# Designing an intuitive Wearable Device Selection Tool for stress monitoring research

*Creative Technology Bachelor Thesis*

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# Abstract

Daily situations or events that causes individuals to feel stressed, no matter how unimportant they may seem to be have been proven to negatively affect our health and well-being. However, the current research into stress physiology primarily relies on short laboratory based assessments. This is why the Stress in Action Consortium (SiA) has created a database of wearable devices for ambulatory stress measurement. On behalf of the SiA, this research was aimed at creating a wearable device selection tool based on the existing database created by researchers from the SiA.

In order to properly carry out this assignment, a research question was set up, aiming at finding the best solution and design in order for researchers to use the existing Stress in Action Wearables Database (SiA WD). In the background research of this thesis the limitations for wearable devices and their selection for stress measurement was examined. Followed up by an overview of Recommender System (RS), where the advantages and disadvantages of Collaborative Filtering (CF), Content-based Filtering (CBF), Knowledge based Filtering (KBF), and Hybrid based RSs were described. Afterwards existing technologies for RSs in e-commerce, RSs in healthcare, and online wearable device databases were examined during the state-of-the-art of the background research. These different technologies showed different ways of using existing filtering tools for a certain goal in different fields, which were used as an inspiration for the ideation phase of the project.

During the ideation phase, an expert interview was held from which information was gathered about the challenges with wearable devices for stress research, the needs, design ideas , and additional features for the filtering tool. Afterwards stakeholders were identified and preliminary requirements were set-up accordingly. A brainstorm was set up in order to look at the possible platforms for the filtering tool and their advantages and disadvantages. Then the brainstorm, the requirements and the background research was combined and worked out into concept ideas which were afterwards combined into a final concept.

Following up on the ideation, the specification phase specified the different aspects of the final concept. Personas were created to assess the behaviour of different types of users: a user with high technical knowledge to a more user oriented researcher. Then the different components for the front-end and the back-end were defined as well as Time Sequence Diagrams to show the order of interactions between the user, the front-end and the back-end.

In the realisation phase, the three sub-parts of the product were identified: the pre-processing of the data, the front-end and, the back-end of the filtering tool. For each of these parts the steps taken to create or handle them were explained in detail, making sure that the end-product can be re-created on the basis of reading through this thesis. In addition, a working prototype was created and tested in order to be evaluated based on the functional requirements. Some suggested changes were given after the evaluation based on the functional requirements.

After creating the prototype, the prototype was evaluated by user testing. 5 participants were asked to participate. They all got the same use case and the same version of the filtering tool to work with. They would use the filtering tool in order to find the best wearable device for the use case. Afterwards they would be interviewed in a semi-structured way. The evaluation showed that the filtering tool as a prototype was a success. All users gave the filtering tool a positive and sufficient score and were happy to have a tool that would facilitate their needs in selecting wearable devices for ambulatory stress research. However, some improvements can still be made in order for the filtering tool to be in its best form.

Finally, the SiA showed real interest in the product and in the functionalities it brings and they would like to further develop the tool in order for it to grow into a functional and working tool to be used for actual research.

Therefore, the research question: "*How can the Stress in Action Wearables Database (SiA WD) be used by researchers aiming to select the most suitable wearable device for a given study purpose?*" can be answered as follows: With the use of the filtering tool created based on the SiA WD, the researchers for ambulatory stress research are able to filter wearable devices based on their specific situation in order to find the best wearable of use for their study purpose. Even when not giving exactly one suitable wearable, the filtering tool gives the researchers the possibility to gain information about multiple suitable wearables in an easy to access way.

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# Chapter 1.
# Introduction

Daily situations or events that causes individuals to feel stressed, no matter how unimportant they may seem to be, have been proven to negatively affect our health and well-being, with long-term stress being linked to the development of cardiovascular and mental illnesses as stated by Akbar et. al [1], Momeni et. al [2], and Parent et. al [3]. However, the current research intro stress physiology primarily relies on short, laboratory based assessments, where participants are exposed to stressful situations that are often irrelevant to their everyday lives. For example the cold-pressor test which requires a participant to put their limbs in near frozen water for a short period of time [3], the Maslach Burnout Inventory which is made up by 22 items which refer to different stressful situations or the Perceived stress scale, where a participant would get asked 14 questions that refer to potential stressful situations during the last month [4]. Consequently, there is a need to shift the measurement of stress from laboratory settings to an individual's daily life in order to obtain more ecologically valid measurements. Wearable devices can be used to facilitate this shift in settings. They are able to gather relevant stress measurements in a non-obtrusive way while individuals engage in daily activities. However, the growth of the wearables market is rapid and it focuses mostly on consumer products instead of research wearables. This presents challenges in keeping up with the latest developments, comparing various wearables and in the end selecting the most suitable wearable for a specific research purpose.

This is why the SiA [5] has created a database of wearables devices for ambulatory stress measurement. SiA is a consortium that enables collaborative efforts with the aim of understanding the origin of responses to everyday situations or events that cause individuals to feel stressed, . Additionally, the consortium seeks to discover how to measure stress in daily life in a reliable and valid way in a specific individual, and how and when potential mechanisms of the stress response will have detrimental effects on an individual's health. The database represents the first step towards selecting wearables suitable for these purposes.

The database created by members of the consortium is quite extensive, and looking through the database to select the best option for a particular research project can be extraneous. Researchers and academic will have to sift through a long list of available devices and their specifications to identify those that offer necessary features for their specific studies. Furthermore, as many consumer devices might be more affordable and accessible, many of them are not necessarily suitable for research purposes. There is a risk that wearable devices may lack the precision and accuracy required for scientific investigations which could potentially compromise the validity of the findings of a research. Therefore, researchers need to exercise caution and should thoroughly evaluate the wearable devices before selecting the correct one for their specific study by considering factors such as data accuracy, reliability, battery life, costs, and compatibility. Due to the high amount of detail in the database, such comparisons become difficult. For this reason, a selection tool is required, one that would enable a researcher to compile a list of the best wearable devices to use based on applied filters. Such a selection tool is known as a RS. An RS, is an algorithmic tool that employs various techniques to generate personalised recommendations as will be explained in Section 2.3. It aims to enhance user experience and deliver tailored suggestions by alleviating information overload and facilitating decision making processes. Functionally an RS operates on various methodologies, commonly including collaborative filtering and content based filtering. Collaborative filtering uses insight from users to create preferences which will be further explained in Section 2.3.1, while content-based filtering uses the intrinsic attributes of items in a database to give optimal recommendations which will be further explained in Section 2.3.2. When it comes to the selection of wearable devices, an RS serves to enhance the decision making process of a user by synthesising their preferences and the characteristics of the items present in the database. The RS provides a user with filtered selections that suit the user's needs and preferences.

## 1.1 Research Questions

During this research, the main goal is to create a selection tool, that would enable a researcher to compile a list of the best wearable devices to use based on applied filters. To be more precise, the main research question is as follows:

> *How can the SiA WD be used by researchers aiming to select the most suitable wearable device for a given study purpose?*

To seek a solution to the main research question as well as to support and delve further into necessary material and literature research the following sub-questions are set-up.

- *What are the important factors to keep in mind when selecting a wearable device for ambulatory stress monitoring?*

- *What are the most prominent algorithms for using a recommender system?*
- *What are the advantages and disadvantages for the most prominent algorithms for recommender systems?*
- *What is the best algorithm to use for a recommender system in the field of wearable device selection?*

## 1.2 Thesis outline

To attain a favourable outcome and effectively address the core research question, the subsequent chapters of this thesis are structured accordingly.

- Chapter 2: Background research
  - This chapter is comprised of three sections, namely 'literature', 'state of the art', and a final section that concludes the preceding two sections.
- Chapter 3: Methodology
  - Within this chapter the methodology and techniques utilised in the graduation project is presented.
- Chapter 4: Ideation
  - In this chapter details regarding the identification and analysis of stakeholders is presented, as well as the determination of requirements for the RS based on the interests of SiA and the literature from Chapter 2 .
- Chapter 5: Specification
  - Following the definition of specifications a more detailed design of the concept is shown. Furthermore, the requirements for the RS are further specified.
- Chapter 6: Realisation
  - Within this chapter the creation process of the RS for the SiA WD is described covering design and software choices.
- Chapter 7: Evaluation
  - In this chapter the methodology used for evaluation is shown, followed by the results of the evaluation and a reflection on the requirements that were made in Chapter 5.
- Chapter 8: Discussion
  - This chapter provides a critical analysis of the research findings, addressing the strengths and limitations of the study.
- Chapter 9: Future work
  - Finally, this chapter shows suggestions for future work.

# Chapter 2.
# Background research

This chapter provides a background on the subject of wearable devices, their limitations and their selection for stress research. It is then followed up by an overview of recommender systems, where the advantages and disadvantages of CF, CBF, KBF, and Hybrid based RSs are described. Lastly, this chapter dives into the state of the art of current RSs.

## 2.1 Stress measurement through wearable devices

This section explores the possibilities of measuring stress through the use of wearable devices in a research setting. Stress has become an undeniable aspect of people's lives in the current fast paced world, and it impacts both a person's physical and mental well-being as stated by Akbar et al. [1], Momeni et al. [2], and Parent et al. [3]. Akbar et al. [1] also state that stress occurs when a person would perceive demands that would exceed the available resources, thus triggering a series of physiological responses. These responses are controlled by the autonomic nervous system. According to Akbar et al. [1], this system handles our body's reactions to stress, involving both the sympathetic branch, which activates the "fight-or-flight" response, and the parasympathetic branch, which helps our body restore balance and relaxation . Understanding stress is crucial, as it affects various aspects of our lives. Beyond the immediate physical responses, like increased heart rate and muscle tension, stress can lead to negative emotions such as anger and fear, and can even impair cognitive functions like decision making as stated by Akbar et al. [1], Momeni et al. [2], and Parent et al. [3]. Moreover, long exposure to stress could have long-term health consequences. To effectively measure stress, and monitor stress levels, wearable devices equipped with sensors have emerged as promising tools. These devices offer a convenient and non-obtrusive way of capturing physiological signals in real life. By using wearable devices, researchers are able to dive deeper into the nuances of stress outside of laboratory settings.

### 2.1.1 Utilising wearable devices for stress measurement

Shifting the focus towards wearables, it's evident that they play an important role in enhancing the objectivity of stress assessment. While self-reported stress offers subjective insights into perceived stress levels, wearables equipped with sensors like Photoplethysmography (PPG), Electrodermal activity (EDA), Electrocardiogram (ECG), and Accelerometer (ACC) offer a more objective means of measurement. These sensors enable the continuous monitoring of physiological changes associated with stress, providing valuable insights into an individual's stress response.

For example, Sethurman et al. [6] highlight the utility of smart garments in capturing physiological signals related to stress, emphasising the convenience and unobtrusiveness of wearable technology in monitoring vital signs such as Heart Rate (HR) and skin conductance. Expanding on this, Momeni et al. [2] advocate for multimodal monitoring, which combines various physiological signals to enhance the accuracy and reliability of stress assessment. They argue that this approach is effective in capturing nuanced stress responses. Additionally, wearables with ECG sensors allow for the assessment of Heart Rate Variability (HRV) as a marker of stress, as highlighted by Parent et al. [3], who showcase the association of HRV with human autonomic nervous system activity. Moreover, Linssen et al. [7] shed light on the integration of machine learning techniques with physiological signal analysis in wearable devices, emphasising its pivotal role in developing accurate stress detection models. This integration has the potential to predict stress levels in real time, offering users timely insights into their stress physiology.

In conclusion, wearables equipped with physiological sensors offer a promising approach to stress measurement, complementing subjective self-reports with objective data. Through multimodal monitoring and the integration of machine learning techniques, wearables enhance the reliability and accuracy of stress detection.

### 2.1.2 Limitations of wearable devices for stress measurement

As stated in Section 2.1.1 above wearable devices offer a promising approach to stress measurement. However, wearable devices also come with their limitations and challenges in the field of stress measurement. One common limitation stated by Akbar et al. [1], Sethuraman et al. [6] and Linssen et al. [7] is the influence of motion artefacts on physiological signals obtained from wearable devices. These artefacts can significantly impact the accuracy and reliability of stress measurements, especially in scenario's involving physical activity or movement. Momeni et al. [2] also agree, but state that motion artefacts can distort the

data collected by wearable sensors. This challenge shows the importance of mitigating motion artefacts by wearable devices to ensure the validity of stress research. According to parent et al. [3] another significant limitation that builds upon this challenge is the multidimensionality of an individual's psychological states and the effects of movement and physical activity on stress measurements. Parent et al. [3] also highlight the complexity of assessing stress in a realistic setting where individuals are mobile and engaged in everyday multitasking activities. Movement artefacts and physiological responses triggered by physical activity can obscure stress signals, thus posing challenges for accurate stress measurement through wearable devices.

Moreover, the placement and positioning of sensors on wearable devices pose a significant challenge in the field of stress research. Sethuraman et al. [6] highlight the importance of this to ensure accurate readings of physiological signals related to stress. De Arriba-Perez et al. [4] elaborate on this by stating that issues such as sensor detachment, friction, or changes in pressure on the skin can affect the reliability of stress measurements. Furthermore, the sensitivity of sensors to position changes especially in wrist worn devices, can reset measurements and thus introduce inaccuracies.

Beyond these limitations, wearable technology also faces challenges related to measuring the autonomic nervous system (ANS) activity, which plays a key role in stress responses according to Mehl et al. [8]. Traditionally, researchers have relied on lab studies to measure ANS activity, but these often involve artificial stressors and short durations, not reflecting real-life experiences. Wearables offer a more ecological approach by capturing physiological signals in daily life, but they rely on indirect measures. For instance, HRV is a common marker of parasympathetic activity measured by wearables, but it's important to validate these indirect measures to ensure they accurately reflect ANS activity. Additionally, individual differences in anatomy and receptor sensitivity can influence sensor readings, making it challenging to establish universal stress thresholds based on wearable data as stated by Mehl et al. [8].

Another critical limitation of the use of wearable devices in the field of stress research is the battery life. Cho & Lee [9] highlight that the constrained battery capacity of wearable devices poses challenges in continuous monitoring of stress. This is agreed upon by Connely et al. [10], Phillips et al. [11], Momeni et al. [2], De Arriba-Perez et al. [4] and Linssen et al. [7]. Linssen et al. [7] explain this by stating that the power requirements of bio-sensors drain battery life fast, limiting the duration of stress monitoring sessions. This is a great constraint that hinders the feasibility of long-term stress research or makes it necessary to frequently recharge or replace batteries, thus impacting the User-Experience (UX) of users.

Additionally, the implementation of stress detection methods on wearable devices presents challenges due to its complexity. Momeni et al. [2] highlighted that multimodal machine-learning approaches, while promising for accurate stress prediction as written in Section 2.1.1, face limitations in memory, energy consumption and duty cycles. They emphasise the need for robust and efficient algorithms tailored to the use of wearable devices and its constraints in the field of stress measurement.

### 2.1.3 Conclusion

In conclusion, wearable devices offer a promising approach to stress measurement, using a combination of subjective self-reports and objective physiological signals such as HR, PPG, EDA, ECG and ACC. These signals provide valuable insights into an individual's stress response. Through the use of multimodal monitoring and the application of machine learning techniques, wearable devices enhance the reliability and accuracy of stress detection. However, the field of stress research using wearable technology faces challenges such as motion artefacts, sensor placement, battery life limitations, algorithm complexity and multidimensionality of psychological states. These limitations should be addressed with careful consideration in order to fully realise the potential of wearable devices in understanding and managing stress effectively.

## 2.2 Wearable device selection for stress research

The field of wearable technology has grown immensely recently, thanks to advances in sensors and miniaturisation. These devices have applications in healthcare, fitness, and research. When it comes to research, selecting the right wearable device is crucial for gathering accurate data. This section delves into the current landscape of wearable device selection for research, covering key factors and challenges.

### 2.2.1 Key factors

The selection of wearable devices involves an evaluation of the various factors to ensure the optimal adoption and usability for users during a research period. Small form factor and a long battery lifetime are critical aspects that ensure the uninterrupted functionality and integration into user's daily life as highlighted by

Cho et al. [9]. These attributes are essential for maintaining user engagement and satisfaction during the course of a research as they directly impact the UX. Moorthy [12] continues on this with empirical findings that underscore the importance of effectiveness, efficiency, and satisfaction in shaping user's perception of wearable devices. This aligns with the notion that positive UX is essential for adoption and continuation of usage of wearable devices during a research period. However, the usability of wearable devices extends further than just functionality. Connely et al. [10] discussed that factors such as the ease of setup and device wearability significantly influence user satisfaction and overall usability. Moreover, Liu & Han [13] state that the adoption behaviour of users towards wearable devices is influenced by a combination of functional characteristics and perceptions. While the functional characteristics like perceived usefulness and ease of use play a vital role in adopting decisions. Subjective norms and the surrounding group of people also influence user's attitude towards wearable technology.

Besides factors influencing the adoption of wearables by a participant, concerns regarding privacy and data security are also dominant considerations in the evaluation of wearable devices, as highlighted by Lee et al. [14]. They state that users and researchers exhibit varying levels of apprehension regarding the collection and storing of sensitive information. The importance of privacy protection is further emphasised by the potential implications of data breaches or data misuse, which could further erode a user-researchers trust, and hinder the adoption of wearable technology. However, Phillips et al. [11] state that most individuals are open to sharing device data with researchers and healthcare systems, thus facilitating data driven insights and interventions. Thus, even though we might expect most individuals to be willing to share their data, data integrity continues to be an important factor in selecting a wearable device for stress research.

To continue in the field of healthcare applications, wearable devices play an important role in monitoring and managing cardio-metabolic health. However, Lazaro et al. [15] state that ensuring the accuracy and reliability of wearable devices is essential for getting meaningful insights and guiding clinical decision making. They define functionality metrics such as: accuracy, connectivity and customisation capabilities and state that these are important in ensuring the efficacy of wearable devices in the field of healthcare. Furthermore, Zhao et al. [16] examined that the choice of sensors in wearable devices has implications for both usability and privacy, with sensors such as heart rate monitors and activity trackers generally perceived as involving fewer privacy concerns than other commonly used sensors in wearable devices. Thus slightly going against the statement of Lee et al. [14]. However, Zhao et al.[16] state that the nature of data collection and its potential implications on privacy vary across different types of wearable devices. In the end we can conclude that wearable devices play an important role in monitoring and managing cardio-metabolic health. The combination of functionality metrics and implications of usability and privacy help a researcher understand the goal and differences of wearable devices.

Transitioning from healthcare applications to technological advancements in wearable devices, we observe a shift towards diverse applications.Technological advancements such as the pyrolyzed silk carbon fabric-enable wearable actuators as discussed by Tao et al. [17], underscore the potential of wearable technology in diverse applications, since they meet series of functional requirements such as thermal management, physical therapy, entertainment, and communication. Advancements can also be seen by the proliferation of smart wearables equipped with PPG sensors, which provide an opportunity for researchers to easily monitor cardiovascular health in daily life as stated by Charlton et al. [18]. The design of PPG devices must also consider factors such as signal quality, user acceptability, cost and power consumption adding to the list created by Connely et al. [10] and Liu & Han [13]. One strong point of PPG signals is that they can provide valuable insights into cardiovascular health which can help in mental stress assessment as stress tends to increase heart rate and pulse variability.

### Conclusion

From this section several key factors of selecting a wearable device for stress research can be acquired. Below a table is given as an overview of the section:

| Key factors |
|---|
| Small form factor |
| Long battery lifetime |
| Effectiveness, efficiency, satisfaction |
| Usability (setup and wearability) |
| Subjective norms |
| Privacy concerns & data integrity |
| Technological advancements |

**Table 2.1:** Key factors of wearable device selection in stress research

### 2.2.2 Challenges

The selection of wearable devices is filled with challenges which stem from technological limitations, usability concerns, privacy considerations, and healthcare requirements, despite advancements in semiconductor and battery technologies. Cho & lee [9] note that the fundamental trade-off between performance and battery life remains a critical concern. Wearable computers face hardware constraints such as a small-sized memory, limited battery life and low processing power which pose challenges to their functionality and usability. Kristofferson & Lindén [19] add to this by stating that one of the major obstacles in the adoption of wearable devices is the need to retrain the algorithms present in a wearable device for new sensor contexts. This adds complexity to the development and the deployment of these wearable devices which hinders their widespread adoption and usability. Additionally, Moorthy[12] highlights that the lack of well-defined attributes or methods for assessing the usability of wearable technologies creates a gap in research, and thus hinders the effective evaluation and selection of wearable devices.

Moreover, the flexibility and versatility of wearable technology poses challenges in clinical settings, where the suitability of a wearable device for a specific study purpose and certain specific populations needs to be evaluated. Connely et al. [10] highlights the scarcity of guidance for researchers in evaluating and selecting the appropriate technologies for their respective studies. Challenges related to usability, manageability, interoperability and security further complicates the selection process, which ends up creating barriers to the use and adoption of wearable devices in research settings. Lee et al. [14] add to this by stating that in healthcare applications, challenges related to accuracy, reliability, and user adherence present hurdles in the selection of wearable devices. They discuss the limitations of wearable devices in accurately measuring physiological parameters such as heart rate and glucose levels, particularly in clinical settings. Additionally, the rapid evolution of wearable devices their design, features, and software poses challenges in constantly ensuring compatibility and consistency across multiple devices. Phillips et al. [11] outline challenges such as in-equivalent metrics outputted by devices, proprietary algorithms, and limited access to raw data, which hinders the interoperability and data standardisation. Furthermore, they state that factors such as durability, ease of use, battery life and cost contribute to the complexity of selecting wearable devices for healthcare and research applications.

### 2.2.3 Conclusion

In conclusion, the selection of wearable devices requires a comprehensive approach that considers technical, usability and human factors. Addressing aspects such as usability, privacy, accuracy, validity of data and application-specific requirements is crucial for increasing adoption and realising the potential of wearable devices in various fields. These considerations are present in the SiA WD, facilitating the selection of wearables. However, with the abundance of information and the complexity of factors to consider, manual comparison and selection can become overly challenging. Thus, the development of a selection tool is essential to streamline the process and aid users in making informed decisions.

## 2.3 Recommender systems

This chapter dives deeper into RSs, which play a pivotal role in assisting users in navigating the vast landscape of available options by providing personalised recommendations tailored to individual preferences. This chapter will first take an in-depth look at CF, CBF, KBF, and ends with the exploration of Hybrid RSs.

### 2.3.1 Collaborative Filtering

The term "recommender system based on CF" was first used by Goldberg et al. in 1992.[20] These systems aim to predict user preferences based on past interactions. However, challenges such as user profiling, adaptability, the cold-start problem, data sparsity, scalability issues, and biases still exist within these systems. The following sections will explore these challenges and discuss various approaches proposed in recent research.

#### Advantages of Collaborative Filtering

The use of CF within an RS has three advantages, the utilisation for user-item interactions for prediction, the ability to capture complex user preferences, and the ability to provide the so-called serendipitous recommendations. A CF RS makes a recommendation based on a user's profile and their previous interactions with items, it takes into account the rating and opinion of other users in the system to synthesise a single ranking of an individual user. According to Herrera et al. [21] this is a clear advantage of CF, Adomavicius et al. [22] agree with Herrera as do Sereno et al. [23], Yu et al. [24] and Soltani et al. [25] but Soltani et al. [25] argue that for this approach users will have to be divided in groups which ensures that the users in each group have the same interests and attention. Kamyshev et al. [26] also agree with Herrera and Soltani et al. [25] but do state that it should be divided in two methods, namely, the user-based method using a neighbourhood, which is the grouping method explained by Soltani et al. [25], and the model based method which would focus on the items in the system instead of the users. Etemadi et al. [27] however, do not agree with Soltani et al. as they believe neighbourhood-based methods include both user-based and item-based methods. Whilst model-based models would include decision tree and regressions models, rule-based models, latent factor models and deep learning models. This advantage of *Utilisation of User-Item Interactions for Prediction* enables the RS to provide personalised suggestions based on past user behaviour, thus enhancing user experience.

Another advantage of CF would be its ability to capture complex user preferences. According to Herrera e. al. [21] this capability to capture intricate user preferences by analysing patterns in user-item interactions is one of the bigger advantages of CF. Aggarwall [28] agrees with this as do Adomavicius et al. [22] , Liao et al. [29], Zhou et al. [30] just like Kamyshev et al. [26] however Kamyshev et al. state that this is only a theoretical accuracy. In contrast Herrera et al. [21] state that CF RSs are prone to failure when a user has interests that are uncommon. Nonetheless, by using the advantage of *Capturing complex user preferences* the recommendation of items that align closely with the interests of the user are more likely to be recommended thus increasing user satisfaction.

A third advantage of CF is the possibility for offering serendipitous recommendations. These are recommendations of items that the user might not discover on their own. Kamyshev et al. [26] believe this to be a clear advantage since they believe that the user profile a system uses should be able to adapt to the changes in user's interests. This feature would allow CF for items to be recommended to users which they themselves might not believe are of interest for them. Zanker et al. [31] agree with Kamyshev et al. even stating that this is even a "common argument that only collaborative filtering systems can achieve good results in terms of novelty and serendipity". In addition to this, Breese et al. [32] propose a way of CF that builds upon this by stating that it might be beneficial to use *Inverse User Frequency* in order to make less common items more useful in making recommendations. However, Kavu et al. [33] do not agree with the others as they state that current recommender algorithms are lacking in terms of serendipitous recommendations and they propose a new way of recommending by using a context-aware system. Which is a RS that dynamically adapts its behaviour or output based on the context or situation in which it is used.

#### Disadvantages of Collaborative Filtering

Regardless of the advantages mentioned in Section 2.3.1 CF also faces four challenges, namely: user profiling and adaptability, the cold start problem, scalability and sparsity and the vulnerability to biases. User profiling is essential for understanding long-term user interests and preferences. However, according to Soltani et al. [25] maintaining accurate and dynamic user profiles poses challenges, particularly with the rapid evolution of user interests over time. To mitigate the user effort and to enhance system-user interaction Herrera-Viedma et al. [21] propose that user profile generation and updates should ideally require minimal explicit user involvement. This way the disadvantage of *User profiling and adaptability* can be minimised in order to enhance the interaction between the system and a user.

A second challenge within CF is the well-known *Cold start problem*, a significant obstacle in CF RS, wherein new users or new items lack sufficient data for accurate recommendations. Feng et al. [34] state

that this issue not only hampers the effectiveness of RSs, but also risks losing user confidence in the system. Kamyshev et al. [26] agree further stating that without knowing anything about the user's interest, the results are virtually useless. CF systems do struggle due to the absence of a sufficient amount of data, which would cause less accurate recommendations thus leading to a sub-optimal UX, potentially even undermining user's confidence in the capabilities of the system.

The third challenge of CF is the issue of *Scalability and Sparsity*, scalability issues arise with the growth of the user and item databases in CF systems. Soltani et al. [25] state that the sparse user-item matrices hinder the ability of an RS to generate accurate recommendations due to the lack of overlapping ratings. However, Soltani et al. [25] also state that item-based CF approaches offer a potential solution to scalability concerns by constructing neighbourhood sets for items, thereby reducing the amount of online computation needed. However, Aggarwal [28] believes that neighbourhood based methods face numerous challenges because of data sparsity, and users often specifying only a small number of ratings. They propose to use model based CF RS. Etemadi et al. [27] agree with Aggarwal, but propose to look into model-based approached in order to minimise the problem of data sparsity. Whilst Zanker et al. [31] proposes to not look into CF and use a contextual filtering model instead to solve this problem. In conclusion, the combination of data sparsity and scalability poses challenges for accurately modelling user preferences and increase computational complexity resulting in a diminished overall system performance.

The final challenge of CF is the *vulnerability to biases*. Data and algorithmic biases are common in CF RS. According to Schedl et al. [35] data biases arise from non-representative user samples or disproportionate interactions with certain items, while algorithmic biases comes from variations in recommendation quality based on user personalities and adopted algorithms. Bresler et al. [36] agree with Schedl et al. as does Etemadi et al. [27] but Etemadi et al. [27] add that biased results can also include privacy problems when the CF system uses specific information from a user. Kavu et al. [33] also agree with Schedl et al. and Etemadi et al. and add that CF is mostly biased to system-centric factors for example: scalability, accuracy and diversity. These biases could be detrimental to an RS as they could skew recommendations, potentially leading to unintended consequences.

#### Conclusion

To conclude, CF methods have multiple advantages and disadvantages which makes the system unique, but not without flaws. The advantages and disadvantages can be seen in Table 2.2. In the scope of the creation of the filtering tool for the SiA WD CF has a good advantage of being able to provide serendipitous recommendations. These recommendations could help in the field of research, since it opens up the possibility to help every researcher with their goals for their specific research. However, CF has multiple disadvantages for the goal of the creation of the filtering tool. Since CF has scalability issues, it is not a good option for the ever growing field of wearable devices. Furthermore, the cold start problem encountered by collaborative filtering is a significant obstacle for the goal of this research. Since new researchers are using the database for a different research multiple times the system will not be able to give meaningful recommendations to a user.

### 2.3.2 Content Based Filtering

CBF recommender systems recommend items based on the characteristics of items and the user's preferences. The basis for the works on CBF can be considered from Pazzani et al. [37].De Gemmis et al. [38] continue from the work done by Pazzani et al. [37] by stating that these systems utilise attributes or features from items to create user profiles and recommend items that match these profiles. Due to this CBF has several advantages such as: User-independence, transparency and new item recommendations. These will be further explained in Section 2.3.2. Despite these advantages, CBF also faces several disadvantages such as: Limited Content Analysis, Over-Specialisation and the New User Problem. These will be further explained in Section 2.3.2.

#### Advantages of Content-based Filtering

CBF RS make a recommendation based on a user's profile and their history of selections and characteristics of the selected items, without taking into account the rating/opinion of other users in the system. Due to this one of the advantages of CBF is *User Independence* De Gemmis et al. [38] state that CBF are less prone to data sparsity issues and more effective with a small amount of data available because they exploit solely ratings provided by the active user.

Furthermore, CBF uses items and their attributes to provide recommendations to a user. Due to this nature another advantage is *Transparancy*, Aggarwal [28] states that CBF systems can provide explanations on the recommendations in terms of features of items, which is not possible for CF. De Gemmis et al. [38] agree with this by stating that explanations on how the recommender system works can be provided by explicitly listing content features or descriptions that caused an item or items to occur in the list of recommendations. This makes a CBF RS easier to use since user are able to better understand the workings of the system.

Another advantage, due to the nature of using items and their attributes is *New Item Recommendations*. CBF can avoid the first-rater problem according to De Gemmis et al. [38]. Aggerwal [28] explains this more clearly by stating that when a new item is added to the matrix of all possible items and ratings, items rated previously by a user are used to make recommendations. Therefore, as long as a user is not new, meaningful recommendations can always be made.

#### Disadvantages of Content-based Filtering

Despite the advantages mentioned in Section 2.3.2, CBF systems also face several disadvantages, for example *Limited content analysis*, CBF RSs have a natural limit in the number and types of features associated with the objects they recommend. De Gemmis et al. [38] add that without sufficient descriptive features, these systems may struggle to provide suitable suggestions. Aggerwal [28] continues on this by stating that a clear distinction may not always exist between various features and items.

Furthermore, CBF has no method to find something unexpected or novel for a user. This is a problem of *Over-Specialisation* Aggerwal [28] states that it is always desirable to have a certain amount of novelty and serendipity in the recommendations towards a user. However, CBF tends to only find items that are similar to the items the user has liked so far. De Gemmis et al. [38] agree with this by stating that CBF contributes to over-specialisation of the system by suggesting items similar to those already rated by a user.

Following up on that, CBF (just like CF) encounters the cold-start problem. CBF does fix a part of the cold-start problem though, according to Kamyshev et al. [26], since it is able to recommend items that are not yet evaluated by every user in the system. However, CBF still encounters the *New User Problem*, which according to De Gemmis et al. [38] occurs because new users must first rate enough items before the system can understand their preferences and thus provide accurate recommendations. Adomavicius et al. [22] agree with this, as does Aggerwal [28]. However, Kamyshev et al. [26] disagree since CBF can at least make recommendations to new users, thereby bringing these new users into the service of the RS.

#### Conclusion

In conclusion, CBF offers unique advantages such as user, independence, transparency, and the ability to recommend new items to existing users. However, it also faces challenges such as limited content-analysis, over-specialisation, and the new user problem. These advantages and disadvantages do make CBF different from CF and thus unique to use in certain circumstances. In the scale of the project CBF has the ability to translate the items in the SiA WD into a more ease-to use environment. It can help share explanations and features of items to researchers which could help them with the final selection of the best wearable for their specific research. Furthermore, CBF is able to recommend novel items to existing users which supports wearable device selection as the field of wearable devices is constantly growing and new innovative wearable devices are constantly emerging. However, the disadvantage of the new-user problem makes it hard to use CBF for the filtering tool since new researchers should also be able to work with the filtering tool. The advantages and disadvantages are shown in the Table 2.3

### 2.3.3 Knowledge Based Recommender Systems

KBFRS are RSs which unlike conventional approaches, as CF and CBF that rely heavily on collaborative patterns or explicit user ratings, leverage domain specific knowledge to generate recommendations. Instead of solely focusing on past interactions or item attributes, these systems use a repository of a domain of expertise, which allow them to create recommendations based on the inherent characteristics of items and the implicit needs of users. However, as with CF and CBF, KBF is not without drawbacks. In this section the advantages and disadvantages of KBFRSs are explored.

#### Advantages of Knowledge Based Recommender Systems

KBFRSs offer a solution to challenges encountered by traditional approaches as CF and CBF. As highlighted by Bouraga et al. [39] KBF leverage domain knowledge and user-specific preferences to generate personalised

recommendations.

One of the key advantages of KBF according to Bouraga et al. [39] is the immunity to cold-start problems. They also state that by not using historical data sets consisting of past interactions and user ratings KBF can ensure reliable recommendations from the outset. Uta et al. [40] agree with them and state that this immunity to cold-start problems positions KBF as a versatile solution and option for personalised recommendations in changing environments. Tarus et al. [41] agree with them as does Aggarwal [28].

Furthermore, KBF offers detailed preference feedback to users, enabling users to express their preferences in an easy manner. As stated by Martinez et al. [42] this qualitative approach enhances the accuracy and relevance of the recommendations given to a user by capturing aspects of a user's preferences that otherwise might not be well represented in traditional CF and CBF. Burke[43], Aggarwall and Bouraga et al. [39] agree with them. Bouraga et al. [39] continue by stating that these recommendations by KBF are more reliable. This way users are allowed to provide the system with explicit feedback and preferences whilst gaining relevant recommendations. Thus improving transparency and trust in the recommendation process.

Additionally, KBF bypasses the new item and the new user start problems. According to Martinez et al. [42], Burke[43], and Tarus et al. [41] KBF does this by generating recommendations based on knowledge about users and items rather than relying solely on historical data or user interactions/ratings. Towle[44] states "this proactive approach to recommendation generation ensures that recommendations remain accurate and relevant even in the absence of extensive historical data". In this way KBF can enhance user satisfaction and engagement.

#### Disadvantages of Knowledge Based Recommender Systems

KBF offers a more custom made approach to recommendation systems, by using domain knowledge and user preferences to provide personalised recommendations. However, KBF is not without limitations.

One significant disadvantage of KBF according to Uta et al. [40] is the high setup costs associated with the knowledge acquisition and knowledge exchange between domain experts and knowledge engineers. This is agreed upon by Bourage et al. [39] and Cena et al. [45]. The process of defining recommendation knowledge can be time-intensive, requiring extensive collaboration and expertise. This high setup cost poses a barrier to entry for organisations looking to implement a KBFRS.

Moreover, Bouraga et al. [39] state that most KBF systems rely on dialog based conversational processes between system and the user. Uta et al. [40] build upon this by stating that while this approach fosters user engagement and transparency, it can also lead to challenges in knowledge elicitation and representation. This is agreed upon by Aggarwal [28]. Due to this users may struggle to articulate their preferences effectively, particularly when faced with a large set of products or attributes to consider. This can then result in vague or incomplete preference information, which diminishes the precision and effectiveness of the recommendations provided by system.

Another notable disadvantage of KBF according to Burke [43]is the static suggestion ability of KBF. Unlike CF and CBF methods that adapt and evolve based on user interactions and feedback, KBF relies on predefined knowledge bases and recommendation rules. This static nature limits the RS's ability to respond to changes in market trends, potentially leading to outdated suggestions over time.

#### Conclusion

In conclusion, KBFRS offer a promising approach to recommendation generation, by harnessing domain knowledge and user preferences to deliver personalised suggestions. Despite the inherent advantages of KBF including immunity to cold-start problems, provision of detailed qualitative preference feedback, KBF also faces significant challenges. These challenges are: high setup costs, challenges in preference elicitation and static suggestion ability. However, the combination of harnessing domain knowledge and user preferences to delivered personalised suggestions makes KBF a good choice for the creation of our filtering tool for the SiA WD. In this case, the disadvantage of high setup is significantly lowered since the SiA WD has already been created and the knowledge acquisition phase is done already.

### 2.3.4 Hybrid Recommender Systems

With the growth of the amount of information on the internet and the fast pacing of inventions concerning information retrieval, hybrid RS have emerged due to the significant advancements in the field of RS. Adomavicius et al. [22] believe hybrid RSs to be a promising approach to address the limitations of individual recommendation techniques by leveraging their complementary strengths. Soltani et al. [25] agree with

this and continue by stating that by integrating CF and CBF methods, hybrid systems aim to enhance recommendation accuracy while mitigating issues such as the new user and new item problems. However, this integration process of different methods brings disadvantages which can be found in Section 2.3.4 and advantages which are explained further in Section 2.3.4.

#### Advantages of Hybrid Recommender Systems

Hybrid recommender systems offer a versatile solution by integrating diverse methods such as CF and CBF. According to Aggerwal [28], this integration results in an improved recommendation accuracy. Soltani et al. [25] agree with Aggerwal on this. Kamyshev et al. [26] also agree but expand on this by stating that leveraging the strengths of these different approaches leads to more robust and personalised recommendations. As written in Section 2.3.1 and Section 2.3.2 CF and CBF both suffer from the cold start problem. Schedl et al. [35] believe that hybrid systems can effectively mitigate this problem by incorporating content-based recommendations for new users/items. The ability of a hybrid RS to use the strong aspects of different algorithms makes it a strong tool to handle a lot of different situations. Adomavicius et al. [22] believe this flexibility to enhance user satisfaction and overall recommendation quality.

#### Disadvantages of Hybrid Recommender Systems

Even though a hybrid RS solves problems encountered by "standard" CF and CBF methods, designing and implementing hybrid recommender systems pose challenges. According to Aggerwal [28] complexity may increase due to the need of integrating multiple algorithms and handling diverse data types at one time. This complexity could result in a higher computing time. Furthermore, Kamyshev et al. [26] state that certain hybrid RS models may demand higher initial data requirements. Especially hybrid models which rely on CF. Moreover, Adomavicius et al. [22] believes that the performance of hybrid methods relies heavily on the quality and diversity of available training data. This data can often be limited in sparse data environments.

#### Conclusion

Despite the challenges mentioned in Section 2.3.4 hybrid models also bring a lot of advantages see Section 2.3.4 and have the potential to improve recommendation outcomes across various domains. The advantages and disadvantages are shown in the table below. In the scope of this research, a hybrid RS could be a good outcome as it is able to use both CBF and CF in order to use the strong points of both filtering methods. However, the hybrid RS needs high initial data requirements and does increase complexity. This will make it harder and more complex to build the final filtering tool and could result in a tool that is hard to be updated by different developers later on.

### 2.3.5 Conclusion

To conclude, the four algorithms for RS all have different advantages and disadvantages where Hybrid models stand out the most since they are made to combine both CF and CBF. However combining two algorithms into one does not come without challenges. These challenges could be detrimental to such an extent that just using CF, CBF or KBF would be better for an RS based on the circumstances. The advantages and disadvantages of each algorithm are shown in the tables below.

| Advantages | Disadvantages |
|---|---|
| Utilises user-item interactions for prediction | Cold start problem for new users/items |
| Can capture complex user preferences | Data sparsity due to limited ratings per user |
| Can provide serendipitous recommendations | Scalability issues with growing user/item databases |
| | Vulnerable to biases such as data and algorithmic bias |

**Table 2.2:** Advantages and Disadvantages of Collaborative Filtering in Recommender Systems

| Advantages | Disadvantages |
|---|---|
| User Independence | Limited Content Analysis |
| Transparency | Over-Specialization |
| New Item Recommendations | New User Problem |

**Table 2.3:** Advantages and Disadvantages of Content-Based Filtering in Recommender Systems

| Advantages | Disadvantages |
|---|---|
| Immunity to cold-start problems | High setup costs |
| Detailed preference feedback | Rely on dialog based conversational processes |
| Bypassing the new item and new user start problem | Static suggestion ability |

**Table 2.4:** Advantages and Disadvantages of Knowledge Based Filtering in Recommender Systems

| Advantages | Disadvantages |
|---|---|
| Increased recommendation accuracy | Higher complexity due to multiple algorithms |
| Mitigates the cold start problem | Higher initial data requirements |
| Higher flexibility | Varying design and implementation complexity |
| Robustness against sparsity and data scarcity | Performance relies on the quality and diversity of data |
| Diverse recommendations | Challenges in interpreting and explaining recommendations |

**Table 2.5:** Advantages and Disadvantages of Hybrid Recommender Systems

## 2.4 State of the Art

When you are designing for a new tool, one should first explore everything that is already available and use that to draw inspiration for their own creation. It is important to know everything that is already known on the market and in this specific case, what elements/algorithms have been shown to be effective in RSs in healthcare specifically. In order to gain insights into the tools that are already on the market, a search was performed in order to discoverer innovative and interesting tools used.

### 2.4.1 Recommender systems in e-commerce

Currently, most used RSs are used in the field of e-commerce think about websites as Coolblue.nl [46], Bol.com [47] and Booking.com [48]. These websites however, do already use their RSs in different ways. When looking at Coolblue.nl for example they share more data and more explanations with the users in order to make them understand the products better. They use a product filter/“Keuzehulp” Figure 2.1 as a decision support tool which guides the users step by step to help them find the most appropriate product.This support is useful even when a user does not understand all the electronic parts of the product.

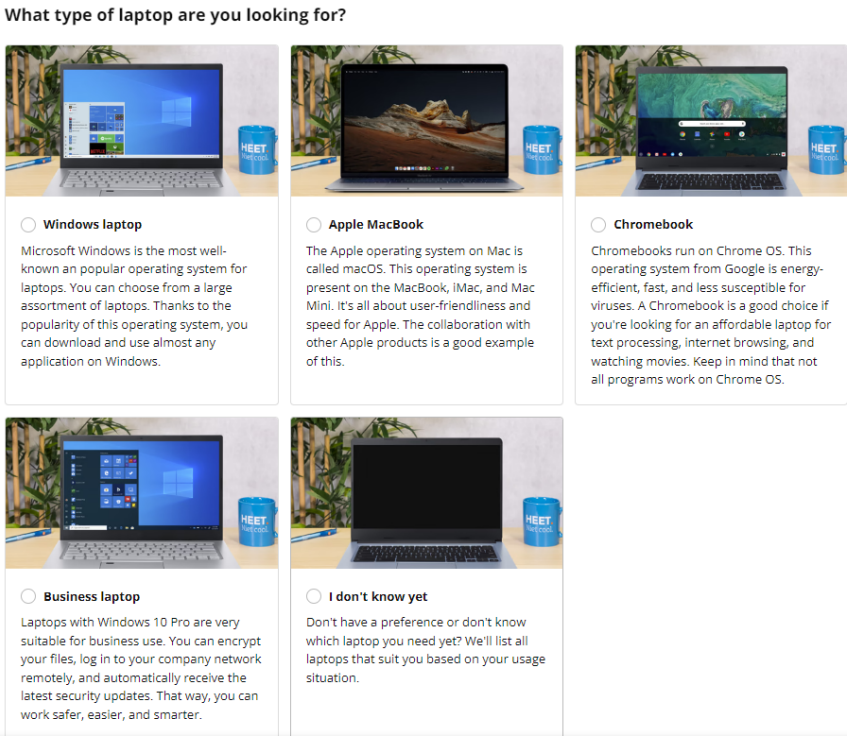


**Figure 2.1:** The product help filter system from Coolblue.nl

Not only does Coolblue take users by the hand through the entire process, the most important part is in the fact that they share explanations of separate parts of the product with both textual and visual information in order to show the user what exactly a given part of the product does and why they might need it, see Figure 2.2. This additional information helps users make decisions regarding their needs, even if the user does not have any initial knowledge on the technical specifications of the product.

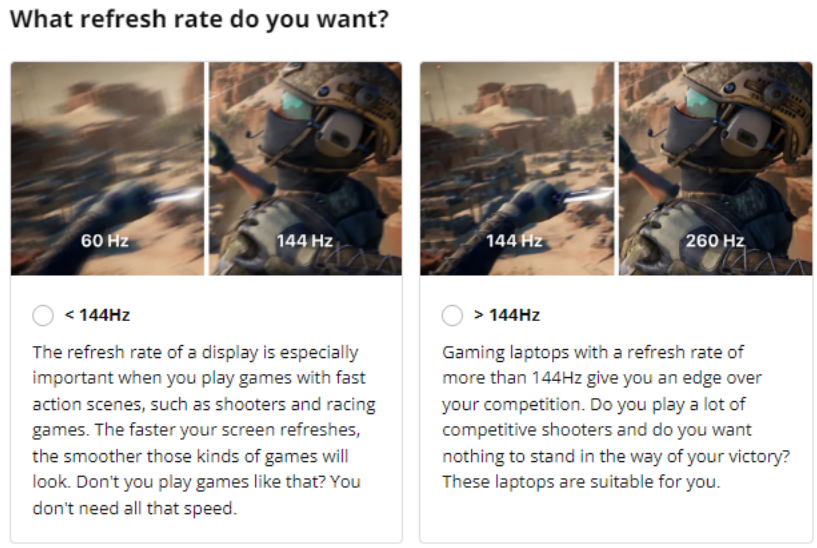


**Figure 2.2:** informative explanations within the product filter of Coolblue.nl

Bol.com handles the information challenge in an entirely different way than Coolblue.nl. They use separate advice pages on their website see Figure 2.3. On these advice pages they show several use case scenarios for a product and then advice a user which minimal requirements they should filter on in order to use the laptop for their use case. This however, does not explain to users why these requirements are necessary.

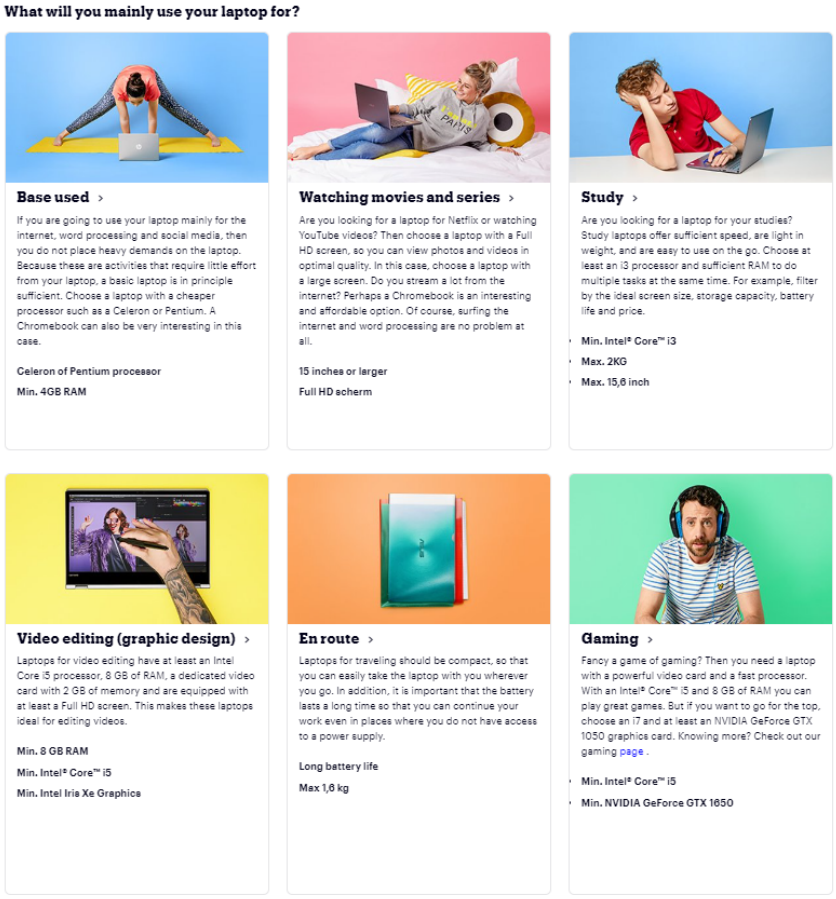


**Figure 2.3:** Use case scenarios from Bol.com

Nonetheless, on these advice pages Bol.com does try to show users how they can interpret the advice from the use cases. They do so by showing the most important specifications of a certain product and then showing textual explanations of these specifications to the user, see Figure 2.4

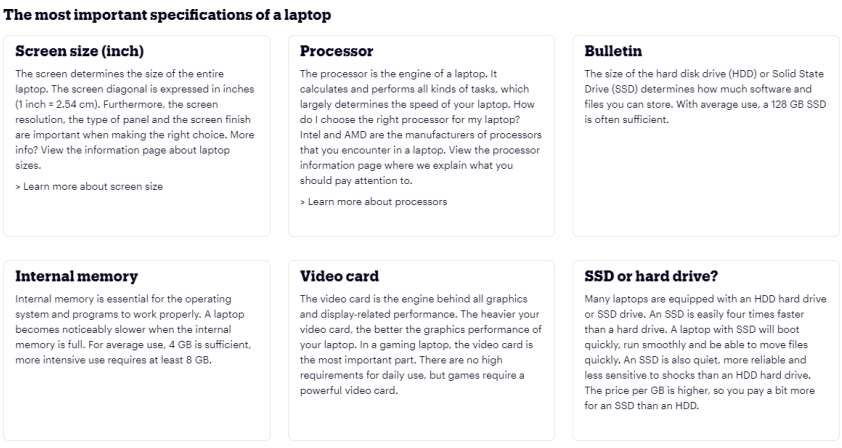


**Figure 2.4:** Textual explanations for important specifications from Bol.com

These textual cues are for some users, sufficient to understand the specifications of the product. However, for other users this might not be enough. In which case they would need to spend more time and effort to figure it out for themselves, or have prerequisite knowledge about the subject. So, between Coolblue.nl and Bol.com one could state that Coolblue.nl handles their UX better because they take their user by hand with visual cues and textual cues whereas Bol.com uses only textual cues for specific important specifications and leaves out the rest of the information, so a user would have to spend more time and effort to get to

their best recommendation.

One other feature both Coolblue.nl and Bol.com use to help their users in the recommendation process is in comparing certain products. On both their websites users are able to set up products to be compared to each other in their separate comparison screens. Both websites use the same lay-out and the same features for this see Figure 2.6 and Figure 2.5.

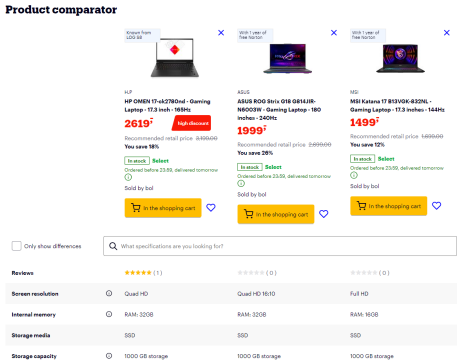


**Figure 2.5:** Comparing different kinds of laptops on Bol.com

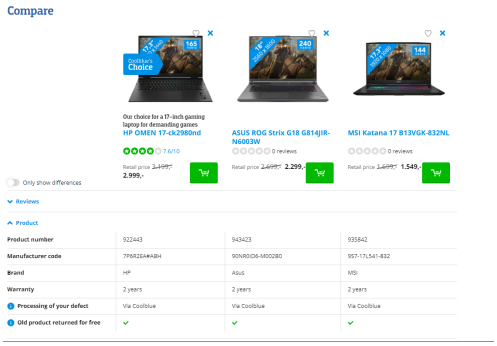


**Figure 2.6:** Comparing different kinds of laptops on Coolblue.nl

This way of comparing products can be seen to be informative to a user as it utilises explanatory popups to clarify the different specifications while also outlining the important comparison factors. This once again gives an experienced user a good overview of all the specifications of each device without having to look through explanations of each detail. Additionally, it gives inexperienced users the possibility of using explanations in order to give them more sense and experience in comparing devices.

To summarise, websites like Coolblue.nl and Bol.com are using recommender systems to help customers find the right products. Coolblue.nl, for example, has a feature called "Keuzehulp" which guides users through selecting products step by step. It doesn't just stop there; Coolblue.nl also provides explanations and pictures to help users understand what each part of a product does. This makes it easier for users to make informed choices, even if they're not experts on the technical details.

On the other hand, Bol.com takes a different approach. They have separate advice pages that show different ways people might use a product. But while Bol.com does provide some explanations for important specifications, they don't cover everything. This means users might need to do more research or already know a bit about what they're looking for to make the best decision.

Both Coolblue.nl and Bol.com let users compare products side by side. They use similar layouts and features to help users understand the differences between products. This comparison tool includes pop-ups with explanations about product specifications, which is helpful for users who want to compare without diving into every detail.

Overall, Coolblue.nl's approach seems to offer a more user-friendly experience. By providing both visual and written explanations, they make it easier for users to understand products and make decisions. Bol.com's reliance on written explanations might make it harder for some users to grasp all the details they need. However, both websites are trying to make the shopping experience easier and more informative for their customers. In the end, it's about finding the balance between giving enough information to guide a decision without overwhelming the user.

### 2.4.2 Recommender systems in healthcare

As stated in Section 2.4.1 most known RSs are used in E-commerce, but that does not mean that there are no RSs used in healthcare. Etemadi et al. [27] have created an overview of existing recommender systems and their purpose. Etemadi et al. have also specified the different RSs in the three categories that have been discussed in Section 2.3. namely: CF, CBF and KBF. These RSs that are discussed by Etemadi et al. [27] offer new ways of using RSs within the different fields of healthcare. These new ways again come with different advantages and disadvantages. For example, in Section 2.3.1 we discussed the advantages and disadvantages as can be seen in Table 2.2, but some of the disadvantages mentioned in Table 2.2 have been "solved" by the recommender systems created over the years. Davis et al. [49] had already created a CF engine which relied on a patient's medical history to predict the risks of future diseases. Their engine was actually able to handle bigger databases so it was able to handle the scalability problem.

However it gained the disadvantage of needing a medical expert to use the system, which made it very dependent. Besides Davis et al., Also Deng & Huangfu [50] were able to solve the scalability problem of CF by incorporating deep learning within their model in order to "use multi-sourced information and thus provide proper healthcare recommendations in the primary care service"[27]. This however does lead to another problem arising namely the problem of time. Incorporating deep learning within an RS does make the processing time of a system longer. This could then negatively influence UX. Besides Davis et al. and Deng & Huangfu more CF RS are discussed by Etemadi et al., and they show that the main advantage of CF is the ability to capture complex user preferences and thus resulting in a high accuracy. This is agreed on by Davis et al. [49], Yang et al. [51], Kaur et al.[52], Mogaveera et al. [53], Guzmán et al. [54], Hussein et al. [55] and Motwani et al. [56]. All of them have the advantage in their healthcare recommender system of being able to capture complex user preferences and thus having a high accuracy. This is very important in the field of healthcare as a lower accuracy might result in false research results and could lead to a false conclusion about a person's health or the best way to handle a patient.

When it comes to CBF RSs, they are created in one of two ways. Either by using Learning based models or using Mathematical based models. Most Learning based models are known for their accuracy in recommending new items to users. This matches the advantage of new item recommendations given in Table 2.3. Etemadi et al. [27] describe that one of the Learning based models that handles accuracy well is the recommendation engine from Folino & Pizzuti [57], which uses a "combination of association and clustering rules to create a predictive disease model"[27]. Their system uses past history of a medical patient to determine whether an individual would be infected with which disease in the future. However, as with other CBF systems the engine created by Folino & Pizzuti [57] does have a hard time scaling with new users or as seen in Table 2.3, with the New user problem. This is a problem as they are not able to easily add new users to their system. However, in the field of healthcare there are constantly new users needed in the system as new users are born. In contrast to Learning based models, Mathematical based models are known for its faster computing time. They are able to use mathematical formulas as their base and thus speeding up their processing time. They can do so by either using the vector space model as used by Agarwal & Mostafa [58] in their content-based image retrieval application to leverage users related information and feedback in order to gain performance much better than other engines. Thus also resulting in a high precision. Mathematical based models can also use a statistic analysis as shown by Mustaqueem et al. [59] for the purpose of suggesting appropriate medical advices to heart disease patients. Using a statistical analysis model over a vector space model does mean that computing time goes up a bit so it loses its processing-time advantage over Learning based models but it does gain higher accuracy and user independence.

In conclusion, the exploration of recommender systems in healthcare reveals both progress and hurdles. CF systems excel in understanding user preferences and accuracy, yet grapple with scalability and reliance on expert input. The integration of deep learning, exemplified by Deng et.al [50], offers promise for scalability but introduces processing delays that affect user experience.Similarly, CBF systems, whether through Learning or Mathematical approaches, show strengths and weaknesses. Learning-based models, like Folino et.al. [60], boast accuracy but struggle with scaling up, especially with new users. Conversely, Mathematical-based models, such as those by Agarwal & , Mostafa [58] and Mustaqueem et al.[59], offer speed and precision, albeit with a slightly slower processing pace compared to Learning-based ones. In summary, the development of recommender systems in healthcare requires a delicate balance of accuracy, scalability, and efficiency. Researchers must tackle these challenges to ensure widespread adoption and effectiveness in enhancing patient care. The following sections will delve deeper into specific methodologies and implementations, aiming to contribute to this evolving field while addressing identified gaps and opportunities.

### 2.4.3 Online wearable device databases

The field of online usable wearable device databases is diverse. Each platform offers different features in order to address the needs of various user groups. Below, five notable platforms are examined: Vandrico Wearables database [61], OWEAR [62], Datarade [63], Aparito [64] and, IoT-Lab [65]. This section will discuss their similarities and differences.

#### Comparison of the five platforms

Each of the five websites offers a distinct approach and functionalities within the field of wearable technology. Vandrico [61] provides a detailed database of wearable devices that are usable in various industries. Their

database also offers extensive technical specifications, use cases and industry applications. Vandrico [61] is particularly notable for its industry-wide scope, providing comprehensive device profiles.

In contrast, the Open Wearables Initiative (OWEAR) [62] is a community driven-hub that focuses on the open sharing of algorithms and datasets related to wearable technology. OWEAR [62] aims to promote the use of sensor-generated health measures in clinical research by providing a searchable database of bench marked algorithms and source codes. This emphasis on open-source resources and community contributions set OWEAR [62] apart from other databases, promoting collaboration and standardisation in digital health.

Datarade [63], on the other hand, offers a database of wearable devices with a strong focus on marketing and consumer data. It provides verified records of individuals using wearables for targeted marketing campaigns. Datarade [63] stands out by emphasising data quality and customisation for marketing, which contrasts with the other platforms more focused on healthcare or device specifications.

Aparito [64] integrates wearable data into global clinical studies, thus enhancing data quality and patient monitoring. By leveraging commercial-grade wearables, Aparito [64] collects real-time health data to support clinical research and remote patient monitoring. Their strength lies in their application with clinical trials, by providing actionable insights from wearable data.

The IoT-Lab's [65] FLIRT project centers on developing digital biomarkers through wearables and other connected devices. FLIRT aims to create innovative tools for health monitoring and disease management. The project's focus on the practical application of wearable data in developing new biomarkers and health measures underlines the IoT-Lab's [65] commitment to advancing digital health solutions.

### Contrast of the five platforms

While the above mentioned five platforms share a common goal of leveraging wearable technology, their primary focus and target audiences do vary significantly. Vandrico's [61] broad industry focus and detailed device profiles suits businesses and developers across multiple sectors. This approach contrasts a lot with OWEAR's [62] focus on open source resources and community collaboration, which targets researchers interested in clinical applications of health metrics.

Similarly, Datarade [63] and Aparito [64] differ in their core functionalities. Datarade's [63] primary strength lies in their marketing and consumer data, which offers verified contact information for targeted marketing campaigns. This commercial focus differs from Aparito's [64] integration of wearable data into clinical studies, where they aim to enhance patient monitoring and provide healthcare professionals with real-time health insights.

On the other hand, the IoT-Lab [65] and OWEAR [62] both emphasise research and innovation but do so from different perspectives. the IoT-Lab [65] focuses on creating new digital biomarkers and health solutions, emphasisin the practical appliction of wearable data. OWEAR [62], however, provides open algorithms and datasets to support broader clinical research, thus promoting collaboration within the research community.

Vandrico [61] also provides a comprehensive database across multiple industries whereas Datarade [63] has their focus on consumer data to support marketing. Aparito [64] and the IoT-Lab [65] also have different purposes despite both being in the health domain. Aparito [64] uses wearable data or clinical trials and patient monitoring, while the IoT-Lab [65] is dedicated to developing new health metrics.

In summary, these platforms all provide comprehensive resources for various aspects of wearable technology. Each different in target audience and functionality but all working towards the goal of making wearables more usable in daily life.

# Chapter 3.
# Methods & Techniques

The method used to design the filtering tool follows the Creative Technology Design method by Mader et. al. [66]. By using this approach a guideline for creating for creating a design for the filtering tool is used. The method of Mader et. al. [66] suits this project since it is developed for design processes that "make use of existing technology in novel combinations – in contrast to developing new technology" [66]. The Creative Technology Design method is a process that consists of four different phases: Ideation, Specification, Realisation and Evaluation see Figure 3.1.

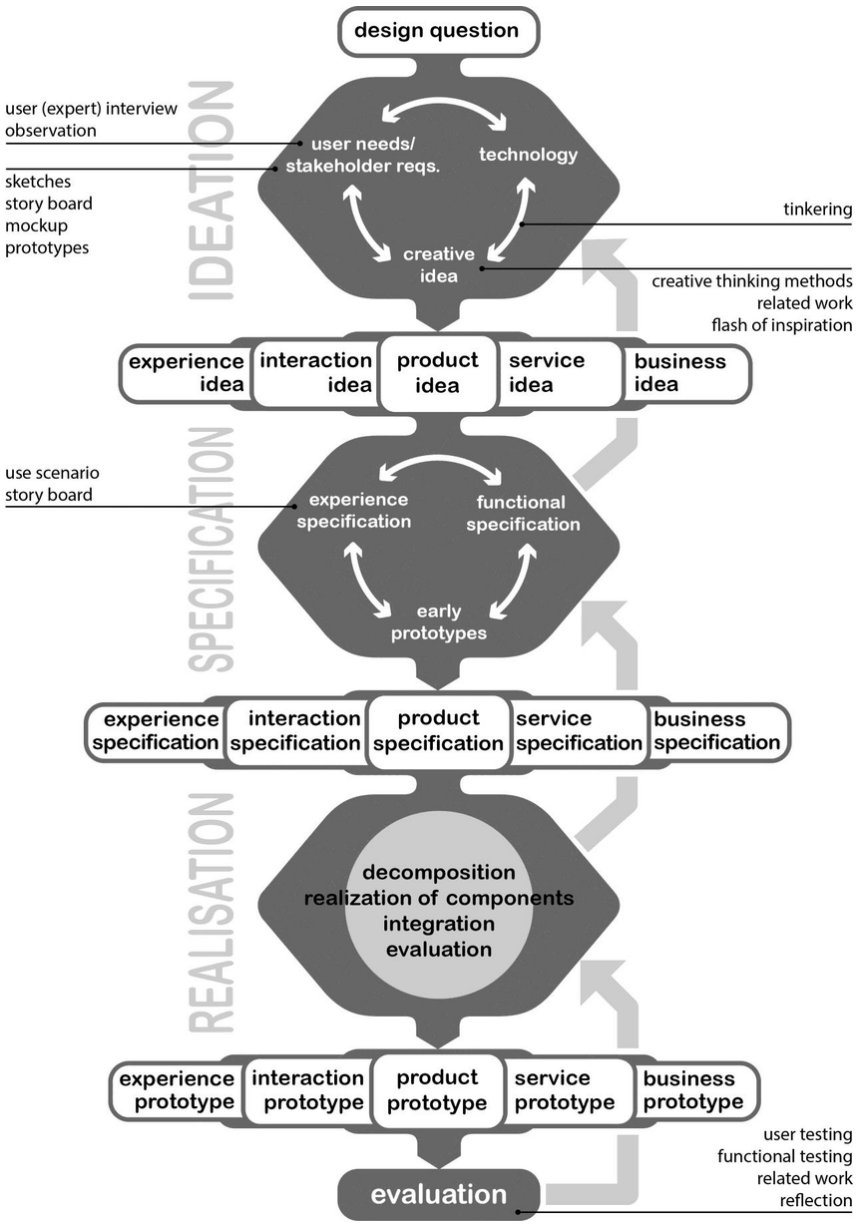


**Figure 3.1:** The Creative Technology Design Process

## 3.1 Ideation

The first phase in the Creative Technology Design process is the ideation phase. This phase uses the research question to start exploring technologies as the source of the design process and to set a design space. Afterwards there is an iteration phase of the technology which narrows the design space down to a specific solution. Requirements, constraints and other boundaries are set to help specify the design even further, whilst making sure the research is still within scope. In Figure 3.1 it can be seen that the ideation phase can have three different starting points: user needs/stakeholder requirements, technology and creative

ideas. Since this project is for a specific user group and for the SiA project the user needs/stakeholder requirements is the best starting point for the ideation of the filtering tool.

## 3.2 Specification

Within the specification phase the goal is to understand the needs of the project. The project will build upon the ideation phase by creating a final list of requirements aimed at creating the building specifications for a prototype of the filtering tool. These requirements will then be structured by the MoSCoW method [67] to assign priorities for the realisation of the design. Priorities can be categorised as *Must* have, *Should* have, *Could* have or *Will not* have. Before it is possible to create a full list of requirements for the product, an identification of stakeholders must be done. This product will mostly focus on researchers in ambulatory stress research, but other groups of users might want to use the filtering tool as well. This could result in different requirements. For this purpose a stakeholder analysis should be conducted.

## 3.3 Realisation

The third phase of the Creative Technology Design Process is the realisation phase. This phase will focus on creating the actual product. The list of requirements created in the specification phase will be used as a basis for the start of the realisation process. During this phase the product will be created in steps. first the data from the SiA WD will be pre-processed into a format that will be compatible with the to be chosen recommendation library. Secondly, a back-end for the filtering tool will be set up by using Python flask. Python flask will be used for this project because of its flexibility in the environment and implementation of features and its ease of use. Afterwards, a front-end will be created for the filtering tool. When the front-end has been created JavaScript can be added into the front-end. After the creation of a back-end and a front-end the first parts of an RS can be integrated into the back-end by including recommendation logic. Then the different kinds of recommendation logic can be implemented. For this, the best recommendation algorithm will have to be chosen and configured. This algorithm can then be loaded and trained by using the pre-processed data from the first step. Afterwards this algorithm should be able to generate recommendations. These recommendations then will have to be displayed into the frond-end dynamically while incorporating the filtering decisions made by the users. The second to last step will be to enhance the user experience of the filtering tool. This could be done by integrating interactive filtering options or personalised recommendations and by implementing correct error handling and sending clear feedback in order to guide users in case of incorrect inputs or failed requests. Finally, the filtering tool should be tested by users in order to ensure that it functions properly and will provide accurate results.

## 3.4 Evaluation

The evaluation phase is the fourth and final phase of the Creative Technology Design Process and will focus on evaluating the requirements that were set up in the specification phase in respect of the final product. Some requirements might not be functional in the end so these will be evaluated. Furthermore, the product will be tested by users in this phase. This can be done in two ways. The first way is a physical session where a user will walk through the filtering tool for a specific set of tasks whilst the creator of the filtering tool observes and notes down any notable actions or situations. Afterwards an interview will be conducted by the creator of the filtering tool, asking the user about their experience with the filtering tool. Another way of testing the filtering tool would be to send the final tool to potential users, since it will be a web-link together with an online form. The users then again use the filtering tool for a specific set of tasks, whilst afterwards they will fill in the online form with their experiences. The first way of testing will most likely gain more in-depth results from the interview as the interviewer is able to ask follow up questions on certain answers the interviewee gave. Whilst the second way will be able to reach a greater audience which will result in more feedback.

# Chapter 4.
# Ideation

The Creative Technology Design method of Mader et al. [66] mentioned in Chapter 3 begins with the ideation phase. This phase will start off with a semi-structured interview conducted with the three experts from the SiA that created the SiA WD. This interview was conducted in an exploratory way in order to find requirements and needs from the experts for the filtering tool. afterwards the phase focuses on the analysis of the stakeholders and their requirements for the creation of the filtering tool. The analysis of the expert interview and the stakeholders will result in a list of requirements sorted with the use of the MoSCoW [67] method. These requirements will be taken into account during brainstorming which will focus on the different platforms to build the filtering tool on and the front-end/experience of the filtering tool.

## 4.1 Stakeholder Analysis

The success of any project, particularly a project aimed at addressing complex health issues like stress measurement, relies heavily on understanding and engaging with stakeholders effectively. In this section, key stakeholders will be identified and analysed with their involvement in the development and utilisation of the filtering tool. This will be done by using the Stakeholder Salience Model (SSM) created by Mitchell et. al [68]. This model will be used to categorise stakeholders based on their power (the ability to impose their own will onto the project), urgency (need for immediate action) and legitimacy (appropriate involvement). Based on the possession or lack of these attributes there are eight different types of stakeholders as can be seen in Figure 4.1.

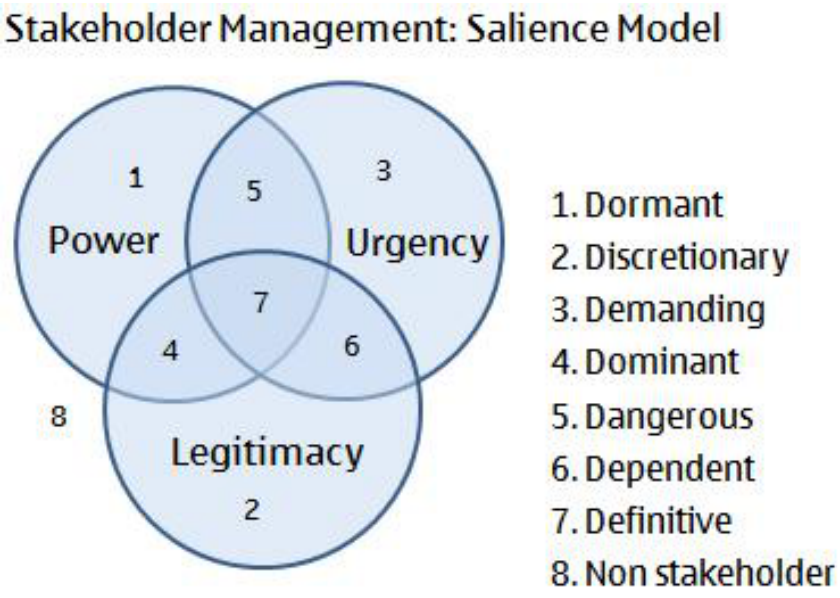


**Figure 4.1:** Stakeholder Salience Model

### 4.1.1 Stress in Action members

SiA plays an important role in driving the creation of the filtering tool forward. As the initiators and creators of this project, SiA members hold great legitimacy in shaping its direction and objectives. Their involvement ensures that the project aligns with the consortium's overarching goals of understanding stress responses in everyday life and improving stress measurement methodologies. Moreover, SiA members demonstrate a high level of urgency in addressing the issue of stress measurement. With the creation of the SiA WD they have created the option of helping researchers with their research of stress. Yet, this database needs to be translated into a tool as soon as possible so that the impact of the database and the tool remains significant. In terms of power, SiA members maintain a high degree of influence over project decisions and collaborations. Their first leading step in establishing the SiA WD for stress measurement shows their ability to drive change and innovation in the field. The combination of legitimacy, urgency, and power positions SiA members as *definitive* stakeholders for this project.

### 4.1.2 Researchers and Academics

Researchers and academics are a diverse and influential stakeholder group within the project of the creation of the filtering tool. As the filtering tool will eventually be created and used by these researchers and academics, they play a crucial role in shaping project objectives. With their expertise in various disciplines ranging from psychology to physiology, researchers and academics bring valuable insights and perspectives to the project. Their legitimacy stems from their experience in stress research, making them trusted authorities in that field. Furthermore, researchers and academics are motivated to find solutions to issues in stress measurement. However, as stated by an expert in the expert interview Appendix A.1 most researchers show a low level of urgency as they are likely to just use tools and wearables known to them. As stated before, researchers and academics play a crucial role in shaping project objectives and methodologies. Through knowledge exchange, they contribute to the design and validation of wearable devices for stress measurement. The input from researchers and academics when sending feedback to the SiA after usage of the filtering tool will ensure that the project remains relevant and responsive to the needs of the research community. The combination of legitimacy, low urgency, and power positions researchers and academics as dominant stakeholders for this project.

### 4.1.3 Individuals using wearable devices

At the core of stress measurement in ambulatory research lie the individuals who participate in stress research in their daily lives. These users of wearable devices are a diverse group with varying needs and preferences. However, as stated in Section 4.2.1 the participant compliance is important to a researcher when conducting ambulatory stress research. This group of users does not exhibit a lot of power in the project of the creation of the filtering tool. But their need for effective and easy to use wearables shows their urgency in the completion of the filtering tool. Furthermore, these participants of stress research show their legitimacy with their lived experiences of stress and their input during research. This combination of urgency and legitimacy positions individuals using wearable devices as dependent stakeholders for the creation of the filtering tool.

### 4.1.4 Healthcare professionals

Healthcare professionals are authoritative voices that guide clinical practice and treatment decisions in the field of stress management and patient care. These healthcare professionals have great experience in diagnosing and treating stress-related conditions and are commitment to patient care and well-being. Therefore, the can be seen to have a great power in this project as they might want to rely on research done in the field of stress research where a researcher used the filtering tool in order to select the appropriate wearable. Their legitimacy comes from their commitment to patient care and well-being. They however, do not exert a great sense of urgency as they are not the main users for the filtering tool. This combination of legitimacy and power positions healthcare professionals as dominant stakeholders in the creation of the filtering tool.

### 4.1.5 Wearable device manufacturers

Wearable device manufacturers are the driving force behind the ever changing landscape of wearable technology. They show expertise in engineering and design for creating the wearable devices that the SiA WD is based on and thus the filtering tool will be created on. They show power in shaping the development and production of new stress measurement tool. Furthermore, their legitimacy is grounded in their record of already delivered solutions for stress measurement to the market. Their power does not match that of for example SiA but they do possess the resources and expertise to translate research findings into new practical and novel solutions. This combination of legitimacy and power positions wearable device manufacturers as dominant stakeholders for the creation of the filtering tool.

### 4.1.6 Conclusion

Upon analysing the different stakeholders involved in the project, the SiA members are considered to be the most important stakeholders within this project. They are followed by academics and researchers who will be the end users of the final filtering tool. As the end users of the tool the opinions and needs from the academics and researchers are important to take into considerations.

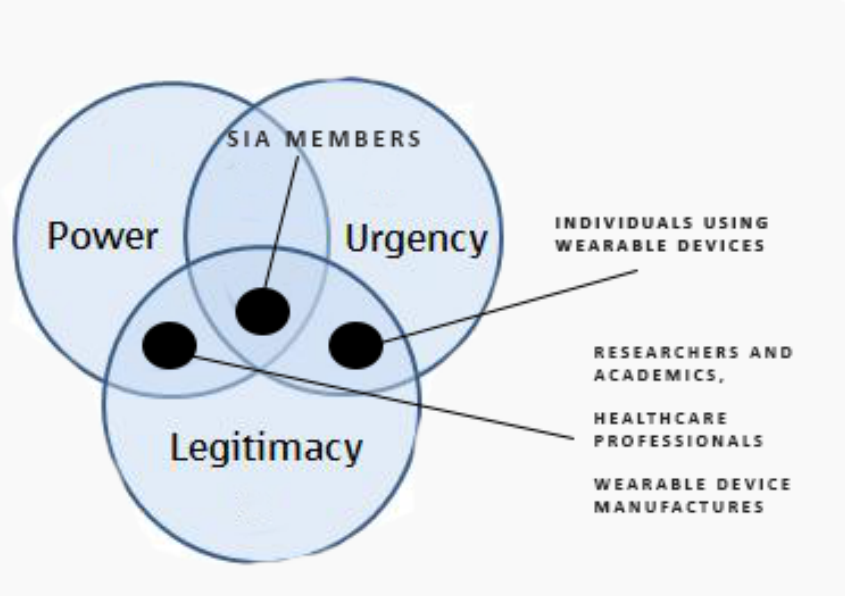


**Figure 4.2:** Stakeholder Salience Model for the creation of a filtering tool for stress research

## 4.2 Expert interview

The interview conducted in Appendix A focused on gathering the expert opinions for designing the filtering tool for the SiA WD. The experts interviewed for this interview are the same experts that created the SiA WD. These experts come from the following field:

- Expert 1:
  - *Focusses on combining scientific medical and technical knowledge for innovating and improving in health care.*
- Expert 2:
  - *Focusses on psychophysiological -primarily EEG- studies in relation to anxiety, borderline, schizophrenia, dissociation, and misophonia.*
- Expert 3:
  - *Focusses on Human Factors and Engineering Psychology.*

From this interview information in the form of four different categories are acquired through deductive analysis. These are: The challenges with wearable devices in the field of research Section 4.2.1, the needs for the filtering tool Section 4.2.2, the design ideas for the filtering tool Section 4.2.3 and additional features the filtering tool could have Section 4.2.4.

### 4.2.1 Challenges with wearable devices for stress research:

Throughout the interview multiple challenges for the selection on wearable devices as the use of the filtering tool were discussed. One of the challenges is on selection of a wearable device. Expert 2 stated in the interview that surprisingly many researchers do not even consider validity of their data as much as one would think. It is believed by expert 2 that in the field of ambulatory research researchers care much more about usability and participant compliance and that participants would continue the whole study whilst wearing the device and not dropping out. However, some researchers hardly look into what data they can actually get from using a wearable device and whether it is usable for their study. Expert 3 goes one step further stating that researchers sometimes are not aware of all the factors they should consider when selecting a wearable and that the SiA WD and the filtering tool could help with solving this challenge.

Another challenge is the challenge concerning the logistical part of an ambulatory research. This challenge has different limitations from the side of a participant or the side of a research. Expert 3 stated that one of the most important challenges on the side of a participant during ambulatory research is

participant adherence in order to gather the data over the course of the entire research period. This then means that certain limitations like battery life become more important. If a user has to charge their wearable device often a researcher would lose that time as data but more importantly it might become irritating for the participant of a study. Other challenges which also could end participant adherence are water resistance or just participant comfort. If a participant has to restrict themselves in their daily lives in any noticeable or obtrusive way in order to continue the study then the participant might get irritated with the wearable and end up dropping out of the study. This also involves the effort a participant has to take in order to take off the wearable device and to put it back on. How long is that process and is it complicated? Does it need to happen often? Does a participant need a lot of instructions every time in order to do so? Another part that fits participant adherence is the aesthetics of a wearable. If a wearable is very ugly, some participants might not feel inclined to wear the wearable as much or at all. This is difficult to keep track of and score since everyone perceives beauty and ugliness differently however, this should be something for a researcher to think about if they want to acquire as much data as possible. From the side of a researcher there are also logistical challenges like the possibility of data extraction. Researchers need to be able to know how they can extract the data or even whether it is possible at all. They need to know what kind of data they would get and whether it is possible to work with that type of data. Another challenge from the researchers side could be the fact that some wearable devices have been tested more than others. it might be that some researchers want to work only with wearable devices which are thoroughly validated whilst other researches just need devices which fit their participants or study purposes the best.

Besides logistical challenges there are also challenges with longitudinal studies. Expert 2 stated that the participant related concerns stated above will only weigh harder in the case of a longer, ongoing research. For example the aesthetics or comfort, even though they are hard to score or keep track off this starts to really matter if a participant has to wear the wearable device for multiple weeks or even months. From a researcher's point of view, the challenge that occurs with longitudinal studies is related to the management of the increasing data volume. It could be a bigger hassle to get and handle such big amount of data. If a researcher would get data from different signal channels, with high sampling rates measured over the period of three weeks, the amount of data could be enormous.

Last but not least, are the ethical considerations for wearable device selection. One of the most critical ethical consideration is the General Data Protection Regulation (GDPR) compliance. This means the way the data from participants is handled not only during the research but also afterwards. Does the wearable use external servers to store their data? For example a participant from Europe could be participating in a study that involves wearable devices that send their data to an external server in the United States. That server might not follow the GDPR and might not be compliant. Would you want to wear that wearable? Also for a researcher that is something to consider, since researchers in the The European Union (EU) have to apply the GDPR rules they would like to know whether a technological device sends and stores their data on a place that is not GDPR compliant.

In conclusion, the expert interview highlighted several challenges in selecting wearable devices for research purpose. It emphasised the importance of a focus on participant adherence especially for longitudinal studies. Furthermore, ethical considerations noticeably the GDPR compliance, came out to be a critical aspect of the wearable device selection. These challenges are currently addressed by the SiA WD by including the information on server location when it comes to GDPR compliance & are integrated into the requirements for the filtering tool in Section 4.3.

### 4.2.2 Needs for the filtering tool

From the interview, several underlying needs for the filtering tool were identified, which can be addressed by specific requirements. The first need is to facilitate selection. Researchers need an efficient way to find devices that meet their specific research needs based on various criteria. Therefore, the filtering tool must help researchers quickly and accurately identify suitable wearable devices. To address this, the filtering tool should include features that recommend a list of wearable devices aligned with the filters applied by the researcher. These filters need to be based on various criteria of the wearable devices present in the SiA WD.

The second need is the inclusion of comprehensive filtering options. Researchers need to filter devices based on critical factors such as price, signal type (e.g., ECG, PPG), validity scores, and participant burden. This need highlights the importance of user control and precision in device selection. Consequently, the filtering tool should provide a range of filtering options that are intuitive and easy to use, fitting seamlessly into the User-Interface (UI). Ensuring that these filters are user-friendly and logically structured will support the goal of facilitating device selection.

A third need for the filtering tool is to offer a user-friendly interface. Researchers require a tool that enhances the usability of the SiA WD, making data interaction simpler and more intuitive. The tool should be designed so that even researchers with only a basic level of knowledge of wearable devices can use it effectively. This implies the interface must be straightforward and avoid overwhelming users with unnecessary details, striking a balance between simplicity and functionality.

Another identified need is the ability to sort based on specifications. Researchers benefit from having the option to sort filtered results by essential criteria, such as price, validity scores, or user-defined importance (e.g., prioritising ECG over PPG). Addressing this need involves integrating sorting functionality into the filtering tool, ensuring it aligns with an easy-to-use UI while meeting researchers' specific prioritisation preferences.

Lastly, the need for future-proofing the filtering tool must be considered. The wearable device market is continually evolving, with new devices regularly added to the database. Researchers need a tool that can adapt to these changes. Therefore, the filtering tool should be developed using programming languages and platforms that allow for easy updates and modifications by the SiA. Additionally, incorporating user feedback mechanisms for reporting errors or suggesting improvements can ensure the tool is continuously refined and improved. Another future consideration is ensuring that users have a sufficient level of pre-knowledge. This could be managed through account-based access control, requiring researchers to register with their institutional email addresses, though this functionality is not immediately necessary.

By addressing these underlying needs with specific requirements, the filtering tool can effectively support researchers in their selection and use of wearable devices, providing a user-friendly, adaptable, and future-proof solution.

### 4.2.3 Design ideas for the filtering tool

From the interview the challenges mentioned in Section 4.2.1 also prompted insightful design ideas for the filtering tool. One of the foremost concerns addressed was the need for a user-friendly interface as the online shopping platforms like booking.com [48] and Coolblue.nl [46]. The interface of the filtering tool to be created should prioritise ease of navigation, with clear and concise categories guiding users through the filtering process. By recreating the familiar layout of the online shopping platforms, users will be able to seamlessly transition from one filter to another, thereby facilitating efficient exploration of available options. Moreover, visual cues and interactive elements should be incorporated to enhance the user engagement. This was done quite well by Coolblue.nl [46] as can be seen in Section 2.4.1. To further enhance user engagement dynamic feedback mechanism such as real-time updates on the selected criteria and their impact on results empower users to make more informed decisions and adjust their preferences accordingly.

Besides the need of a user-friendly interface, another design idea is with the optimisation of the filtering process, as the core of the filtering tool lies in its ability to distil a vast array of possible options into relevant choices for a user's needs. From the interview two options were proposed to achieve this goal: a step-by-step method and a combination approach. The first option of a step-by-step filtering process lets users progress through various filters one at a time. This method of filtering ensures that there is a focused and systematic exploration of the different criteria. It allows users to dive deep into each aspect before they move onto the next. The same way of working is utilized by the keuzehulp of Coolblue.nl [46] which is described in Section 2.4.1. It breaks down the selection process into manageable steps which helps users navigate through the complex decision tree while ending up with a selection aligned with their preferences and requirements. Conversely, the second option presents a combination approach that caters to users of varying levels. This approach uses an open filter view, providing users an unrestricted access to all available criteria. However, this would show a lot of complexity which might be harmful for the ease of use especially for novice users. Therefore, this approach combines the open filter view with the optional guided filtering for users seeking additional support as explained in the first approach. Such a combination allows to create balance between flexibility and guidance tailored to the experience of a user according to their expertise and preferences.

A third design idea for the filtering tool would be the aspect of dynamic feedback. Dynamic feedback is a fundamental aspect of a filtering tool with a good user friendly UI. Dynamic feedback allows users to assess the impact of their filtering on their selections in real time. By visualising the consequences of their choices on the displayed results, users can iteratively refine their criteria and optimise their search parameters. As such, dynamic feedback servers multiple purposes in our filtering tool: it enhances user engagement, promotes exploration of the filtering categories, and gives users a sense of control.

In conclusion, the design ideas for the filtering tool derived from the expert interview offer options for

creating an easy to use and promising framework for improving the selection process of wearable devices. By prioritising intuitive interface design, optimising the filtering process, and implementing dynamic feedback, the tool will be able to empower users with the information and resources needed to make informed decisions for their specific research.

### 4.2.4 Additional features

Besides challenges, needs, and design ideas the expert interview also pointed out some possible additional features of the filtering tool. These additional features, ranging from skippable steps in the guided filtering to clear explanations of technical terms would enhance the usability and functionality of the filtering tool, and in the end facilitate informed decision making in the selection of wearable devices for stress research.

The first additional feature mentioned is that of skippable steps in order to tailor the UX. This feature came up since the diverse needs and preferences of users have to be recognised. Not all users need all the steps and help while filtering whilst others might want this help. The inclusion of skippable steps in the filtering process offers a flexible and personalised approach to the selection process. By allowing users to bypass certain criteria they deem irrelevant or less crucial for their research objectives, the filtering tool will allow them to focus on the factors most important to their needs. This additional feature enhances UX and efficiency, it enables researchers to navigate through the filtering process with greater ease and precision. Users will be able to tailor their experience of the use of the filtering tool with their expertise and preferences.

Besides skippable steps another additional feature is the feature of essential versus additional filter categories. The effectiveness of the filtering tool is in the differentiation between essential and additional filter categories, by ensuring clarity and efficiency in the selection process. Essential categories cover fundamental criteria directly related to research objectives, like sensor types and data accuracy, while additional categories offer supplementary options for further optimisation. By prioritising relevance, the filtering tool would guide users toward critical decision-making factors while providing flexibility. A clear distinction between essential and additional categories streamlines the filtering process.

A third additional feature would be clear explanations of technical terms. Complex concepts such as ECG and PPG are cleared up through concise and accessible explanations, this would enable researchers to make informed decisions with confidence even if they do not know of these concepts. However, most researchers that do researcher with the use of wearable devices will have a base level of knowledge of these terms. Yet, clear explanations can serve as a bridge between the technical jargon and more user-friendly language.

After envisioning the integration of the above-mentioned additional features into the filtering tool, several questions came up. For example, should the filtering tool be publicly available or require an account-based access? Making the tool publicly available offers the advantage of unrestricted access, allowing users to utilise the filtering tool without the need for registration and access creation. This promotes inclusivity, aligns with open-science practices, and supports the ease of use of the filtering tool. However, this openness also raises concerns about the potential commercial exploitation of the Stress in Action database. While originally designed as a purely scientific project, the database could easily be used for commercial purposes such as market analysis or as a source of commercially beneficial information that companies could exploit. On the other hand, implementing account-based access provides the filtering tool with an additional layer of control over who can access the data. By requiring users to create accounts, the tool can authenticate and authorise access, potentially mitigating the risk of unauthorised commercial usage. Nonetheless, this approach may introduce barriers to accessibility, particularly for users who are hesitant to create accounts or unwilling to share personal information.

Another question that came up was: How can user-submitted feedback be managed effectively? Effective management of user-submitted feedback is essential for the continuous improvement of the filtering tool and the contents of the database itself. Robust mechanisms for collecting, analysing and responding to user feedback play an important role in iterative enhancements and addressing user needs. Implementing spam filtering mechanisms helps to identify and mitigate irrelevant or malicious feedback. By leveraging algorithms and heuristics to detect patterns indicative of spam or abuse, the filtering tool can maintain the integrity of its feedback system and preserve the quality of user submissions. Furthermore, the categorisation of user feedback facilitates organisation and prioritisation, allowing developers to identify recurring themes, common issues, and areas for improvement. Lastly, establishing channels for transparent communication and responsive engagement stimulate a collaborative feedback loop between users and developers. Prompt acknowledgement and meaningful responses to user feedback can demonstrate a commitment to user satisfaction.

In conclusion, the integration of additional features derived from the expert interview holds promise for enhancing the filtering tool's usability and effectiveness. By incorporating skippable steps in guided filtering, differentiation between essential and additional filter categories, and offering options for combining basic and guided filtering, the tool gives users flexibility, guidance, and clarity in their decision making process. Moreover, clear explanations for technical terms stimulate understanding and inclusivity, thus bridging the gap between expertise and accessibility.

## 4.3 Preliminary requirements

Besides the identification of stakeholders, the needs and requirements for the important stakeholders and the filtering tool should be investigated. From Chapter 2, and Section 4.2 preliminary requirements for the creation of the filtering tool can be acquired. These requirements can be structured with the use of the MoSCoW method [67].The formulation of these requirements was guided by established practices in requirements engineering, as detailed in recent research by Tukur et al. [69], and further refined by approaches from Beecham et al. [70].

**Must Have**

- Facilitating selection
  - The filtering tool **must** provide a recommendation list of wearable devices based on various criteria, allowing researchers to find devices that meet their specific needs.
- User-Friendly interface
  - The filtering tool **must** feature an intuitive interface that enhances usability and interaction with the SiA WD, making it easier for researchers to navigate without overwhelming novice users.
- Filtering options
  - The filtering tool **must** allow users to filter wearable devices based on factors such as price, signal type (e.g., ECG, PPG), validity scores, and participant burden aiding researchers in gathering a suitable recommendation list efficiently.
- Future adaptability
  - The filtering tool **must** be developed using programming languages and platforms that enable easy adaptation to accommodate new wearable devices added to the database, ensuring the tool remains relevant and effective over time.

**Should have**

- Dynamic feedback mechanism
  - The filtering tool **should** provide real-time updates on selected criteria and their impact on results, allowing users to refine their search parameters and make more informed decisions.
- Skippable steps in guided filtering
  - The filtering tool **should** allow users to bypass certain filtering steps they deem irrelevant or less crucial, thus enhancing UX and efficiency by tailoring the filtering process to individual preferences.
- Differentiation between essential and additional filters
  - The filtering tool **should** distinguish between fundamental criteria related to research objectives (essential) and supplementary options for further optimisation (additional), thus streamlining the filtering process while offering flexibility.
- Sorting functionality
  - The filtering tool **should** have the option to sort results based on essential criteria such as price, validity scores, or user-defined importance, thus improving UX and aiding decision making.

**Could have**

- Clear explanations of technical terms
  - The filtering tool **could** provide a user with concise and accessible explanations of complex technical terms (e.g., ECG, PPG), facilitating understanding for researchers with varying levels or fields of expertise.
- Account based access
  - The filtering tool **could** have account based access in order to handle data security and user privacy concerns.
- Effective management of user-submitted feedback
  - The filtering tool **could** have effective management of user-submitted feedback to help the future adaptations of the SiA WD and the filtering tool.

## 4.4 Concept generation

The stakeholder analysis conducted in Section 4.1 provides a clear overview of the people involved in this project and the needs to be considered when designing concepts for the prototype. During the concept generation phase it is essential to focus on the designs, in combination with the state of the art from Section 2.4 and the preliminary requirements from Section 4.3.

The phase of concept generation will be split in two parts: brainstorming and concept selection. The brainstorming mostly consisted out of concept/idea generation in respect to the platforms for the filtering tool.

### 4.4.1 Brainstorming

In the first section of the concept generation phase a brainstorming session was conducted for the possible platforms for the filtering tool and their advantages and disadvantages. At the start of the brainstorming session four platforms that could be used for the filtering tool were set as a design space in order to give the brainstorming phase a direction.

The first platform would be a website/web application. By opting for a web-based RS for selecting a suitable wearable device a lot of perks would be added to the project. It would make the RS more accessible to all researchers, regardless of their device as long as they have a working internet connection. This inclusivity is key for the project since it involves a wide range of researchers working from various locations. Furthermore, the interactive features of web apps make filtering and customising easy, thus making the whole process smoother. However, relying on a valid internet connection might cause a setback for researchers in remote areas of with a poor internet connection. Also, making sure that the RS works well across different web browsers and devices is crucial for a consistent UX.

The second platform was the mobile application. Developing a mobile app for the filtering tool would bring a lot of convenience for the project. With almost everyone owning a smartphone or tablet nowadays, having a mobile app would mean that researchers can access the filtering tool whenever and wherever they need to. Furthermore, by using a mobile application it would be easier to incorporate device features which could strengthen the filtering tool in the long run. But, creating and maintaining a mobile application is not easy. It means having to use platform specific languages like Swift for iOS and Java/Kotlin for Android, which adds a layer of complexity to the project. Besides this, it is also harder to get an app approved and listed in the app stores.

The third platform would be a desktop application, which would provide a robust platform for implementing the filtering tool. Thus offering researchers a feature-rich environment optimised for desktop or laptop use. By efficiently leveraging systems resources, a desktop RS application can ensure seamless performance, even when handling large datasets. Additionally, the incorporation of offline functionality allows researchers to access the filtering tool without a working internet connection, which could be a helpful feature for researchers in remote areas. Nonetheless, the development of a desktop application introduces certain complexities. It would need to be updated manually in the system every time there are changes made in the database. This would make multiple version which will not all be the best version of the database. Furthermore, Unlike web applications, desktop applications are bound to specific operating systems such as Windows or macOS, necessitating separate development efforts for each platform.

Ensuring cross-platform compatibility requires meticulous attention to detail to ensure a consistent user experience across different operating systems. Furthermore, distributing the application may entail manual installation or utilising third-party platforms, potentially impeding accessibility compared to web or mobile applications.

The final platform would be an interactive physicalisation. By implementing the filtering tool in the form of an interactive physicalisation, the filtering tool would be presented in a novel approach, offering a tangible presence suitable for academic institutions, research centres, or public spaces. Physicalising the tool means creating a physical, interactive interface using elements such as touchscreens, physical buttons, or voice commands, making it more engaging and accessible. This approach allows the filtering tool to reach a broader audience, including researchers, students, and the general public. Furthermore, integrating the interactive physicalisation with technologies such as RFID facilitates personalised experiences, enhancing user engagement and satisfaction. However, the deployment of interactive physicalisations entails upfront costs and logistical considerations. High initial setup expenses, including hardware acquisition and installation, must be factored into project planning. Additionally, the physical nature of interactive physicalisations limits their mobility and accessibility compared to web and mobile applications, necessitating strategic placement to maximise visibility and impact. Moreover, security considerations regarding physical tampering and data privacy are important to safeguard sensitive research information.

From the brainstorm we can conclude that each platform would offer unique benefits and challenges to the creation of the filtering tool. A web based filtering tool would enhance accessibility and UX but might be limited by connectivity issues. Developing a mobile app would provide convenience and the ability to incorporate device features, yet it entails complexities in development and approval processes. A desktop application would offer robust performance and offline functionality but requires meticulous attention to cross-platform compatibility and distribution. Implementing the filtering tool as an interactive physicalisation would present a novel approach, catering to a broader audience, even though there would be upfront costs and logistical considerations. The advantages and disadvantages of the four above mentioned platforms are also shown in Figure 4.3 below.

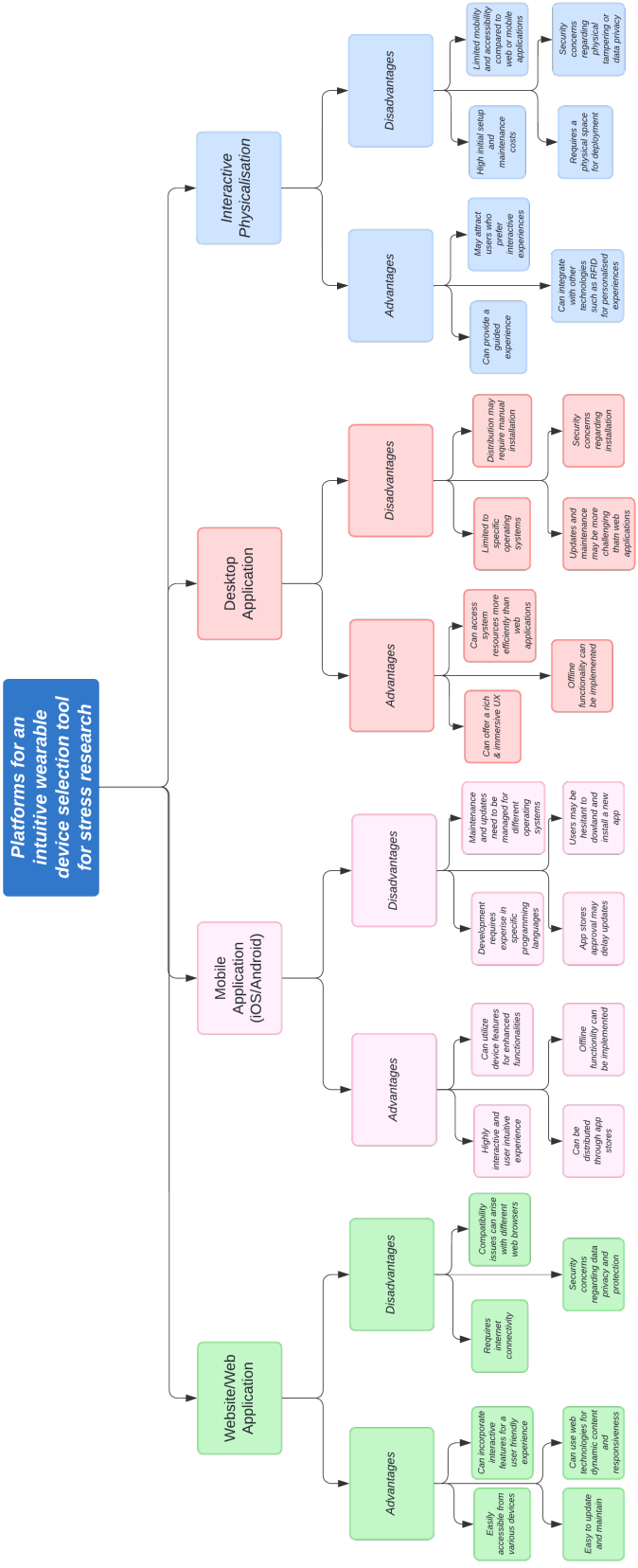


**Figure 4.3:** Flowchart of platforms for the filtering tool

### 4.4.2 Concept selection

Looking at Figure 4.3 in respect to the creation of the filtering tool it is concluded that a website/web application would suit the project best due to its inclusivity and ease of use. However, this website/web application would need an RS to go with it in order to make the filtering tool work properly. From Chapter 2, it can be concluded that in most cases a hybrid RS would be best to use in order to gain the most accurate recommendations and have an as smooth as possible flow. However, due to the complexity of a hybrid RS in combination with the requirement future adaptability gained from the expert interview (see Appendix A.1) a hybrid RS is deemed to be too complex and not suitable for the filtering tool at this point in time. Therefore, KBF is the best method to be used for the SiA filtering tool. This is due to the advantages listed in Table 2.4, in combination with the already created SiA WD which thus nullifies the disadvantage of high setup costs. Therefore, the final concept should be a website/web application with KBF.

However, this website can have three different work flows that can influence the ease of use of the filtering tool. These three different work flows are the following concepts.

#### Open filtering tool

The first concept is the usage of an open filtering website. This is a RS as it is nowadays known in its basic form, a list of filters on the left with check boxes allowing to include them, and a list of the corresponding items on the right. This would be a basic version of the filtering tool without much help for a user.

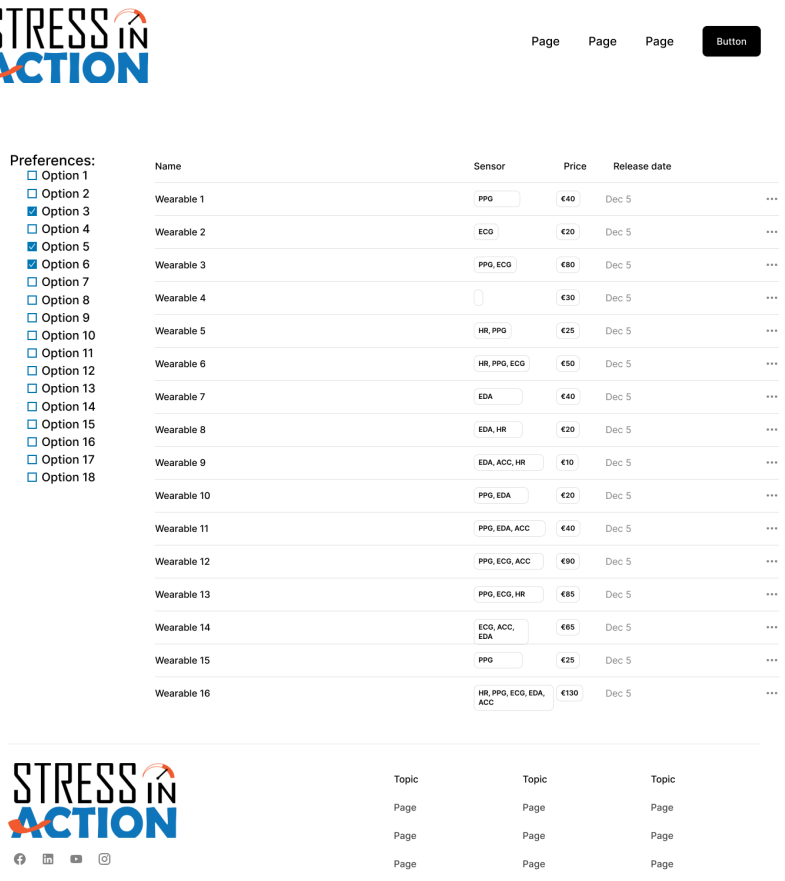


**Figure 4.4:** An open filtering website

#### Mandatory popup filtering

A second concept would be the same open filtering website but with the addition of a product filter as Coolblue.nl [46] also uses as is shown in Section 2.4. This product filter would be an instant pop-up upon entering the website by a user. A user would then be able to continue through the product filter by clicking on their desired option, by skipping one question or by skipping all questions if they want no help at all.

This product filter could help new users find their way around the filtering tool and make the filtering process easier than having to look through the big list of filters on the left side of the screen.

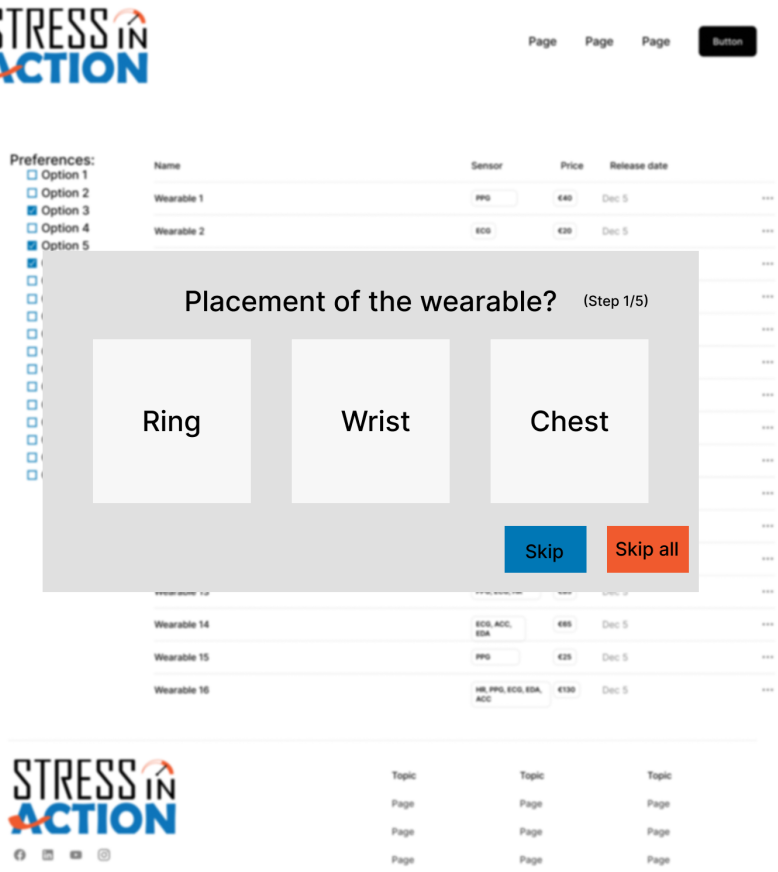


**Figure 4.5:** The filtering website with the pop-up

An option for this version would be to have the product filter only pop-up the first time a user would view the website. This could be done by the use of a cookie which would remember a user/device that has previously entered the website. If a user has the cookie the product filter could be a normal button above the filtering list which user can then choose to click if they would like to be helped in their process.

### Search bar filtering

The final concept for the filtering tool would be the usage of a search bar in order to filter through the list of wearables. A user would be able to enter a filter in a search bar that would auto complete a word (as long as a user does not make a typing mistake). Then a list of filters responding to that word or that part of a word would show up below the search bar. A user could then click on the filter they would like to be added. Consequently, the filter would be added to the list of active filters and the list of wearables on the right side would react accordingly to the filter added and dynamically show the wearables that are compliant with the list of existing filters. A user would be able to deselect a filter by clicking on the filter under the list of active filters, whilst hovering over the filter the filter will be strik through. This way of filtering would give a lot of freedom to the user but also a lot of responsibility. A user would need to have appropriate knowledge to know what to search for in order to get to the good list of wearables.

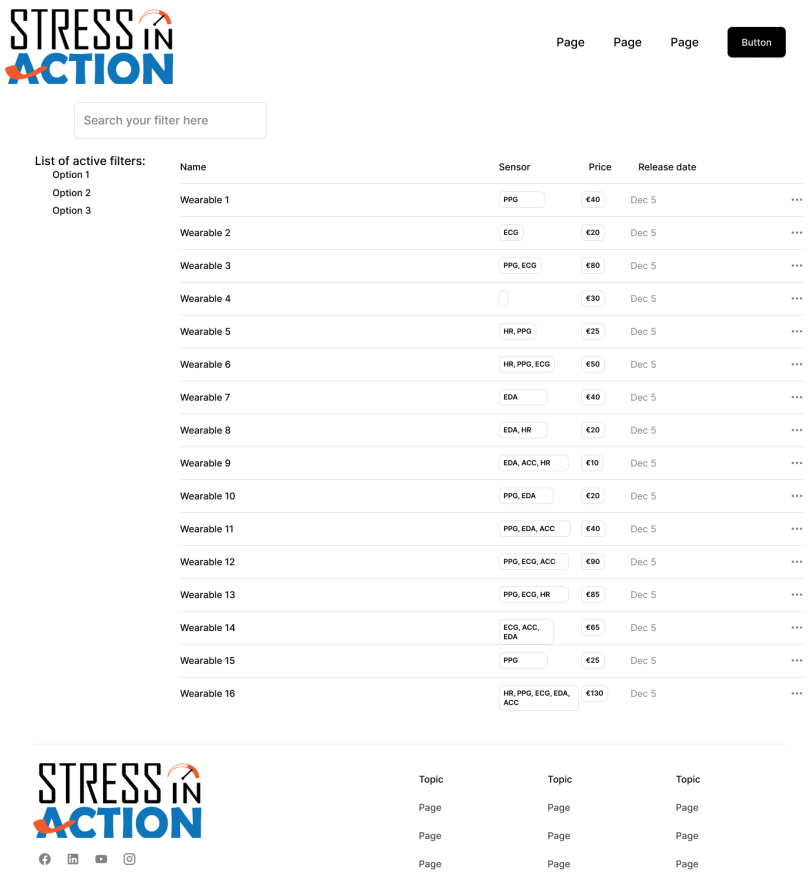


**Figure 4.6:** The filtering tool with a search bar

## 4.5 Final concept

Based on the brainstormed concepts, a selection has to find place in order to see which concept and which elements could be part of the final concept, and therefore the solution. It is important to check whether a concept is conform to the preliminary requirements set by the stakeholders (Section 4.1) and the background research (Chapter 2). This is done by creating table which sets the different requirements against the concepts generated. This will then show an overview of which concept would be best suited for the creation of the filtering tool.

| No | Requirement | Requirement |
|---|---|---|
| 1 | The filtering tool **must** provide a recommendation list of wearable devices based on various criteria, allowing researchers to find devices that meet their specific needs | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 2 | The filtering tool **must** feature an intuitive interface that enhances usability and interaction with the SiA WD, making it easier for researchers to navigate without overwhelming novice users. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 3 | The filtering tool **must** allow users to filter wearable devices based on factors such as price, signal type (e.g., ECG, PPG), validity scores, and participant burden aiding researchers in gathering a suitable recommendation list efficiently. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 4 | The filtering tool **must** be developed using programming languages and platforms that enable easy adaptation to accommodate new wearable devices added to the database, ensuring the tool remains relevant and effective over time. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 5 | The filtering tool **should** provide real-time updates on selected criteria and their impact on results, allowing users to refine their search parameters and make more informed decisions. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 6 | The filtering tool **should** allow users to bypass certain filtering steps they deem irrelevant or less crucial, thus enhancing UX and efficiency by tailoring the filtering process to individual preferences. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 7 | The filtering tool **should** distinguish between fundamental criteria related to research objectives (essential) and supplementary options for further optimisation (additional), thus streamlining the filtering process while offering flexibility. | Open filtering tool, Mandatory popup filtering |
| 8 | The filtering tool **should** have the option to sort results based on essential criteria such as price, validity scores, or user-defined importance, thus improving UX and aiding decision making. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 9 | The filtering tool **could** provide a user with concise and accessible explanations of complex technical terms (e.g., ECG, PPG), facilitating understanding for researchers with varying levels or fields of expertise. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 10 | The filtering tool **could** have account based access in order to handle data security and user privacy concerns. | Open filtering tool, Mandatory popup filtering, search bar filtering |
| 11 | The filtering tool **could** have effective management of user-submitted feedback to help the future adaptations of the SiA WD and the filtering tool. | Open filtering tool, Mandatory popup filtering, search bar filtering |

**Table 4.1:** Preliminary requirements compared to concepts

Comparing our three concepts with the preliminary requirements stated in Section 4.3 follows that all concepts follow most of the requirements only search bar filtering does not qualify for requirement 7: *The filtering tool should distinguish between fundamental criteria related to research objectives (essential) and supplementary options for further optimisation (additional), thus streamlining the filtering process while offering flexibility.*. Comparing the concept of Open filtering tool and Mandatory popup filtering with the State of the Art from Section 2.4 it shows that Mandatory popup filtering is a version oriented more towards a helping new users approach in the same way as Coolblue.nl [46] is doing. Whilst Open filtering tool is a basic version of a filtering tool which could be used by any website. From the expert interview (Appendix A.1) followed that a version like Mandatory popup filtering would be a nice version of the filtering tool in order to welcome new users, but with options that make the product filter skippable for experienced users that would like to not use it. Therefore the final concept will be Mandatory popup filtering Figure 4.5.

# Chapter 5.
# Specification

The fourth phase of the Creative Technology design cycle is the specification phase. Within this phase the chosen concept from Chapter 4 is elaborated upon by gathering user-specific requirements from stakeholders. These requirements are then turned into functional and non-functional requirements which allows the designer to put more details into the design making it a better, more functional and more appealing product for the end-user. This methodology aligns with best practices in requirements engineering, as discussed by Sommerville [71], where user needs are systematically transformed into functional and non-functional requirements to ensure the development of effective systems .Furthermore, Personas will be identified which can be seen as possible users of the end-product.

## 5.1 Personas

### 5.1.1 Persona 1: High-Technical knowledge

The first persona, is dr. Emily Johnson, a researcher with a strong focus on the impact of chronic stress on mental health. Emily Johnson has the goals of identifying specific stress markers and their correlation with mental health outcomes. To meet her research needs, the filtering tool must offer advanced options of filtering which will help her narrow down her options quickly, with detailed information on accuracy and validation of wearable devices to ensure data reliability. Additionally, she has trouble with time constraints due to her clinical responsibilities and administrative tasks. She would benefit from a user-friendly interface as it would help her streamline her workflow making it easier for her to manage her time. By providing, these functionalities the filtering tool would help Dr. Johnson by allowing her to focus on developing new therapeutic interventions and publish high-quality research.

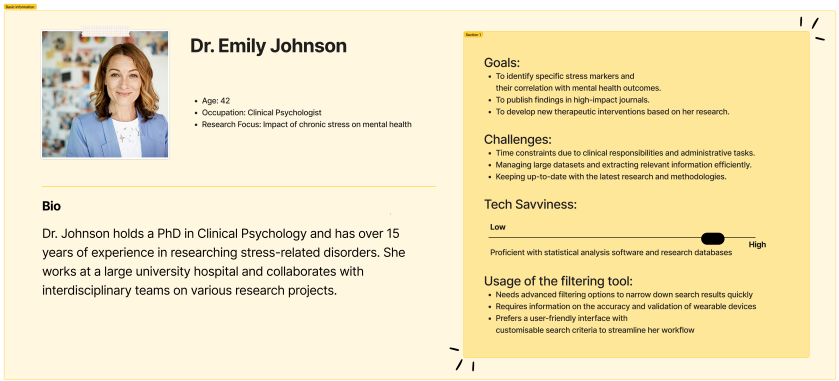


**Figure 5.1:** Persona 1 - Dr. Emily Johnson

### 5.1.2 Persona 2: Intermediate-Technical knowledge

The second persona is Dr. Ahmed Malik, a behavioural neuroscientist researching the neurobiological mechanisms of stress response. Dr. Malik aims to uncover the neural circuitry involved in stress responses and secure funding for large-scale studies. To meet his research needs, the filtering tool must allow him to filter wearables by measurement capabilities, data sampling rates and storage capacities. Dr. Malik also balances multiple research projects and grant applications, making it essential for the filtering tool to provide intuitive interfaces for efficient data analysis. By offering these specific filters, the tool would help Dr. Malik handle complex data accurately and focus on his research goals.

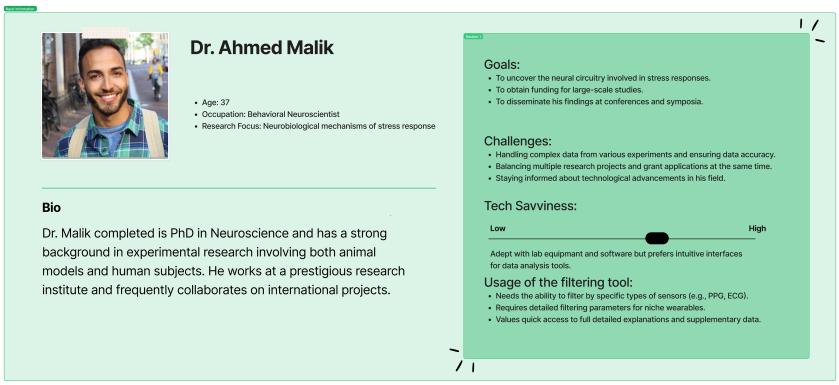


**Figure 5.2:** Persona 2 - Dr. Ahmed Malik

### 5.1.3 Persona 3: User-oriented

The third persona is Dr. Maria Lopez, a health psychologist focused on stress and coping strategies in diverse populations. Dr. Lopez aims to understand how different populations experience and manage stress and to inform public health policies and intervention programs. To meet her research needs, the filtering tool must allow her to filter wearables for ease of use, participant compliance, cost, and availability to accommodate budget constraints. She also prefers wearables that have been used in similar demographic research studies. By providing these functionalities, the filtering tool would enable Dr. Lopez to effectively conduct her research and disseminate findings to both academic and non-academic audiences.

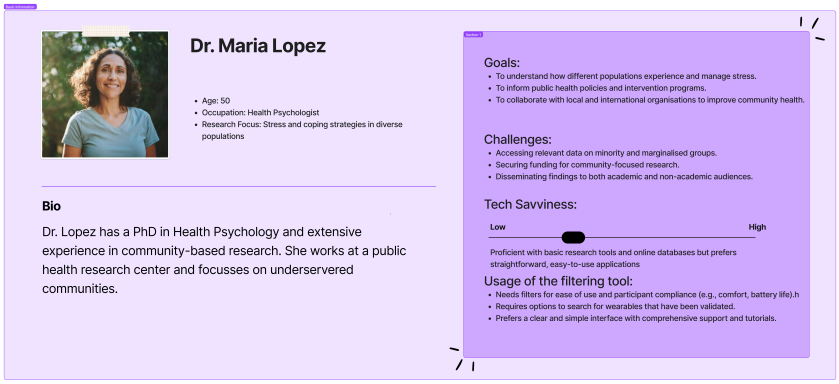


**Figure 5.3:** Persona 3 - Dr. Maria Lopez

### 5.1.4 Persona 4: SiA Researcher

The fourth persona is Dr. James Peterson, an occupational health psychologist focused on investigating the effects of workplace stress on productivity and employee well-being. As part of the Stress in Action consortium, he is conducting a large-scale study to identify key stressors in various work environments and their impact on employee mental health and performance. His ultimate goal is to develop evidence-based interventions to reduce workplace stress and improve overall employee health. In order to meet his research needs, the filtering tool must allow him to filter wearable devices by measurement capabilities, cost and availability and participant compliance. Dr. Peterson's work is pivotal in shaping policies and practices that foster healthier and more productive work environments so it is important for him to be able to find wearables that are GDPR compliant and devices that have been properly validated. By integrating all these functionalities, Dr. Peterson would be able to focus on writing new policies for workplace productivity and employee well-being whilst gaining correct and good data through the correct wearable for his research.

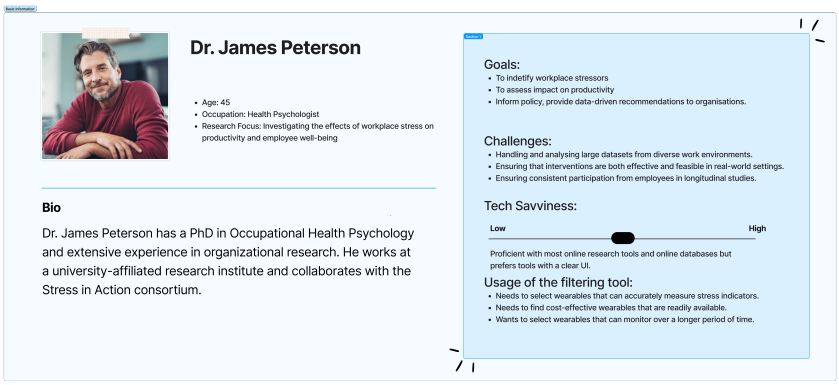


**Figure 5.4:** Persona 4 - Dr. James Peterson

## 5.2 Requirements

The user interview (Appendix A) and the creation of personas help with creating a list of features that the product should include in order to make it work on a technical and user level. In order to create an overview of these features two lists have been made and prioritised according to the MoSCoW Method [67]. The first list is the list of functional requirements whereas the second list is the list of non-functional requirements. By prioritising these requirements the design can be steered into the most optimal state in order to prepare for the realisation phase in which the most important requirements should be met first.

### 5.2.1 Functional requirements

Functional requirements are the requirements that describe what the final product should do. These are presented in Table 5.1 below.

| No | Requirement | Priority |
|---|---|---|
| 1 | The filtering tool **must** provide a recommendation list of wearable devices based on various criteria, allowing researchers to find devices that meet their specific needs | Must |
| 2 | The filtering tool **must** allow users to filter wearable devices based on factors such as price, signal type (e.g., ECG, PPG), validity scores, and participant burden aiding researchers in gathering a suitable recommendation list efficiently. | Must |
| 3 | The filtering tool **should** provide real-time updates on selected criteria and their impact on results, allowing users to refine their search parameters and make more informed decisions. | Should |
| 4 | The filtering tool **should** allow users to bypass certain filtering steps they deem irrelevant or less crucial, thus enhancing UX and efficiency by tailoring the filtering process to individual preferences. | Should |
| 5 | The filtering tool **should** distinguish between fundamental criteria related to research objectives (essential) and supplementary options for further optimisation (additional), thus streamlining the filtering process while offering flexibility. | Should |
| 6 | The filtering tool **should** have the option to sort results based on essential criteria such as price, validity scores, or user-defined importance, thus improving UX and aiding decision making. | Should |
| 7 | The filtering tool **could** provide a user with concise and accessible explanations of complex technical terms (e.g., ECG, PPG), facilitating understanding for researchers with varying levels or fields of expertise. | Could |
| 8 | The filtering tool **could** have account based access in order to handle data security and user privacy concerns. | Could |

**Table 5.1:** Functional requirements of the filtering tool

### 5.2.2 Non-functional requirements

Non-functional requirements describe how the system should achieve its functions. These are presented in Table 5.2 below.

| No | Requirement | Priority |
|---|---|---|
| 1 | The filtering tool **must** feature an intuitive interface that enhances usability and interaction with the SiA WD, making it easier for researchers to navigate without overwhelming novice users. | Must |
| 2 | The filtering tool **must** be developed using programming languages and platforms that enable easy adaptation to accommodate new wearable devices added to the database, ensuring the tool remains relevant and effective over time. | Must |
| 3 | The filtering tool **must** load quickly and efficiently handle large amounts of data to provide a smooth UX. | Must |
| 4 | The filtering tool **must** be compatible with all major web browsers (e.g. Chrome, Firefox, Safari, Edge) | Must |
| 5 | The filtering tool **could** have a responsive design to ensure it is usable on various devices, including desktops, tablets, and smartphones. | Could |
| 6 | The filtering tool **could** have effective management of user-submitted feedback to help the future adaptations of the SiA WD and the filtering tool. | Could |

**Table 5.2:** Non-functional requirements of the filtering tool

## 5.3 Front-end components

The filtering tool will only be able to clearly communicate to the user when a user can properly understand the tool and what the screen is telling them. In order to reach that goal, several front-end components are key. For example, the colour scheme to be used in the website, the fonts used by the filtering tool and the styles of icons etc. These will be discussed in the subsections below.

### 5.3.1 Colours

For the colour scheme of the filtering tool inspiration is taken from the website of the SiA [5]. Since the filtering tool is created for the SiA it would suit the filtering tool to use the same colour palette as the main website of the SiA. From the HTML and CSS code of the website of the SiA the colours presented in Figure 5.5 were acquired. These will be considered during the selection for the base colours and the final colour pallet of the filtering tool.

**Figure 5.5:** Colour pallet of the Stress in Action Consortium website

From this colour pallet of the original SiA website combined with the colours of the SiA logo some colours were taken and put together into the colour scheme that will be used to create the filtering tool. These can be seen in Figure 5.6 below.

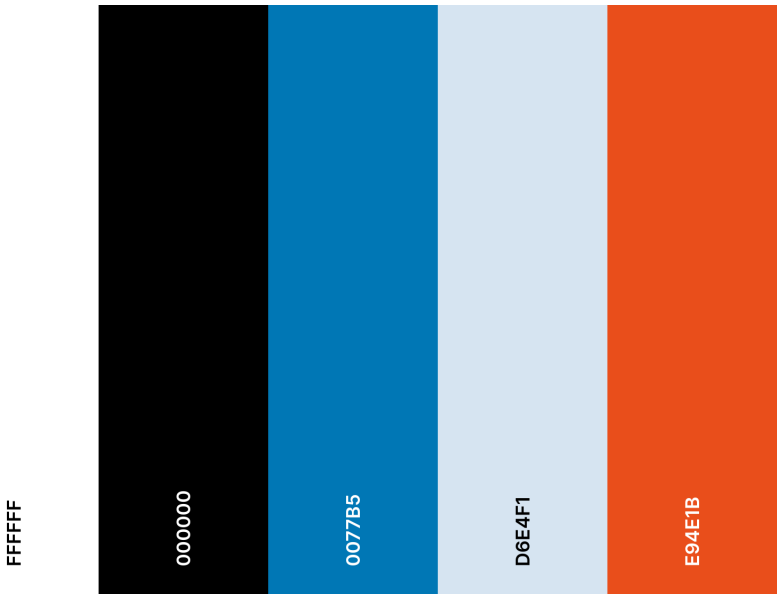


**Figure 5.6:** Filtering tool colour scheme

### 5.3.2 Fonts

Next to using the original SiA house-style colours, the website from the SiA [5] also has a house-style font. The website from SiA uses a combination of the Cormorant Garamond font. and the Noto Sans font. These fonts with their different styles can be seen in Figure 5.7 and Figure 5.8 below respectively.

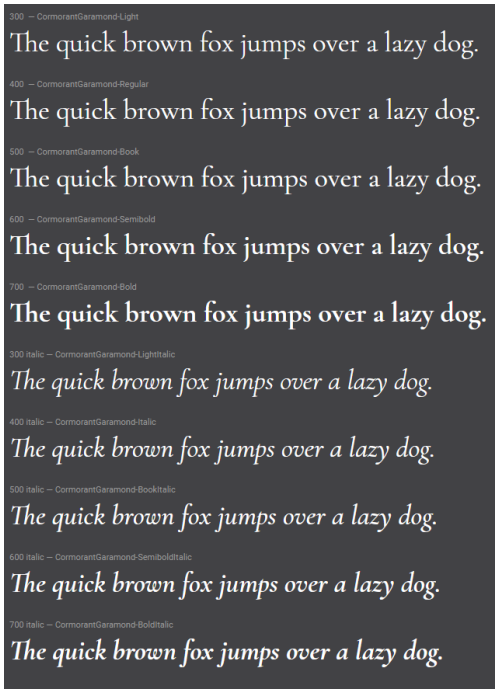


**Figure 5.7:** The Cormorant Garamond font

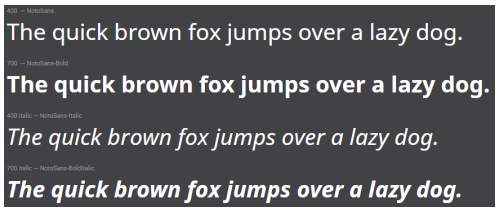


**Figure 5.8:** The Noto Sans font

Ultimately, the Noto Sans font was chosen as the main font as is also done on the original SiA website with the Cormorant Garamond font used for big titles and the footer of the filtering tool.

### 5.3.3 Styles

As was presented in the first concepts in Section 4.4.2 the filtering tool will have certain check-boxes and a popup with symbols and text. These check boxes and the pop-up will have to adhere to an overall style in

order for the filtering tool to have an intuitive interface that enhances usability.

The overall style for the website is chosen to be simplistic since the focus should be on the items and information given and it would be unhealthy to overfill the website with a lot of hefty colours and interactions. Therefore, the background of the filtering tool is chosen to be the standard white #FFFFFF as taken from Figure 5.6. The footer and header of the website will be in another easy colour but one that does stand out from the white background of the rest of the filtering tool. So for this case the colour #D6E4F1 from Figure 5.6 is used. The check-boxes and sliders of the preferences list for filtering should attract the attention of the user since that is the interaction between the user and the website. Therefore these icons will have a brighter colour that will attract the eyes of a user. This colour will be #0077B5 as shown in Figure 5.6. There will be no difference between the edge of the check-box and the infill in order to make it a smooth whole. Therefore, the checkbox and sliders will look as presented in Figure 5.9 and Figure 5.10 respectively.

**Figure 5.9:** Checkbox styles

**Figure 5.10:** Slider styles

## 5.4 Back-end functions

Just like the user interface plays a crucial role in communication, the back-end is equally important. While the frond-end components provide a user-friendly experience, the back-end functions act as the engine, powering the filtering process and delivering accurate results. In this section, time sequence diagrams will be shown which will make the role of the back-end in the filtering tool clear.

### 5.4.1 Time sequence diagram

A time sequence diagram can be used to help visualise what happens over time whilst a user is interacting with the filtering tool as stated by Il-Yeol [72]. It can help show what happens during an interaction and how the different aspects of the system should act upon a certain user action. The time sequence diagram Figure 5.11 below can show how the back-end and front-end together help the user gain the list of wearables that suits their filters.

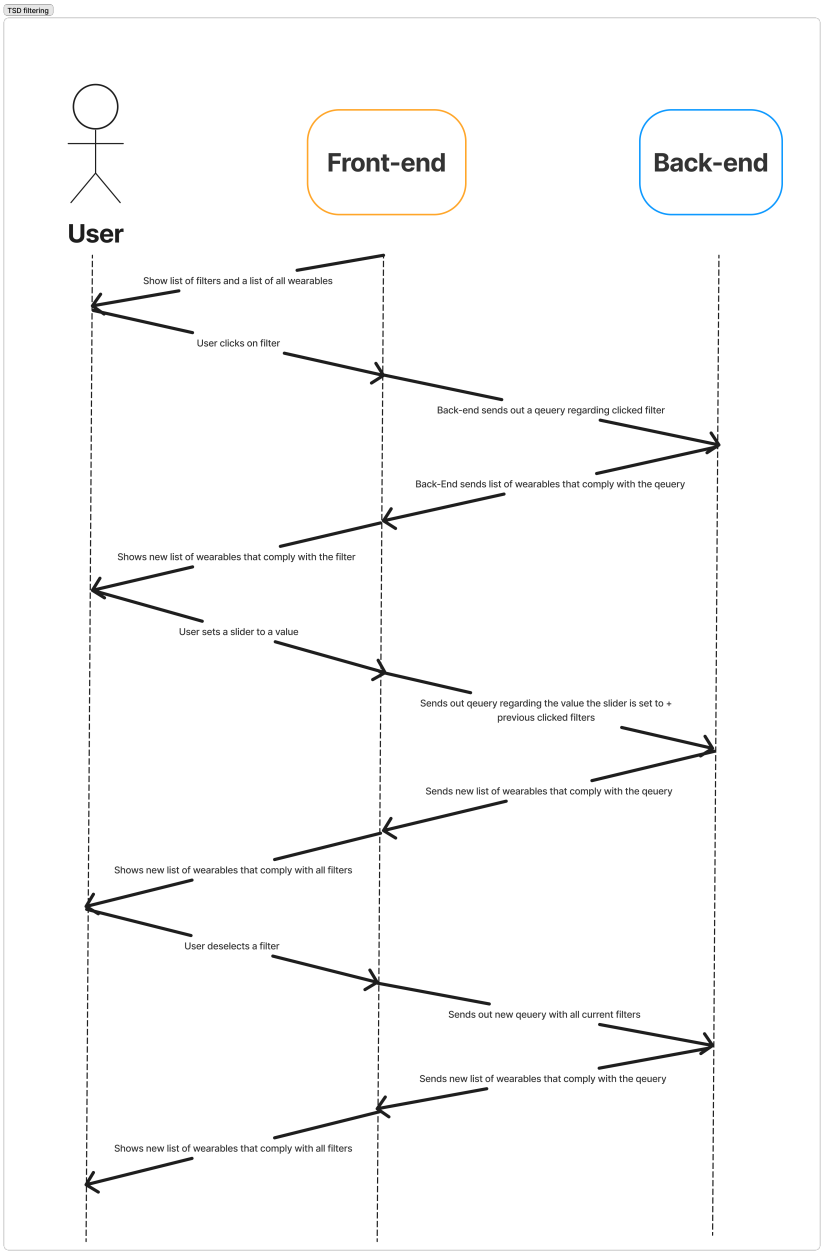


**Figure 5.11:** Time Sequence Diagram for filtering

Furthermore, according to functional requirement 6: “The filtering tool **should** have the option to sort results based on essential criteria such as price, validity scores, or user-defined importance, thus improving UX and aiding decision making”, the user should be able to sort the list of wearables. Therefore, a time sequence diagram for sorting the list is created and can be found below (Figure 5.12).

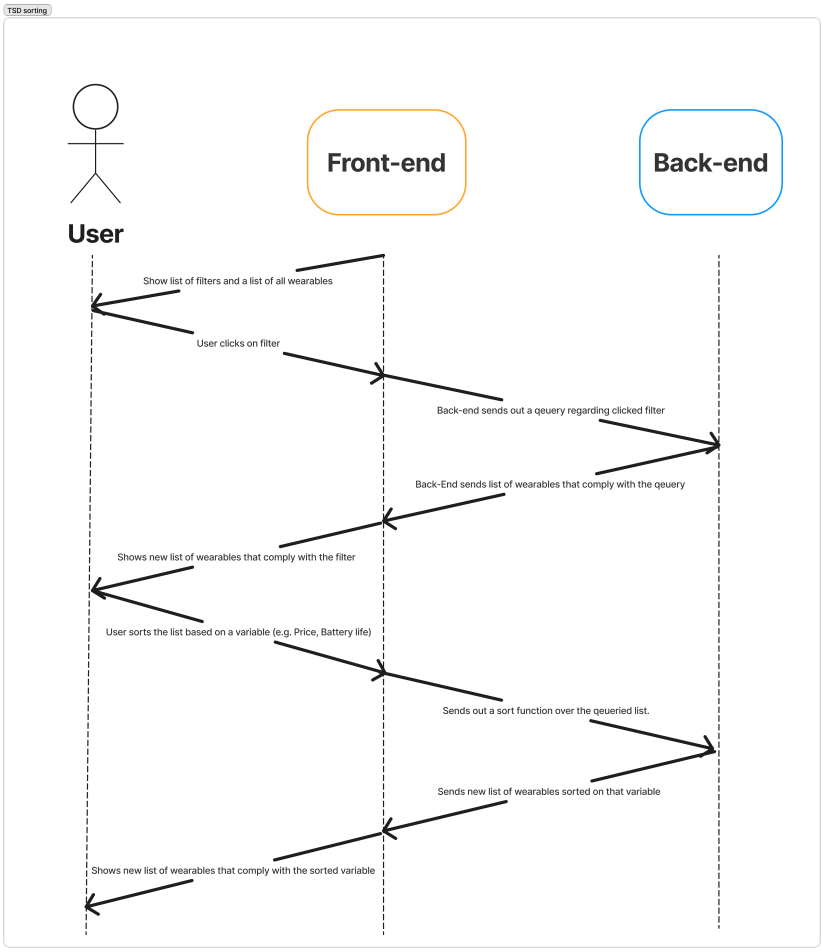


**Figure 5.12:** Time Sequence Diagram for sorting

Lastly, a user could be able to click on a wearable from the list in order to gain concise and accessible explanations of complex terms of that wearable. So that a user would be able to gain more insight in a specific wearable if they would like to do so. A time sequence diagram for this process is created and can be found below (Figure 5.13.

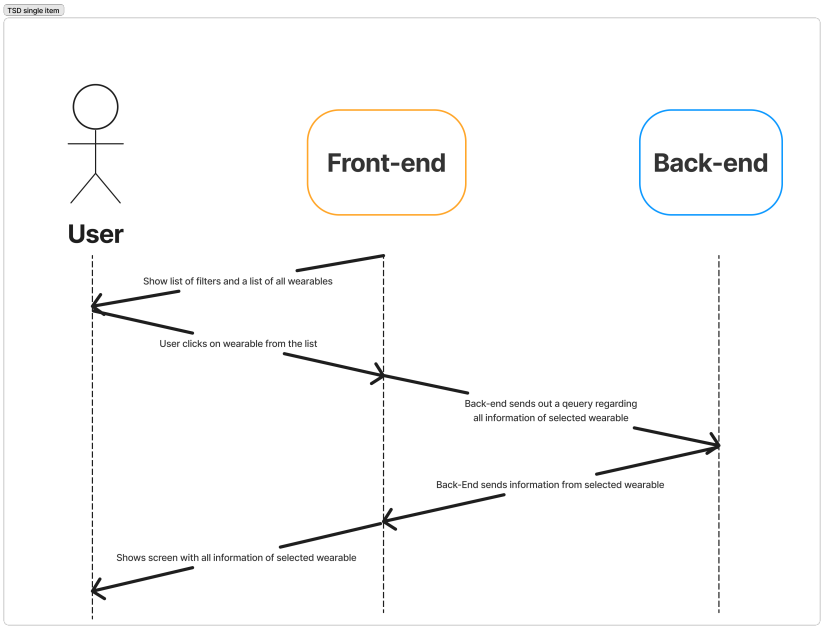


**Figure 5.13:** Time Sequence Diagram for single item information

# Chapter 6.
# Realisation

The realisation phase of the creative technology design phase has a focus on creating the product that was conceptualised during the ideation and specification phase. First all separate parts that need to be create have to be identified, followed by an explanation of how they are realised into the product. Finally they will be reflected on by using the functional and non-functional requirements created in Chapter 5.

## 6.1 Identifying sub-parts

In order to create the final prototype, the concept needs to be separated into the different parts that make up the full design of the prototype. This way the designer will be able to optimise each function of the prototype and test which implementation strategy works best. For the filtering tool there is a clear distinction of three parts of the prototype: the pre-processing of the data, the front-end and, the back-end of the filtering tool.

## 6.2 Realisation of sub-parts

After identifying the three sub-parts the realisation process was started. The three sub-parts were broken down into components necessary to get each sub-part working. Per sub-system the realisation will be discussed.

### 6.2.1 Pre-processing

To properly handle the database in our filtering tool, initial pre-processing is essential to transform the data into a format compatible with our code. Initially, we filtered out columns deemed unnecessary, such as those used to compute the final SiA Expert score for short-term and long-term evaluations. Given that these scores were already established, retaining these columns was redundant. Subsequently, it was necessary to ensure that each column correctly identified its data type. In its original format, the database contained columns where data types were not accurately recognised—for instance, a date column displaying as ####### instead of the actual date. These issues were solved manually.

The entire database then needed to be formatted into a readable format for our code. As described in Section 3.3, the back end of our tool is constructed using Python Flask [73]. To enable Python Flask to read our data, we utilised the Pandas library [74], which is adept at handling comma-seperated values (csv) files. Consequently, it was necessary to convert our database from an Excel file to a csv file. Although our data is now processed and readable by our program, additional data processing is required. This further processing will be executed through our Python code, as described in Section 6.2.2.

### 6.2.2 Back-End

For the back-end of our filtering tool, multiple different coding languages were necessary to set up a proper working tool. It involved several stages as explained below, integrating various technologies and methodologies to achieve a functional and efficient system. The back-end was developed using Python Flask [73], which facilitated the creation of the web application and its application programming interface (API) endpoints.

The data handling was initiated by loading the csv file of our database. This was accomplished using the pandas library [74], which allowed for efficient manipulation and cleaning of the dataset. Key steps included stripping any leading or trailing white-space from column names and values, handling irregular cell values by splitting and trimming strings, and replacing special or empty values with NaN to standardise the dataset. The cleaned data was then converted into a list of dictionaries, making it suitable for further processing and filtering.

To support the user interface, the data was categorised into checkbox columns and slider columns. Checkbox columns contained binary or categorical values, while slider columns contained numerical values suitable for range filtering. The back-end dynamically determined these categories by analysing the unique values in each column. For slider columns, minimum and maximum values were calculated to set the limits for user input on the front-end.

The Flask application defined several API endpoints to interact with the front-end. The home endpoint served the main Hypertext Markup Language (HTML) page, passing the necessary column data for rendering the filter options. The items endpoint provided the full dataset to the front-end, which was essential for

displaying the initial set of items in the table. The slider-limits endpoint returned the computed minimum and maximum values for each slider column, allowing the front-end to set appropriate ranges for user interaction.

The core functionality of the filtering tool was encapsulated in the filter endpoint. This endpoint received filter parameters from the front-end via query strings, parsed these parameters, and applied them to the dataset. For slider columns, the back-end checked if the values fell within the specified ranges. For checkbox columns, it ensured that only items with the desired binary value were included. The filtering logic was robust, handling various data types and ensuring that only relevant items were returned to the user.

Error handling and logging were used during the development process, ensuring that issues could be quickly identified and resolved. Exceptions were caught and logged, providing detailed error messages when data loading or processing failed. This approach not only improved reliability of the application but also facilitated debugging during development.

In conclusion, the realisation of the back-end for the filtering tool involved data handling, dynamic categorisation of filter options, and the implementation of multiple API endpoints to support front-end functionality. The use of Flask and pandas, combined with error handling and logging, resulted in a robust and efficient back-end system.

### 6.2.3 Front-End

The front-end of our filtering tool was developed using HTML, Cascading Style Sheets (CSS), and JavaScript. The initial step in the front-end development was structuring the HTML to create a layout that included the filter options and the table for displaying the filtered items. the filter options were organised into two sections: checkboxes for categorical data and sliders for numerical data. Each filter element is encapsulated into cards, enhancing the overall aesthetic and usability by reducing information overload.

The CSS styling was enhanced using custom rules to align with the application's branding and improve user experience. The styles ensured that the filter options and table were well-spaced, readable, and interactive. Hover effects and transitions were added to provided visual feedback when users interacted with the filters and table rows, making the application feel more dynamic and responsive.

JavaScript played a crucial role in the interactivity and functionality of the front-end of the filtering tool. The front-end logic began with a request to fetch the initial dataset and slider limits from the back-end API. This data was then used to populate the filter options dynamically. For instance, the slider elements were initialised with the minimum and maximum values provided by the back-end, ensuring that users could only select valid ranges.

The table displaying the filtered items was constructed using table classes, ensuring it was both functional and visually appealing, JavaScript functions were used to dynamically update the table rows based on the filtered data received from the back-end. Each table row represented an item from the dataset, and the rows were regenerated each time a new set of filtered data was received, ensuring the table was always in sync with the user's filter selections.

In conclusion, the realisation of the front-end for the filtering tool involved creating a responsive and visually appealing layout using HTML, enhancing the UX with custom CSS styles, and implementing dynamic functionality with JavaScript. The integration of real-time data fetching and updating ensured a seamless and interactive experience. This combination of technologies and techniques resulted in a front-end that efficiently supported the filtering tool's requirements and provided a smooth engaging user experience. The tool can be seen in Figure 6.1.

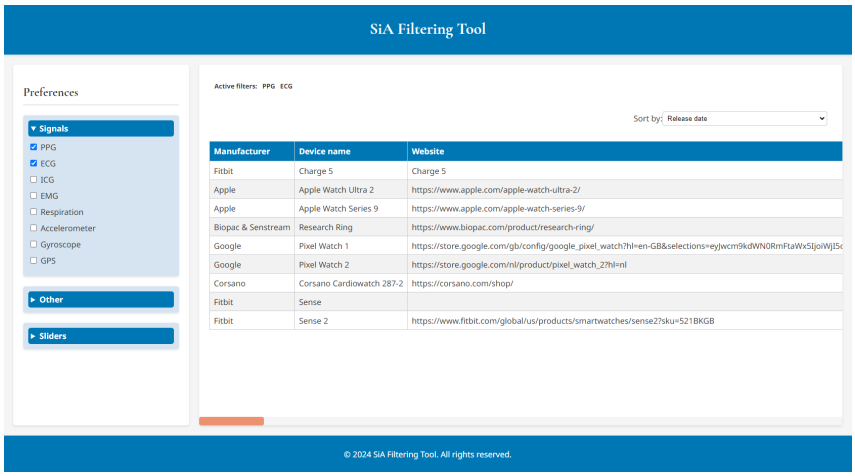


**Figure 6.1:** The filtering tool before the user evaluation phase

## 6.3 Evaluation based on functional requirements

After integrating the different sub-parts, the system was evaluated to see if it met all the functional requirements. Table 6.1 shows whether a requirement is met or not. In conclusion, all “Must” requirements are met, it was especially important to meet those “Must” requirements as they formed the core of the filtering tool. However, as some requirements are not met, there is still room for improvement in order to optimise the system.

| No | Requirement | Priority | Implemented? |
|---|---|---|---|
| 1 | The filtering tool **must** provide a recommendation list of wearable devices based on various criteria, allowing researchers to find devices that meet their specific needs | Must | YES |
| 2 | The filtering tool **must** allow users to filter wearable devices based on factors such as price, signal type (e.g., ECG, PPG), validity scores, and participant burden aiding researchers in gathering a suitable recommendation list efficiently. | Must | YES |
| 3 | The filtering tool **should** provide real-time updates on selected criteria and their impact on results, allowing users to refine their search parameters and make more informed decisions. | Should | YES |
| 4 | The filtering tool **should** allow users to bypass certain filtering steps they deem irrelevant or less crucial, thus enhancing UX and efficiency by tailoring the filtering process to individual preferences. | Should | NO |
| 5 | The filtering tool **should** distinguish between fundamental criteria related to research objectives (essential) and supplementary options for further optimisation (additional), thus streamlining the filtering process while offering flexibility. | Should | NO |
| 6 | The filtering tool **should** have the option to sort results based on essential criteria such as price, validity scores, or user-defined importance, thus improving UX and aiding decision making. | Should | YES |
| 7 | The filtering tool **could** provide a user with concise and accessible explanations of complex technical terms (e.g., ECG, PPG), facilitating understanding for researchers with varying levels or fields of expertise. | Could | NO |
| 8 | The filtering tool **could** have account based access in order to handle data security and user privacy concerns. | Could | NO |

**Table 6.1:** Functional requirements of the filtering tool after evaluating

### 6.3.1 Suggested changes to the filtering tool

The evaluation of the filtering tool shows that while the essential “Must” functionalities are met, several “Should” and “Could” functionalities are not. The tool successfully provides a recommendation list based on various criteria and allows filtering by price, signal type, and validity scores, and it does so dynamically in real-time. However, it lacks the ability to bypass irrelevant filters, clear distinctions between fundamental and supplementary criteria, and concise explanations of technical terms. Additionally, it does not support account-based access for data security and privacy concerns.

To address these shortcomings, the filtering tool needs several improvements. Allowing users to bypass irrelevant filters would significantly improve the UX. This could be done by implementing a product filter as was shown in Section 4.4.2.

Distinguishing between essential and additional criteria could be accomplished by redesigning the filter interface to categorise filters into “Essential” and “Additional” groups instead of the current “Signals”, “Other”, and “Sliders” groups. Providing explanations for technical terms such as ECG and PPG would make the tool more accessible. Integrating a glossary or tool tip explanations using JavaScript and CSS for interactive tool tips would help users with less technical knowledge.

Adding account-based access would enhance data security and user privacy. Implementing a user authentication system using standard web authentication protocols or libraries such as OAuth or JWT would allow for personalised settings and better tracking of user interactions and preferences.Expanding the sorting functionality to include multi-criteria sorting and user-defined sorting priorities would provide users with more control over how results are displayed. This could involve modifying the sorting algorithm and interface to allow multiple criteria selection and priority setting.

Finally, incorporating advanced filtering techniques such as natural language processing (NLP) would allow users to input queries in plain language. For example, typing: “find devices under €300 with ECG

and high validity scores" would enable the tool to interpret and apply the filters accordingly. This would make the tool more user-friendly and accessible, especially for those who are less familiar with technical filters.

# Chapter 7.
# Evaluation

The final part of the Creative Technology design process of Mader and Eggink [66] is the Evaluation phase. In this phase the product that was created during the realisation is tested and the non-functional requirements will be assessed. These non-functional requirements were evaluated during user-testing.

User-testing was done with 5 different researchers affiliated with the SiA. Semi-structered interviews were conducted to complete user-testing, giving the interviewer the opportunity to ask predetermined questions to make sure that each aspect of the product was properly evaluated as giving the participant room to give their own view and opinion on the product.

## 7.1 Evaluation methods

Participants for the study were recruited through an e-mail sent to members of the Stress in Action consortium. While the initial goal was to involve a larger number of participants, time constraints and the demanding schedules of consortium members limited the final participant pool to five individuals. This decision was made in consideration of the practical limitations faced during the research.

The study utilised both physical and online settings for the evaluations and interviews. For the online user tests, sessions were conducted via MS Teams [75]. Initially, the interviewer sent out the information brochure and consent form to the participants in advance. Upon receiving the signed consent forms, the interviewer then provided the program necessary to run the filtering tool locally. During the online sessions, participants were given a detailed explanation of the research aims and evaluation procedures once more and were asked again for consent to use the data gathered from both the user test and the interview. Participants were then instructed to run the filtering tool application and share their screens through MS Teams to facilitate the evaluation process.

In the case of physical user tests, the procedure began similarly with the distribution of the information brochure and consent form. At the start of each physical session, the interviewer reiterated the research aims and evaluation procedures and once again obtained consent to use the collected data. Subsequently, the interviewer operated the filtering tool on their own laptop, with MS Teams running in the background to record both the screen and the interview.

The evaluation design aimed to thoroughly assess the usability and effectiveness of the filtering tool. Participants engaged with the tool in a controlled environment, either remotely or in person, depending on their availability. The evaluation process included interactions with the tool and structured feedback obtained through interviews.

Data analysis involved examining both qualitative feedback from the interviews and quantitative metrics where applicable. The interviews were fully transcribed and can be found in Appendix B. The collected data was analysed to evaluate the tool's performance and to gain insights into the user experience.

Ethical considerations were addressed by obtaining approval prior to the study's initiation. All participants were informed about the research and provided consent for the use of their data, ensuring that the study adhered to established ethical guidelines.

### 7.1.1 Use case

After the participant has the filtering tool up and running, they will get a use-case from the interviewer. The use case is the following:

**Objective:** Identify the best wearable device for a study aimed at assessing the relationship between daily physical activity and stress levels in 100 participants over 6 months.

**Background:** A team of beginner researchers in the field of stress research plans to conduct a study to understand how daily physical activity influences stress levels. They require a wearable device that can accurately measure stress and physical activity parameters. The researchers need a device that participants can wear continuously with minimal maintenance and burden. The study should comply with GDPR regulations for data protection.

**Requirements:**

- **Stress Measurement:** The device must be capable of measuring stress levels, by recording the physiological effects of autonomic nervous system activity, for example through cardiovascular- or electrodermal activity-related measures.

- **Physical Activity Measurement:** The device should track daily steps and other relevant physical activity metrics (e.g., active minutes, calories burned).
- **Battery Life:** The device should have a long battery life, ideally requiring charging no more than once a week.
- **Data Compliance:** The device and its data storage should be GDPR-compliant.
- **Ease of Use:** The device should be easy for participants to use and should require minimal interaction for data collection (passive recording).
- **Validation:** Proven validity and accuracy of recording would be a plus.
- **Budget:** The total budget for purchasing devices is €25,000.

As can be seen in the objective of the use case. The participant of the user test will have to identify the best wearable device for a study aimed at assessing the relationship between physical activity and stress levels in 100 participants over 6 months. The participant of the study will have to use the filtering tool and its filters to find the best wearable device for the given problem.

After using the filtering tool to solve the use case. The participant will be asked some questions about their experience with the filtering tool. The questions can be found in Appendix B.

## 7.2 Results

During the different evaluation interviews, the filtering tool was discussed in general, on its specific features, its functionality and performance, and its usability and satisfaction as can be seen in Appendix B

### 7.2.1 General feedback

Experts generally appreciated the tool's layout and design, describing it as nice and visually appealing. The categorisation of features such as accelerometer and gyroscope was positively noted for aiding in navigation and the initial filtering processes. Users found the tool responsive once loaded, contrasting it favourably with slower interfaces encountered elsewhere. However, several common themes emerged across the interviews. Navigation, particularly through the table of items was a consistent point of confusion. Experts suggested clearer categorisation of table headers or using collapsible columns or hover over explanations. Specific request included but were not limited to comprehensive checkbox options and bidirectional sliders in order to enhance precision in filtering.

### 7.2.2 Specific features feedback

While the checkboxes were generally effective, issues arose regarding missing options (e.g. EDA) and the need for a more exhaustive list of selectable criteria. Experts recommended improving the clarity of checkbox selections to avoid initial confusion during use.

For the sliders the feedback was mixed but generally positive. Experts appreciated their functionality but highlighted the necessity for clearer unit indications and the inclusion of bidirectional sliders to refine selection criteria effectively.

The tool did receive positive feedback for its sorting capabilities, though suggestions were made to expand sorting criteria for more comprehensive device comparisons. Customisable column placements were also proposed to facilitate easier access to frequently referenced data.

### 7.2.3 Functionality and performance feedback

Overall the experts rated the tool positively for its ability to narrow down wearable options based on specified criteria. However, concerns were raised about the clarity of certain parameters, such as continuous measurement capabilities, which were not explicitly clear within the tool.

The responsiveness of the tool was also appreciated by users. Its quick response time positively influenced their overall UX, however, all users encountered problems with the device costs slider slowing down response time. This was due to the loading of every possibility of the entire list and the slider of the device costs going from €140 all the way up to €5995. So the table might have to reload 5855 times until it gave the appropriate overview.

### 7.2.4 Usability and satisfaction feedback

A recurring challenge highlighted by experts was the difficulty in finding specific information within the tool, as the table of information is just too large. Suggestions included, clearer categorisation of table headers or using collapsible columns or hover over explanations in order to enhance information accessibility.

While the experts generally understood and were satisfied with the final list of wearable devices generated by the tool, they emphasised the need for improvements in how information was presented and accessed. Suggestions included integrating device images for a more intuitive selection process and enhancing interface aesthetics to reduce complexity.

Overall the experts evaluations provided valuable insights into both the strengths and the areas requiring improvement in the filtering tool. The findings underscored the importance of improving navigation clarity, refining sliders and improving overall user satisfaction through better information presentation and accessibility. Future iterations of the tool should prioritise these improvements in order to further optimise UX and effectiveness in selecting wearable devices.

## 7.3 Evaluating non-functional requirements

The evaluation of the filtering tool's non-functional requirements, based on insights from expert user tests, offers a comprehensive overview of its current performance and areas for improvement. These requirements span critical aspects such as interface usability, adaptability to new devices, data handling efficiency, compatibility across web browsers, responsiveness across devices, and management of user feedback and can be seen in Table 7.1. The results presented are derived from structured testing and feedback sessions with expert users, which were instrumental in identifying performance levels and areas needing enhancement.

| No | Requirement | Priority | Implemented? |
|---|---|---|---|
| 1 | The filtering tool **must** feature an intuitive interface that enhances usability and interaction with the SiA WD, making it easier for researchers to navigate without overwhelming novice users. | Must | YES |
| 2 | The filtering tool **must** be developed using programming languages and platforms that enable easy adaptation to accommodate new wearable devices added to the database, ensuring the tool remains relevant and effective over time. | Must | YES |
| 3 | The filtering tool **must** load quickly and efficiently handle large amounts of data to provide a smooth UX. | Must | YES |
| 4 | The filtering tool **must** be compatible with all major web browsers (e.g. Chrome, Firefox, Safari, Edge) | Must | YES |
| 5 | The filtering tool **could** have a responsive design to ensure it is usable on various devices, including desktops, tablets, and smartphones. | Could | PARTIALLY |
| 6 | The filtering tool **could** have effective management of user-submitted feedback to help the future adaptations of the SiA WD and the filtering tool. | Could | NO |

**Table 7.1:** Non-functional requirements of the filtering tool after evaluation

The filtering tool aims to provide an intuitive interface that enhances usability for both researchers and novice users. Feedback from expert users highlighted the interface's visual appeal and initial layout design, with features like categorised filters being particularly appreciated. These insights were collected through user testing sessions where experts interacted with the tool and provided detailed input on its usability.

Regarding adaptability to new wearable devices, the tool shows potential in integrating new data sets. During testing, experts noted that while the tool efficiently incorporates new data, it does not facilitate the instant addition of new filters based on new columns within the database. However, the code structure is designed to allow easy modifications, even for non-programmers, as confirmed through code reviews and technical assessments.

Efficient data loading and handling are crucial for a smooth UX. Experts acknowledged the tool's responsiveness in general testing scenarios, but optimisation was identified as necessary for large sliders to minimise delays and enhance performance.

Compatibility across major web browsers was confirmed without issues, ensuring consistent access and functionality across different platforms. This conclusion was reached through extensive cross-browser testing, which demonstrated the tool's effectiveness in various web environments.

Responsive design is essential for usability across devices. While the tool functioned adequately on desktops, small improvements are needed for smartphones. The feedback revealed that the current responsive layout becomes too small for effective use on smartphones, suggesting that a new layout is necessary to ensure a cohesive UX for smaller screens. This observation was based on usability tests conducted on different devices.

Managing user-submitted feedback is critical for continuous improvements. However, the tool currently lacks an option for users to submit feedback or suggest improvements. This gap was identified through user feedback sessions, where the absence of a feedback mechanism was highlighted as a significant shortcoming.

In conclusion, while the filtering tool meets most non-functional requirements effectively, improvements can be found in the responsive design and layout for smaller screens and the implementation of a user feedback system. By addressing these recommendations, the tool can evolve into a more robust and user-centric platform.

# Chapter 8.
# Discussion

After all steps of research and the design process, it can be concluded and understood that a solution for the usage of the existing SiA WD would be the usage of a filtering tool. Therefore, the research question: "*How can the Stress in Action Wearables Database (SiA WD) be used by researchers aiming to select the most suitable wearable device for a given study purpose?*" can be answered as follows: With the use of the filtering tool created based on the SiA WD, the researchers for ambulatory stress research are able to filter wearable devices based on their specific situation in order to find the best wearable of use for their study purpose. Even when not giving exactly one suitable wearable, the filtering tool gives the researchers the possibility to gain information about multiple suitable wearables in an easy to access way. The filtering tool is flexible in its workings and has multiple different functionalities in order to get to the final list for different studies. In this way, a researcher would be able to properly look at the information given by the database in easier to digest amounts and thus compare and in the end select wearables.

While at this point in time the main end-user of this filtering tool will be researchers in the field of stress research, the tool can also be used by others wanting to look at the best wearable for their specific case. The only downside would be that the tool does assume a certain level of knowledge about signals and parameters for filtering.

The filtering tool also makes it easy for researchers to justify their choice for a wearable for their research. As it makes it easy for them to show the specifications of different wearables in one clear view towards others. They are able to combine their own knowledge with the ease of use and clear information given by the database, in order to show and validate their choices.

As the SiA aims to gain insight into the causes and consequences of daily life stress, and to provide a path towards more stress-resilient citizens. One of their tracks is focused on developing increasingly sophisticated versions of a cutting-edge, low-burden, ecologically valid ambulatory assessment toolkit to quantify stress in daily life, and to design, test, and iteratively improve stress interventions using that toolkit. The filtering tool can be a good step in this process as it is able to help researchers make more informed decisions about selecting wearable devices for research purposes. Thus moving forward to creating more stress-resilient citizens.

In conclusion, even though the filtering tool might be only responsible for a small part in the process of the SiA, it can still help the SiA to build a foundation for their path in order to reach their goal. Therefore, the SiA would like to further develop the filtering tool from a prototype into a working product that can be used to support researchers.

## 8.1 Limitations

The project also faced some limitations over the course of the whole process. One of the big limitations is the small amount of user tests conducted on the prototype. As only 5 users have user tested the product, more information and validation could have been acquired in order to properly evaluate the prototype. This limitation occurred due to the need to test with members of the SiA which were all quite busy and not readily available in the last weeks of this project. This of course also comes with another limitation which is the fact that all of these researchers would benefit from this project being released and used in real life which might make the results from the evaluation biased in an opportunistic way.

Another limitation within the field of testing was the limitation of the filtering tool not being hosted as a website yet. This made it so that some users had to install a coder themselves and run the program locally, which in some cases resulted in more work than they would have liked, and this made the speed and performance of the filtering tool very reliant on the quality of the computer or laptop that it was tested on.

Furthermore, a limitation can be found in the combination of the background research into the final filtering tool. As was stated in Chapter 2 the best RS to use for the project would be a KBF RS. However, the filtering tool in its current state could not actually be called a proper KBF RS, since it does use the features of a KBF and it does show a list of recommendations at the end. But it does not have several features that would make it easier to actually compare items which makes it a weaker version of a RS. However, it can be stated that a full RS would be too imposing for the goal of the tool, as well as it then not adapt to non-functional requirement No. 2: "*The filtering tool must be developed using programming languages and platforms that enable easy adaptation to accommodate new wearable devices added to the database, ensuring the tool remains relevant and effective over time.*". It would still be created using programming languages that enable ease adaptation, but the tool and code itself could be too difficult for easy adaptation.

## 8.2 Reflection and comparison

In reflecting on how our solution compares to other existing solutions, it is beneficial to consider recommendation systems used in different domains. For example, e-commerce platforms like Amazon utilise sophisticated filtering and recommendation algorithms to enhance user experience. Amazon's recommendation system leverages collaborative filtering, content-based filtering, and hybrid approaches to suggest products based on user behaviour and preferences as stated by Gomez-Uribe & HUNT [76]. By analysing users' past purchases and browsing history, Amazon's system provides personalised recommendations, which can inspire improvements in our filtering tool by incorporating similar data-driven approaches.

Similarly, content streaming services such as Netflix use advanced recommendation algorithms to suggest movies and TV shows. Netflix employs a combination of collaborative filtering, content-based methods, and deep learning techniques to tailor recommendations to individual users as stated by Gomez-Uribe & HUNT [76]. This system's ability to analyse user interactions and preferences could inform the development of more sophisticated filtering mechanisms in our tool, allowing it to handle diverse data types and offer more precise recommendations.

Another relevant example is the recommendation system used by Spotify for music recommendations. Bangera et al. [77] state that Spotify's system utilises a mixture of collaborative filtering, content-based filtering, and natural language processing to provide users with personalised playlists and song recommendations . The integration of these diverse methodologies can offer insights into enhancing our filtering tool's capabilities to accommodate various types of wearables and research needs.

Examining these examples highlights the potential benefits of adopting advanced recommendation techniques and integrating multiple data sources to enhance the effectiveness of our filtering tool. The use of collaborative filtering and hybrid models, as seen in Amazon and Netflix, could improve the tool's ability to process and present relevant data. Additionally, incorporating elements from Spotify's recommendation approach could offer valuable insights into handling different types of data and user preferences.

Overall, while the filtering tool developed serves its purpose within the context of the SiA project, understanding and integrating lessons from other recommendation systems can provide valuable insights into refining and enhancing its functionality.

## 8.3 Conclusion

In order to conclude the discussion and answer the research question: *"How can the Stress in Action Wearables Database (SiA WD) be used by researchers aiming to select the most suitable wearable device for a given study purpose?"* it can be stated that the filtering tool developed based on the SiA WD addresses this question effectively. With the use of the filtering tool, researchers involved in ambulatory stress research can filter wearable devices based on their specific requirements and study objectives. The tool facilitates the identification of the most suitable wearable devices by presenting multiple relevant options in an accessible manner.

Even if the tool does not provide a single definitive recommendation, it enables researchers to obtain comprehensive information about several suitable wearables, thereby supporting informed decision-making. This capacity to filter and present relevant options enhances the researchers' ability to select the most appropriate wearable device for their study, fulfilling the primary objective of the filtering tool.

# Chapter 9.
# Future work

Though the filtering tool is a successful prototype according to this research, there is still room for improvement. Following from the evaluation phase in Chapter 7, there are some recommendations for future research.

First and foremost, a key area for improvement is the expansion of the filtering options. The current tool would benefit from a more exhaustive list of select-able criteria, particularly for stress measurement options like EDA or the current market status of a wearable. By broadening the range of filtering options, users can tailor the tool more precisely to their specific research needs, thus improving its overall utility and effectiveness. For instance, e-commerce platforms like Amazon and content streaming services such as Netflix offer extensive customisation options for filtering and recommendations, allowing users to refine their searches based on detailed criteria according to Gómez-Uribe & Hunt [76]. Adopting a similar approach to expand the filtering options in our tool could enhance its usability and adaptability for different research contexts.

Another crucial step would be improving the UI and navigation. The feedback received highlighted the need for clearer categorisations of table headers, additional navigational aids, and more intuitive filtering options. Implementing features such as collapsible columns, hover-over explanations, and bidirectional sliders will enhance the UX significantly. Moreover, integrating images of the devices and refining the overall design to be more aesthetically pleasing will simplify the selection process and reduce cognitive load on users. This approach is similar to the user-centric design improvements seen in platforms like Spotify, which according to Bangera et al. [77] utilise visual elements and clear navigation to enhance user engagement and satisfaction. Drawing from these practices can help create a more intuitive and visually appealing interface for our filtering tool.

Furthermore, performance optimisation is necessary, particularly addressing the issues with the device cost slider and its data loading process. The lag caused by extensive data lists needs to be minimised to maintain the tool's responsiveness, ensuring a smoother and more efficient UX. The performance optimisation strategies employed by high-traffic websites and applications, such as those used by Amazon and Netflix, provide valuable insights into handling large datasets efficiently as stated by Gómez-Uribe & Hunt [76]. These strategies could be applied to improve the tool's performance and responsiveness.

Additionally, ensuring the tool's responsiveness and compatibility across all devices, including smartphones and tablets, is critical for accessibility. Developing a simplified layout for smaller screens will improve usability on these devices. Even though most users will use their laptops or computers, accommodating the smaller group that uses smartphones and tablets will ensure inclusivity. According to Marcotte [78] this approach is supported by best practices in mobile application design, where responsive design techniques are employed to ensure optimal user experience across various device sizes and operating systems.

Another important improvement would be the implementation of a user feedback mechanism. Allowing users to submit feedback directly through the tool will facilitate continuous improvement by helping the developers identify and prioritise areas for enhancement based on actual user experience and suggestions..

Finally, exploring ways to scale the tool for use in different research environments and customising it for specific research domains can broaden its applicability. Integrating the tool with other research platforms and tools can further enhance its effectiveness and utility. This approach is comparable to how integration with external systems and platforms enhances the functionality of recommendation systems in various domains as is stated by Ricci et al. [79].

By addressing these recommendations, the filtering tool can develop into a more robust, user-friendly, and adaptable platform. This will ultimately enhance the research capabilities of its users and contribute to more effective and efficient wearable device selections, benefiting the broader research community and the SiA in taking steps towards their goal.

# List of abbreviations

**ACC** Accelerometer 3, 4

**ANS** autonomic nervous system 4

**API** application programming interface 44, 45

**CBF** Content-based Filtering i, 3, 6, 8–12, 15, 16

**CF** Collaborative Filtering i, 3, 6–12, 15, 16

**CSS** Cascading Style Sheets 45, 47

**csv** comma-seperated values 44

**ECG** Electrocardiogram 3, 4, 23–27, 33, 37, 47

**EDA** Electrodermal activity 3, 4, 53

**EU** The European Union 23

**GDPR** General Data Protection Regulation ii, xxvi, 23, 35, 49

**HR** Heart Rate 3, 4

**HRV** Heart Rate Variability 3, 4

**HTML** Hypertext Markup Language 44, 45

**KBF** Knowledge based Filtering i, 3, 6, 10–12, 15, 30, 52

**NLP** natural language processing 47

**OWEAR** Open Wearables Initiative 17

**PPG** Photoplethysmography 3–5, 23–27, 33, 37, 47

**RS** Recommender System i, 1–3, 6–12, 15, 16, 19, 27, 30, 52

**SiA** Stress in Action Consortium i, xxvii, 1, 2, 19–21, 24, 30, 38, 39, 44, 49, 52, 53

**SiA WD** Stress in Action Wearables Database i, 1, 2, 6, 8, 9, 11, 19–24, 26, 27, 30, 33, 38, 51, 52

**SSM** Stakeholder Salience Model 20

**UI** User-Interface 23, 24, 53

**UX** User-Experience 4, 5, 8, 14, 16, 25–28, 33, 37, 38, 41, 45, 47, 50, 51, 53

# List of glossaries

**ambulatory** The ability to walk around and not be confined to a bed or hospital 1, 21

**Learning based models** Algorithms that learn from data to make predictions or decisions. They improve over time through iterative processes, adapting to new information and tasks 16

**Mathematical based models** Algorithms that use mathematical techniques to recommend items to users based on their preferences and the features of the items. These models analyze the characteristics of items and user preferences to make personalized recommendations 16

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# Chapter A.
# Appendix A
## A.1 Expert interview

**Interviewer:**

Then I've started the recording. As you might have read in the information letter as well, I had two separate parts for questions. The first one involving current challenges in device selection for ambulatory stress research.

And then the second part more for the use of the filtering tool that I would create. So I would suggest starting on just the first part. And I would like to ask you what your opinion would be on the current state of the ambulance stress research.

**Expert 2:**

Can I start?

**Interviewer:**

Sure.

**Expert 2:**

I'm getting the impression that although so many different devices are being released, so you can even spot a new one like every week or every few days. People who actually use wearables in their studies, they just pick kind of the ones that the others use. And these are mostly just limited to watches and rings.

For example, I always remember just like from a wearables kind of conference that was one new conference I went, there were also other researchers using wearables from around the world. And they were, I was surprised that they were not even considering things like vests or, you know, like the WMS 5FS. Yeah.

So there is just an inclination towards going for watches and just the mostly previously used devices.

**Interviewer:**

Okay. Did you also hear from any of the researchers, why they were inclined to use those or do they just not have knowledge of the new ones?

**Expert 2:**

Exactly. I think they are heavily concerned about participant burden. That's the main reason. And the other reasons such as validity, surprisingly, they did not consider even that much. Okay.

**Expert 1:**

I think I agree with this fully, that they really think of only the usability and the participant and compliance and the fact that they go through the entire study wearing the device without dropping out. But they do not look that much into, okay, what data can I actually get from this? Is this usable for my study even?

**Expert 2:**

I think that's also because maybe they are, because I mean, when you do an ambulatory research, they could be primarily concerned with having any data. And yeah, as expert 1 said, like dropping out this kind of, or like relatively more frequent. So they just rather have any data than a very valid, but probably a bit more burdensome one.

**Expert 3:**

Yeah. And people also sometimes might not be aware of all the factors that they should consider when selecting wearable. So in that regard, the SEO wearable database might help with that as well.

**Interviewer:**

All right.

**Expert 1:**

If you think of that, it's a little bit weird, right? And surprising that they would not consider the important stuff.

**Interviewer:**

Yeah, definitely. Also in your experience, what would be some of the logistical challenges that are associated with using those wearable devices? For example, in diverse participant populations and diverse environments?

**Expert 3:**

Very good question. It can be various challenges, I think. Like they already said, like participant adherence. So whether people actually keep wearing them or take them off, forget to put them on, charging them. So in that regard, the batteries, for example, important if you have to charge a lot, can be very annoying. Waterproof ability, wearing comfort. Other challenges can be regarding the data. If you need

certain data, how can I extract it? Can you actually extract the data? What do you get? And then there's of course the ethical, like the logistical, legal stuff with GDPR. I think there are various challenges.

**Expert 1:**

So both for participants and for the researcher, right. Those maybe could be separated. If it comes to the participants, it's mostly a usability of the device. Two smartwatches can also be very much different. Like one can be irritating for your skin, for example, and that's really difficult to know as well. Just from a researcher's point of view, those devices maybe are not tested enough, so we don't have that knowledge. So yeah, and then for the researcher, what expert 3 said already.

**Expert 2:**

And for the participants' point of view, specifically under the umbrella of usability, I would definitely add just how much effort it takes for people to take it off and put it back on in terms of how long is the process and also how complicated. How many pages of instructions do you have to give them for them to keep doing that? I would consider that to be one of the primary ones.

**Expert 3:**

Aesthetics can also be part of the participant part, because if it's very ugly, people are not inclined to wear it as much or a bit weird or odd, but that can have an effect. So it's always good to keep in mind. But difficult, we don't include that yet. It's not like an aesthetic score or something.

**Expert 1:**

For the researcher, also, of course, the practical stuff such as price of the device, especially for ambulatory research, if you have to run a big cohort study, for example, with many participants and you need to buy multiple devices, then the price also becomes very important.

**Interviewer:**

And you just said like, hey, all the different factors that influence the participant, but how would you perceive the role of more longitudinal studies within the field? Does long-term monitoring have different considerations than short-term?

**Expert 2:**

Yeah, for example, I think all the participant-related concerns that we mentioned, they start to weigh even more heavily, like the aesthetics. There, it really does matter. If the device causes a lot of tension or allergic reactions, or again, how easy is it to use it? That really becomes important. Other than that, I would say things like the battery life, just all the different things that the participants also have to deal with. And if it's a long-term study, I'm just thinking from the researcher's point of view, maybe it's more of a hassle, how to get the data, because then the amount of data also really increases. And if you're having data from different signal channels, and if they have very high sampling rates, the amount of data can be enormous.

**Interviewer:**

Yeah, I definitely understand. Would you also say that there are any special ethical considerations that researchers should be taking into account when using those wearables for their research?

**Expert 1:**

So, expert 3 mentioned already GDPR compliance. So, this has to do with the safety of the data, the way that data of your participants is handled. And many of the wearable devices will just use the commercial side of it to store your data, so external servers.

So, the way this normally works, if you buy a device like this, which might be okay if you just agree to it as a normal person, but if you're a participant in a research that's based in Europe, and then all this data is sent and kept somewhere in the US, and you have no idea if this is GDPR compliant, because most of them aren't, then you're kind of in a grey zone. You're not even able to tell, is this something that I could be using or not? So, we are checking, for example, in the wearables database, can the data be stored internally on the device, or really on the phone of the participant without syncing with the servers? But yeah, that's also difficult information to find out exactly. But if we know that the servers are, for example, using the Amazon structure, then we know that this is more likely to be GDPR compliant than something that isn't really specified, for example.

**Expert 2:**

And yeah, an interesting addition to that, that I recently started to come across is sometimes some devices will say that, like the companies will say they are GDPR compliant, but still indicate that they cannot guarantee the privacy of personal information. Yeah. So, for example, we did not, I think, entirely integrate this into the database. Maybe we will add some, add this as a note at the end, but even so, GDPR compliance by itself doesn't always cover the ethical considerations. Yeah.

**Interviewer:**

Okay. That's actually very interesting.

**Expert 1:**

But you can also think of, for example, some of those devices, they will automatically record some GPS data or some other, they can have access to some other sensitive data, which gets stored also. So then it's your job as a researcher, to make sure to remove that data. This is not identifiable in any way, if you're not using that.

**Interviewer:**

Okay. As I have already said, and you might know, I'm currently researching how to create such a filtering tool for your database. But why would such a filtering actually be needed for this research, for the database?

**Expert 3:**

Good question. It would be really great to have a system like that, because there were going to be a lot of wearables in there. And there's of a lot of factors. So there are quite a lot of columns, and it's very, it can be fairly tricky to think of all the factors or criteria that you have.

So you want to have it within this price range, you want to have raw data, you want to have these and these signals, and then you need to find in this massive table, which device you need, or suits the best, that can be very tricky. So then a booking.com like filtering system or something can be great. If you think of booking.com, they have like 1000s of places, of course, but what if you would have like 100 or something, it can still be tricky to select the right one. If you want a swimming pool, you want three beds, you want this and available around this time, I don't know. So you would have to filter that all of that yourself in your head can be very tricky. So that's where you really would like to have that automatic filtering system.

**Expert 1:**

Yeah, also doing that in Excel is just too difficult for most people if they just get the Excel file. So just having something that's easy to use and intuitive and really puts that into more of an easy to use tool that would be perfect. And like expert 3 said, people will have different factors that they consider important. So it's impossible for us to create any type of structure like this in the database itself for now.

**Interviewer:**

Yeah. Okay. I also would like to know what exactly are the requirements from your side for this filtering tool? Like what do you really expect it to do? So should it only be filtering according to the columns that you have? Or should it also say like, hey, you put out this filter and this one shouldn't actually be included, but it agrees with all your other filters? Or should it also sort the items on a certain rating or something?

**Expert 2:**

I would say, okay, so we'll discuss about this now, but as an initial idea, I would put only the actually needed options for people to filter in and not just all of them or even most of them. Because then, well, one, it is always potentially the case that they have no results found after all of that filtering. And it is a nice idea to also give the researchers the option to like by themselves kind of compare between maybe a few devices. So they should also have that kind of freedom and option to choose. Maybe filtering on things like price and the actual type of device. I'm sure we can come up with some more, but then maybe when you are listing the results, it can be ordered by our validity score. Maybe the CI usefulness score is another score we are now inserting.

**Expert 1:**

Yeah. I also think, what do you want to measure? That that should be like, if you have people come in, of course, who are just interested in heart rate, for example. And I'm not sure if we then should also specify that by signal and say, okay, do you want ECG or do you want PPG type of sensor? That could also be an option.

**Expert 3:**

Yeah, I think it's a good question. Like, do people always know that they can use ECG for heart rate and PPG, for example? Or do we then need to look at the process signals? Because that might be actually something to consider. I think it also depends, to add to the discussion. We can't filter on anything. Like, some things are more descriptive. I don't think we can filter on that, but we can just filter on certain items, such as, indeed, signals and perhaps any process values. Sampling frequency could be done, but I'm not sure we would want that.

**Expert 1:**

I think for so many of them, that's also not available.

**Expert 1:**

No, so that's something to keep in mind, maybe. Battery life, of course. Yeah, so I think most items can be filtered, maybe. Or do you really think that's bad, expert 2?

**Expert 2:**

I mean, with battery life, we could do like a, you know, how booking.com has like min-max. So also the price. And for the different variable types, they can just click some of them. That kind of filtering. And maybe signals as well. I missed the signals. That's a very good point. We need to include the signals. Then that's another discussion, like you say. Do actual people know, if they're interested in heart rate, they should click on ECG and PPG. Maybe we can have a very shortened, like. Explanation. Just one, like, passage. Very nice, not full of many words kind of an explanation. And then let them pick the signals. Because I'm thinking picking the parameters might be more difficult. But that's just my opinion.

**Interviewer:**

Yeah, okay.

**Expert 3:**

I was linked or something. I'm not sure if that's possible. It might be tricky. And then what do we link with one another?

**Expert 1:**

Yeah. We are also doing this part of the database where we're looking at the literature. So we're checking if the device has any validity studies or studies on the reliability of the signals or their usability. So I think that could also be something that we could filter on. Does this device have any previous studies, any proven validity? Or maybe not even proven or not proven, but have we found any studies on this device? And then we maybe list that information, you know? Yeah, like the number of validity studies, right?

**Expert 3:**

That's a common denominator. That could be. If it's like NA or like, yeah, zero or.

**Expert 1:**

If it's zero, then those devices wouldn't show up. Yeah.

**Expert 3:**

And maybe we should also not make it too complicated and then just say, are there validity studies about this device? Yes or no. And don't focus on which parameters are valid.

**Expert 2:**

Because that's difficult.

**Interviewer:**

Yeah, I would understand. Would you also say like, because we're going about filtering and the signals, etcetera, would you say that there's a certain level of knowledge that would be the minimum for a researcher to be able to use the database? Or should it be like really easy to use, very self-explanatory?

**Expert 1:**

No, I think this is in the end for researchers. I think they should know what a PPG signal is, for example, if they're using the filtering tool, right? We're not going to explain those kinds of things in there.

**Expert 3:**

I think so too. No, I think possibly the only addition that we could have is a little bit of usable tips or tips for use and something like, okay, did you consider your budget? Did you consider the signals you want to measure, your outcome measures? Did you consider these things? And then that's more like an introduction and then more just tips to think about rather than indeed giving a full explanation. So I think people should have a bit of knowledge, but yeah, if the filtering system itself is easy to use, that would be great because researchers can be smart regarding research. They can also be very dumb regarding other stuff. So it's good to know.

**Expert 2:**

I would just like, for example, put the PPG itself to the actual filtering, but it is always possible that some researchers are just interested in maybe step count and, even they would know, but still, maybe we would ourselves like write this nice brief description like ECG and PPG and in parentheses, like examples, heart rates and that, you know, accelerometer example, step count. So just something like this, but the filtering can indeed be really researcher oriented, I would say.

**Interviewer:**

Yeah. Okay. Great. And would you say that certain filters should be more impactful than others, or should everything be on the same level?

**Expert 3:**

Can you explain a little bit more?

**Interviewer:**

So you have certain filters that you could add. Should a researcher be able to say like, hey, this filter would be more impactful for me. So items that have this should show up higher on the page or lower on the page.

**Expert 1:**

Oh, so for sorting? Yes. That could be very cool. I think if you could sort based on stuff, that would be awesome.

**Expert 3:**

Yeah. Because I would love to have that in differences.

**Expert 1:**

Yeah. If you could make that work. Sort by price, for example, or sort by, I don't know, number of studies or validity score that we have.

**Expert 3:**

Or say ECG is essential or PPG is essential. And if it also has EDA, it's like a bonus, then it goes up a little bit, something like that. That would be very, that would be cool.

**Expert 2:**

I don't know if it's possible, but you know, also for Booking.com and for all the other websites that do this, like also for even fashion retail websites, after you search for something, then you can also yourself choose which sort of sorting you want to see. So if possible, I think that would be very useful for people.

**Expert 3:**

I think so. It's a sorting thing. And if you could do something in the filtering itself saying ECG is essential, PPG is a bonus, that's like different than a sorting, right? That would be very cool. Yeah.

**Interviewer:**

Oh, great. I'll have to look into that.

**Expert 1:**

Although that, yeah, that sounds a bit complicated.

**Interviewer:**

The second part might be a bit complicated, but it's also like if it has like one of the two, the other one should also never be excluded. So they might, they would have to read it themselves, but they might also see like, hey, this also has the other one.

**Expert 3:**

So, yeah.

**Interviewer:**

But that would then be based on the researcher. Would you also anticipate this tool to be used by researchers, but for a purpose that might be different than stress research?

**Expert 2:**

Yes. I think for sleep research, like expert 1 also mentioned in a presentation we had yesterday, we have a lot of sleep-related parameters. So, I mean, that is sort of a different line of research. Other than that, maybe people who are just interested in like activity and physical exercise, they could also use it.

**Expert 3:**

I think people who just use wearables for studies, I think could use it. So, I think kind of broad. Yeah.

**Expert 1:**

And I think for anything, you have those, I don't know, activity scores, like you said, not even step counts, but you know, like body battery or something like that. Or we had someone looking at mental states, emotion recognition, those kinds of things. So, I think this, yeah, like what expert 3 said, everybody that works with wearables in daily life for any type of research could potentially benefit from using it.

**Interviewer:**

Okay. Would you also say that the filtering tool should include separate mechanisms for users to provide different inputs, like for example, suggesting improvements or reporting any issues that they find or whether they don't agree with certain things that are stated within the tool?

**Expert 1:**

What I would like to have, what I would find helpful, I'm not sure if this is also something that you, expert 2 and expert 3 agree with, but I was thinking that if they are aware of a study, for example, or if they're aware that we made a mistake somewhere, that we have this kind of call to action that if you notice some discrepancies or something like that within the database, feel free to message us or something like that or reach us out. Maybe at the same time, the amount of requests could be too much or for silly reasons or something.

**Expert 3:**

Yeah. Then we could always close it after if it's too much. I think it would be nice, yeah, to have a possibility to send us a message.

**Expert 2:**

I think including a nice kind of a text box with a minimum number of characters to include, so they have to kind of give some effort into their explanation would be nice and we would be, we would be happy

to update if we agree with them. And it's not just about the researchers or the users, I think, but also about companies. Of course, even in our database, we even make the differentiation between external and internal. We give the message that we find the external studies a bit better because they're not influenced by the manufacturers themselves. However, if the validity study list for a device is not updated and the company spots an actual study and they want us to update it, they should be able to do so, I think. So they can also use that kind of text box that we would put to notify us maybe.

**Expert 3:**

Maybe way too foreign, way too much. But what do you sometimes have if you email a company or something, then you have these options, right, that you can, I have a drop down menu saying I want to report something within the database, like an error or a typo or anything. I want to add a validity study, I want to add a new device, I want to have an others option, just random message, something like that could sort things for us, maybe, which might be nice. But I'm not sure if this is even a thing, but this might be difficult, but it's perfect.

**Expert 1:**

I am only still thinking, should we really make it for people to message us or should we keep it a bit more difficult so that only those that really want to message us about it would, you know?. If it's like a contact form online, it can be very easy and you can have those issues that you get spam.

**Expert 2:**

Yeah, I think it may be possible because that's, I think, what I heard at some point from our supervisor, that you can put some sort of spam filter that filters out some, but that's not really needed now. But yeah, I really like the idea of giving different categories to people who want to submit something and then maybe we request their email address and their affiliation so that they have some sort of responsibility and let them know that they should write at least 250 words or something like that. I think it's doable.

**Expert 1:**

I remember we also had this discussion quite some time ago, I think the three of us back then, whether or not the tool itself, if it's online, if it should be public and made available to everyone or if it should be account-based that you, for example, have to register with your email, with your institutional email. But maybe that's too much of a requirement for now and maybe also something that we still have to discuss.

**Expert 3:**

Yeah, but maybe also something for the future and good to keep in mind at least that that's something we're considering.

**Expert 1:**

I think if it's openly based it can be also easily scraped.

**Expert 3:**

Is that good or bad?

**Expert 1:**

Bad. I think then it can be used for commercial purposes a little bit too much and then if you only make it available to scientists or companies that are affiliated with research in any way.

**Expert 2:**

Oh yeah, it's a good idea. So we can also add some sort of short statement and then an I agree kind of click for them.

**Expert 1:**

I can send to the license going on now. Yeah.

**Interviewer:**

Yeah. Then for, well, basically my final question already. What would you envision the filtering tool to look like? So if you look at it on your screen, what should it look like?

**Expert 1:**

Good question. I think I'm open to a lot of things. I'm not a designer. That was your department right? No, I don't know. And if maybe you have any clear thoughts, I think I might have clear thoughts in my head or like an expectation, but I don't know.

**Expert 2:**

Okay, I'm just thinking of some thoughts like at this very moment. I like the idea of showing one filter to focus on per page. Uh, that's how some websites do it because it is already kind of complicated. It's not as easy as picking like, you know, how many beds or rooms or a pool if you want that in a time. It's kind of, yeah, it will also require them to think more and just seeing all the different things at once might not be as pleasant. So then maybe first starting with a screen of like which wearable types should be displayed and then say ring and then you list them if you really want.

If we really want to be fancy, we can have to have some nice pictures, but that's not needed. So then they click on, let's say, a ring, a watch, something else, and then they click next, and then that's, yeah, you know, and then keeps on like this for a few steps. And we can also have a small kind of progress bar, so they will know at what point it will end.

**Expert 3:** The only thing you should, it's essential to have a skip button, I think, and I think some people might be, feel forced to describe the wearable type, although they don't want to. Yeah, I'm thinking also, maybe more of a fan having like, maybe some set filters, like essential filters, and those are like signals, wearable type, two things, and then additional filters. Maybe that's a way to, like on the sides or something.

I see the filters on the side, and then the device is like this, and then if you press rings, then it's gonna go down, or if you press rings, it's open, and all the wearable types are there, and you press, I want to have ECG and EDA, and then it's gonna go like, bloop, so now we still have 20 options left. And then if you want, oh, but I really want it to be waterproof, well, that's under additional filters, and then you press waterproof, and then, bloop, there's none left, or one, or that's more how I envision it.

**Expert 1:**

I also see it more like that, more like a typical online selection tool, if you're buying something, or if you're looking for a house, or on a booking.com kind of system. **Expert 2:**

Yeah, that's also fine. Yeah, what I meant is actually the exact same thing, it's just the displays different. Some websites, like supplement websites, I don't know if you've ever been on those, but they would ask you like one by one, because the questions tend to be not as straightforward sometimes.

So then first asks, you know, what is your typical energy level, then you pick something, and then you skip. And I mean, we can still discuss about this later, but even then, you can still indicate if it's required or optional, and skip steps. So, but yeah, I'm fine with both. It's a cool thing, something different, yeah.

**Interviewer:**

I think that Coolblue uses a certain product filter, which you can choose yourself to use, or not. In Dutch, they would call it their keuze help, that would just help them. Then at that point, it shows the thing that expert 2, you were talking about, only after you click on it, you get the steps. But before that, it's just your normal, open one.

**Expert 3:**

Would something like that be possible, do you think, interviewer? Like for our purposes, combining that?

**Interviewer:**

I mean, I have not made it before, but I was actually looking into that today myself, like, hey, would this actually be interesting to use? Because it would also really help researchers to use the tool, to not have the enormous amount of filters at once. And for researchers that are like, oh, I know my way around this, they don't have to use it. And for those that think like, hey, I'm new to this filtering tool, they can just click on the product filtering that will help them. And they'll just go through the main ones first. So let's say they have five steps or something.

**Expert 3:**

Yeah, cool. Good thought.

**Expert 1:**

I think a combination would be perfect, actually. If it's doable, of course. But what I also like is, if you have this normal setup, is that you see how your choices, immediately how they affect the results. And that's, I think, very valuable. Because maybe you want to narrow it down even more so that you have less options. And if you have this kind of a flow where you have to make choices and you don't really see the results yet, that feeling gets lost a little bit.

**Expert 3:**

What do you think it will look like? Is it going to be like an interface website thing? Is it going to be in Excel? Do you have any idea already? Or you don't?

**Interviewer:**

I am currently thinking about making like an interface-based website.

**Expert 3:**

Oh, yeah. Nice.

**Interviewer:**

But I am just still looking for how it exactly would be as a design. So for example, this discussion that we just now had was something that was going through my mind just today. Like, hey, could we be including this? And in what way should we then implement it?

**Interviewer:**

I don't have any further questions. I don't know if any of you have anything to ask or add.

**Expert 3:**
No. I think it was good to have this discussion.
**Expert 1:**
Maybe also just, you know, I think we talked about it in the beginning when we were describing the assignment. But I think what we would really like is that if you keep in mind that the database can change, for example, so that it's a little bit error-proof, you know, that if we change something, it's not going to affect and make the entire tool fail, for example. There is some kind of error prevention in there.

And that we can still make changes to the database. And if it would be also easy for us to adjust the tool to make up for those changes, that would also be perfect. Maybe good documentation of how it's created, so others can continue with your work. Or comments in the post, like what's responsible for something. Yeah. Keep in mind that this could be used then by other people.
**Expert 3:**
Yeah. We really want you to go use this tool.
**Expert 2:**
Also to keep in mind, we both use NAs and NPs in the database. So NA standing for not applicable and NP for not provided. Just maybe there you can think of some way to integrate this so they are treated differently.
**Interviewer:**
I would have to look into that during the pre-processing of the data. So from the Excel to your website, how would it show? It's a good one to keep in mind, certainly.
**Expert 3:**
Yeah. We're also separating some information in a single cell. So we have, for example, for some sensors, we have zero, one for is it available or not, as in one for available. And then we have a semicolon, and then we have a sampling rate, semicolon, location, something else. So how do we get... So yeah, for you, it's also a matter of figuring out, is this the correct way they're doing this?

Is this working with, I don't know, whatever language you're going to use? Or should they do this differently? So it's also kind of both ways. If we have to adjust something in the database because you think it will work better in the end with programming languages, that's also then for us good to hear if you have that type of feedback.
**Expert 2:**
Do you know which programming language you'll use? Just because I'm curious.
**Interviewer:**
I'm probably going to be using Python for the backend.
**Expert 3:**
Nice.
**Interviewer:**
And then a combination of HTML and JavaScript for the frontend backend part of the website.
**Expert 3:**
That's nice. Yeah. That's then also...
**Interviewer:**
So those are quite common.
**Expert 3:**
Easy for us to use. Yeah.
**Interviewer:**
Awesome. All right. And I'll stop the recording.

# Chapter B.
# Appendix B

## B.1 User test questions

**General Experience**

- Overall Experience:
  - How was your overall experience using the filtering tool to solve the use case?
  - What is your opinion about the ease of use of the filtering tool?
- Ease of Navigation:
  - What was your experience navigating through the different filters and options?
  - Were there any aspects of the navigation that you found confusing or difficult?

**Specific Features**

- Checkboxes:
  - What was your experience with the checkbox filtering for different features (e.g., PPG, Accelerometer, GDPR compliance)?
  - Were there any checkboxes that you think should be added or removed?
- Sliders:
  - What was your experience in setting sliders to certain criteria like device cost, battery life, and weight?
  - Did you encounter any issues adjusting the sliders to your desired settings?
- Sorting options:
  - What was your overall experience with the sorting options in helping you find the best device?
  - Were there any additional sorting options you would have liked to see?

**Functionality and Performance**

- Filter Effectiveness:
  - How would you rate the effectiveness of the filters in narrowing down the list of devices to meet your criteria?
  - Did the filtered results meet your expectations based on the criteria you set? If yes, in what way?
- Response Time:
  - How would you rate the response time of the filtering tool?
  - Did you experience any delays or slow performance? If yes, how did this influence your experience with the tool?

**Usability and Satisfaction**

- Ease of Finding Information:
  - What is your experience in finding specific information about each device after applying the filters?
  - Did you feel that the information provided was sufficient to make an informed decision? If yes, why?
- Satisfaction with Results:
  - How do you feel about the final list of devices that the tool provided?
  - In what ways did the tool help you find a device that you believe is suitable for the use case?

**Improvement and Feedback**

- Improvements:
  - What improvements would you suggest to enhance the usability and effectiveness of the filtering tool?
  - Are there any additional features or functionalities you think should be included?
- Overall Satisfaction:
  - How satisfied are you with the filtering tool overall?
  - Would you recommend this tool to other researchers looking for wearable devices for their studies?

### B.1.1 User test expert 1

**Expert 1:**
Okay, well, I've read it, I'm going to pick up the first thing, because of course I have a budget of €25,000 and I have to measure 100 participants in 6 months. My first question is, do I have to measure 1 participant for 6 months, or do I have to measure 100 participants within 6 months?
**Interviewer:**
1 person, for 6 months.
**Expert 1:**
Ah, okay. Is there a time limit? No. Okay, so I'm allowed to talk about this for 10 years, that doesn't seem very practical to me, but that's possible. So that makes a difference. Well, let's say that you do want to be ready in half a year, but you actually want to be ready within 2 years, maybe. That's nice. Well, let's say that you do it 25 per half year, that's realistic. You need something like 30 devices at the same time, one at a time. So then you can start calculating. Okay, so we have a budget of €800 per device, let's say. And if I want to do it within a year, I only have €400. Well, that should possibly be good enough. The second difficulty is stress measurement. Yes, this is definitely good advice. You have to define how you measure stress yourself. But for this exercise, I would say we take stress as heart rate, heart rate variability. And if he has EDA, so skin conductance, that's a nice bonus. He needs physical activity. Okay, let's move on. The goal. What we need is something from accelerometer data. Let's give it PPG, that would be nice. Oh, EDA is not on the list. Didn't we give that? Well, maybe. I don't know. Oh, I'm going to type it in. I know one that still has it in my head. Sorry, maybe with a detour. Oh, maybe. Oh yes, maybe we have. Oh yes, hey. Okay, first notice is that EDA is here, but I can't filter it. Yes. Why is that? Can I ask? Or do I have to do it at the end?
**Interviewer:**
No, you can do that. That is purely because that column is not added. And I think that's because there is a minus 1 somewhere in that column.
**Expert 1:**
Oh yes, that's right. Oh yes, so you can only filter in this way if there is a yes or no.
**Interviewer:**
Yes.
**Expert 1:**
Yes, logical. Good to know. Good to keep in mind that we might have to adjust that. Yes, logical. Okay, well, I want this, this, something like that. This looks nice. Well, GPS is also a nice bonus. Oh, oh, this is that. Okay, yes, yes, yes. But it could be fine with ECG or PPG. Let's start with ECG. Because then you quickly get very intense units that people don't want to wear at all. You can also take the costs with you. Let's say we do it in two years. Which would also be nice, as I can type here. Then I can say, ah, it has to be so expensive. Yes. Because sliding is always very nice to have. But sometimes you have to be very precise. And some researchers are very precise.
**Interviewer:**
I understand that.
**Expert 1:**
Logical. Oh, that came up. I might shorten this one a bit. If you can't see the whole title of the website. Well, I think that's fine. Oh yes. Device costs, wrist, location. I'll take a look. Okay, so here's wrist. That's pretty nice to wear. Because a torso with a CPU in the vest. Look, this is something people are going to wear forever, I think. No, so you already have watches with ECG. But I happen to know that. Wait a minute. Yes, that those are session based things. So that's not super optimal. And let's take a look at the battery life.

It had to be at least a week. That's nice. I get that. I think that's so many hours. But I don't really know. Double check. Yes, okay. So now the battery life is a week. That's fine. Ah, that's a maximum of eight. Yes, okay. Oh, it would be convenient if you could give a minimum figure here. Because this, or that you do this the other way around. Because you want to score as high as possible. Or that you can drag it from two sides. Because I can say, well, I want to score between a 6 and an 8. Instead of just doing it low. I would, as a researcher, find that a nice bonus. Okay, what if we do PPG and remove ECG? What about our price? Yes, of course they are all good to pay. That's nice. Then I can do it nicely within a year as a researcher. And they all have accelerometers. That's great. They have a PPG. Let's see what kind of data comes out of this. Raw data. Okay. Not a single one has raw data. This one has that for some signals. Which one is that? Apple Watch 9. Oh, you know what would be handy too? If I go to the right like this. We have that in our Excel. The manufacturer and device name. If it were. Go along. Do you understand what I mean? That you freeze that. Yes. Because then I don't have to scroll back to see which device that was. Battery life all looks good. I find this one a bit short. Oh yes. Battery life is of course also. It may be a bit longer. It just doesn't have to be shorter. So maybe you should also have a slider on the other side. Well, they're all pretty good. Because this one for example is too short. It should actually be out. But that's not possible. But then I'll skip these two. This one. Five. And the last one. This one. 1, 2. With the Fitbit charge and the Garmin. And it combines for the Garmin. Let's take a look at the process values. Oh, and raw data they didn't have. Oh yes. They have a heart rate at least. The other process values are no longer in it. But I didn't select that, did I? No. They must be a GDPR anyway. Oh, which side do I put? Oh. Oh, we probably just haven't filled that in yet. Well, this seems good to me. There are quite a few options. Let's take a look at more requirements. Ease of use. I think they're all watches. So that seems to be all right. Oh yes. Or a ring. Well, that's all ease of use. Check. Stress, battery life, data compliance, its data storage, PPG. Well, let's take a look at the validation. What else comes out of there? Can I select something there? Yes, you can. But only less. That might also be a two-sided slider. Well, we already tested this heart rate. Just like this one. Did it still work with the battery life? We have to scroll back again. Because I couldn't filter it out. Difficult. Can almost. Also good enough. And the top two also had long enough. What is that? Oh yes, all Fitbit. Fitbit, Fitbit, Fitbit. Well, that's nice. Well, this is also nice. Bonus news for usability. That we're doing well, boys. This might also be a kind of pop-out thing. Or something like that. If you hold on to it, it will pop up. Now I have to scroll a lot. Let's take a look at the CI usefulness score. Because this is a long-term study. So that's what we're going for. Sort of important. Well, that's all good. Oh, this one is even better. The best-following SiA researchers. Well, then I'll take this one. The Aura Ring. I'm going to take that. I'm going to give it a good score. Logistic validity studies. Meets the other requirements. How? Yes, well. I think that makes it a bit more convenient. Well, right? Nice. And did I pass?

**Interviewer:**

Yes. Okay. Well, if you want. You can close it now. Or if you want to show me something. Especially open during questions.

**Expert 1:**

Yes.

**Interviewer:**

Then I have a few questions that I would like to ask you. But if you come up with something yourself. Then especially in between. Sure. What was your overall experience of using it? What did you think of it?

**Expert 1:**

Yes, good. I think the layout is nice. Also nice and neat. And fun. With the two colours of SiA. That's a nice bonus I see now. Scrolling is, Good to do. But also difficult. Because if you don't know where something is. Is that difficult, Oh, what would be very nice. I think. Would be if you. Okay, we use a kind of overlapping categories as it were for the columns. For example, these are all signals. Maybe. I don't know if you have any kind of signals up here. That you can also fold it in per signals. Or unfold it. I'm thinking of something like that. And then technical specificity's. But good. These may be very detailed. But that might still be cool. For the future. Further. No, as I said. It's handy that some of the sliders. Can also be raised. Yes, at least. Yes exactly. Maybe just all of them. Yes. It probably won't happen. That someone wants a minimum cost. Or a minimum wage. But on the other hand. If people do want research grade devices. Which are a bit more expensive. You could also select that. Oh yes. Because here it says main use. I'm going to. Unselect. Oh yes. Because you can't yet. I wanted. I knew I had to buy a new one with this use case. Because we didn't have devices.

**Interviewer:**

Yes.

**Expert 1:**

Then, for example. Market status. Also handy. Yes.

**Interviewer:**
Oh yes. I don't know from the top of my head.
**Expert 1:**
I'm also curious. Is this a best-of option? Yes.
**Interviewer:**
That's what I wanted to say. It's a bit. There's a lot of stuff on here. Do you want to sort the market status? Or do you only want to filter on market status current, market status discontinued, only market status?

**Expert 1:** The second, I think. So that you select it, I want to throw it out again and not necessarily the sort. Oh yeah, but I haven't used it yet. Oh, I could have done that. Release date, oh yeah, device cost. Also a good one. Maybe it's also quite handy. Oh, it's already there, device cost. Yes, nice. That's why you chose these options for this sort by. Because those are hard numbers.
**Interviewer:**
Yes, especially because they are numbers, that is easier.
**Expert 1:**
Sortable, yes, logical.
**Interviewer:**
And those are also the categories that we mentioned in the first interview.
**Expert 1:**
Nice, great, good action. Logical, understandable. Oh, we are a bit crazy. Oh, I wanted to adjust them as well. These are of course never a comma. There is always 0 or 1. It never counts a comma.
**Interviewer:**
Oh, never a comma number.
**Expert 1:**
Say, it's always 0, 1, 5, 8, 20, it's never 24.1. So the dot came away, because that's a bit of a bummer. I think it's good. Did we have ... I don't know what your database looks like. Because it came a while ago. Were there more things in it? Or what did it look like? Because this is good in itself, that you have two ... Oh yeah, no, at output parameters. Where is it? Oh yeah, process values. I suspect there is more here, right? Maybe not you, there is nothing around.
**Interviewer:**
You still have the device cost down there. In your sliders.
**Expert 1:**
Here, yes.
**Interviewer:**
So I hope that if you set that to maximum, you will get more.
**Expert 1:**
Oh yeah. Oh yeah, I mean more because ... I happen to know that for the Empatica E4 ... there are more process values than just this.
**Interviewer:**
Oh, I see.
**Expert 1:**
That's what I mean, look. Empatica E4. And then, I don't know what we gave you. But here you see that there are more.
**Interviewer:**
I see it.
**Expert 1:**
That's what I mean, more process values.
**Interviewer:**
Yes.
**Expert 1:**
Because there are more here.
**Interviewer:**
I think I know where that comes from.
**Expert 1:**
Comma and semicolon.
**Interviewer:**
Yes, so I have all columns with a 0 of 1.
**Expert 1:**

Yes.

**Interviewer:**

I had my code filtered to the semi column, so to speak. So that it shows the data on it and can filter on it. And that's probably what he was looking for. That he also says in that column. Hey, I looked up to the first comma.

**Expert 1:**

Yes, logical.

**Interviewer:**

But that's a good one.

**Expert 1:**

Yes, that would be it. And yes, I think it can sometimes be useful for researchers. Especially if you're looking for a research-grade device. To do show that detailed ... Oh, stop. He finds it difficult to share the screen. And to zoom in and out. Yes. Look, you just filled in a 0 of 1. And you give that back, right? Yes. I don't know how far that goes. That you could write this as advice for the next or for the future. For some people, of course, it is useful to have this information. Yes. Maybe in the future we will also have a kind of device-specific page. Suppose you say, well, I want it to have ECG. That you can then say, okay. Well, ECG. They all have it, fine. That you never go to the page of this device. Or that you ... I don't know what to say. That you hover over it with your mouse. And that it then gives a kind of pop-up. Okay, these are the details. Or a kind of fold-out option. I don't know. I just say something. I don't know if that seems useful. But at least something to make sure that you get this information. Yes. That's something. Because I don't know what is useful. But you may have thought about how that might be possible.

**Interviewer:**

No.

**Expert 1:**

How long do you have left?

**Interviewer:**

I still have two weeks.

**Expert 1:**

Yes, logical.

**Interviewer:**

Yes.

**Expert 1:**

It is also logical that you will no longer implement everything.

**Interviewer:**

Yes, that's right.

**Expert 1:**

But if you could at least write it down. Also as tips for the future. Maybe like this or that. No, that is also super useful for us. Because this is already great.

**Interviewer:**

Hey, sure. That was the plan.

**Expert 1:**

Nice.

**Interviewer:**

By the way, what did you think of how you had to go through the different filters. And through the sliders. That there were three of those different pop-up menus, for example.

**Expert 1:**

Yes, I thought that was nice.

**Interviewer:**

And was it logical what the titles were? Good question. Then you have signals. Then you have others. And then sliders.

**Expert 1:**

Yes, I understand your point. I think signals speak for themselves. What I had as a confusion was that I thought. Oh, I want. How you select this was true. Because I thought. Oh, I want all wearables that have accelerometers. And ECG or PPG. And I can't do that. You only get.

**Interviewer:**

No, you get both.

**Expert 1:**

Yes, that might be good. To explain something with an I or something. Sort of information. Or people who might be fast enough. Because you can sort of. This and this. And or this. But that might be a bit too difficult. The signals are logical. Others might be more. Yes. Yes, I get you. If you click it, you'll see it very quickly. Because it's not an endless list. I would say for now it's okay. In principle, I would say others and sliders. Of course, a bit vague. Yes, I get that. Yes, but I also understand that it is difficult. To find a good term for it. I wouldn't know that either. Measure another term. No, so I get that you did it that way. Oh, so you can see this too. That's convenient. And besides, I think the exhaust minutes are beautiful. That's clear. Oh yes, the signal is now ready. Oh yes, I get sliders. Oh, maybe I want to do something here.

**Interviewer:**

Yes, that's great. And filtering in principle. Did you think it was clear that the list was getting shorter? That there were fewer devices? Did you feel that the things you used really did things? Here in the menu.

**Expert 1:**

Yes, definitely. Yes, I thought you could see that it was getting shorter. It responds very quickly. I think it's nice that you don't have to click and then have to search for it. Because it's nice and fast, so that's possible. That you are of course of that Bob.com or Booking.com. Those are of course much bigger. So it makes sense that you have to click there and then search. But I think that's nice. Because you immediately see it skip. You immediately see the effect of it. Yes, for sure. No. I think that's good actually.

**Interviewer:**

Nice. Are there any other filters, for example check boxes? You already said that EDA is not in between.

**Expert 1:**

Yes.

**Interviewer:**

Are there any more of those that you would like to see?

**Expert 1:**

Yes, I would like to see all signals myself. Oh, what would it be? But difficult. You have for a lot of signals Process Values. Some researchers are less interested in a certain kind of parameter. For example, HR stands for Heart Rate. That's easy. And HRV can also be Heart Rate Variability. Very hip and happening. Some researchers find the signals completely uninteresting. They don't really know what's coming out of it. So they wouldn't filter so quickly on that signal box. But what they would like, I think, is also a kind of option menu. With all the Process Values that are there. So they can choose from that. Now we have a kind of list next to it. Where we have all the options. But as you can see, there are a lot. A lot. Yes, because each device has its own name. And we don't know if it's just different. So it's quite difficult to do that. So if you have a good idea of how you could use this. That would be great. Because some things also belong together. Some devices. This is too small for you. Just put down HRV. Other people use RMSSD. That is again a form of a parameter. Or a value, as it were, that they use for HRV. Other people use this term again. So there are a lot of variables, as it were, parameters. Which then belong within one concept. So actually you would. In theory. So we have to make something easy for you here. But I would like to give you a good idea of how you would like to do it. Because you have a lot of different kinds of parameters. Some of which also belong together in clusters. For example, you could have a cluster of sleep scores. So someone would just want to click on sleep. While other people may want a specific sleep stage. So then they would want to look at REM sleep again. Or want to look at something else. So you might end up in the subcategory again. This would possibly be a handy thing to be able to filter on. But how exactly do you have to do that? That's difficult.

**Interviewer:**

No, good point. I understand where you're coming from.

**Expert 1:**

Great. Can you give me some more ideas?

**Interviewer:**

Yes.

**Expert 1:**

Tell me.

**Interviewer:**

No, I'm fine.

**Expert 1:**

Cool.

**Interviewer:**

Let me see.Yes. What did you think of the final list you got? Was it easy to deal with? And did you understand why it was there?

**Expert 1:**

Yes, definitely. Now I'm biased, of course, because I made the database. So I know very well where everything is. I think for some people it could be quite a challenge. That you have to go through it like this. Where is everything? How do I find that? So there's a kind of category in there. Or a kind of click menu on the left. That you can say, okay, these are all columns. I just want to go to the battery life. And that he clicks like this. And that he jumps to a pop. This is the column for the battery life. Okay, I don't see him right now. But do you understand what I mean?

**Interviewer:**

Yes, I know what you mean.

**Expert 1:**

Something like that would ideally be even nicer. But also difficult. But yes, I thought it was fine.

**Interviewer:**

Okay.

**Expert 1:**

Sometimes scrolling a long way.

**Interviewer:**

Yes.

**Expert 1:**

For example here. So you think.

**Interviewer:**

Yes, I understand that. And are there any other features or functionalities? Of which you would say Because that would be. I would like to have that extra. In addition to, for example, that you have check boxes. In addition to that you have sliders. In addition to that you can sort. Is there still a real functionality? Of which you say. Because I actually missed that.

**Expert 1:**

No, the only thing. In addition to the things we mentioned. Could possibly be a kind of page. With a kind of easy. Oh! That you have two. Well, this is of course already. That you can compare the two. But that was.

**Interviewer:**

Yes. You would still like to have them. That you select the two. And then you get a separate page. Where you have those next to each other. With all the data.

**Expert 1:**

Yes, I thought something like that. Then you say. Compare, compare. That's just fine sometimes. And this reads easier. Than like this.

**Interviewer:**

Than like this. Yes.

**Expert 1:**

That would be it. But in itself. Further. And so. Those two columns. Of the device name And the manufacturer. Go along with the text. Yes. If you have to call. Because then it jumps. Ah, what was that again. Yes.

**Interviewer:**

No.

**Expert 1:**

No, that. Sorry.

**Interviewer:**

Okay. How would you score this tool?

**Expert 1:**

Yes. I'm really very happy with the thing. But I. I think it will be difficult. Because I know what kind of huge database it is and how difficult it is to do it differently So do I have to give it a number based on the usage? Based on the usage, yes Well, that I couldn't select from left to right was a minus The minimum But I also find it very smooth to use, so that's just very nice I would give it an 8 Something like that

**Interviewer:**

And after using this, would you like to say to other researchers in this field If you are looking for something, use this tool?

**Expert 1:**

Yes, I would definitely do that

**Interviewer:**

Well, nice Those were all my questions Are there other points of concern that you haven't addressed yet?

**Expert 1:**

No, actually I think we have addressed quite a lot of things I think it has become a very nice tool, I am very happy We have shown this at our SiA consortium meeting, which we had last week.

**Interviewer:**

Ah right.

**Expert 1:**

Everybody was like, ooooh. Because we first let them work with the database on paper. And then they saw this afterwards and they were like: Ooh yeah, this is good! This is very handy.

**Interviewer:**

Haha nice, they were kind of biased in that case since they had to work with the entire thing in paper version first of course.

**Expert 1:**

Of course, that was the plan

**Interviewer:**

But very nice to hear.

**Expert 1:**

Exactly and then they realise how difficult it is to create such a tool and to find the best wearable. And how hard it would be to normally work with a big database. And that such a tool would really help especially if it is so nice to click, slide, sort and filter. So my compliments!

**Interviewer:**

Thank you, great to hear.

**Expert 1:**

Great.

**Interviewer:**

Alright, thanks a lot. Then I will not stop the recording.

### B.1.2 User test expert 2

**Interviewer:** There we go. All right. So, first of all, this is the filtering tool in its current state. As I told you, there's some changes that need to be happening still, but those probably will be written down as future work. For now, I'll give you a use case, which you can read through, look for the requirements, and then look at, hey, what would I need in order to select the best wearable for this research? And then it's up to you to use the tool in order to find the best wearable for this use case. And please just speak out loud, whatever you're thinking, and I know what's going on inside your head and what change that might be to make it more clear. So, without further ado, here's the use case. Feel free to highlight anything if you need.

**Expert 2:**

Okay. I can still refer to this one? Okay. And how should I go to the selection tool? Okay. Can I see the case again? Okay. It just takes a while, right? If I slide? Oh, okay. I think it takes some time. Yeah. Can I ask you some questions?

**Interviewer:**

Yes.

**Expert 2:**

So, I'm still not familiar with all the columns. So, do you know where I can find whether it's continuous measurement or not?

**Interviewer:**

I honestly don't know either.

**Expert 2:**

I think it should be somewhere, but yeah.

**Interviewer:**

Honestly, I'll just take them from the database.

**Expert 2:**

Okay. So, it doesn't offer any additional information for this column, right? So, it's just one or zero, I guess.

**Interviewer:**

In order for filtering. Okay. Yeah.

**Expert 2:**

So, I think I'll choose Fitbit Sense. Okay. Do I need to give the reasons?

**Interviewer:**

If you have reasons, then please.

**Expert 2:**

Yeah. But I think the only thing that I'm not sure is about whether it could offer continuously passive sensing. Yeah. I think in the database, it has such information, but I'm not sure whether it's still here. So, that's the only part that I'm not sure. And also, regarding battery life, I think this could last six days. So, it's about one week. So, I guess that's fine. Then the price is, yeah, that's one of my considerations as well. So, the price, also the signals, PPG, ECG, accelerometer. So, these are the requirements. And lastly, about the validation of the device. So, I think among these three, it has the most validation, I think. And also, it has external validation. Yes. Yes. So, I think this is basically my reasons. Yeah.

**Interviewer:**

Okay. Good choice. Great. Then I'll quickly ask you some questions regarding the usability of the team, if you're okay with that. So, first of all, I would like to ask you, how was your overall experience with using this tool in order to solve the case to gain the right wearable?

**Expert 2:**

Yeah. I think the selection columns on the left, it's pretty useful because you can already eliminate a lot of options that are not suitable. So, I think, yes. So, it is quite user-friendly. But then I think because, I mean, it's the database problem as well, it has too many columns. So, sometimes it's a bit difficult to find the information that you want to see, which are not part of the selection columns.

**Interviewer:**

Yes. Yeah.

**Expert 2:**

So, I think, yeah.

**Interviewer:**

So, you have to scroll too far to the right or left.

**Expert 2:**

Yeah. Yeah. Yeah.

**Interviewer:**

Okay. And what is your experience with navigating through the different filters and options? So, you had the three tabs, one with the check boxes called signals, one checkbox is called other and one called sliders.

**Expert 2:**

Can I see the checkbox again? Yeah. Yes. So, I think it is pretty useful, but I think maybe in future, maybe it's not possible to finish it now, but maybe for this checkbox for others, you can add like, of course, like more columns, and also you can group it as what signals does, you can give it like a title of, for example, you can see like GDPR, FDA/CE approval, it's more like, yeah, the compliance, so the regulations, like legal regulations, you can have this title, titles, I mean.

**Interviewer:**

Yeah.

**Expert 2:**

Yeah. Or just like device information, then you can like have these stuff. So, I think, yeah.

**Interviewer:**

Okay, good.

**Expert 2:**

Yeah. But generally, yeah, it's fine. Yeah. Because there are not so many columns for others. So, yeah.

**Interviewer:**

Yeah. Good to know. And for the check boxes specifically, what was your experience with that, using that to filter?

**Expert 2:**

Yeah, I think it's really useful. Yeah. Because they're like, originally, there are like a lot of devices that I need to scroll down to check everyone. But then, yeah, with a checkbox, it's a lot easier for me to find the information. So, after I filter the information that I want to use, there are only three devices left. So, I think it's pretty nice.

**Interviewer:**

Yeah. Okay, great. And were there any check boxes in this list that you think like, hey, those aren't really necessary, or are there any that you think like, hey, I would like to see those added?

**Expert 2:**

Actually, I want to see approval because I'm not so familiar with this term.

**Interviewer:**

I must say that all the explanations are in the database itself.

**Expert 2:**

Yeah. Yeah. Yeah.

**Interviewer:**

I think it's just some kind of regulations. Yeah, probably.

**Expert 2:**

Yeah, I think, yeah, for the, I mean, for the existing columns, I think they're fine. Yeah, I don't feel like any one of these is not necessary to be here because I think they're, I mean, I believe there are researchers who are interested in one of these columns. So, yeah, I think it's okay. Yeah.

**Interviewer:**

Okay.

**Expert 2:**

Yeah.

**Interviewer:**

And are there any columns that you think like, hey, I would really like to see those as well? Maybe some that are in the database.

**Expert 2:**

Yes. Yeah. So for me, maybe it's also good to add the main use because I think for some researchers, they want to use only like research available devices or for some others, maybe it's not even researchers, but they want to buy the consumer product. So I think it's good if we can add this.

**Interviewer:**

Yeah.

**Expert 2:**

Yeah.

**Interviewer:**

Okay.

**Expert 2:**

Yeah.

**Interviewer:**

Good to know. And within the sliders, you used only the slider for the device cost.

**Expert 2:**

Yeah.

**Interviewer:**

But how was your use with this?

**Expert 2:**

Yeah, I think it's all right. I mean, it's a bit slow, but yeah, I understand. So yeah, actually I do have like some doubts about like the number here because I believe there is like a unit after that. But then for example, for the device capacity or for, I don't know, like even weight or something, so I, or device cost, I do want to know like, yeah, what's the unit after that. Yes. And also does this number suggest like just the maximum value here? Right. Okay. Yeah Yeah. I think just, yeah. The unit of the number. Yeah.

**Interviewer:**

Okay. Good one. And you use the sorting menu to sort on device cost.

**Expert 2:**

Yeah.

**Interviewer:**

How was your experience with using that menu?

**Expert 2:**

Yeah, I think, yeah, I think it's all right because yeah, it just works fine. And then, but in my case, because there are not so many devices, so it's not, yeah, that's difficult even without the sorting button. But yeah, in general, yeah, I think, yeah, it's good to have this buttons. If the researchers, they don't have like a lot of criteria on the left, so they could sort based on one column. So yeah, I think it's good.

**Interviewer:**

Okay. Good to hear. And how would you rate the overall effectiveness of the tool? So in narrowing down the data from the database into something more easy for you to read.

**Expert 2:**

Out of 10, maybe?

**Interviewer:**
Yeah, out of 10.
**Expert 2:**
Okay. And I, yeah, just try it again. So maybe I want to see like originally how many devices are there.
**Interviewer:**
Yeah.
**Expert 2:**
So I think I would give it like an eight because I think with like a lot of devices, it's really useful. And I can also give some suggestions.
**Interviewer:**
Yeah. Please do.
**Expert 2:**
So yeah, because there are like so many columns here. So, and now you're like freezing the like first two, but I feel like if I, I don't know whether it's possible like for the users to kind of move the columns they're interested the most to the left, or I don't know like how easy it is, or when I'm doing the sliders or when I'm doing like sort by device cost, then I can have this columns just like here or something because yeah, it's just easier to find. And also for columns, like where is it? So for example, maybe for this website, because now like the, this row, it just fits all the yeah. Websites URL until the end. So yeah, it's pretty long. So I feel like maybe it doesn't, yeah. It's not necessary to have this, like such a wide column here so that the users can like just see more information.
**Interviewer:**
Yeah.
**Expert 2:**
And it's also like for the release date and things like that. Yeah. I mean, you can also do it maybe like with one click, then you can see all the information or something, but sometimes, for example, for the websites, I don't think it's necessary to have like, yeah the complete URL here. But I think, yeah, with this, yeah, generally it's really good.
**Interviewer:**
Nice. Right. What was your feeling about the final list of devices that was provided by the tool? Did it suit exactly what you thought it was going to give you?
**Expert 2:**
Yeah, I think, yeah, I think it's all right. I think that with the final selection, it's reasonable. And also it's something that I've heard of. So I think, yeah, if it's what I want to search, so yeah, I think it's good.
**Interviewer:**
Okay. Yes. In the overall usability of the tool, what would you say are more points for feedback on the usability itself? So what were features that you missed or things that you got into?
**Expert 2:**
Yeah. So I'm not sure whether it's easy to incorporate, but it will also be nice if you can have like a picture maybe of each device. So yeah, it's just more intuitive for the researchers, I guess. And I think other than that, yeah, I think it's already pretty good until now as like a preliminary version of the selection tool. So yeah, I don't have like any other points to say here. So maybe just like fitting the size of the columns and then, oh yeah. So maybe like one thing, like I said, like just how to group the others. So maybe you can also like give like a title, I mean, like a grouping to the column title here.
**Interviewer:**
In order to make it less needed to scroll-able. You could just group this under signals.
**Expert 2:**
Yes, yes, yes. Something like that. Yeah. I think in the original database, they actually have it like a, yeah, these are kind of the subtitles of those titles, but yeah, I think with maybe like a signal here, so maybe with just one extra column on top, it's just easier for user to find what they want. So maybe when I want to find the cost, I will just scroll through all the signals. So yeah.
**Interviewer:**
Yeah.
**Expert 2:**
Yeah. I think it would be good.
**Interviewer:**
Okay. Then if you look at the whole tool, what would you rate it as? Like out of 10, what would you score it? In this case, knowing that there are still functionalities to be improved on.
**Expert 2:**

Yeah. I think I will give it a seven. Yeah. Because yeah, I feel like the framework is already there. It's just some functions that could be added. So after that, I think it would be good. I mean, from the design, how it looks, it's good. So yeah, I think just with the functions that I suggested, then yeah, I think generally it's good now. So I'll give it a seven. Yeah.

**Interviewer:**

Okay. And would you recommend this tool to other researchers within this field of research or would you use this yourself more often?

**Expert 2:**

Yeah, I think I would do both. Yeah. Because I think it's really useful and I feel like in this field, we don't really have a tool like this. So yeah, I would definitely recommend it to others. Yeah.

**Interviewer:**

Okay.

**Expert 2:**

And also will use it myself, of course. Yeah.

**Interviewer:**

Glad to hear. Well, those were all my questions. Do you have anything more to add?

**Expert 2:**

No, I think, yeah. Yeah. I think I've already said what I wanted to say. Yeah. In general, it's good. Yeah.

**Interviewer:**

Nice. Glad to hear. Then I'll stop the recording.

### B.1.3 User test expert 3

**Interviewer:**

Yes, well, great. Okay, then I have a use case for you in a moment. Read through it, highlight what you need if necessary. I have the filter tool open, you can switch between the two with Alt-Tab. Okay. And it's up to you to go through the use case and see which wearables I think fit. And think out load please. In the meantime, I type in a few things that I see and hear. And then I have a short list of questions that we go through. Okay. But most of it is just you going through the use case with the filter tool. Yes.

**Expert 3:**

Okay, can I also add a piece of paper?

**Interviewer:**

Yes, of course.

**Expert 3:**

Sometimes I just need to have a piece of paper instead of everthing in my head. I know how difficult it is. Okay. User testing use case for the filtering tool. Okay, if you want to follow 100 test persons for six months. Okay, you're going to follow them for half a year. Daily physical activity and stress levels. 100 test persons, that's really a lot. So wearables that can measure stress and physical activity. So one wearable device probably that can do both. Continuously, minimal maintenance and burden. GDPR, data protection. Yes, so they want to measure stress levels through physiological effects. It may be cardiovascular or electrodermal, so that's comparable. Flexible test. It doesn't really say whether it should be continuous or not, those stress levels, but I'll just assume. Important description. Physical activity should track daily steps. It's just about parameters, not really about signals. So the parameters are stress, physiological stress. Steps. Oh, but there are other things as well. Steps and... The others are also parameters, active minutes. Battery life, long battery life. Yes, seven days. Ease of use. There is also validation. Would be a plus, not a must. Budget is €25,000. Purchasing devices. It doesn't say how long the study will take. It says six months. Can you say anything else about how long... When they should be ready, I would say. Do they have to do it within a year, or do they have to be ready within those six months?

**Interviewer:**

Within those six months, that would be nice, but I think... but two years would also be possible.

**Expert 3:**

Two years, so then they would need €25,000. If we pass it on all the time, but of course that doesn't work. Then things go wrong, so let's say you need 35 As a backup. So then I'm going to assume we use 35 wearables. So €25,000 divided by 35. So that you don't close any other... I already said that. Just don't. Oh, quite a lot of money. Should I have €714,000? If I assumed that I would really have to be ready in six months. Then it would be a little over €100,000. €105,000. That's €38,000. It doesn't matter what I... We can get back to that later. Okay. Yes, I think I have it. So now I can go back to the tool and I can use it, you

said. Here are the signals, that's nice, but in itself... The use case didn't say anything about signals, but everything about parameters.

Things about here in the tool. No, not really. Sliders. Things, costs, weight, battery life. I am unable to slide from the bottom of battery life, oh no wait... No, it's one slider. It goes in hours. I have it in days, so seven times. Actually, I don't really have a slider, because it indicates an upper limit. I need a lower limit. I am going into this way too quickly. Here I can immediately turn on the GDPR Compliant. Click of course, because it was mentioned very clearly. Those things. Maybe not entirely relevant for now. Yes, so I don't have parameters in this tool. But I really have to go back to the signals. And EDA is not here yet. Then it must be PPG. ECG is nice, but of course you can never measure it for seven days. They actually fall away. Accelerometer is also nice. Gyroscope is also better, but it is not strictly necessary. Yes, those sliders, can I do something with them? Some maybe. Here I have an upper limit, so that I would keep that one at 238. Nice and restrictive. I would like to be able to type in here. If I had thought of a number in a very specific way. Yes, it took a while. When I was done. Well, if I assume that it should be ready in half a year, then... There are actually only three devices that are current. It is convenient that this is immediately visible here. Of course a very important one. I can still buy it. Although they may still have it somewhere in the lab. The Apple Watch SE costs € 250,00. I thought an Apple for € 250,00. So that works well. Then the Battery Life. Yes, they didn't go there, because then I actually have a lower limit. There is not much to do with it. Charging, I didn't say anything about that. Device storage, blah blah blah. This is more nice to have, I could look at it like that. Of course SiA expert score is also nice, but... For now this is a bit what I can do right away.This is nice to sort. Device cost weight. Battery life. Number of validity studies. Look. I think the one at the top has the most. Not very clear. Oh, yes. Oh, that one is now sticky. That's nice. Let's take a look here. EDA is included, by the way. There is no selection by signals. Gyroscope. they do not all have gyroscope, the Apple Watch does. If that was still there, then you would have a better signal. Of course you also want minutes and such. Maybe it's gyroscope. Yes, I do. That's the problem. I do lose my fitbits. I don't know. Already now. Here is the battery life. I just have to find it myself. 7 days is... I don't understand it well. Yes, it's exactly 7 days. 168. Well, it would all be acceptable. The Apple Watch has no battery life. That's right, I think. Immediately it became different. That's why it dropped. Do we have anything else on my list that was important? Yes, usability. Available. Process values. Oh, that one also has EDA. Right. Stress, they say something about that? Well. Sense 2 has not yet been validated. The Charge 4. The Charge 5, yes. That was also still available. Well. Well, now it's getting a bit of a puzzle. Would you like to mark something here? Well, validation. Reliability is a bit comparable. Something between those things. Usability. Only for the Fitbit something. It takes a long time scrolling like this. For the long term. Yes, actually only the Fitbit. The Fitbits have that. 6.6. In any case, above average. That in itself is of course very useful. Okay. Yes, then the Charge 5 will come out very well. All in all. Sense 2 is newer and not so clear. But where are the costs? Where are they? Here is the cost. Oh, those two. The Charge 5 is also much cheaper. But money is not really a hindrance. So the only thing I'm curious about is if I go out of a much more expensive device. What will appear 714. 714. Okay. A number of others are added. Rings are also added. More expensive Apple Watches. But they all have battery life. Not acceptable. I don't know. No watch. Pixel watch. So the Pixel watch, the No watch and the Aura are added. Yes, would you actually want to be able to select it now? Then you would say, I want those three now. Are they added now? I have a preliminary conclusion from the one I just had with the Charge 5. I think, well, that's a nice, cheap option. That's what I'm going for. But yes, I also have another scenario in which I follow the more expensive route. Measure much longer and use them more often. Then I can do it in an easier way. Then I also want a gyroscope, of course. Then that Aura also falls away again. That ring is of course an interesting factor. People don't need feedback. Now I would actually only have to look at the Pixel watch 2. 400 euros. But it is also not validated. That is difficult. I'm a bit clueless right now. Oh, but wait, there is a long-term score. 6.3. That is later than the Charge 5. Well, there is no reason to choose that according to this database. Except that it is then. The only thing is that I would like to test that ring now. I think. I could also choose that. Oh, I didn't look at the battery life. If you've been at it for too long, you have to say something.

**Interviewer:**

No, no, no.

**Expert 3:**

Where are those hours? Here. Oh. I think 24 hours. Well, that's not at all possible. Okay. So that would be handy again. And let's have an underline here. That is also a very unclear thing for me. What does it look like now? I'm going to turn off the gyroscope. We go back again. Oh, we also have the Nowatch. I had deleted that. I forgot. Battery life. Nowatch is better. Why did I just delete that? I don't know anymore. No validation. Oh, I think the aura has also been validated. High validity. For nocturnal. It's not bad. It's a bit unclear. Compliance was high. Usability is also good. Nowatch. Long term. Even lower. 5.5. Aura 7.3.

Okay. Yes. So in summary. If I go for the expensive option, I would go for the aura. If I go for the cheaper option, I would go for the charge 5. Okay. I do notice. Do you want to continue talking about things that I experience with using the tool now?

**Interviewer:**

Well, if you've made your choice, then I'll go through a question list. Yes. Okay. Yes. Okay. Yes. Well, great. Two options actually for the different scenarios.

**Expert 3:**

Yes. The aura for expensive. If I reuse it several times. So to speak. If I have it for a long time. Yes. If I leave it for two years. And then for cheap. Then the charge 5.

**Interviewer:**

Okay.

Yes. Well, let's just start a bit standard. What did you think of the overall use of the tool?

**Expert 3:**

Well, it's very nice that I can immediately touch on a few main things here on the left. For a moment I thought to myself that I was going to touch on parameters. Because in the use case, not much is said about signals. But there were no parameters in between. So that requires some choices or knowledge of how to do that. In my case, of course, that's not such a problem. I like that. Then I could tweak other things with it. But that was possible. And yes, it's nice that you split the accelerometer and the gyroscope here. That also gave me something to choose from. The difference in technologies that are in it. Yes, these things were largely not so relevant now. But of course it is possible for other use cases. So that just depends on your use case. What you need. Yes. So that was fine that I could choose the GDPR now. Or maybe I forgot that another one was also relevant. I didn't go back to the use case. Yes, and I noticed that at some point, because you have a kind of comparison task. I had my book with me to write down a few things. But not very systematically. And that was a bit difficult in general.

**Interviewer:**

Because of the large amount of information?

**Expert 3:**

Yes, you have a large amount of information. You have a number of things that are interesting for the use case. You have a number of different wearables. Also for different prices. Yes, then you would almost be able to select a few columns. And that suddenly makes it very small. If you select and save, then you become a comparison. Okay. I want that one and that one. And I want that one and that one. And make a kind of final summary column or something. Where I can take a look through it. While now that remained a bit inconvenient. What I was doing, I think. But yes, not impossible to do or something. But yes.

**Interviewer:**

But to have to compare all the information with each other yourself. That was a bit difficult.

**Expert 3:**

Yes, and at some point I just forgot why I had excluded that Nowatch earlier. Yes. And maybe it just wasn't like that. It was just a mistake. Yes, so that. And I also noticed that the sliders are actually only useful if you have an upper limit. Like with the costs. But not if you have a lower limit. Like with the Battery Life. So you actually want that here. The slider should perhaps also be here.

**Interviewer:**

Yes, the other way around.

**Expert 3:**

Yes. Yes, that's good. Yes. Yes, I didn't use this one that much. Because I just wanted to see everything. I do read what is there. But of course there are also. And this one remained. Of course, because I know the people who make the expert scores. Yes, I'm going to trust that. Yes. Well, I can also imagine that. Maybe I don't have to live in other raters. But that is of course a very easy heuristic. And even there you might want a lower limit again. Well, it must be sufficient here.

**Interviewer:**

Yes. So especially those sliders on the lower limit. Yes.

**Expert 3:**

Yes, by the way, that's nice that it was so sticky. That it just stays there. That's very nice.

**Interviewer:**

Yes. And navigating through the tool. So that you had to go through those different menus. Left or through the whole table. How did that feel?

**Expert 3:**

Yes, okay in itself. But I noticed that I doubted whether I saw everything. We can do it like this. It's a digital. There are now three things. But because I missed those parameters, I thought I had everything.

Well, I don't know if I could do that. Because I just have everything. So that's okay in itself. I didn't think the sorting was that clear. In any case, it is now from top to bottom, from bottom to top. Also because you don't see it right now. So then of course you have to go to the actual column. Hey, where do I go to the column? Oh, here it is. You actually have to go to the ... Where is the right button? Well, I'm already at ... Oh, here it is. Yes, oh, okay. From bottom to top. Yes, that's clear.

**Interviewer:**

Yes.

**Expert 3:**

Well, okay. You can sort that out at that point. Yes, I can imagine that for someone who uses this for the first time, this is quite a lot of information. Of course, I have already been involved in making the columns. Thinking about that. And so I know a little bit, I have a mental model of what I want to look for. If I don't have that, I can imagine that it feels very infinite. A lot of information. A lot of information. And yes, wouldn't you actually have to have some kind of column selector or something? So of course your preferences are a filtering tool. You also say that you somehow limit the number of columns to help new users or something. That is really a lot. Maybe it can also be done in other ways. Yes, in itself a good option.

**Interviewer:**

Well, that's it. And if we just look at the checkboxes themselves. You just said that the user has parameters and not signals. Furthermore, the use of the checkboxes. Was that easy?

**Expert 3:**

Yes, fine.

**Interviewer:**

And are there a number of things where you say, well, you don't have to be in the list. Or where we say, well, I would have liked to also have you in the list.

**Expert 3:**

Yes, well, maybe one more thing. When I did it for the first time, I think it went a bit. Was he still working or something? Or did it seem like there were more at first and then less? Or I don't really know what happened. It was like he was loading or something. So I can show it again. Populate the database. When I did this, I did this. No, that's not it. I thought it would be better if I showed it. It's loading or filtering. Yes, the things that are there. I missed the parameters.Check boxes. Yes, otherwise they will of course be check boxes in relation to the columns that are there. So that's basically fine. Yes, and this is a kind of preferences for filtering, but also maybe preferences for visualisation or something. What do you see now? Maybe that's a different term. That might be interesting. Although it can confuse people again. Yes, but fine.

**Interviewer:**

And for the same thing with the sliders. There must be a minimum limit for many. Do you have other things that you would see for that? Or do you mean other columns that I would like to filter through a slider?

**Expert 3:**

No, I think I had for this use case. The other things on signals and stuff, that's all categorical. That's not continuous. Now? Yes, look, it's now. I noticed that too when we were at the consortium days. If you then have all the other use cases, everyone starts puzzling about the required costs. Nice. Of course, you could also say, shouldn't you just use a study duration option here? So that you actually calculate yourself how much it can cost at most. I mean, now there was no slider for it. Then half a year, then two years. That's the study duration. If you would have a slider study duration. And then also a slider budget. That it can calculate that for you, possibly.

**Interviewer:**

Yes, then you don't have to do that yourself. You don't have to do that. It's not that bad.

**Expert 3:**

You could also say yes, that's risky again. There may be certain, I mean, now it's nice that you have the flexibility to just go for it. Yes, and here it says the number of validity and reliability studies reviewed. So for one device there are apparently 24. Well nice. You could say yes, isn't the option here just, and then it might be a bit, I found it a bit finicky. To enter an exact number. Actually, I just want one. And there must be one, at least one. And I can't do that now.

**Interviewer:**

Yes, that is again that you would like to have a minimum.

**Expert 3:**

Yes, but also that you might be able to type that in. Because that is also here at device costs. Of course, at some point I had calculated a nice 714. Yes, that's the slider, not so nice. So you just have to be able to click here and then say 714. And that he just puts that slider there. Yes. Sometimes it's just nice that you can put it there. Yes. Okay.

**Interviewer:**

And sorting, what did you think of that?

**Expert 3:**

Yes, I was puzzled for a moment. How does it work? Then I gave up a bit. But I had a number of wearables that was just visible.

**Interviewer:**

Yes.

**Expert 3:**

If you keep a longer list, of course, then that might be more relevant. So for me it was not as important as very important. Yes, okay.

**Interviewer:**

Good. And how did you find the effectiveness of your filters? Did you notice that your list was getting smaller and that you were finding it more easily?

**Expert 3:**

Yes, certainly. Yes, it could very quickly become a relevant set. And oh yes, I might have had another one. That availability could also be a filter.

**Interviewer:**

Yes, that market status. Yes, market status.

**Expert 3:**

Yes, I don't think it was. And I did notice that he used it as a filter in my head. Yes.

**Interviewer:**

Because you still had to buy it.

**Expert 3:**

Yes, because I still had to buy it. Yes, so now it's up to you. Yes, I think they are second-hand somewhere. It's nice that they are just visible. But yes, I had a very large budget. So I'm going to buy a new device, I think. Yes. Yes, so it was a good filter for me.

**Interviewer:**

Okay, And what was your opinion about the response time of the tool? Did you feel that when you clicked somewhere or when you were sliding, it changed quickly enough?

**Expert 3:**

Yes, eventually. Yes, in the beginning it seemed to need the time. But I can't replicate that anymore. Maybe it was still working. Oh yes, I had one more thing, by the way, that comes to mind now. What I was experiencing in the beginning. But it was also not so clear in the use case. But a very critical parameter that often goes wrong. Whether it is continuously measured. And so, for example, I don't know if there was a column for that now. But for example with that aura ring. Yes, it's nice that it can measure HRV so well. Which in general doesn't go well with the wearables. But that seems to come from the fact that it was only in the night. So it was not continuous. In fact, you couldn't measure it at all while you were busy during the day. And it was also about the relationship between physical activity and stress. Yes. Yes, so you can never measure that continuously. Because it can't measure at all during the day. So yes, maybe when you measure, but is it really continuous? Some of those things, like this one claims to measure ECG. But then I have to press it on my screen like this. And sit still. Yes, that's a bit different than if you want to measure ECG continuously. Yes. So that's a very important filter, I think. But you might have to, that might be difficult. Then it goes per signal or something. Per parameter. But other than that, it was responsive.

**Interviewer:**

Okay, great. And what did you think of your list in the end? Was that clear? Did you understand why it was there?

**Expert 3:**

Yes, definitely. Yes. No, I could explain that. Well, I do know some of them, of course. But I don't really know the names. Maybe Nowatch is a bit newer.

**Interviewer:**

Yes. And what are the standard improvements or other improvements that you still have for the tool?

**Expert 3:**

Yes, the most important thing is that it now in some way violates a kind of basic usability principle. Of the knowledge has to be in the world. And I was just memorising things now. And that's just not so nice.

**Interviewer:**
Yes.
**Expert 3:**
Yes, that's error sensitive. Well, it's fine to have a book with you. But yes, if you can make the flow in one way or another, that you have to write down or remember the knowledge even less. For example, by being able to see things. You can't really select a wearable, let's say. You say, I want to continue with this, that and that now. Yes, you could make a kind of comparison page. Yes, or maybe that's a new page or something. Yes, where you take your choice and leave the other one. Yes, that's it. Okay. Yes. I thought you could filter here. Yes. Good option.
**Interviewer:**
Yes. Okay. And how would you rate this tool in its current state? Out of ten?
**Expert 3:**
Out of ten, okay. Well, if I could use it in this way, I would definitely give it a sufficient. Because I get a relevant use case and I can filter with it. I can get away with it quite quickly. Well, it does still violate a kind of basic usability principle, so that I would have to think about it. So there is really a lot of work to be done. I would say a six and a half, just as it is now. Look, especially if this were to run on a website now, if we could make it available to the community now, then yes, there would really be a demand for it right away. You know, after they showed it in the video. That's a very good sign. Until that point, they were also a bit hesitant. But if that is there, then I can work with it. So that's definitely enough. So yes, it's really about points like that.
**Interviewer:**
Great. Those were all of my questions.
**Expert 3:**
Okay.
**Interviewer:**
If you have any other questions, you can send me an email later, if you would like
**Expert 3:**
No, yes, the breadth of the table, that gives it a bit of an 80s feel as a tool. I don't know how they solve that. Maybe that's also just with Coolblue and Booking. They often have longer lists, I think.
**Interviewer:**
They work more with items like blocks. So it's not a problem.
**Expert 3:**
Yes, exactly. They can also sort it differently. But that's beyond. There's a lot of effort in that. To fix that, so to speak. While, on the other hand, you have so much... Anyway, that back and forth may not be necessary at some point. For the appearance of the tool, it is important that all those options are there. A bit like tweakers, if you have those reviews. They are very extensive. With all kinds of tests. Most people don't look at that. They jump to the conclusion. But some people do look at it. And that makes a tool go deeper. But you also want people to be able to select quickly. Or just want to do that. To quickly show a simplified version.
**Interviewer:**
Yes.
**Expert 3:**
You also only have a week. It would be nice if it was in the report as Nice to Have. No, that's fine.
**Interviewer:**
That's the goal.
**Expert 3**
Nice. I think it's quite list able. That's what I expect. I hope so too.

### B.1.4 User test expert 4

**Interviewer:**
I will give you my laptop with the use case and the filter tool. You can switch between the two with Alt-Tab. Try to think out loud when you are working on the use case. You can highlight what you want in the word file. It is up to you to use the tool to see which variable you like the most to use when researching the use case. If you have any questions let me know. Here I have the use case here. Here is the tool.
**Expert 4:**
This is a study to understand how daily physical activity influences stress levels. They require a wearable device that can measure stress and physical activity. These are the two important parameters. The

researcher needs a device that participants can wear continuously, so in daily life, with minimal maintenance and burden. Studies should comply with the GDPR and data protection. There are a number of specific requirements. Stress measurement, The device must be capable of measuring stress levels. According to the physiological effects of the autonomic nervous system, for example. I does not say which is prescribed. It could be either GSR or heart rate. But it can be both. It must also measure physical activity. Activity, steps and calories. Or, in any case, physical activity. And then maybe something else. Then there are also some technical requirements and requirements for users. Technical requirements are battery life, data compliance. The user requirement is actually user comfort. Then you have a nice to have, that is proven validity. And you have a budget constraint. So you want to have a wearable device that can measure 100 tests in 6 months. It does not say whether you can wear it over several iterations, several batches. So you can of course also do 50 in 6 months and then 50 in 7 to 12 months. Or 50 the first year, 25 the first 6 months, 25 the second 6 months and then the second year again. But I assume that you want 100 devices at the same time. Because it is not entirely clear what is written here. It does not say how long you have the time. So I assume that you have the time for 6 months and not longer. Because then you would of course be able to take less wearables and therefore more expensive wearables. Well, the whole egg eating starts with something that fits within the budget. Either GSR or cardiovascular activity and physical activity. You have a wish as far as how long the battery lasts. That is actually a nice to have, ideally. Then you look at your tool. Nice and tight. I had already seen it. I have not worked with it yet. In an ideal situation you can always know the way of navigation. It is a mental model. Do I have to go from left to right, from top to bottom or from left and then unfold. Left bottom and then right bottom. Actually, I would like to start by sorting on money. Because that is just a hard limit. You have 25,000 euros for 100 devices. Sorry, 25,000. You have 25,000 euros for, where I assume, those 100 devices. So that you can't do more than 6 months. Then I just put the device cost at 250 euros. That makes a good difference. Then it would be convenient if you could type that in. Because now I have a bit of trouble to find the right pixel. It is now at 270 euros. Yes, that makes a good difference. Then you don't have that much choice. I also take a look at what I think is nice, how it goes from left to right. What is noticeable is that it goes through here a bit.

**Interviewer:**

Yes.

**Expert 4:**

It is convenient that we can identify data from the device in the image. You could still choose to sort by column. By property. To make. Here I want to know what is in it. I see manufacturer, device name, website, release date, market status, main use, device cost. I have filtered that. Wearable type, location size, weight and what it can and cannot. Battery life. You can sort on that. Sorting. That would be interesting. Battery life. Then I come to the second person. I know for sure that the devices I have chosen now fit within the budget. This is a very long construct. I said before, maybe I want to choose what makes it clickable. That would be nice anyway. If you can click on one row, you get a kind of overview of that one row. You can also put it in your shopping bag or something. Add to your shortlist. You can't do that. I want to have a few things in my device. Because I have to measure stress. What immediately stands out to me is that there is no skin tissue here. GSR or EDA. Signal. I see photoblastogram, electrocardiogram, impedance cardiogram, muscle, electromyography, muscle tension, respiration, accelerometer, gyroscope, GPS. I actually miss a signal that we often use here in the BMS lab. That is skin tissue. That is also an important measure for stress. Other things I see are... He should also be GDPR compliant, so I can probably click on that. Then the list gets shorter. What I would like to do now, as a next step, is to look at the two things I need to have. Stress measurement, so cardiovascular and electrodermal activity. But the latter is not possible. So what is possible is to say something about the heart rate. That could be possible with an ECG, ICG. Oh, then he should have it all, so that won't work. And you want him to have accelerometer data. There are only a few left. That makes the choice a lot easier. And then you could choose something that is still available. Fitbit Sense 1 is discontinued, so that is not a good choice. There are only two left. So I'm going to... That is also not a thing, you see. I notice now that it is discontinued. That doesn't make much sense, of course. I also notice now that if I click on it, I can click on it, and the column gets a bit bigger, but I don't really see what that does. It doesn't do much. I don't know if you... Do you have the development toolkit somewhere? No, I don't see anything at the moment. I don't need to as a user test, of course. But that would be a suggestion that I would like to include in this process, because I can't filter on devices that are discontinued. In general, that is not such a smart choice. As a researcher, you can't work with that. Certainly not in the time limit. Then you spend months with a device that is already discontinued. That is a risk. Then I'm going to... I had already sorted them on Battery Life. There is one that is discontinued. So that seems to be the best choice. Because you probably want to... I'll check for some data requirements. I actually expect those two devices to be more or less separate when it comes to ease of use. The device should be easy for participants to use

and should require minimal interaction for data collection. Well, you just do both like all other wearables on the wrist. So there is not much difference in my assessment. And we can still see if one of the two is validated. Can I indicate that somewhere? I can't indicate that. I can indicate if there is a pipeline available. They don't have that yet. It still needs to be made. That would also be nice if you could indicate whether it is validated with a filter option. So with a checkbox on the left. That is not possible. So I'll take a look at the columns. And I have a slight preference for one of the two that is not discontinued. But I'll take a look at what I see. You have to scroll horizontally and that is a bit difficult. The nice thing is that you can actually see them next to each other. It's a kind of price and goods comparison. I see different additional software. Well, that's just a description. There is server storage at Fitbit Sense 2. Apple doesn't have that. They are both compliant. It also has to be, because I indicated that as a requirement. Well, the top one is validated. The Apple Watch SE has a minimum CE mark anyway. Otherwise it is not allowed to enter this number on the market. So there are also errors in the input data. So nothing is known about validation at the Apple Watch. I think he said something about it. Well, I don't want to say that anyone knows what he meant. Well, based on this. I end up on the Fitbit Sense 2. It meets my requirements. And it fits within the budget. And it is unlike the Apple Watch SE according to this database, it has a valid mark. I assume that the Apple Watch SE actually has that too. From the Apple Watch SE it stands out that there is not that much data anyway. According to the fillers of the database. So as a researcher, you should always look at it a little more critically. I noticed another difference. I'll walk through it again. Yes, look, it also measures ECG. They always ask how good that is with a watch. Locations of the electrodes are all very close together. And the skin conduction, I want that. Because that is a good measure to measure arousal. Yes, nice. Well, I missed a few points. I think it looks clear. It is clear. It works well. I also miss some export possibilities. And overview and comparison next to each other. Possibility to show a report of a row. Then you really have to scroll from left to right.

**Interviewer:**

Yes, just a kind of comparison tool.

**Expert 4:**

Yes, this is an investigative form of Tweakers Price Watch. With validated content. You can expect that the person who fills it, of course, will also try to do his or her best to fill in the missing data. Especially if it is about clear errors. But yes, the interaction is quite intuitive.

**Interviewer:**

Great. Thank you. I have a few interview questions. Yes. You just said that a number of core things went well. But there are still opportunities to improve.

**Expert 4:**

Yes, certainly.

**Interviewer:**

As we look a little deeper, especially navigating through the tool. We start with the screen on the left. We start with those three pop-up menus. Yes. How was that? Is it possible to work with that?

**Expert 4:**

Yes, it is possible to work with that. You kind of assume that you have to work from left to right. That you have to unfold things. It looks a lot like the websites of quite a few web stores. Only you can really search there. Here you don't see a search option at the beginning. So what you could do is take people's hands a little more visually. That you really have to work from top to bottom from left to right. But with those arrows, for example, that speaks for itself. Other is a bit like other what? Maybe that's where you can think of a more comprehensive name. The same goes for sliders. Yes, I also see that they are sliders. But is this in itself a certain kind of category of filter parameters? Suddenly you have a number of constructs here that you can filter. All properties of the devices that are not entirely clear. I know it by chance, but I can imagine that a lot of people don't know what the SiA expert score means. So you could also consider it with a tool-tip or something. With question marks so that people can see what it actually means. Because they probably have an idea. Then they go through with a more or less fixed process. Like I do now. First read the skin and then build a bit of the filter strategy. Or more straightforward. But if you don't know and you do know at some point what the SiA expert score means. Then you can think, especially as a beginner researcher. Hey, let's just trust the expert opinion. Maybe that's easier. Or maybe this is even a better choice.

**Interviewer:**

And overall the checkboxes themselve?. Easy to use, difficult to use.

**Expert 4:**

Yes, that's fine to use. What you often see is that people... You've done that too. Make the whole word clickable. Then you don't have to type anything precisely. That's nice, that's easy.

**Interviewer:**

Are there... you've already mentioned it. For example, EDA. Are there other filters? Oh, I would like to see that as a checkbox.

**Expert 4:**

Yes, there was one. Let's see if I can find it so quickly. My last... EDA indeed. Well, respiration. It's a bit of a research question, of course. Which is important. There are almost no blood pressures. We haven't been able to measure blood pressure. But if that's your study, then that's relevant. So if you have to do all of them right away, I don't think so. I think you're more of a sea and then the less common column where you could filter. That's how it should be. On the other hand, if you're programming, then of course you can program them separately. Or you can say, program for all the columns that exist. That's just as much work. But that makes it a bit more accessible. Server data storage is of course important for some research. If you want to read it from a distance. Then you don't have to have the devices back. If people are halfway, you can watch them. That can be useful. That was the difference. This seems a bit long. You have to scroll quite a bit. Okay, yes.

**Interviewer:**

And what was your experience with the sliders?

**Expert 4:**

I didn't use them. Yes, I used them. As I said, I would like to be able to type in here. Then it's like trying to set numbers to exactly 250. That just doesn't work. It doesn't seem to work. On the other hand, you can do that. You can make it very wide. Then you have relatively many pixels. Yes, that's what I said. You can make it even bigger. We might hear that. If you make it wide, you can do that easily. It's also easy to type in. Yes, I believe so.

**Interviewer:**

And the sorting menu, you used it for the Battery Life.

**Expert 4:**

Yes, I also said something about that. You could also leave it out. And then do it per thing. Although some people don't quite understand what sorting up and down means. Do I sort Battery Life like this? Otherwise I can click again. Do I sort it the other way around? No, I don't, because I don't see anything wrong. Yes, but sometimes you also want to know. It's just as long. Let's take another one. Suppose I sort it by price. Device cost. Look, if I click on it again, they might think I'm sorting it the other way around. But that doesn't happen. But apparently it's from small to large.

**Interviewer:**

For other columns.

**Expert 4:**

Battery Life. That's the most... Yes.

**Interviewer:**

If you have a longer list, you might want to put it the other way around. Yes, exactly. You wouldn't want to put it up. And you would also... And what did you think of the... the effectiveness of the filters? Aside from the items.

**Expert 4:**

Yes, some do. Because actually both this and this are filters. Here you filter by the presence of properties. And here you filter by a part of the list that fits within the filter criteria. So that's necessary. So I think the most important are relatively at the top. At least, I would... In many cases, the research we do here is quite comparable. A number of wearables available. Can it be used in the lab or not? Do you want the raw data? Do you want to use it in the field? How long does it take? If you want more of it, how much does it cost? Weight is not so often decisive. How long? So yes, you could still look at the order. What do researchers who work here think? Well, most importantly... Well, that's a pretty good case. So, compliments for that. But yes, then I would actually go to the cases that often have to come up. In terms of order, what is at the top.

**Interviewer:**

That it is also a bit more intuitive, so to speak, that they don't have to go so far and then it's done.

**Expert 4:**

And cost, for example, is often longer.

**Interviewer:**

Yes, okay. And the responsiveness of the tool? Did it take long? Was it fast?

**Expert 4:**

No, I noticed nothing strange.

**Interviewer:**

Okay. That's good to hear. And after you've made your list, three items left, how was it for you to find specific details?

**Expert 4:**

Yes, that's a bit more difficult, because you have to scroll horizontally. You can't make a price comparison. So then you're really looking at how to make the smartest choice. Look, a person can... can make a good choice based on about five properties. If you have to do 16 things a day, then you can, for example, plan your route, then you can look at the distance, but it's going to be pretty fast. People are much worse at that. So yes, you have to take that into account. If you have to limit yourself until the last choice, could you provide some support in that? Or tips, like, where can you look? What do most people do? How relevant is it at all to show something that is discontinued? You can have questions about that. You can make it grey, because you're probably not going to use it anymore, or at least not buy a new one. And if you already have it, then the costs don't matter at all. So that's a bit of a hassle, that you have to scroll horizontally.

**Interviewer:**

But the information that was there, was that enough? Or do you want more of it?

**Expert 4:**

No, that's a bit too much even.

**Interviewer:**

Okay. And what did you think of the final list? Was it logical for you? Did you have something in mind?

**Expert 4:**

Well, the point with wearables is that every three months, one comes out. So it's almost impossible to keep up. Research wearables, we know pretty well what's out there. But even there, there are so many new ones on the coast, that have to prove themselves more and more. So that's very difficult. Oh yes, you do have a global overview. You see those two more often. But whether you also included the latest of the latest in your own comparison, you can never be sure.

**Interviewer:**

No, I believe so. And do you have any other improvements that you haven't mentioned yet? For the future?

**Expert 4:**

Search options?

**Interviewer:**

Search options, yes.

**Expert 4:**

That you can click on one and then get a more readable overview of the properties of that one wearable. Can I go back to home? I can't. Maybe a button to go back so that then all your filter things are gone. You could think that if you want to be able to compare them next to each other, then you want to be able to indicate that. For example with a heart or something. Or if you see the comparison by putting them into your shopping basket. How do you go back? A question. Tooltip with explanation. What does it mean? Name of a few columns, order and sliders. Not much more to say. How you work with it, then what those elements actually are. Device properties. And I missed EDA.

**Interviewer:**

Okay. And what score would you give the tool? Is it a current state? Out of ten?

**Expert 4:**

Seven. It works fine. But I think there could be a few things that could be added. Because really good in practice to make. There should also be some extra wearables. I think. I think this is an example.

**Interviewer:**

This is a shorter list I got from the group. Okay. And in the current state, if it is already usable with the actual existing list, would you use it? Or would you say to other researchers you could use this one?

**Expert 4:**

This tool assumes that you will always buy new devices In reality, like in our faculty, we have 2,600 sensors in the cabinet that people can borrow. And only if necessary, you will buy something. You look at the quantities. But in many cases you can work with what is already there. Within the faculty. But it depends on the faculty and the university how that is arranged. We don't have all the tools that are in here. Of course. There are too many of them. But you can what would be interesting for us is that you can indicate that they are there and you can use them. Otherwise people will find the Empathica, the Embrace Plus of a certain research that is already there. They don't have to buy them. The costs are not that relevant because they are already paid by the faculty. So it depends on where you work. You don't always have to have the money for the purchase of new devices. I think that is important.

**Interviewer:**

That is a good point. Do you have any other questions?

**Expert 4:**

No, I happen to see a Portapress. We have the Finapress. That is a different one. From Finapress Medical Systems. The Finapress, not the Portapress. But the Finapress. That is an example.

Did everyone get the Fitbit Pulse 2? Sense 2.

**Interviewer:**

Yes, a lot.

### B.1.5 User test expert 5

**Interviewer:**

I'll give you time to read through the use case and to highlight whatever you need and take your time to find the correct variable, use the filtering tool. You are allowed to ask me questions but try to just think out loud and take your own time to go through the tool and find the wearable that you deem to be best for this case.

**Expert 5:**

Let's start then. Okay, well first thing I'm thinking of is the GDPR. It's like a, yeah, good first filter so we can be more and more specific in every step. So I'll do a GDPR. I see some devices disappeared so that's good that it did something. Then let me continue reading requirements. I think it's also the use case, it's very general. So for stress measurements when I read, okay the first opinion I had was during the objective that it should like give a stress score but now in the requirement it's like basically any autonomic nervous system activity. So I don't know if I should even filter for the signals at this point actually but let me still take a look at the signals though. I mean I don't think I necessarily need to filter on it because, well but that's just because I know so let me do that anyways. So let's see with which signals I can actually have some autonomic nervous activity. Well not EMG, respiration would help and of course we need physical activity so Accelerometer. But again I think that's just because I know that I have knowledge about the signals and what I would do if I didn't know is I would definitely want to have like a list of the parameters so I can just pick like steps, distance, energy expenditure. I think most people will rely on the process values column. I don't know if you had that. Anyways so this is I think like 10% of people who will use it who will I think filter based on signals. The people who are more informed I mean a lot like the signal. Okay let me continue then. Um yeah and then the battery life. You have to have long battery life no more than once a week. Once a week wow that is well I wouldn't personally be that strict about it but okay I'll just follow this use case and do 7 times 24. Let me calculate. Yay 168. So now also it's not clear to me like what is happening. Am I getting things that have more than 165 or like less than 165? So I know it is like okay when I really think about it okay I know it's like well to be honest I don't actually. Let me take that back. So yeah my feedback is what is happening now I don't know because yeah am I getting like the.

**Interviewer:**

Yes those are maximum sliders so you're setting a maximum.

**Expert 5:**

Yes okay. Maybe it would be useful to have like I don't know for a future iteration later on you know just be a bit more clear to have max and min at the end written out. I think you would also have that for like in the in other similar apps like you still see the min and max there. Well that made everything disappear. So right so I'll just take it back actually.

**Interviewer:**

Everything disappeared earlier when you applied ICG I believe in the signals.

**Expert 5:**

Oh okay so that's the thing. So that is an add and do not add right like an end statement. Yes. Okay that's good to know. That is very good to know. Okay then I will try one by one. Thanks for letting me know. Well because it will be a long-term study I believe. Yes six months is very long. Okay so I'll of course give up for the ECG and ICG. Let me see what happens when I add respiration. Nothing. Okay okay let's just do PPG and accelerometer then. That's very typical. Then let's see the other requirements. We already did the data compliance. Ease of use. Well let me see then if there is the wearable type yet here. I don't know so I'll just maybe look at it myself then. Okay so because there is no wearable type place yet because if there was I think that's I would definitely filter based on that but well here it's already clear that they're all okay in terms of like comfort. So I'll also tick this box in my head then. Well of course budget is a big one. So the total budget is 25 000 or no. Another calculation. Okay one okay if I can have oh but there is no like total duration of the whole study. That's good. Then I can say that I want to complete this in one year if I'm ambitious and so I would do approximately 500 in the first half. Then I say 500 over 25 000.

Okay then actually we don't have budget if I'm correct about this. No wait no we have we only need 100 participants. That's okay. That's easy. Sorry I thought it was a thousand. Okay then we have 500 euros. Let's go to the sliders. Oh you know what actually at this point I would do a sort by if we have price there yet but if not it's okay. I can't see it though on Teams.

**Interviewer:**

Oh you are not able to see the sorting on Teams?

**Expert 5:**

No. Oh I'm sorry I can't see it.

**Interviewer:**

Device cost is the second one. So I have now added that for you.

**Expert 5:**

That's great. Let's see where the costs are. Yeah nice. Okay so then I can only consider let's say up to 451 and now I think this makes more sense to me. Like after I have seen the sorting to then actually go and put in 451 something like that. Nice. Then I think I'm left with validation. I consider all of them to be easy to use. Well I could think more about it but I think I'll just go into validation now. Okay so for Apple I know you need an Apple device as well. I am not including that. Let's go to validation. Oh we completely forgot to well I completely forgot to take a look at the processed values but I don't think they're all written here yet so I'll skip this. Let's look at compatibility. Where is that? Yes I think I'll just read the conclusion so we can understand maybe from here. It's actually also I find it convenient like with this filtering tool that I don't see anything if it's not there. I don't like that for like the Excel you know it says so I like this front end view. It's way better than like seeing a bunch of NPs. Very nice. I'm just trying to read and it's kind of tricky to turn this on Teams but I'm about to be done with my selection so it's good. Will they all sleep? Okay at this stage I know my brain may be working very differently than others but at this stage I actually need to go back to the signals because we were kind of generalistic about which signals to use and I was only able to pick PPG so now I want to see if there is like more signals. So yeah because for validity I mean I don't think there's a lot of different information for any of them or at least I don't find them to be a very convincing so I'll just skip this and I can see that they are all like Fitbits or Google watches. Actually I don't think there were any validation for the Google watches so I won't like any of these versions so I will just not consider that and also not the Apple watch because of my budget. So well it's interesting that like also we didn't include the fact that Apple requires an Apple, an iPhone. Anyways I'm trying to find the signals without messing up things here. Okay well of course we don't have respiration for any of them. We do have EDA for the Fitbits and then also the Google one. I wonder if the Google one is less expensive than Fitbits. I mean it's very interesting to look at actually. It's very fun. Where is costs here? Okay so Google watch is more expensive. Wow okay then I'll eliminate it. And of course I want to definitely see. Oh it says iOS or higher but I think Fitbit also works for Android phones. I think so. Probably the database given to you wasn't that final. Okay I was looking at signals. Let me just go back quickly and okay I think I'll also pick one with EDA since it's my understanding that like the more measures are better for this study. So I'll do not this one. Maybe Fitbit charge 5. Well not this one. I never even considered no watch actually. Let me also check out the price of Nowatch, and validity of course. Well its storage capacity is only 24 hours. Let's say limited for like a six month study. Not realistic I think. If that is hours which I think it is. So that I also eliminate. And I think I'll say either Fitbit Sense 2 or Charge 5. Okay let me look at the signals again. Fitbit charge 5 also has better battery life. That's good. And then ECG although no one will use it but still it's good to have. So then I'll say Fitbit charge 5.

**Interviewer:**

All right good.

**Expert 5:**

Really like this though.

**Interviewer:**

I mean in the end the choice is always up to you as a researcher.

**Expert 5:**

I think what would really increase my satisfaction or I don't know usability of this is if I was able to pick something or something like an or statement stuff easier maybe. And then process values for like as I said like 90 percent of people. Because I think it's also us like we think that everyone does research like this like thinking about the signals but they don't. They're just like let me pick heart rate and this and then like steps. So I think it will be nice. And I think it's like literally the same logic right. So you just well it's of course a bit different but it's again just like picking from a list kind of a filtering tool. But instead of the zeros and ones from the different columns we just look at the same column and like the different listed statements. But anyways but they are just points for some points for future and this already was very

helpful for me to like decide and not get lost in an Excel file. And I think yeah things like some random comments or nulls or NPs and NAs they really make a difference in that you see just like occluded spaces and you don't really like visually your brain I think doesn't like instantly get the idea that there are there's nothing for this study. There's like still something you know at least that's how my brain sees it or I see it. And now I'm like oh wow there really is no studies for this this and this. So it's very clear and I like the colours and the tones and like things are easy to read. I think that's very important personally.

**Interviewer:**

So if you will be all right I have some more questions listed. So you're already telling it about it quite a bit but just the overall experience how was it for you the overall experience to use the tool in order to solve this specific use case?

**Expert 5:**

It was because there wasn't a and or statement the overall experience ended up being me like going back and forth between different columns in the database in that it wasn't like me picking the signals all at once and then being done with it but I still like got some help from the filtering tool and then still had to like look at stuff by myself which was but still very easy to do so that wasn't like a problem. I really think that the sorting tool in general was very helpful in making sense because I think it's natural for many people and researchers to like still have that list of like sorted in some sort of importance metric so that really overall gives you like a clear idea and doesn't make you feel lost at all so you can always kind of you have that as your anchor and you know like order stuff so that's very good but overall overall it was I mean I didn't feel lost at all it was very helpful and I had confidence that this could like save a lot of time for a researcher and researchers don't like to spend time on a variety of stuff so okay I'm just mumbling now but yes I thought that this would actually save a lot of time for many researchers.

**Interviewer:**

That's great to hear and what was your experience navigating through the different filters and options so you started out with those three collapsed menus with different titles like were those clear was it clear for you where you could change what aspects of the list?

**Expert 5:**

I think that the three main parts of the filtering on the left column you had that was very clear yeah the only important thing I think is to when you're like using the sliders is putting the min and max still that will save some brain power but it's very easy to find where things are I don't think there were any issues with that it's just yeah I think it's again relates to the end or stop but to me yeah I picked mostly the the checked boxes yeah but then of course

**Interviewer:**

Were there any checkboxes that you think should be added or checkboxes that you think that could be removed from the list?

**Expert 5:**

Process values given by the device I think that's a big one so they we should have checkboxes for that.

**Interviewer:**

Yes okay, all right and how would you rate the effectiveness of the filters in narrowing down the list of devices in order to meet your criteria?

**Expert 5:**

They were very effective but I can assume that people also want to look at: I want like EDA and respiration or accelerator whatever just like that statement without everything included yes other than that it was very nice yeah.

**Interviewer:**

All right and did the end filtered results meet your expectation based on the criteria that you had set?

**Expert 5:** Yes it did yeah

**Interviewer:**

and in what way?

**Expert 5:**

That's an interesting question I mean I think it was also useful to have the use case and the requirements so so it also highlights the importance to me of knowing what you want for your study because usually people don't know all of those things yet but well it did meet all the requirements and it was also encouraging to see that the lists get smaller and smaller as you picked new stuff so I was like yeah that something is happening and something is going right so yeah basically there was a nice stepwise elimination at every stage that was all right.

**Interviewer:**

And how would you rate the response time of the tool when applying filters and sorting?

**Expert 5:**
It's very fast.
**Interviewer:**
So you did not experience any delays or slow performance in the tool or?
**Expert 5:**
No I don't.
**Interviewer:**
Okay good to hear and what is your experience in relation to finding specific information about each device after you had applied the filters?
**Expert 5:**
It was still easy but yeah maybe there could be a way to show that but people don't have to scroll a lot themselves but I mean I think it's still doable to be honest it is acceptable yeah they can just look at themselves without like emails.
**Interviewer:**
So you do say that it's doable but it would be nice if the amount of horizontal scrolling for example were less?
**Expert 5:**
Well it can't really be less though right? Maybe there can be like another tab or something that separate about just like having the abbreviations of everything so maybe they at least know which direction to scroll to or something like that or maybe an option to just reorder the columns by like alphabetically yeah things like that so also like order the columns so it's easier to scroll.
**Interviewer:**
Okay and what other improvements then that you have already mentioned would you like to suggest in order to enhance the usability and the effectiveness of the tool?
**Expert 5:**
Okay I repeat myself but one even putting the process values before the signal well maybe okay not that but just after the signal and being able to do this or that for the signal part at least that is important especially for example ECG, PPG maybe there's a way to group them or like even have another box saying ECG or PPG instead of like selecting them separately something like that because that will be very common for people to use but I think that will be it.
**Interviewer:**
Okay good to know. How satisfied are you with the tool overall? What would you rate it like out of 10?
**Expert 5:**
I would do 8.
**Interviewer:**
All right and if you look at the tool in its current state would you still at this point recommend it to other researchers looking for wearable devices for their studies?
**Expert 5:**
Yes I would.
**Interviewer:**
And then also for researchers in other fields than stress research would you say like oh it's mostly for stress research at this point?
**Expert 5:**
I think also for people doing sleep research they can also use that.
**Interviewer:**
Yeah okay good to hear. So those were all of my questions. I don't know if you have anything else left to add?
**Expert 5:**
No that was it actually.