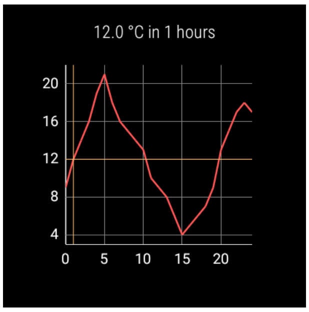
Figure 4.11: Examples of the sunrise and sunset visualization.

Design of the Detailed Temperature Screen

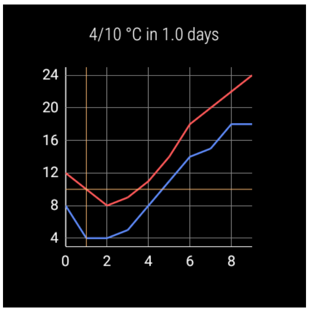
The detailed temperature screen contains information about the temperate forecast for the next hours and days. The screen can be accessed, with a short press on the temperature representation. Both data are represented with a line chart, and the y-axis of both charts shows the temperature degree in Celsius. On the x-axis of the hourly forecast, the next 24 hours are enumerated, while on the x-axis of the daily forecast, the next ten days are listed. We choose to display all ten days, for which a forecast is given. While the hourly forecast only consists of a single line for the estimated temperature, the daily forecast comprises two lines, a blue one for the minimum temperature of the day and a red one for the maximum temperature of the day. The reason for the different data is, that the API returns no average daily temperature, but only the minimum and maximum temperature for the next ten days. For both charts, it is possible to press on a point, and the precise temperature value is given as text above the chart, as Figure 4.12 shows. The point is then highlighted with a crosshair cursor, to give users visual feedback. If the user opens the detailed temperature screen, the hourly forecast is shown first, and if the user scrolls down, they get to the daily forecast.



(a) Hourly tempearture forecast.



(b) Temperature in 1 hour selected.



(c) Daily min- and max-temperature forecast.

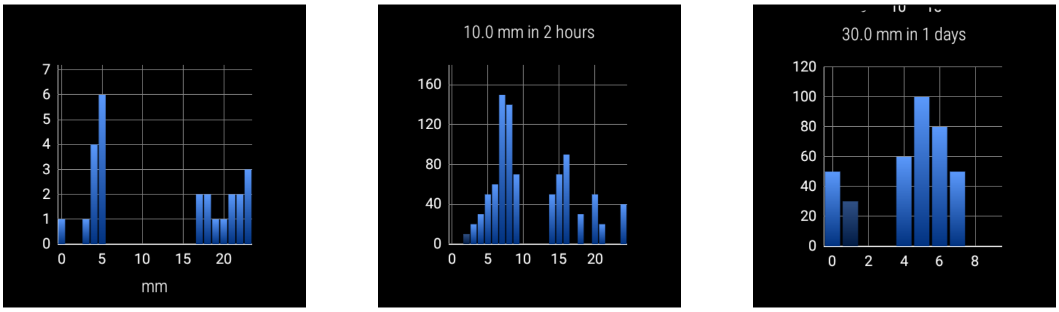
Figure 4.12: Examples of hourly and daily temperature visualization.

Design of the Detailed Precipitation Screen

Similar to the detailed temperature screen, the detailed precipitation view consists of an hourly and a daily forecast. The screen can also be accessed with a short press on the precipitation representation. Both representations on this screen are made with bar charts. The x-axis enumerates the next 24 hours for the hourly forecast, and respectively the next ten days for the daily forecast. Both charts can be selected, like the temperature charts, so that the exact amount of precipitation is given as text above them. In Figure 4.13 are examples of different precipitation forecasts shown.

4.2.3 Data Explanation Pop-ups

Because some data representations used in the application are not self explainable, and some weather data is not that common, we added a pop-up with explanations for every data representation. These pop-ups can be opened with a long press on the data representation from the main screen. Every pop-up consists of three pages, through which the user can swipe. Because we wanted to conduct different interaction methods for smartwatch applications, we also added a variant, in which the pages can



(a) Hourly precipitation forecast.

(b) Precipitation in 2 hours selected.

(c) Daily precipitation forecast.

Figure 4.13: Examples of the precipitation visualization.

be scrolled. We investigated, in the user study, which interaction technique participants would prefer.

The explanation for the data representations contains the name of the weather information, the unit, in which the information is given, and three images with some text, explaining different states of data. The Figure 4.14 shows the explanation of wind strength, with the respective Beaufort scale, so that the user can classify the current wind strength accordingly.

(a) Popup page one.

(b) Popup page two.

(c) Popup page three.

Figure 4.14: Explanation pop-up of wind strength.

Interaction differs for both pop-up variants. For the swipeable pop-up, users have two possible ways of navigating through the pages. First option would be, to swipe to the left, to iterate to the next page, or swipe to the right for going one page back. The other option is, to use the arrows on the bottom of the pop-up. The scrollable pop-up only offers the option to scroll horizontally. Users also have to do a swiping motion with their finger, but iterating through the pages is seamless. Therefore, it is possible, to stop the iteration between two pages, as shown in Figure 4.15.

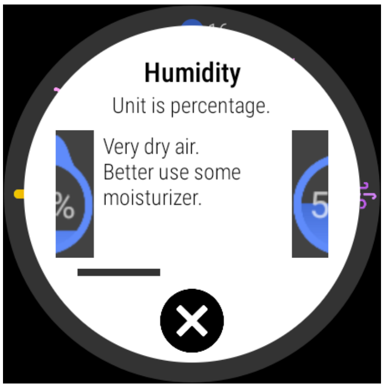


Figure 4.15: Explanation of humidity with scroll.

Figure 4.16 shows an overview of the different views and the navigation between these views.

4.3 Implementation

The following section describes the implementation of the weather application. In order to realize the draft of our weather application, we used the Android Studio IDE with Kotlin. To test the application, we used the Fossil Gen 5 smartwatch.

4.3.1 Retrieving Weather Data

In order to retrieve the latest weather data, a get-request is sent with the station ID of Stuttgart Leinfelden-Echterdingen. The request is sent with Retrofit 2 [squ], an HTTP-client for Android. When the response is received, the raw JSON gets converted into a weather data object with the GSON library [ope]. Afterwards, it is possible to access the single data entries. The weather data is first updated when the app is started. The request can be re-sent, when the user swipes down on the main screen of the application, or if the user presses the weather condition icon in the middle of the screen. Each time the request is resent, the screen gets refreshed, in order to show the updated weather data. When the user opens the detailed temperature or precipitation screens, another request is sent, to retrieve the forecast data.

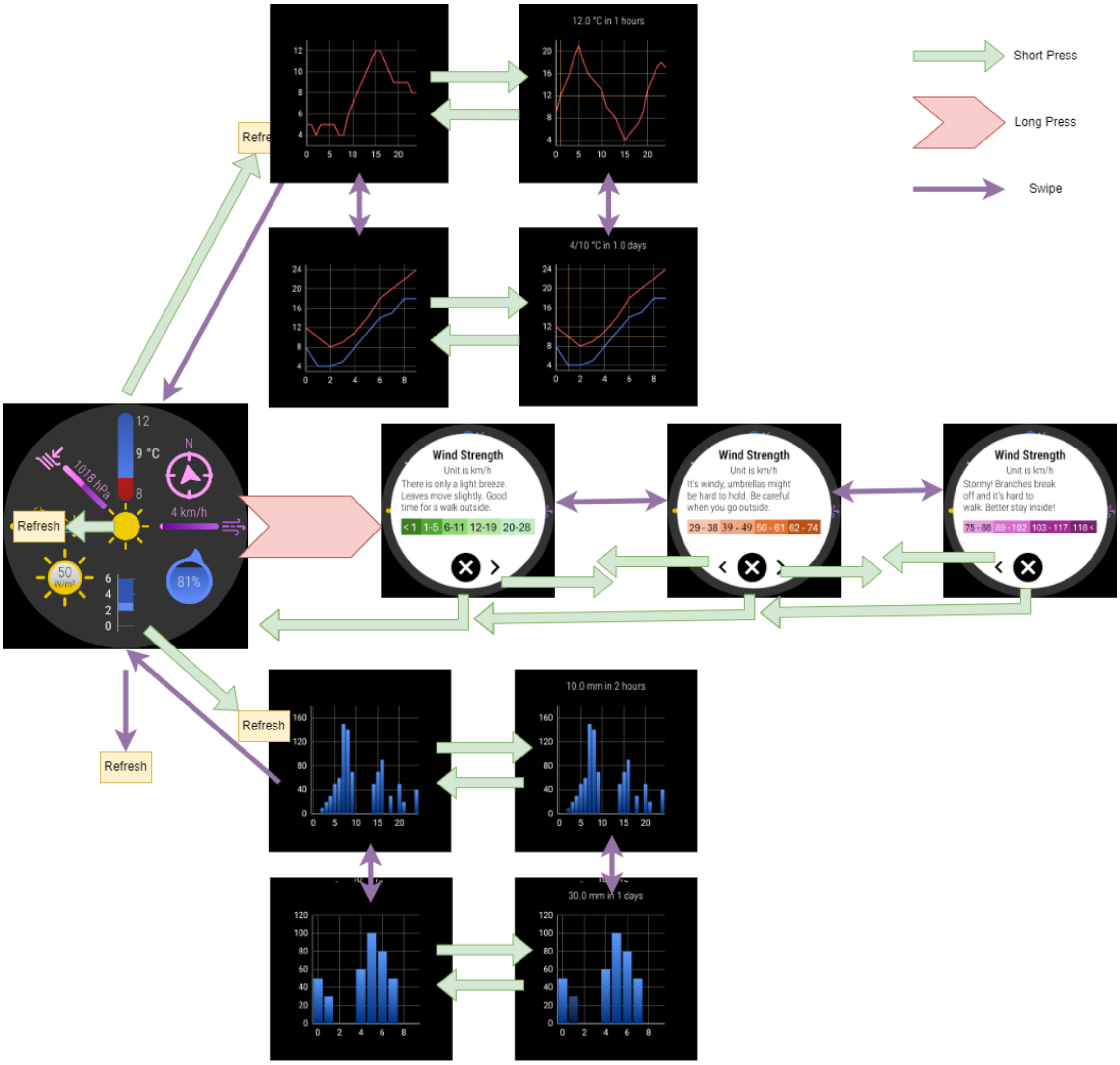


Figure 4.16: Navigation of *WeDaVis*.

4.3.2 Visualizations Implementation

There are two ways to design the layout of a Wear OS application with Kotlin. The old way is to use layout-files. A layout file is an XML-file, in which different android components can be declared. There are different types of layouts for different arrangements of components. For example, with a linear-layout, all components are placed vertically. A relative-layout allows more complex structures, where the position of a component can be defined in relation to another component, for example to the right of another component. A layout is connected to an Activity, a Kotlin class, where the behaviour and functionality of the layout is defined. There is also a new way to set layouts in Android. With Android Components, it is possible to declare components directly in the

Activity class. That way, components, and their functionality, are no longer separated and defining them is much easier. The disadvantage of using the new method is, that many components, especially from third parties, are not available yet. For example, currently only radial progress bars are available for Wear OS, which were not suitable for the *WeDaVis* weather application. That is the reason we decided to take the old way of using an XML-file. Layouts can be nested and can differ in detail. There are three main layouts in the weather application. One for the main screen and respectively one for the detailed view for the temperature and the precipitation.

To fully customize components, drawable-files are used. In a drawable, it is possible to adjust the shape and the colour of a component. For every progress bar, we created a drawable file. For the progress bars, as for the temperature representation on the main screen for example, we defined the shape as a rectangle with some round edges. For the sun strength and the humidity, we defined the shape as an oval. We also created two gradient colours for the progress bar to make it look more interesting.

All charts are made with the MPAndroidChart library [Jay]. We used a stacked bar chart for the precipitation representation on the main screen. It consists of only one bar, which is divided into equal sections. The difference of the sections is the colour, which refers to the rain amount. For the two temperature forecasts, we used line charts and for the precipitation forecasts, we used bar charts. The touch interaction is used, in order to select exact data points. Additional text is displayed above the chart to describe the exact values.

For the sunrise and sunset representation, the current time is compared to the next events, to determine, if the next event is a sunrise or a sunset. The icon image and the progress colour is set accordingly. With the system-time of the watch, the remaining time in minutes to the next event taking place is calculated. If the remaining time is longer than one hour, the time gets rounded to the next whole hour, but if it is less than one hour, the exact minutes are displayed.

The wind direction consists of two image views. The ground image shows a circle with the four direction marks. The second image contains the needle, which is rotated according to the degree, which is retrieved by the request.

To get the sun strength into a sun form and the humidity into a drop form, a picture of a sun and a drop is put above the circular progress bars.

4.3.3 Animation and Transition

We additionally added animations for every data representation, just to make the transition to updated weather data more smoothly. Animations last 700 milliseconds, as we found this time appropriate. For progress bars, the animation transforms the old value to the new one, when the displayed value changes. For the compass needle, it rotates the needle to the new direction, and for the weather condition, it blends in the new icon. The charts' animation draws the charts again with the new data.

4.3.4 Implementation of Pop-ups

Pop-ups are implemented as new views, which get displayed on top of the main screen. A cross-button allows closing the pop-up. The scroll-variant is made by simply declaring the explanation layout as scrollable. The swipe-variant uses the component View Pager. Two arrow buttons can turn the page forwards and backwards, as well as a swipe gesture.

5 Methodology of User Study

In the scope of this work, we conducted a user study, which is described in the following sections. The purpose of the study was to evaluate the *WeDaVis* application. First, we will explain the approach of the study, followed by the design, the stimuli and apparatus, and the participants. Afterwards, we describe the procedure and the pilot study. The results of the study will be described in Chapter 6.

5.1 Approach

The use of weather applications running on smartwatches can be evaluated from various aspects, including: the application design, performance, and user interaction. We decided to focus on the design and the interaction of the weather application.

5.1.1 Research Questions

The study contained three main parts, each to answer a specific research question.

Because designwise, the *WeDaVis* application differs a lot from other weather apps on the market right now, we wanted to compare how participants would rate the data visualizations in general but also in comparison to data representations of a common weather app. We define a weather application as common, if it has the typical data representations found in our analysis. So data represented majorly as text or text and icon. Therefore, the first research question we are going to answer is:

- How good would data visualizations be at providing insight on weather data compared to representations in other common applications?

To find a suitable app for comparison, we verified, which app, out of those we analysed at the beginning, shows the most information in common with our weather application. In order to do so, we noted all the information, every weather app provides. In total, there were 18 different kind of weather information. Then we compared the entries. The application which had the most information in common with *WeDaVis* and also the most information out of all the inspected apps, was *SimpleWeather*. *WeDaVis* and *SimpleWeather* show the same eleven out of 18 weather information, which are the temperature, minimum and maximum temperature, weather condition, wind direction, wind strength, precipitation amount, air pressure, humidity, sunrise and sunset, temperature forecast for next hours, and forecast for the next days with minimum and maximum temperature. As the majority of smartwatch weather applications, *SimpleWeather* uses text or text and icon as data representation, which provides a suitable contrast to the visualizations of *WeDaVis*.

For the interaction part, we wanted to evaluate, on the one hand, how intuitive and easy people can find and access the detailed temperature and precipitation information. On the other hand, we wanted to evaluate the interaction modalities with pop-ups, by inspecting, how people would rate the way to open them and inspect the displayed information. The two interaction modalities with the pop-ups included: 1) a continuous scroll and 2) a discrete swipe through the explanation pages. We are going to answer the two research questions:

- Are the interaction techniques used to open additional information (e.g. forecasts, and pop-ups), intuitive and easy to learn by our participants?
- Do participants prefer the scroll or the swipe interaction to read explanations on a smartwatch?

Because we are also interested in, how participants would rate the high amount of information on the main screen of *WeDaVis*, and what an appropriate number of data representations would be for them, we wanted participants to decide for themselves, how much information they would like to see on the main screen. The associated research question for this part of the study is:

- What is an appropriate number of data representations for participants, and what kind of data are participants most interested in?

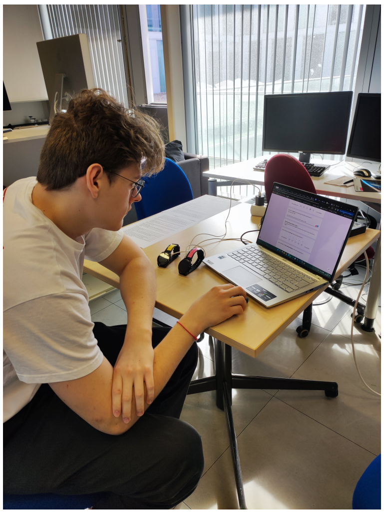
For every aspect of these research questions, we designed appropriate tasks and formulated questionnaires that participants had to answer.

5.2 Design of the Study

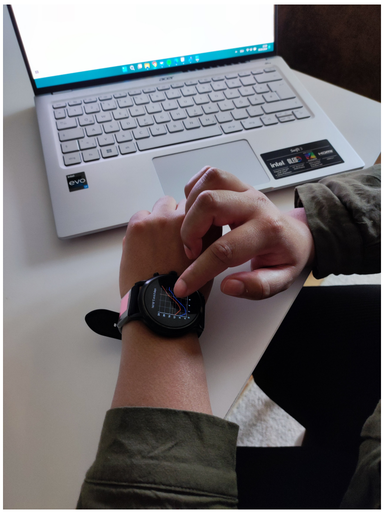
Participants were asked to follow a questionnaire with guided explanation on the different study tasks. The questionnaire was made with Google Forms and was divided into four parts. All questions were set as mandatory, so participants needed to answer them. That even applied for follow-up questions, which maybe did not need to be answered, because that way we could make sure, that participants read them, and thought about those questions properly. Questions, which require participants to provide a rating, were on a scale from one to five. One represented the worst rating and 5 would have been the best rating. Questions, where participants were asked about their preference also included an open-ended question about the reasons of their decision.

First, participants had to answer general questions about themselves, their interest in weather information and their experience with smartwatches. Besides generic questions, like age and gender, they were asked, how often and when they check weather information. Participants had to rate for common weather information, how interested they were in those. Lastly, they were asked about the devices and applications, on which they check the weather, and if they were familiar with smartwatches.

In the first part of the study, participants were asked to evaluate and compare a set of weather data representations that were simultaneously displayed on our app and the *SimpleWeather* app. The questions referred to the data representations themselves and not the overall design of the app. For weather data type, e.g. temperature and wind, they were asked to rate the look, the understandability, and the readability. Additionally, they were given the possibility to suggest ideas on how to improve the data representation. After rating the corresponding data representations of the two apps, for example the current temperature, they had to decide, which data representation they liked more.



(a) Participant comparing the two applications.



(b) Participant interacting with *WeDaVis*.

Figure 5.1: Participants during the study.

In the second part, participants were instructed to interact with the application. They firstly were asked to search for specific information and rate the accessibility and interaction styles. Afterwards, they had to compare the two interaction techniques with the pop-up information. Figure 5.1 shows participants during different tasks.

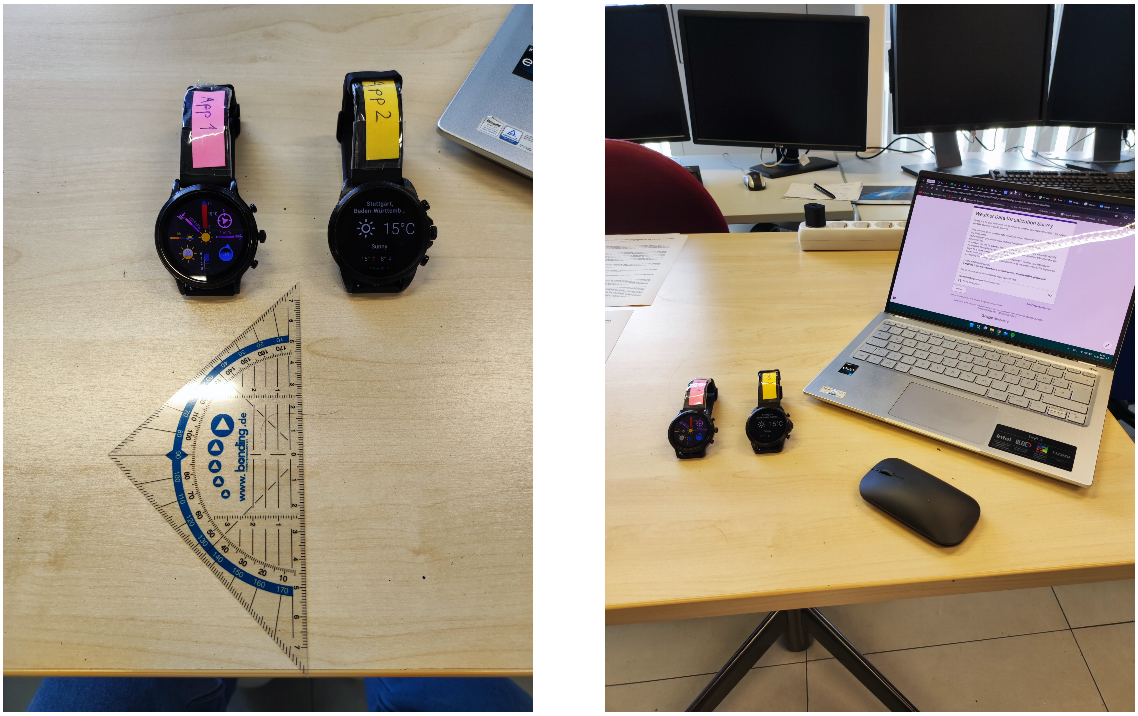
Lastly, the participants could assemble their own user interface by dragging data representations at a desired position. In order to do so, they were given a paper version of a smartwatch with paper versions of the visualizations of *WeDaVis*. They were intentionally instructed, that not all representations had to be used. The idea of this task was, to see, how many and which data representations they would choose to be displayed on the main screen. The *WeDaVis* app uses nine representations on the main screen. With this final task, we wanted to inspect, if people are confident with viewing high information load, or if they would prefer a simpler structure, to see less data at a glance.

5.3 Stimuli and Apparatus

For the study, we used two smartwatches. The *SimpleWeather* app was running on a Fossil Gen 6, and the *WeDaVis* app, was running on a Fossil Gen 5, both watches have a 44 millimetre wide watch case. To ensure stable values throughout the study, we took screenshots of the *SimpleWeather* application and copied the weather information on the *WeDaVis* app. The screenshots of *SimpleWeather* were shown through the app *FileTransfer*, where they could be shown in full screen mode, so that participants did not realize, that it was not the actual application running. In contrast, the corresponding data representations on *WeDaVis* were displayed directly through the app. To help participants recognize which watch runs which app, we labelled the watches with App 1 and App 2. To ensure the position of the watches causes no bias, we switched positions of both watches after every participant. The survey was opened in Google Chrome on an Acer Swift 3 laptop with Windows 11 installed. Participants had a mouse and the keyboard to input their answers. For the first part of the study, the watches were placed next to each other at a table with a 15 centimetre distance to the participants, as Figure 5.2 shows. We changed the display to the next data representation after participants finished the questions for the previous one, and participants were instructed to not interact with the applications.

5.3.1 Study Tasks

There were three study tasks, participants had to accomplish. We will describe them in the following sections.



(a) The two watches were placed at a distance of 15 cm from the table border, and with a distance of 2 cm from each other.

(b) Study setting: the two watches and the computer the participants used during the study.

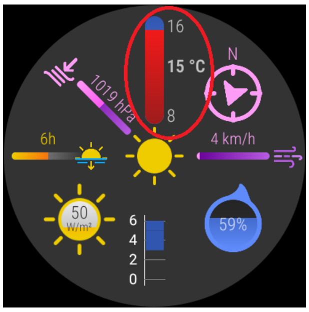
Figure 5.2: Arrangement of the user study.

Task 1: Evaluation and Comparison of Weather Data Representations

First, participants had to evaluate the current temperature representation together with the minimum and maximum temperature of the day. Figure 5.3 shows the corresponding data representation of both apps.

Next data representations were the temperature forecasts of the next hours and days. The hourly and daily temperature representation of *SimpleWeather* is made with a scrollable list. The comparison of these data representations is shown in Figure 5.4. *WeDaVis* uses the number of hours, relatively to the current time, and *SimpleWeather* uses the exact time, for example "16:00". Because of this difference, we asked participants which kind of labelling between the two time formats they prefer to see.

After inspecting the temperature representations, participants were asked to compare the data representations of wind information, precipitation amount, air pressure, humidity, then sunrise and sunset. While *WeDaVis* uses different kind of visualizations, to illustrate this information, *SimpleWeather* uses only text or the combination of text and icon for



(a) Current, min- and max- temperature on *WeDaVis*.

(b) Current, min- and max- temperature on *SimpleWeather*.

Figure 5.3: Comparison of current temperature representations.

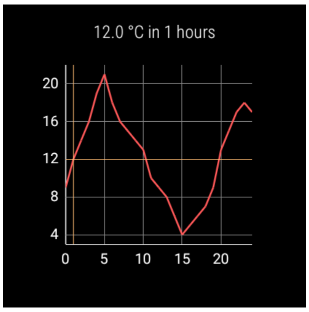
all of this data. It is worth mentioning that the icon of the wind representation of *SimpleWeather* also serves the purpose of indicating the wind direction. In Figure 5.5 the remaining data representations, which participants had to compare, are shown.

Task 2: Evaluation of Interaction Styles used on *WeDaVis*

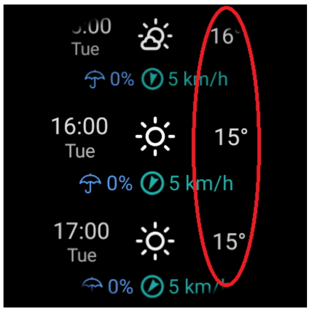
In the second part, participants had to interact with the detailed temperature and precipitation views and charts. They were given navigation tasks. For every task, they had to rate the readability, how accessible and easy to find the information was. To give them an authentic feeling of using the application, participants were now asked to wear the watch, and were reminded, that interaction with the watch is now necessary.

First, participants were asked to search for the temperature in six hours. They started on the main screen, then in order to open the detailed temperature screen, they had to press on the temperature representation. When the temperature forecast view for the next hours is visible, they had to tap on the chart, to select the exact temperature value, which then gets displayed above the line chart visualization. The selected data point is marked with a crosshair cursor. Otherwise, the value can be estimated, by reading it directly from the chart. If we noticed someone struggling and not pressing on the chart, we gave the clue, that they could interact with it.

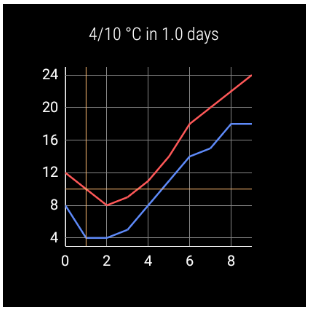
Next, they were asked for the exact minimum and maximum temperature in four days. In order to see the temperature forecast for the next days, they had to scroll down on the temperature forecast view, which they were already seeing. Again they had to press on the chart, to see the exact value.



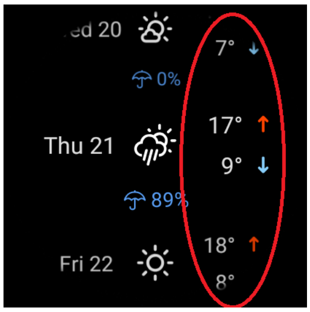
(a) A line chart showing the hourly temperature forecast on *WeDaVis*.



(b) Hourly temperature forecast on *SimpleWeather* represented with text.



(c) A line chart showing the daily temperature forecast on *WeDaVis*.



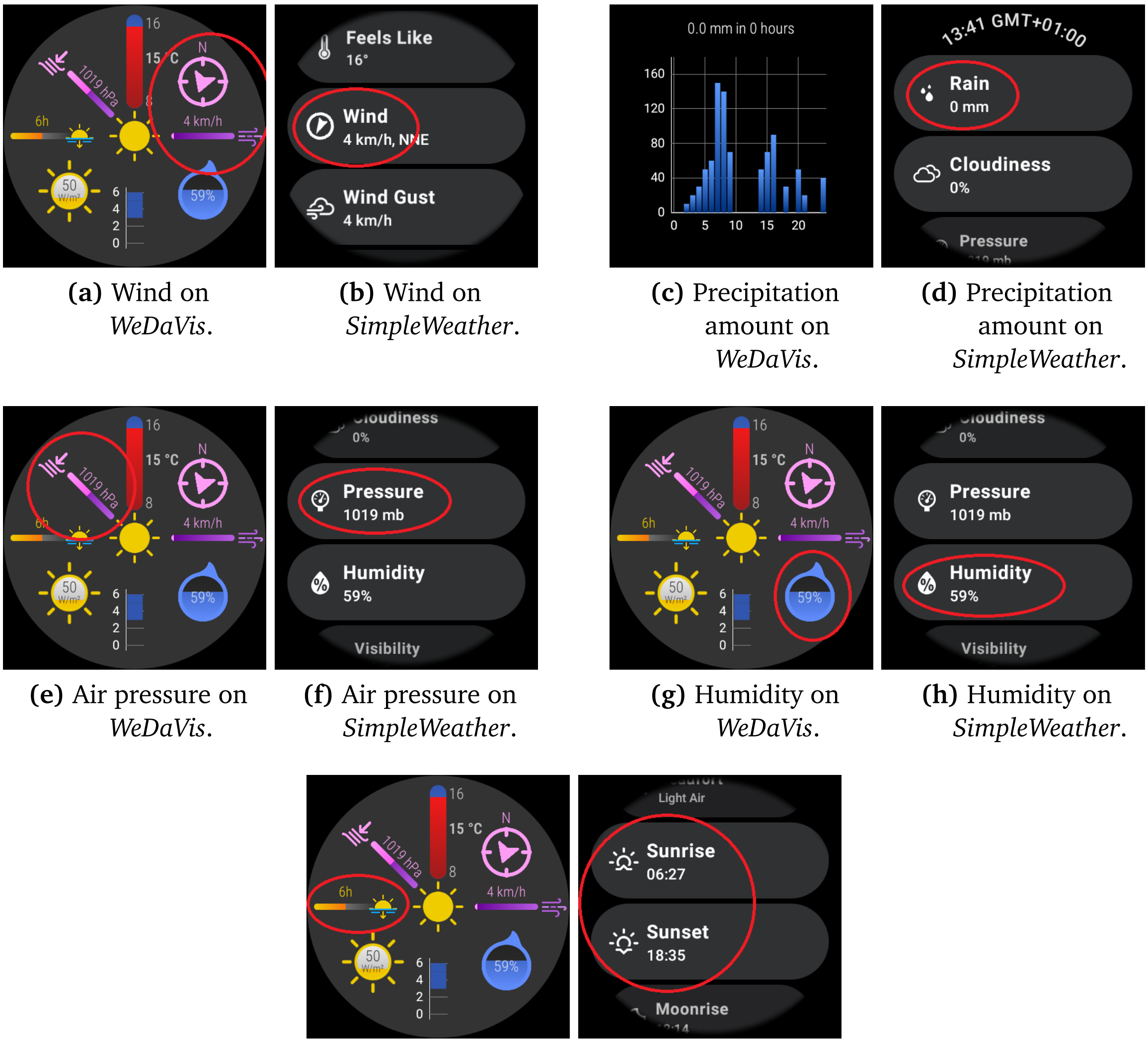
(d) Daily temperature forecast on *SimpleWeather* represented with a combination of text and icon.

Figure 5.4: Comparison of hourly and daily temperature forecasts views.

Afterwards, the same task was repeated with the detailed precipitation screen. Again, participants started on the main screen and had to open the precipitation forecast. Then they were asked about the precipitation in three hours and in five days.

To also get some feedback on information on the main screen, we included the task to look for the current sun strength.

At the end of the interaction part, participants were instructed to look at the explanation pop-ups for humidity and wind strength. They started on the main screen and had to long press on the respective data representations. They were instructed to read all the information given there, and again rate, how easy and intuitive the way of accessing the explanations is. Additionally, we wanted to figure out, if the design of the pop-up made it obvious, that the screen is scrollable. In the end, we wanted them to compare



(a) Wind on *WeDaVis*.

(b) Wind on *SimpleWeather*.

(c) Precipitation amount on *WeDaVis*.

(d) Precipitation amount on *SimpleWeather*.

(e) Air pressure on *WeDaVis*.

(f) Air pressure on *SimpleWeather*.

(g) Humidity on *WeDaVis*.

(h) Humidity on *SimpleWeather*.

(i) Sunrise and sunset on *WeDaVis*.

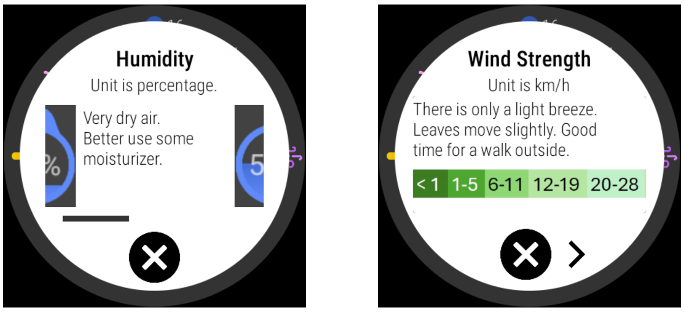
(j) Sunrise and sunset on *SimpleWeather*.

Figure 5.5: Comparison of data representations.

the scroll and the swipe pop-up, which are shown in Figure 5.6, and decide which one they liked more.

Task 3: Evaluation of Number of Data Representations on the Main Screen of *WeDaVis*

In part three, participants were handed a paper prototype of an empty watch screen and also cut out paper prototypes of the weather visualizations of *WeDaVis*, which can be seen in the Figure 5.7. They had to choose the weather data they wanted to display and



(a) Scrollable pop-up. **(b)** Swipeable pop-up.

Figure 5.6: Comparison of pop-up interaction.

where to place them on the smartwatch main screen. Then, once they finish customizing their design, I took a picture of the final result. We decided to make the paper prototype approximately 1.5 cm bigger than the actual watch, as shown in Figure 5.7, otherwise the data items would get too small and hard to grab and place.

Figure 5.7: Paper prototype in comparison to actual watch.

5.4 Participants

Since the study did not require special knowledge of weather data or experience with smartwatches, everyone, who was at least 18 years old, was allowed to participate in the study. Our participants were mainly (71 %) students of informatics at the university of Stuttgart. I also asked some friends and family members (from different backgrounds and age ranges) to take part in the study.

This search leaded to 17 participants in total. Male participants formed the majority with 77 %. More than half of the participants, 58 %, were between 18 and 25, 29 % were between 26 and 35, 6 % were between 46 and 55 and 6 % were older than 55. Most participants (41 %) never used a smartwatch before. 25 % used a smartwatch from time to time, and only 18 % of participants used one daily. 18 % of participants had used a smartwatch in the past, but did not use one any more.

5.5 Procedure

First, participants were informed about the privacy of their data and had to sign a consent form in order to participate. To ensure the anonymity of their personal data, participants were assigned a random number between 1 and 30. Afterwards, we introduced them to the topic and the process of the study. Then they started with the survey. We sat next to them to see their progress and to be able to set the display of the smartwatches to show the proper screen for each step. Participants were instructed, to wear the watch, which had our application installed, during part two of the study. When they reached the third part, they were handed over the paper prototype of the watch. In the end, participants were rewarded with some chocolate.

5.6 Pilot Study

We conducted a test run with one participant, to practice the procedure and to get some feedback on the questions. The pilot study took 52 minutes in total, which was longer than the initial 30 minutes we expected. Therefore, we increased the time, participants should expect the study to take, to 45 minutes. The feedback of the participant was positive for the majority of questions. Only two things within the first part of the study were criticized. Initially, we placed the watches on the table with a distance of 30 centimetres to the participant, but as it turned out, this distance was too far, to properly inspect the small data representations. This distance is also further away, than the distance to the watch, when users would look at it worn on the arm wrist. That is the reason, we shortened the distance of the watches to the participants to 15 centimetres. Secondly, the screens of the temperature forecasts of *WeDaVis* were misleading, because there was no data point selected. Therefore, it seemed, like the user has to estimate the actual temperature value from the y-axis. To avoid this impression, the screen, that was shown to participants, showed an already selected value on the chart, so participants can see the crosshair cursor on the chart and know that they can interact with it. Figure 4.12 shows an example of default selection.

6 Results

In this chapter, we will present and analyse the results from the user study. First, we will present the overall handling of participants with weather information, followed by the results of the first part of the study, which is the evaluation of the design of the data representations. Afterwards we will describe results of the interaction part, and in the end, we will present findings from the third part, in which participants could assemble their own weather application.

6.1 Handling of Weather Information

Participants had really diverse habits of checking the weather. As shown in Figure 6.1, most participants (29.4 %) check weather information a few times a week. Other frequent answers were a few times a month (24 %) or once a day (18 %). Only 12 % of participants check the weather a few times daily, while 12 % check the weather less than the mentioned options, and 6 % never check weather information.

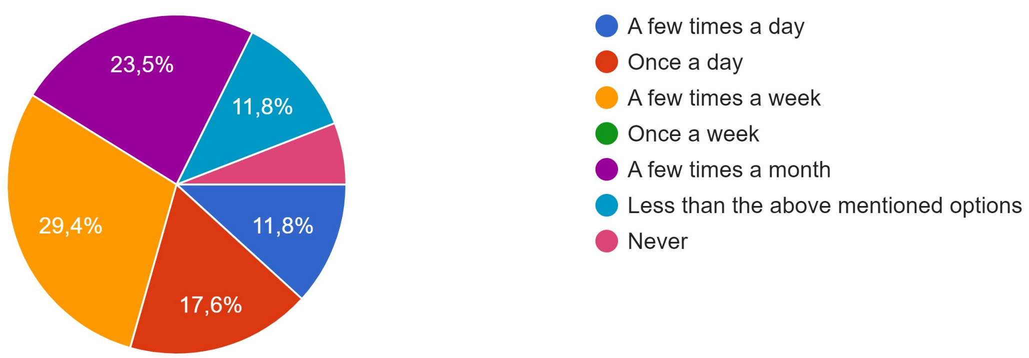


Figure 6.1: Participants answers to the question “How often do you check weather information?”.

Participants had to answer next, when they check weather information. Multiple answers were possible, and the answer was given as free-text. Most participants (53 %) check the weather before they go out. 41 % of participants stated, they check the weather in the morning. Other answers were at night (6 %) or that they never check the weather (6 %).

When it comes to weather data, participants are interested in, as shown in Figure 6.2, the opinions differed. The information participants had the most interest in, is temperature, 88 % agreed, that this is very interesting, and only 6 % voted for interested and 6 % for moderately interested. Similarly, when asked about the weather condition, most participants agreed, that they are very interested (59 %) or interested (24 %) in this kind of information. Also for precipitation, interest was fairly high, with 65 % of participants stating very high interest. Only 12 % of participants stated that they have either no or only slight interest in this kind of information. For cloud cover information, participants had nuanced opinions. While 47 % of entries were less than moderate interest, the same number of entries were more than moderate interest. When it comes to wind, humidity, sunrise and sunset, moonrise and moonset, UV index, air quality, sun strength and visibility, most participants showed either no or only slight interest. Lastly, a majority of 88 % of participants were not interested at all in air pressure information, and the remaining 12 % had only slight interest.

The next question was about the devices, participants used to check weather information. The question allowed multiple choices and adding new devices via free-text. Most participants (64 %) used their smartphone, to check the weather, while seven used a computer, and three used a smartwatch to check weather information. One participant used Alexa for weather information, where interaction is based on voice. When asked about the weather, the device gives an audible description of the weather, but has an additional screen to show information. A majority of 88 % of participants used the preinstalled weather application of their device. Among the weather apps of third parties mentioned, were SRF Meteo, My Weather App, and AccuWeather. Four participants also mentioned the Google search to check the weather.

6.2 Rating of Weather Data Representations

Participants did not favour a specific app, when it came to rating the data representations. Participants picked the *WeDaVis* representations four out of eight times as their favourite, as well as the *SimpleWeather* representations, so no application could predominate. Results are shown in Figure 6.3.

Ratings started from 1, as worst possible choice, and went up to 5, as best possible choice. In general, we classified ratings from 1-2 as bad, 2-3 as acceptable, 3-4 as good, and 4-5 as excellent.

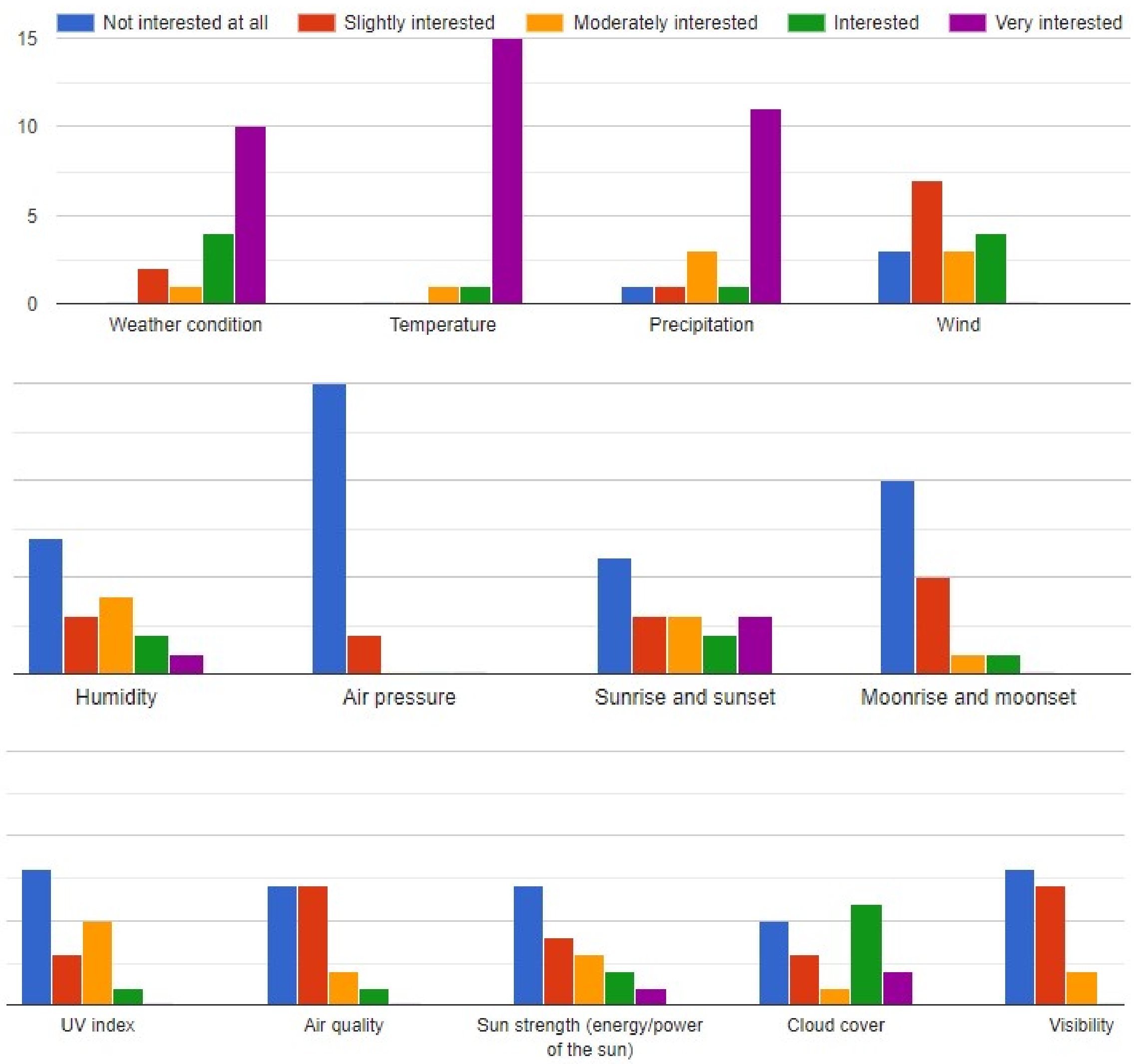


Figure 6.2: Participants' interest in weather information.

6.2.1 Current Temperature Ratings

For the current temperature representation of the *WeDaVis* app, participant's opinions really differed. *SimpleWeather* surpassed *WeDaVis* in the ratings of all three aspects. While ratings of *WeDaVis* were only slightly above 3, so considered as moderately good, ratings for *SimpleWeather* were all excellent, with values above 4. The look of *WeDaVis* got an average rating of 3.59. Participants rated understandability with an average of 3.24 and readability with an average of 3.59. When they were asked about improvement suggestions, five participants stated, they perceived the colour choice as irritating, because the red progress bar is at the bottom and the blue one is on top. Three participants wished, that the font size would be bigger. Unlike participants' opinion

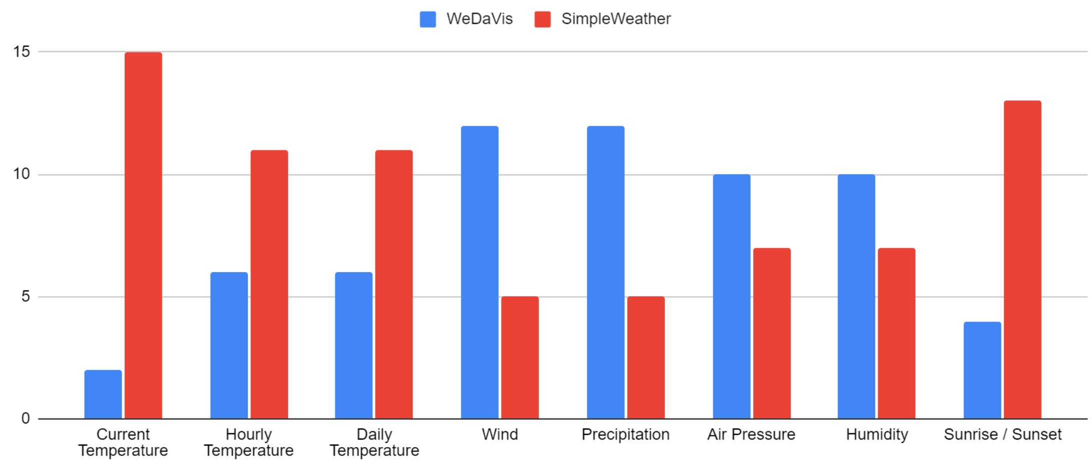
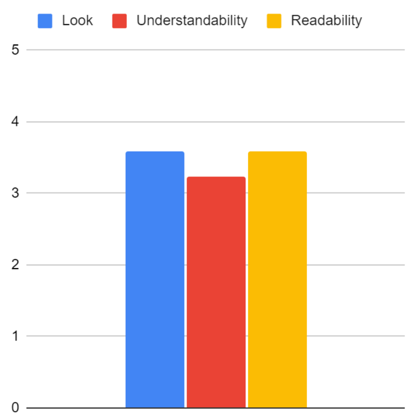
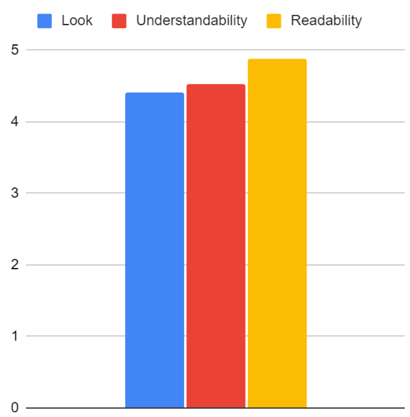


Figure 6.3: Visualization preferences of participants.

differed on the current temperature representation of *WeDaVis*, they mostly agreed to like the current temperature representation of *SimpleWeather*. Eleven participants rated the look of the representation with an average of 4.41. Similarly, they rated the understandability with an average of 4.53 and the readability with a 4.88. Three participants mentioned, that the arrows indicating minimum and maximum temperature may be misunderstood, and three participants criticized the design as “boring” and wished for more colour. Figure 6.4 shows the ratings of both apps in comparison. 88 % of participants preferred the design of the *SimpleWeather* app to the *WeDaVis* app, because the design seemed simpler.



(a) Ratings of *WeDaVis*.

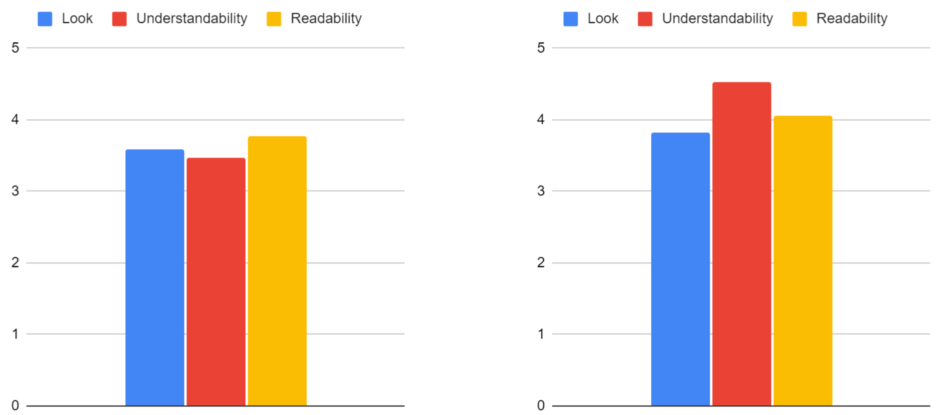


(b) Ratings of *SimpleWeather*.

Figure 6.4: Average ratings of current temperature representations.

6.2.2 Hourly Temperature Forecast Ratings

The hourly temperature forecast ratings for look and readability did only slightly differ, but the understandability of *SimpleWeather* stood out with an excellent rating. Similarly to the current temperature representation, the hourly temperature representation got ratings between 3 and 4. Look got an average rating of 3.59, understandability 3.47 and readability 3.76. The most frequent point of criticism was, that the axes were not labelled. This is a common problem in the field of micro visualizations, as there is often times not enough space for labels, and visualizations need explanations first. When it came to the hourly temperature forecast on the *SimpleWeather* app, participants had a more unified opinion on the representation. Look was rated with an average of 3.82, understandability with 4.53, and readability with 4.06. Five participants criticized, that there is too much detailed information on the screen, and that they want a clearer overview. The comparison of the ratings are shown in Figure 6.5. A total of 65 % preferred the hourly temperature forecast of *SimpleWeather*, primarily because of simplicity and clarity. More than half of participants (53 %) prefer the hourly forecast given in the exact time, instead of the number of hours. While 41 % liked both kind of labels, only 6 % preferred the number of hours. As one participant argued, they would be concerned about the actuality of data, when only the number of hours are given, as there is no way of knowing which hour the first one is.

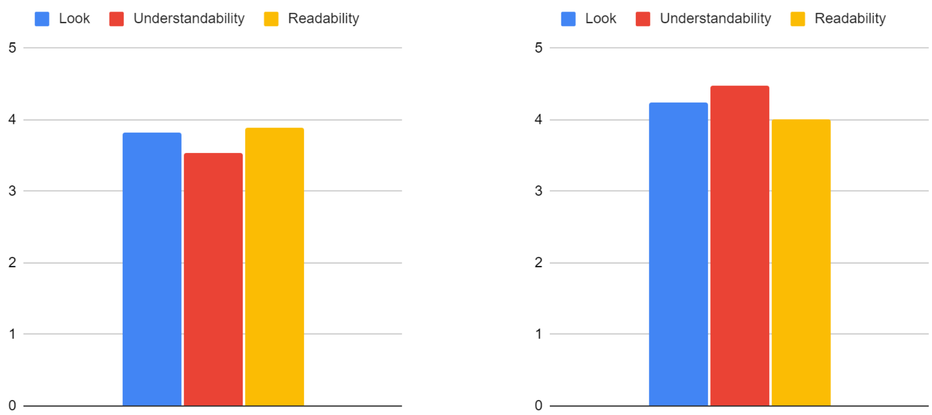


(a) Ratings of *WeDaVis*. **(b)** Ratings of *SimpleWeather*.

Figure 6.5: Average ratings of hourly temperature representations.

6.2.3 Daily Temperature Forecast Ratings

The look and readability ratings of the daily temperature forecast of both apps achieved ratings alike to the hourly temperature forecast. The look of the daily temperature forecast was rated slightly better than the hourly forecast of *WeDaVis*, with an average rating of 3.82. Understandability got an average rating of 3.53 and readability a rating of 3.88. Improvement suggestions included mostly the missing labels of the axes, but also to explain further, what the red and blue line means. Similarly to the hourly temperature forecast of *SimpleWeather*, the look of the daily temperature forecast was clearly rated positive with an average of 4.24. It is noticeable that the biggest difference to the *WeDaVis* representation was the understandability. While understandability was rated as the worst of the three aspects on *WeDaVis*, understandability was rated best, with an average of 4.47 on *SimpleWeather*. Readability got a rating of 4. Twelve participants seemed to be satisfied with the design and had no improvement suggestions. Results are shown in Figure 6.6. With 65 %, the majority of participants preferred the daily temperature forecast of *SimpleWeather* to the forecast of *WeDaVis*. Participants mentioned the simplicity of the representation and selection of a day as reasons for their decision. Similarly to the hourly forecast, a majority of 82 % wanted to see the daily forecast with the exact date, instead of the number of days. No participant selected the number of days as preference.

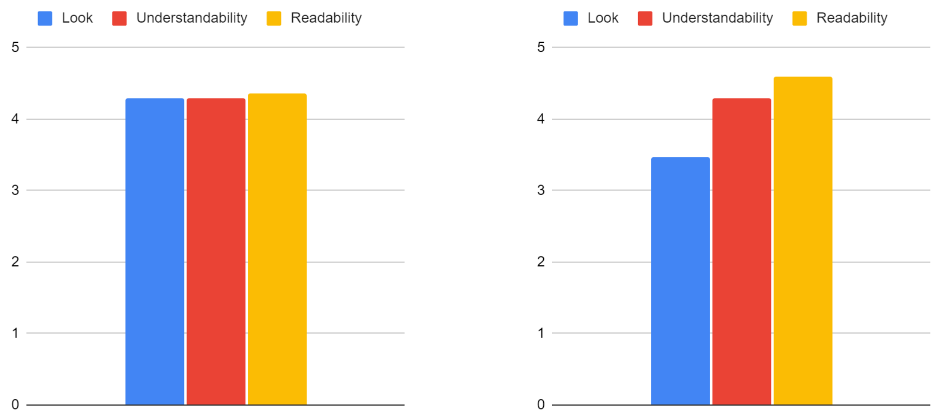


(a) Ratings of *WeDaVis*. **(b)** Ratings of *SimpleWeather*.

Figure 6.6: Average ratings of daily temperature representations.

6.2.4 Wind Ratings

In general, the wind representation of *WeDaVis* achieved excellent ratings, above 4 in all aspects. While this is also the case for understandability and readability on *SimpleWeather*, the look of the wind representation was only considered as good by participants. Participants rated the wind representation of *WeDaVis* with an average of 4.29. The understandability reached the same average rating as the look. Readability was rated slightly better, with an average of 4.35. Three participants suggested changing the arrow of the wind direction visualization, because it is not clear, in which direction it points. Other suggestions were, to make the representation simpler and clearer or explain more about the representation. The biggest difference of the wind representation on *SimpleWeather* to the wind representation of *WeDaVis* was the look. Participants rated the look with an average of 3.47. With 4.29, understandability of wind on *SimpleWeather* got rated the same as on *WeDaVis*. Readability-wise, participants agreed, that the representation is very readable, with 4.59. Two participants suggested, to add some illustration, or scale, because wind strength itself is not really meaningful. Other suggestions were to mark north on the compass, to make the direction more clear, or that the visualization is boring and should have more colour. Average ratings are shown in Figure 6.7. Most of the participants (71 %) preferred the wind visualization of *WeDaVis*, reasons were a more intuitive design, the new approach of visualization and that the bar gives an idea of the actual wind strength.

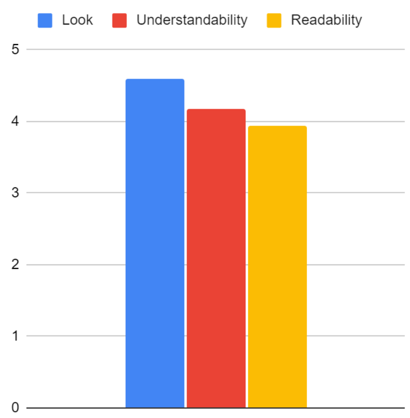


(a) Ratings of *WeDaVis*. **(b)** Ratings of *SimpleWeather*.

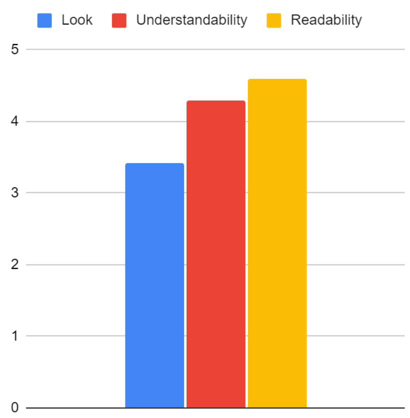
Figure 6.7: Average ratings of wind representations.

6.2.5 Precipitation Ratings

The overall ratings of the precipitation visualization of *WeDaVis* were good, while ratings for the precipitation representations of *SimpleWeather* were similar to the wind representations of *SimpleWeather*. Participants rated the look of the precipitation of *WeDaVis* with a 4.59. For understandability, the average rating was 4.18. Readability was worst rated, with an average of 3.94. Again, seven participants criticized the missing labels for the axes, while other suggestions were to highlight the current hour. Ratings for *SimpleWeather* were the other way around. The look was rated as the worst, with an average of 3.41, understandability had a rating of 4.29, and readability had a rating of 4.59. Points of criticism were that the *SimpleWeather* app provided only the current hour and that the design seemed to be boring. Figure 6.8 shows the ratings of both apps. As for the wind representation, 71 % chose the precipitation representation of *WeDaVis*, because they liked the bar chart visualization showing the amount of rain and because it has a better design. It is worth mentioning, that 18 % preferred the rain to be given in number of hours, starting from current time, while a big majority of 77 % still prefer the exact time, for example 15:00.



(a) Ratings of *WeDaVis*.

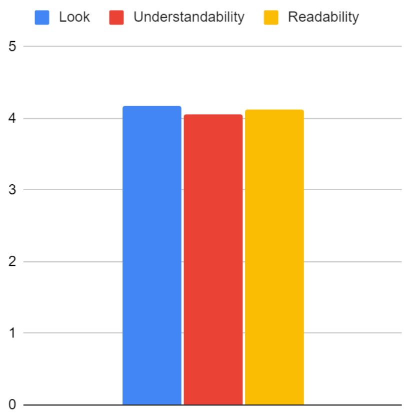


(b) Ratings of *SimpleWeather*.

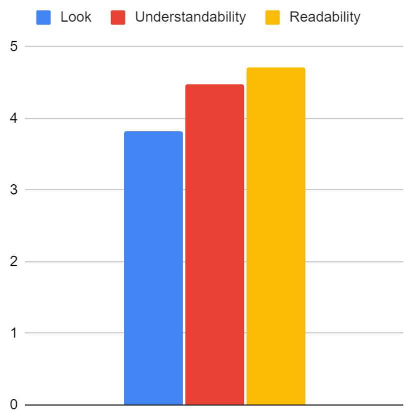
Figure 6.8: Average ratings of precipitation representations.

6.2.6 Air Pressure Ratings

Both ratings of the air pressure representation resemble the ratings of the corresponding wind representation. The look, understandability, and readability of the air pressure visualization of *WeDaVis* achieved ratings roughly above 4. Look was rated with a 4.18 readability got a 4.12. Understandability got a rating of 4.06. The biggest point of criticism was, that four participants did not like the inclination of the progress bar. While the look of the air pressure representation of *SimpleWeather* was rated worse than the look of the *WeDaVis* visualization (3.82), understandability and readability were rated better, with understandability having an average rating of 4.47 and readability having a rating of 4.71. While most people were satisfied with the design, two participants mentioned, that they wished for a scale, in order to classify the air pressure to high or low. Ratings are shown in Figure 6.9. In terms of preference, a majority of 59 % of participants selected the *WeDaVis* visualization, and 41 % picked the *SimpleWeather* design. While most people argued for *WeDaVis*, that the visualization helps to understand the value, participants who chose *SimpleWeather* preferred the simplicity.



(a) Ratings of *WeDaVis*.

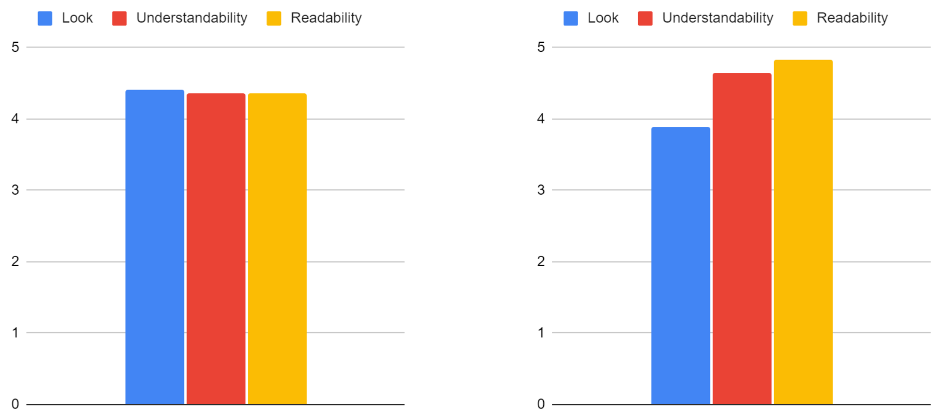


(b) Ratings of *SimpleWeather*.

Figure 6.9: Average ratings of air pressure representations.

6.2.7 Humidity Ratings

Again, both ratings had a similar structure to the wind representation ratings. The humidity visualization on *WeDaVis* was rated similarly in all three aspects too. Participants gave positive ratings of around 4.4. Five participants were confused with the drop, because a drop is more likely to be associated with rain. Two participants criticized the low contrast of the blue with the white text. The ratings of humidity in the *SimpleWeather* app also resembles the air pressure ratings, with look being rated the lowest (3.88), and readability performing best (4.82). Figure 6.10 shows the exact results. Participants complained about the design and the lack of colour. A majority of 59 % picked the design of *WeDaVis*, because they preferred the visualizing design. Participants that preferred the *SimpleWeather* design, stated, they like the simplicity and clearness more.



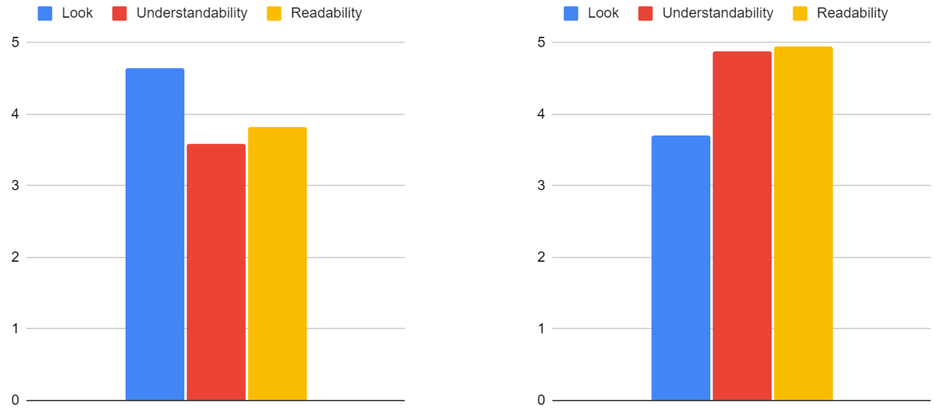
(a) Ratings of *WeDaVis*.

(b) Ratings of *SimpleWeather*.

Figure 6.10: Average ratings of humidity representations.

6.2.8 Sunrise and Sunset Ratings

The last visualizations, participants had to rate, were the sunrise and sunset representations of both apps. In general, the understandability and readability of the *WeDaVis* representation were good, while the rating of look, which was excellent, stood out. For *SimpleWeather*, ratings were the other way around. Sunrise and sunset visualizations on *WeDaVis* could convince participants lookwise (4.65). However, understandability and readability did not perform that well, with average ratings of 3.59 for understandability and 3.82 for readability. Four participants mentioned, they are more interested in the exact time of the events, than the remaining hours. Two participants criticized the understandability. The visualization of *SimpleWeather* was rated the other way around. While look was rated as the worst out of the three aspects, with an average of 3.71, understandability and readability were rated excellent, with 4.89 for understandability and 4.94 for readability, which was the best rating in the study. Participants wished, that the design would incorporate the current time more. Additionally, the lack of colour and the boring design was criticized. Rating results are shown in Figure 6.11 A majority of 76 % chose the design of *SimpleWeather*, with most participants arguing, that the exact time is given, instead of the remaining hours. It is noticeable, that the participants, who were interested in the exact time, were also the ones, which had a general higher interest in sunrise and sunset data.



(a) Ratings of *WeDaVis*. **(b)** Ratings of *SimpleWeather*.

Figure 6.11: Average ratings of sunrise and sunset representations.

6.3 Results of Interaction Techniques

In this section, we will present results from part two of the user study, in which interaction techniques for navigation and finding information were inspected.

6.3.1 Results of Navigation through the different Views and Reading Information

First, we will have a look at the navigation through the different views of *WeDaVis*. Participants should have searched for specific information in our application, and rate the interaction necessary to find this information.

Ratings of Navigation through the different Screens

In general, participants could figure out, how to open the detailed temperature forecast and precipitation forecast views.

They had to rate the navigation and interaction with the detailed temperature view first. All participants managed on their own, to open the second temperature screen. But five participants needed help or did not realize, that they could also interact with the chart itself. Readability was rated good, with an average rating of 4.29. Six participants mentioned, that selecting the exact time was difficult. Four participants mentioned problems with finding the information, because they had to interact with the chart, to get the exact temperature.

Readability for the daily temperature was better than for the hourly temperature, with an average of 4.47. Only one participant mentioned problems accessing the information, especially getting the exact date. Three participants had problems finding the information, because they did not figure out, they could scroll down for the daily temperature.

When asked about the hourly precipitation forecast, participants rated readability with an excellent rating of 4.47. Six participants mentioned problems, when accessing the information, because it is hard to press on the exact position on the screen. Three participants addressed problems of finding the information, because they were unsure about the location of the precipitation information on the main screen.

The ratings of the readability for the daily precipitation were even better than the ratings of readability for the hourly precipitation forecast, with an average rating of 4.71. Unlike before, the only problem with accessing the information mentioned was, that it was not obvious that the screen is scrollable. Also, no problem with finding the information were reported.

The readability of the sun strength was rated very good too, with an average rating of 4.35. The only problem two participants mentioned, when accessing the information, was, that they thought they should click on the sun, instead of directly reading the information. One participant mentioned problems finding the information, but did not explain, what the difficulty was. All results are shown in Figure 6.12.

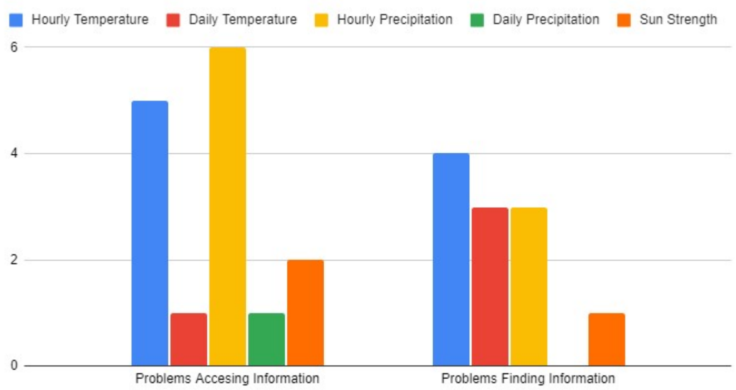


Figure 6.12: Results of problems faced when interacting with data representations.

Results of reading Information on different Screens

The majority of participants had no problem when reading the exact information, that we asked for.

The first information, we asked for, was the hourly temperature in six hours. A majority of participants (88 %) entered the correct amount of 18 °C, but 12 % entered 19 °C.

Almost all participants (94 %) found the correct minimum and maximum temperature, but 6 % entered 10 °C instead of 11 °C maximum temperature.

As for the minimum and maximum temperature, 94 % of participants also entered the correct precipitation amount in 3 hours. Only one participant entered 15 mm instead of 20 mm.

The daily precipitation forecast achieved the best results, with 100 % of participants entering the correct amount for the precipitation in five days.

When asked about sun strength information on the main screen, only 6 % entered the wrong value of 90 instead of 50. Results are shown in Figure 6.13.

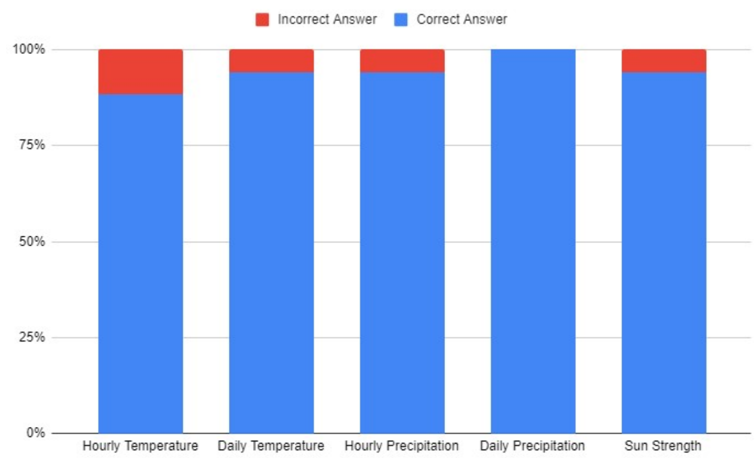


Figure 6.13: Results of finding and reading specific information on the *WeDaVis* application.

6.3.2 Results of Navigation with the Explanation Pop-Ups

The majority of participants figured out, how to open the explanation pop-ups, but 24 % of participants needed help. Only 6 % mentioned, that the interaction technique to open the information was not obvious. For the scrollable pop-ups, a majority of

77 % stated, that the layout did not indicate, that it is scrollable. 53 % participants suggested, that the scrollbar should not disappear. Another idea was, to highlight pressable elements, with, for example, an ⓘ-icon. Only 12 % of participants mentioned problems, when opening the swipeable type of pop-up. One participant explained, they needed three tries, even when they did the right interaction. One participant faced problems, because they accidentally opened the explanation for wind direction first. Unlike for the scrollable pop-up, 82 % stated, it was clear, that the swipeable pop-up contains more information. Results of the interaction with pop-ups are shown in Figure 6.14. Suggestions for improvement included, that the explanation should be in separate views for every weather data, or that the fonts should be bigger. A majority of 71 % preferred the swipeable pop-up, reasons included they could not be stuck in between two pages, and the use was easier.

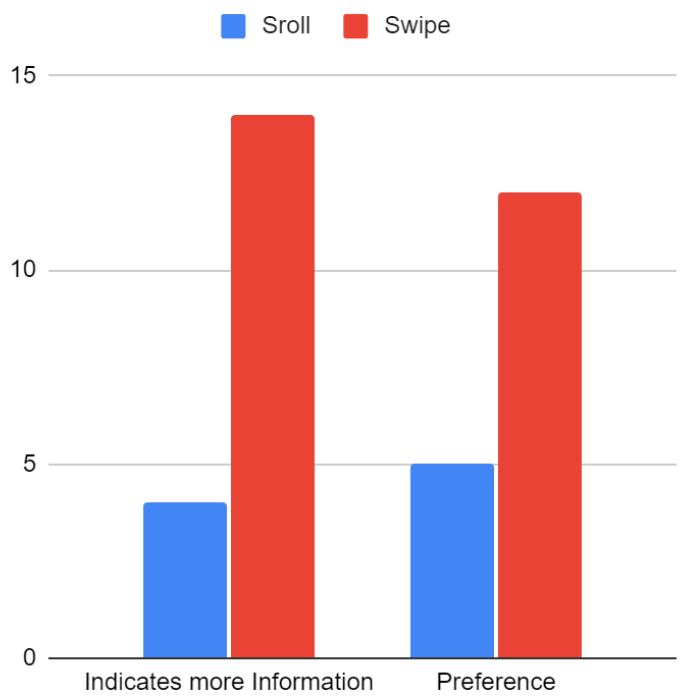


Figure 6.14: Results of interaction with pop-ups.

6.4 Designs of User Interfaces

Participants had different ideas of "good" user interfaces for weather applications. The average number of data items, participants placed on the main screen, was 5.82. Three participants used all nine data representations available, while one participant only picked three elements to be shown on the main screen. Examples of user interface designs are presented in Figure 6.15.

(a) Design with least number of chosen items.

(b) Example of design with an average number of items.

(c) Example of design with the most number of items.

Figure 6.15: Three examples of user interfaces by participants.

There are some trends identifiable, when inspecting the data types, participants selected. All participants selected the temperature to be shown on the main screen. Only one participant did not want to have the weather condition on the main screen, as they seemed not that interested in that kind of information. Both, precipitation and wind strength, were picked by 14 participants. Sunrise and sunset followed, with eleven appearances. Wind direction and humidity were picked by ten participants. On the other hand, only five participants selected the sun strength. Lastly, three participants selected the air pressure for the main screen. It is also noticeable, that all three participants, that selected the air pressure, selected all the other information available too. Exact results are shown in Figure 6.16.

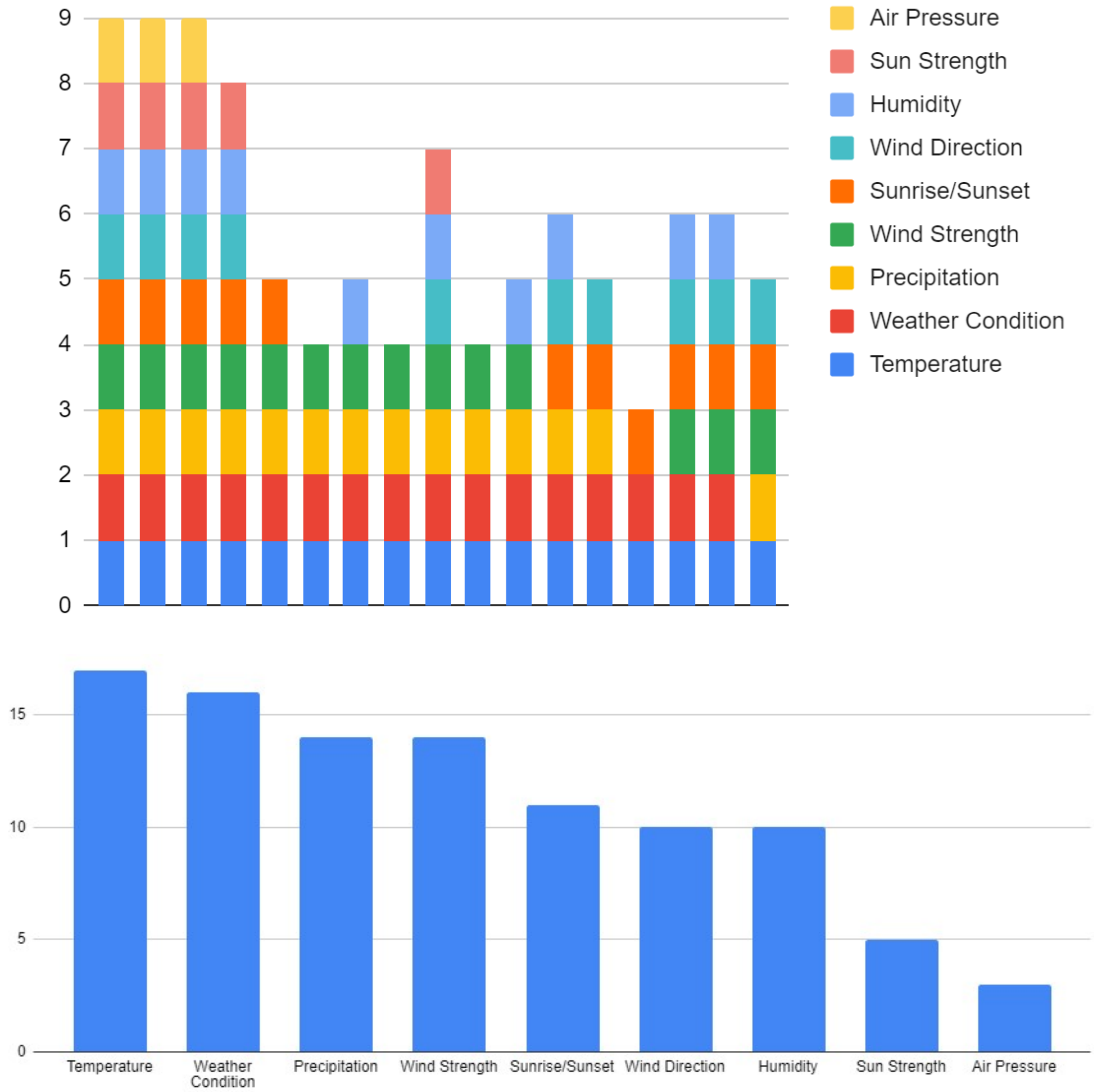


Figure 6.16: Data information participants picked for the main screen.

7 Discussion

In this section, we will discuss and interpret the results of the user study. We start with analysing the outcome of the first part of the study, followed by the interaction results and the designs of the user interfaces. Lastly, we discuss possible improvements on the *WeDaVis* app, in order to respond to the suggestions provided by participants.

7.1 Analysis of Data Representation Ratings

The results of the first part of the study do not indicate a trend towards the use of visualizations than other data representations (e.g., text, icons, or combination of text and icons). Instead, the results imply, that depending on the type of weather information, participants preferred different kinds of visualizations. For current temperature, the temperature forecasts, and the sunrise and sunset, participants preferred the data representations of *SimpleWeather*, consisting of text and text in combination with icon. For Wind, precipitation, air pressure and humidity, participants liked the visualizations of *WeDaVis* more.

7.1.1 Reasons for Participants' Preferences

There are different aspects of the data representations, that influenced the preferences of participants. Depending on the kind of information, the kind of design, the understandability, and the readability, participants preferred different data representations.

Preferences based on the Look

Decisions, why participants preferred a specific data representation, were mostly made because of the look. The majority of participants stated preferences in the look, instead of other aspects, like understandability or readability. There were different preferences in the look. Some participants liked the simplicity and clarity of the data representations of Simple Weather, other participants stated, they found them boring and colours are missing.

Preference for Visualization rather than Text and Icon: Many participants stated, they preferred the visualizations of *WeDaVis*, because the text and icon representations of *SimpleWeather* were boring. For more unfamiliar weather data, as the wind strength, the air pressure or the precipitation amount, participants stated, they liked the visualizations of *WeDaVis*, because they do not simply show the values but add information in order to understand the values.

Preference for Text and Icon rather than Visualization: The most common reason for participants, to like the text and icon representations of *SimpleWeather*, were the simplicity and clarity. Participants agreed the most, that they liked the simpler temperature representation of *SimpleWeather* more. A reason could be, that for the current temperature representation, the progress bar does not add as much helpful information, as it does for other weather data, for instance the wind data. Most participants stated, that they preferred the textual representations of *SimpleWeather*, because they found the information was clearer than the progress bar representation, and it does not add too much information. Therefore, it is faster to comprehend. So there is a tradeoff of additional information and understandability. For some data, for example the wind, the additional information of the min- and max- range is helpful, because it helps participants to understand the information, for other data, the additional information may seem overwhelming.

Additionally, the difficulty of interpretation differs for the data representations. For example, the temperature and sunrise or sunset representations are more easily interpretable than the others. The familiarity of the participants with reading and interpreting some weather data, for example temperature, compared to others that they are less used to, for example air pressure, had influenced their ratings. So in order to make data more interpretable, that participants are unfamiliar with, it helps, to show them in a min- and max- range. As participant 18 said, “I like the progress bar for wind strength, because now I understand, that 4 km/h is not much”. Similar comments came for air pressure and humidity. A reason, why the visualizations of *WeDaVis* seemed more unclear, than the representations of *SimpleWeather*, could also be, that the textual representations are more common. If participants had some time, to get used to the visualizations of *WeDaVis*, maybe participants would rate them more understandable.

Preferences based on Understandability and Readability The look is not the only aspect, users took into account. For example, 77 % of participants did prefer the sunrise and sunset representation of *SimpleWeather*, even though the look of the *WeDaVis* representation was rated nearly one point higher than the *SimpleWeather* one. For this data representation, the readability, and understandability of the *SimpleWeather* representation was rated clearly higher than the readability, and understandability of the *WeDaVis* representation. Participants emphasized the importance of having the time of sunrise and sunset, which also could have influenced the preference.

For weather data, which is not that common and easy to interpret, the visualizations of *WeDaVis* did provide good insights on the weather information. However, participants answers did not indicate a general trend towards more visualizing data representations. Instead, the type of data representation, textual or visual, should be decided based on the weather data.

7.2 Analysis of Interaction Techniques Ratings

In this section, we will discuss the results from part two of the study, which was about navigating and interacting with *WeDaVis*.

7.2.1 Analysis of Navigation through different Screens

We will first analyse the results of the tasks for navigating through our app and reading specific information.

Analysis of Navigation through different Views

The results for interaction with the data representations show differences between the hourly and the daily forecasts. Clearly, more participants had problems selecting and interacting with the data in the hourly temperature and precipitation charts, than in the daily charts. The reason could be the differences between data points shown in each chart. While the hourly forecasts include 25 data points, for the next 24 hours, the daily forecasts only depict the next ten days. So naturally, the points and bars are better selectable for the daily charts, than for the hourly charts. This is also supported by participants reporting more difficulties when selecting data points of the hourly forecasts. Another reason could be a learning process, because the task to select a value in the hourly forecasts always came before the task of selecting a value in the daily forecasts. In general, participants had fewer problems finding the information, than accessing it. Again, there is a difference between the hourly and the daily forecasts. Participants reported fewer problems finding the information of daily charts, than hourly charts, which may be traced back, to a learning process, while using the app. A participant stated, for example, that the accessing of daily precipitation matches the interactions they did before with the daily temperature. This would explain the gap between participants facing difficulties with finding the daily temperature forecast and finding the daily precipitation forecast. Because when it came to the daily precipitation, participants remembered, that they probably have to scroll down, as for the daily temperature. The problem participants faced, when they had to search for the daily forecasts, were mainly caused by the scrollbar, which disappeared after a few seconds, so that they did not realize, that the screen is scrollable. When it came to the problems of accessing information on the main screen, participants explained, that they were influenced by the previous tasks to interact and press on elements, even though this was not necessary for this task. Participants could have read the value directly from the main screen.

Analysis of Readability of Information

In general, only very few participants entered the wrong values, which infers a good readability.

For the hourly temperature task, the two participants, which entered 19 °C instead of 18 °C, probably did not figure out, that they were able to select the exact value. So they probably did estimate the value from the chart.

When it came to the daily temperature task, one of the participants, that entered the wrong value on the hourly task, also entered the wrong maximum temperature of 10 °C, instead of the correct 11 °C for the daily task. So again, the problem was probably, that this participant did not correctly estimate the value from the chart.

Also for the hourly precipitation, it was the same participant, which entered 15 mm instead of the correct 20 mm.

The participant, who entered 90 Wh/m^2 instead of the correct 50 Wh/m^2, did probably open the explanation pop-up for the sun strength, as 90 Wh/m^2 is the first value appearing in the explanation.

Even though there were some wrong entries, we would consider overall readability as good and those mistakes as exceptions.

7.2.2 Analysis of Navigation through the Explanation Pop-Ups

A majority of 76 % of participants found the long press to open the pop-ups intuitive. A reason, participants had problems, opening them, could be, that the elements did not indicate, that they are pressable, or that there is more information available. Again, this is probably caused by the scrollbar disappearing after a few seconds.

The results for the explanation pop-ups clearly state, that participants prefer the swiping version. The swipeable version indicates more clear, that there is more than one page available, probably because of the arrows. More than two-thirds of participants also selected the swipeable pop-up as preference, because the swiping interaction was taken as easier and less error-prone.

To conclude the analysis of interaction techniques, we would state, that the interaction technique, to open the detailed forecast views, is intuitive and easy to learn. Participants mentioned fewer problems finding the information, as they went on with the tasks. When it comes to accessing the information, the hourly forecast charts probably show too many data points. Even though most participants did not have problems with opening the explanation pop-ups, it would be better, to add a hint, that the data representations are pressable. When it comes to scrollbars, it is better to display them all the time, as otherwise, they got easily overlooked by participants. There was a clear trend, that participants preferred the discrete swipe version of the explanation pop-ups.

7.3 Analysis of the Participants User Interfaces

On average, participants selected fewer elements than the nine data representations *WeDaVis* offers. On the one hand, they justified their decision, with feeling overwhelmed and irritated by all the information on the main screen, and on the other hand, because they were not interested in some data displayed.

The data information, participants chose, reflects their interests in weather data. For example, all the participants selected the temperature to be shown on the main screen, which was also the kind of information, participants stated they are most interested in, in the first form we asked them to fill before they start the study. Similarly, air pressure was the least chosen data element, and was also one of the information, participants were the least interested in.

In order to answer the corresponding research question, we would take the average number of six data representations as recommendation of a suitable number of data representations on the main screen. Because participants interests in different weather data differs, it would be best, if participants could choose the weather data displayed on the main screen themselves. Otherwise, we would recommend displaying the six weather information, in which participants showed most interest in. This would be temperature, weather condition, precipitation, wind, cloud cover, sunrise and sunset.

7.4 Possible Improvements on the Basis of Participants Feedback

The study results encourage some possibilities of improvement for *WeDaVis*. General changes would contain, reducing the number of data items showing on the main screen to six instead of nine elements. Data representations, that could be omitted, would be the air pressure, the sun strength, and humidity or the wind direction, as they were one of the least selected elements in the third part of the study. This information could be transferred into another screen, for example, if participants swipe down on the main screen. That way, there would be more space for the other data representations on the main screen. Another option would be to make the app customizable, so that participants can select, which weather data should be displayed on the main screen.

As the first part of the study indicates, should some data representation rather be textual. For the current temperature, we would switch the representation into a simple text, instead of the progress bar. Even though participants preferred the temperature forecasts as lists instead of charts, we think that charts could do a better job of illustrating the data, and could be improved. In general, we would change the labels of the x-Axis to showing the exact time and date, and also add labels for the axes themselves. Additionally, we would add a hint, that charts are interactive. This could be in the form of a text, saying, “Press on chart”, when no point is selected. For hourly forecasts, we would make the charts horizontally scrollable, so that users do not have the whole 24 hours at once, but only have 10 hours at a time, which makes the chart clearer and the data point selection easier. For the detailed temperature and precipitation views, we would display the scrollbar all the time, to indicate more information available. Most participants stated, that they are more interested in the exact time, sunrise, and sunset are happening, so instead of having the remaining time as text, we would change the text to the exact time of the next event.

To illustrate, that all items have pop-ups with additional explanations, we would add a hint, for example the icon ⓘ, to signal participants, that they can press on the data representations. We would realize all pop-ups with the swipeable version, because participants preferred this version.

8 Conclusion

The goal of this project was, to develop a weather application for smartwatches, with a new design approach and through this project, we were able to evaluate it in a user study.

First, we looked into research in the field of micro visualizations and weather data. The lack of research work related to weather data on small personal devices like smartwatches prompted us to conduct a survey and analyse twelve weather apps on smartwatches. The results showed a trend towards simple representations in the form of text or icon in connection with text. This leaded to the approach we followed in this work, in which we favour the use of simple and complex visualizations for weather data representation.

We developed the weather application *WeDaVis*, which shows nine weather visualizations on the main screen. The design goal of the visualizations is, to support people by understanding the displayed values. In order to help users understanding the representations, explanations are available in the form of pop-ups. Detailed information about the temperature and precipitation forecast is displayed in two additional views.

We evaluated the application with a study with 17 people. Results of the study showed no general trend towards simpler textual representations or more sophisticated visualizations. Instead, participants preference depended on the type of information. For more familiar data, participants preferred simpler representations, while for more uncommon data, participants preferred the contextual information of the *WeDaVis* app. Participants selected on average six data representations, to be shown on the main screen. Many participants stated, that the nine visualizations felt a bit overwhelming and distracting. Even though readability was rated as positive overall, the study indicates, that fewer data on the main screen would improve the usability and readability. Also, participants preferred the more intuitive swipe interaction, instead of the continuous scroll interaction, as this interaction technique turned out to be less error-prone. Even though most participants did take the long press, to open the explanation pop-ups, and the clickable charts as intuitive, these interaction techniques should be explained and participants should have been made aware of these techniques. The biggest point of criticism was, nothing indicated, that these elements were pressable.

However, overall feedback for the *WeDaVis* application was positive, and many participants commented on the design, that they liked these new visualization approaches. We think the results prove, that many generic weather applications for smartwatches do not use the full potential of visualizations to provide a better user experience.

Future Works

This project faced some limitations, which should be discussed. Not all weather data was available in the weather data API we used, to be displayed in the application. Data we would have included, if it had been available, would have been the cloud cover, and the UV index. This was the reason, some rather uncommon data, as the air pressure, was directly placed on the main screen as a replacement for other missing data. There is other weather information, in which participants showed more interest, according to the study. For example, cloud cover, UV index and air quality were ranked in total more interesting than air pressure. This could have affected the results of the user study, as some participants mentioned, that they would prefer less, but more relevant data on the main screen. It is also important to mention, that the study was conducted with only a few participants. Results could be different, if the study is repeated with a bigger number of participants. Additionally, the number of participants was not evenly distributed according to the age groups. The majority of participants were between 18 and 25. Having more older people participating, could affect results, for example regarding readability. Also, participants' background could affect results. A majority of participants were students from the field of informatics. The technical background of participants could play a role in the preference ratings.

This project did raise some questions, which should be further inspected, in future works. The *WeDaVis* application was a first step, to investigate the effect of more complex visualizations. As the study results indicate, participants were open-minded about the new design approaches. However, the study also revealed some problems and disadvantages of *WeDaVis*. Foremost, the improvement ideas in section 7.4 should be implemented, as these suggestions were directly stated by participants and would directly improve the user-friendliness of *WeDaVis*. The application misses some options of customization. Because participants interests in weather data is diverse, it would improve usability, if users could choose, which weather data they want to see on the main screen, and also place the data representations to their preference. Additionally, the application does not send any notifications. But especially for smartwatches, there is a lot of potential to show real time notifications for precipitation, temperature forecast and many more. Research should also be further expanded in the field of design. There are plenty of possibilities for visualizations of weather data. This study was a first step into examining, which designs participants prefer, but it did only inspect a fraction of the possible designs.

A Appendix

In this chapter, we will provide additional information about this project.

A.1 *WeDaVis* showing different Weather information

The visualizations of *WeDaVis* depend on the current weather condition. Therefore, we want to provide you a few insights in our application, with various weather conditions. Figure A.1 shows nine examples of how *WeDaVis* would look like in various weather conditions.

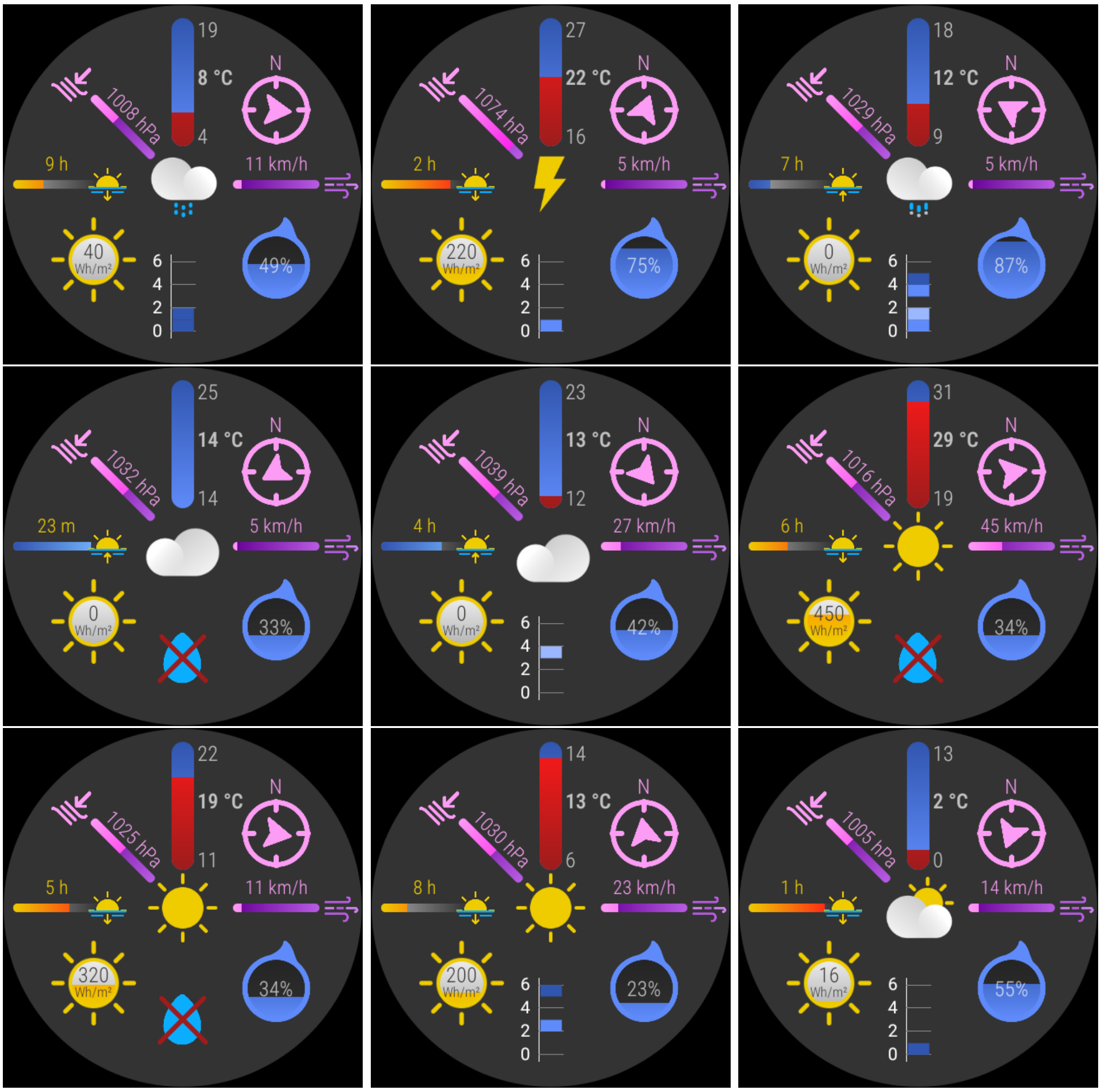


Figure A.1: *WeDaVis* showing different weather conditions.

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Declaration

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

place, date, signature