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The usability of ClimApp: A personalized thermal stress warning tool

Jakob Eggeling [a,*], Christofer Rydenfält [a], Boris Kingma [b], Jørn Toftum [c], Chuansi Gao [a]

[a] Thermal Environment Laboratory, Division of Ergonomics and Aerosol Technology, Department of Design Sciences, Lund University, Box 118, SE-22100 Lund, Sweden
[b] TNO, The Netherlands Organization for Applied Scientific Research, Unit Defence, Safety & Security, Kampweg 55, 3769 DE Soesterberg, the Netherlands
[c] Department of Environmental and Resource Engineering, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

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ABSTRACT

ClimApp was developed to assist individuals in reducing the risk of exposure to thermal stress and to supply the user with individualized advice and recommendations. The tool integrates several human thermal models and heat indices with the local weather forecast and goes on to provide users with a prediction of their thermal stress based on their activity level, clothing level, and heat acclimatization input. Despite its innovative and interactive functionality, ClimApp's utility and ease of use should be considered to increase its usability. The usability of ClimApp was evaluated over two iterations: one usability lab test (n = 10) and one field test (n = 38) where first-time users completed tasks in ClimApp related to navigation, perceived ease of use, and perceived usefulness. Activity theory guided the analysis, and a directed qualitative content analysis was applied to evaluate the usability of ClimApp. The results suggest that there is room for improvement when assessing the universal design aspects, navigation, and information complexity, yet the participants perceived the tool as useful in the situated context.

Practical implications

- In a changing climate, the weather will become warmer and more intense, yet cold weather will continue to contribute to mortality in temperate regions for many decades to come. To improve the resilience of societies and individuals, heat and cold risk warnings, and advisory tools can be of great benefit in order to adapt when facing heat waves and cold spells. ClimApp is a smartphone app developed as a part of the European Research Area for Climate Services (ERA4CS). It aims to assist individuals as an advisory and warning tool when facing hot or cold environments. ClimApp is a novel approach where multiple models that predict physiological responses have been integrated with local weather forecast data so that ClimApp can provide personalized advice and warnings depending on the risk.
- Extreme heat and cold warnings are commonly based only on weather forecasts provided by national weather bureaus or organizations using smartphone apps, webpages, TV, radio or newspapers. Based on previous experience and changes in weather patterns, people can estimate whether or not to proceed as usual in their daily business. However, the effects of heat and cold on human health depend on more environmental and individual factors. More accurate heat and cold stress predictions require calculations using the air temperature, humidity, air velocity and solar radiation along with input of what activity people are performing and what clothing they are wearing. By allowing users to interact with the weather forecast and enter their individual factors, they can gain a better understanding of how to prepare for extreme weather events.
- In this study we have evaluated the usability of ClimApp. ClimApp can predict heat- and cold-related health risks in outdoor environments ranging from −50 to +50 °C and also in indoor environments. The users enter their desired clothing and activity, and whether they are accustomed to the local weather. The app then retrieves the local weather data and predicts the risk. ClimApp also provides the users with advice on how to cope with extreme environments and highlights signs to watch out for such as dehydration, dizziness, or the importance of clothing type to match the weather. However, even if an app provides proper functions and accurate output, it will not be used if the users struggle with the design or if they do not understand the terminology. For ClimApp to provide as good usability as possible, stakeholders were invited throughout the design process to identify desired functions and provide valuable feedback on design decisions.

* Corresponding author.
E-mail address: jakob.eggeling@design.lth.se (J. Eggeling).

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- This study tested ClimApp in the lab and in the field in cold environments and concluded that ClimApp provides the intended functionality with overall positive usability. Further improvements of the app usability are suggested based on this study; however, the app is fully functional and is proving to be a tool of great practical use. ClimApp received an award from the World Meteorological Organization in Category 1: Awards for Innovation and Promotion of the Use of Weather and Climate Information for Development: Honorable Mention in Subcategory 2: Award for Originality and Innovation. ClimApp is freely available for Android and iPhone. It is available in 10 languages and works around the globe.

1. Introduction

According to the Working Group 1 contribution to IPCC's 6th assessment report, the evidence for climate change and the increasing global temperature is unambiguous (Masson-Delmotte et al., 2021). The report provides even stronger evidence of the increase in intensity and frequency of hot extremes and the decrease in those of cold extremes. Climate change threatens to exacerbate already strained working conditions in many countries where production rates can decrease in peak summer months by up to 80% (Dunne et al., 2013). However in temperate zones, cold winters will continue to be the main thermal contributor to morbidity and mortality (Hajat et al., 2014; Holmér et al., 2012; Mäkinen and Hassi, 2009). To provide societies with personalized warning systems that predict thermal stress, recent research has highlighted the benefits of integrating existing weather forecasts and personal factors with available thermal models to predict human physiological responses (Burgstall et al., 2019; Casanueva et al., 2019; Lemke and Kjellstrom, 2012; Morabito et al., 2019; Parsons, 2013; Petersson et al., 2019).

The ClimApp project was launched with the goal of developing a smartphone app that can translate basic weather variables (air temperature, humidity, wind speed, radiant temperature) and user input (activity, clothing, heat acclimatization) into predictions of thermal stress to provide warnings and suggestions on how to cope with heat and cold stress. However, if potential users are going to adopt it, ClimApp must succeed in providing them with a clear flow of relevant information and offer functionalities they understand. At the same time, these functionalities need to correspond to the users' perceived needs (Davis, 1989; Rogers et al., 2011).

ClimApp was developed for everyone who is exposed to thermal stress with a focus on outdoor and indoor workers as well as vulnerable groups and/or their caregivers, all of whom would benefit from using such a tool for strategic planning. Recent publications have documented occupational risks in the heat and conclude that strategic planning and adapting mitigation strategies for the workers reduces the risk of heat strain and dehydration (Ioannou et al., 2021a,b; Piil et al., 2020; Piil et al., 2018). It is challenging to design a tool that can be used by a wide range of individuals, and to communicate the content without compromising the detailed quality behind it (Meyer and Rose, 2000; Steinfeld and Maisel, 2012; Story et al., 1998). If the information fed to the user is too cumbersome, they will not bother to use the tool. If the information is oversimplified and functionality is lacking, there is no point in using the tool. Research has shown that users are more prone to use a tool if it is perceived as being useful compared to being easy to use (Davis, 1989). Both the product's functional utility and its ease of use are considered to be important aspects of a product's usability (Rogers et al., 2011).

The aim of this study was to evaluate the usability of ClimApp and suggest directions for future improvement of usability and development of applications intended to provide personalized thermal stress information. More specifically, we aimed to:

1. Evaluate the overall usability of the ClimApp mobile tool.
2. Evaluate whether the level of information provided by ClimApp and its presentation correspond to user needs and cognitive abilities including prior knowledge.
3. Propose improvements for the future development of ClimApp.

1.1. Theoretical framework

This section introduces relevant theory concerning thermal exposure, warning systems, the concept, and functions of ClimApp as well as the usability of digital artifacts.

1.2. The usability of digital artifacts

Traditionally, human computer-interaction (HCI) research has been concerned with how digital artifacts should be designed to fit the cognitive abilities of the intended users (Card et al., 2018; Norman, 1990). It has become clear, however, that limiting the focus of such studies to user cognition is insufficient. Such interaction is *situated* and *context* also plays an integral part in it (Suchman and Suchman, 2007). Moreover, there is always human *intent* or *motivation* that gives meaning to interaction with digital artifacts (Dourish, 2001; Kaptelinin and Nardi, 2006). For these reasons, one should take both the context of use and the user's intention into consideration when studying interaction with digital artifacts.

The concept of *usability* refers to whether a product is *easy to learn*, *effective* and *enjoyable to use* from a *user perspective*, in relation to the *user's goals* with the interaction (Rogers et al., 2011). This implies that for a product to be considered usable, there must be *a user* who attaches meaning to the use of the product, that is, the user must use the product to achieve goals that she or he, rather than the developers and designers, find *meaningful*. Thus, to study the usability of a digital artifact, one must study the cognitive fit between the user and the digital artifact to find out if it is easy to learn and effective to use. However, this is not enough; the actual context of use and the meaning the user puts into using the product must also be considered.

Activity theory is a framework for the study of human practice and interaction rooted in sociocultural psychology (e.g., the works of Vygotsky) (Kaptelinin and Nardi, 2006; Kuutti, 1996; Vygotsky, 1978). When applied in an HCI setting, it has the advantages of taking into account both the context and the meaning that are put into the interaction. Most theories concerned with human practice or action have the action itself as the main unit of analysis. In activity theory, this unit is expanded to include a “minimal meaningful context for individual actions” (Kuutti, 1996, p. 26). It is this minimal meaningful context that is labeled as an *activity*. An activity is always directed towards something: an *objective*. This means that the user always has an intent with the interaction (Kaptelinin and Nardi, 2006). Since activities encompass actions, they can be broken down hierarchically, with the activity under study placed at the top. While activities are directed towards objectives that give meaning to the activity *as a whole*, *actions* are directed towards the instrumental *goals* to be attained in order to fulfill the activity's objective. In a similar fashion, actions can be broken down into operations. While actions take place on a conscious level, operations are subconscious (i.e., automatic processes we conduct without thinking). In activity theory, technological artifacts have a mediating role between the user (*subject* in activity theory) and the objective. This means that the user interacts with the objective through the artifact (*tool* in activity theory) (Kaptelinin and Nardi, 2006; Kuutti, 1996). As stated above, when evaluating digital artifacts, one needs to consider both the context of use and the meaning the user puts into them. Using activity theory as a guiding framework is one way to ensure that the wider context of use is not forgotten in the analysis.

1.3. Thermal exposure and warning systems

Traditional heat-health warning systems are based on weather forecasts where variable thresholds linked with high risks and disasters trigger a warning. The trigger may be a single environmental variable, a combination of a few weather parameters or a thermal index (Burgstall et al., 2019; Casanueva et al., 2019; Hajat et al., 2010). Even though basic weather parameters are adequate thermal stress indicators that can signal heat waves or cold spells, there is no translation of how the weather affects the exposed individuals by taking individual factors and vulnerability into account. The weather may be the same at a given location, yet everyone will experience it differently because they wear different clothes, perform different activities, and have different heat acclimatization. Using readily available weather forecasts is a common procedure for the public to estimate the thermal risks of outdoor thermal exposure by relating to their previous experiences of similar exposures. However, estimating the thermal exposure based on the weather forecast is not always sufficient since not all parameters, such as radiant temperature, are available. Adapting this information to a wide range of circumstances demands that the level of the information provided is sufficiently simple for most to understand and yet contains sufficient details.

Humans are greatly affected by the prevailing weather through the following different avenues of heat transfer: evaporation (E), convection (C), radiation (R) and conduction (K) (Parsons, 2014). All these factors depend on the clothing we wear (Parsons, 2014), as it traps air inside the fabric of the clothing and between the clothing and skin surface which can be seen as microclimates. Depending on clothing thermal properties (thermal and evaporative resistance), fabric, fabric thickness, fit, and coverage, the trapped air will resist heat transfer to or from the body. By dressing properly, sufficient heat can be trapped within the clothing to remain warm during cool days or dissipated if we are participating in intense activities. Increased intensity of our activity also increases the heat generation. Consequently, both clothing and activity input, as well as heat acclimatization, are highly relevant when assessing the human heat balance and our response to thermal exposures.

1.4. ClimApp

The focus of the ClimApp framework was to predict thermal stress and provide advice on how to cope with it. We initiated several subprojects to develop and design ClimApp. By introducing the concept of ClimApp to stakeholders at the very beginning and receiving their feedback, the outline of what ClimApp could be took form. Throughout the development phase, the stakeholders were consulted and engaged to develop the climate service tool so that it was relevant and useful to their practices (Máñez Costa et al., 2022). In the beginning of the project a low-fidelity prototype was created for initial information gathering followed by interviews to understand better the desires of vulnerable groups and stakeholders (Rogers et al., 2011). A high-fidelity prototype was created in *InVision©* using simulated scenarios to collect feedback for further improvements. The prototype served as the foundation of the first version of ClimApp with limited functionality. We showcased ClimApp to the public during a local cultural event and to industry during an annual industrial theme day where the visitors and participants could test ClimApp and provide feedback.

The feedback guided the design of the first fully functional version of ClimApp, and more thermal models and indices were added so ClimApp could be used for outdoor exposure. The underlying models and indices and their calculations are hidden to the user, and the user is presented with the resulting output *ClimApp index* to make the presentation as simple as possible. During the development of the fully functional version of ClimApp, potential users were invited to test and give feedback on the design on several occasions. It is this part of the development process that this study is focused on.

When starting ClimApp, the user is greeted by a colored bar that represents *thermal stress prediction* (Fig. 1a). The user can now switch between different panels in ClimApp (Fig. 1a-c and Fig. 6a-b presented later) and change his or her personal input such as *activity level* and *clothing level* (Fig. 1c). The user should also enter weight, height, gender, age and *acclimatization to heat* to improve and individualize the prediction. The user can choose between five different *activity levels* implemented from ISO 8996 (ISO 8996, 2004), and five different *clothing levels* implemented from ISO 7243 (ISO 7243, 2017). ClimApp also allows the user to change to a custom location to find the prediction of a travel destination before going there (Fig. 6a) or estimate *thermal comfort* indoors using an *indoor mode* (Fig. 6b). An implemented *forecast graph* presents the user to an overview of the *ClimApp prediction* for the next 24 h (Fig. 1b).

ClimApp is integrated with several functions to be as versatile as possible (Kingma et al., 2021). The main function is the prediction of thermal stress, around which all other functions revolve. Based on the prediction, ClimApp will offer advice and recommendations such as adjusting the planned activity and clothing or making sure to rest and hydrate sufficiently. Specific advice and recommendations are given if ClimApp is set to *Group* with the choice to select either *Seniors* or *Children* to assist caregivers. The non-personalized Universal Thermal Climate Index (*UTCI*) (Błażejczyk et al., 2013) is available with the *forecast graph*. All input parameters are visible in a *detailed information* table in the forecast panel, along with infographics for measures of thermal stress risk reduction.

2. Method

This study collected both qualitative and quantitative data to evaluate the usability of ClimApp. This included audio and video recorded usability lab tests, field tests documented with a survey, and semi-structured interviews with participants after both tests (Kvale, 2008). The study consisted of two iterations of data collection. We updated ClimApp between the two tests and the changes are highlighted in subsection 3.2. Collected data were primarily analyzed using directed qualitative content analysis (Hsieh and Shannon, 2005).

2.1. Design of the usability study

Fig. 2 illustrates the study flow chart. Iteration 1, conducted during the summer, consisted of a controlled usability lab test and a post-test semi-structured interview. A few months later after ClimApp was updated, Iteration 2 commenced with new participants. This included a field test conducted during wintertime to test ClimApp in real conditions, particularly focused on its usability to predict cold stress. After the test, each participant completed a survey with both Likert scales and free text answers, the latter to obtain more immersive responses and nuances of the user experience. The first part of the survey asked for general information about the user and the weather conditions during the field test. The survey was constructed so that the participants had to rate how they experienced using each function in ClimApp; how easy it was to navigate to said function and use it and whether the user understood what the function provided them. Further, the survey asked the user to provide their overall experience of navigating, using, and understanding the app. The field test and survey were pilot tested by two participants prior to the actual field test to avoid misunderstandings when performing the study. A subset of the participants in the field test were also interviewed.

The combined pool of all the data was processed and analyzed.

2.2. Ethical considerations

Each participant signed a consent form and confirmed that he/she had read and understood the terms of the study. The participant could freely withdraw from the study at any time and ask for their data to be deleted without question. They were informed that the usability lab test,

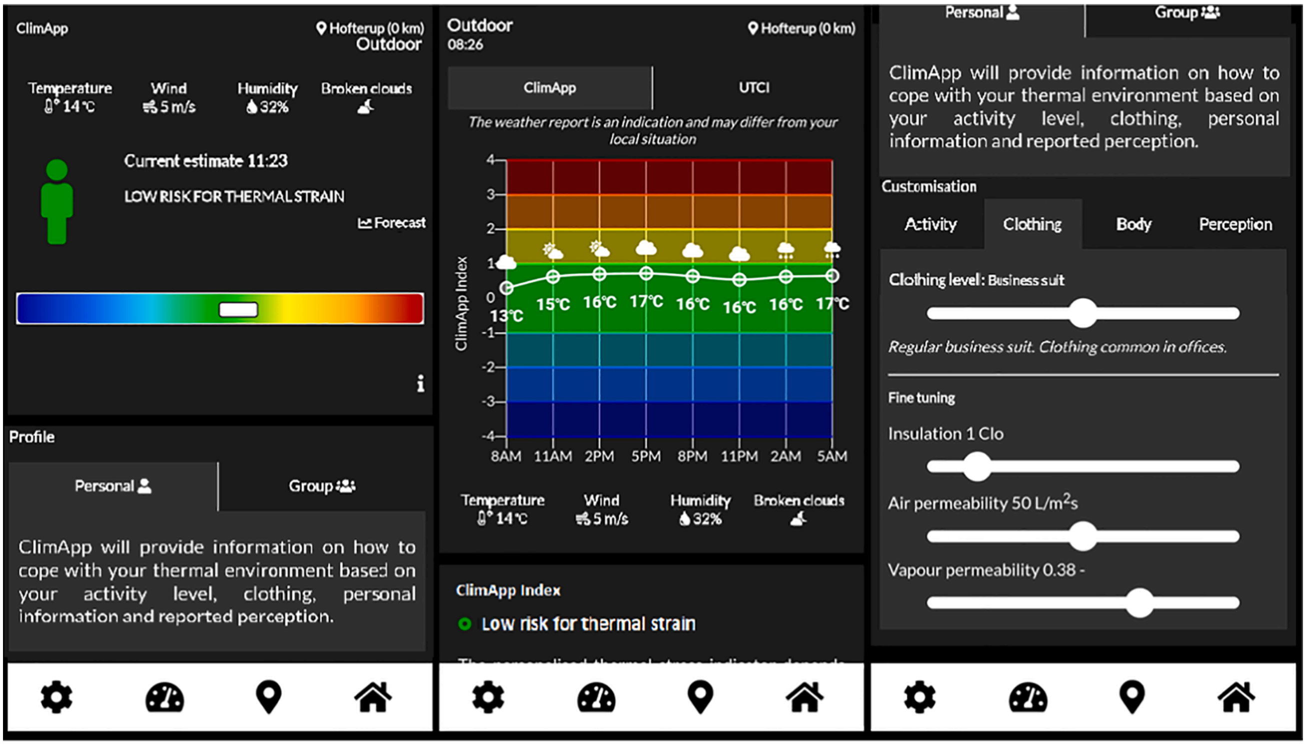

Fig. 1. (a–c) ClimApp Screens. Screens that show the Swedish version of ClimApp used in Iteration 1 with text translated to English for illustrative purposes. (1a) *Dashboard* where the user can find weather forecast data, *thermal stress prediction*, forecast panel access, and personal input by scrolling down. (1b) The forecast panel presents a *forecast graph* for both the *ClimApp index* and *UTCI*. (1c) Personal input including *activity level*, *clothing level*, *personal information* and *perception*. Available as four buttons when scrolling down on the *Dashboard*.

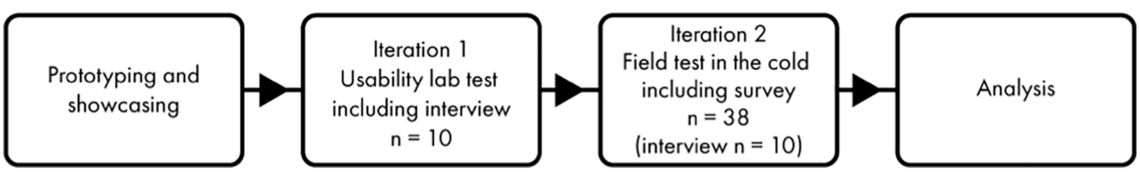

Fig. 2. Study timeline. The timeline of the study process including prototyping, two tests done in two iterations (the core of the study), and analysis.

lab test interview, and telephone interview after the field test would be transcribed and analyzed. The free texts submitted in the survey could be used as material for analysis, similar to transcriptions and suitable quotes, without linking them to any personal information. The participants were asked clearly not to make decisions based on ClimApp that were contradictory to their own habitual choices. They were instructed to evaluate only the information provided by ClimApp. Due to the covid-19 pandemic, Iteration 2 was conducted remotely, and interviews were conducted over the telephone. Vulnerable groups of people were not involved in the usability study due to pandemic restrictions.

2.3. Iteration 1 – Usability lab test

Ten first-time users participated in Iteration 1 (3 males, 7 females, age range 20–35). Each participant tested ClimApp separately. The test was conducted in a usability lab where the researcher could see the participant through a one-way mirror from a control room (Fig. 3). Participants were instructed to sit down at a table with a smartphone and keep the phone at a steady "natural" angle to minimize recording difficulties.

The mobile phone screen was connected by wire to a computer and recorded. The participants were recorded with a video camera over their shoulder to avoid facial recognition. The video camera captured the entire smartphone screen and very little of the surroundings (Fig. 4).

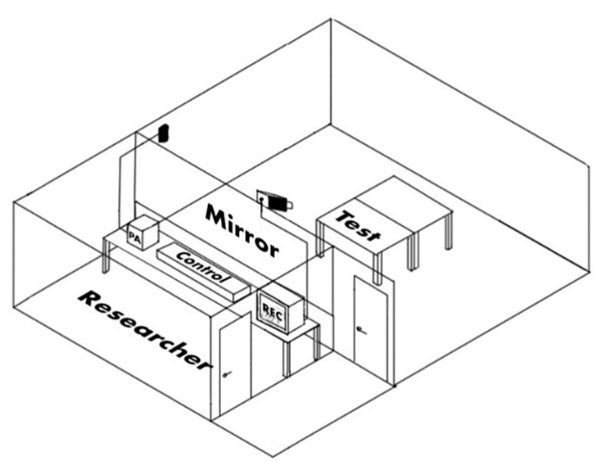

Fig. 3. Sketch of the usability lab. The researcher sat at the control system and had a recording station (REC) and personal announcement system (PA) available. The test person sat at the test table where the smartphone was placed and was recorded by a camera from above. A tinted glass, allowing only one-way vision, separated the test person and researcher (from control to test room). The doors between the rooms were closed during the test.

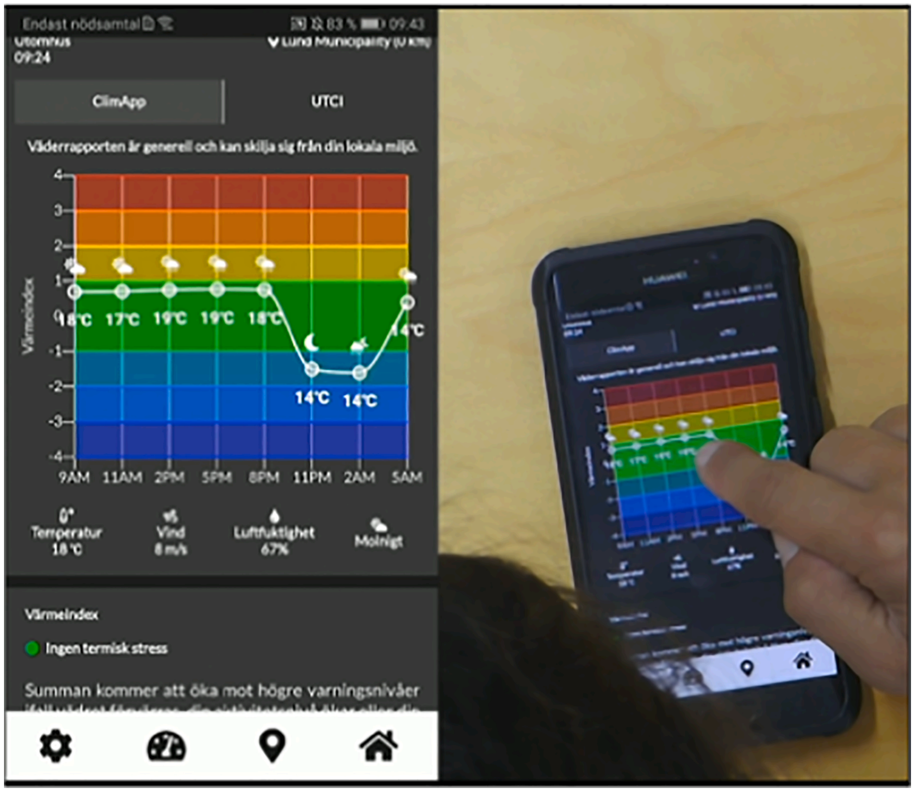

Fig. 4. Recording example. Over the shoulder recording where the participant is inspecting the *forecast graph*.

The participants were asked to complete several tasks that compelled them to find each function and utilize the ones that were most relevant. The tasks included interpreting thermal stress scores for different combinations of *clothing level* and *activity level*, setting a *custom location* in ClimApp, and interpreting the *indoor thermal comfort prediction*. They needed to reflect on the choices that could be made in ClimApp. The test was performed using an Android smartphone.

The follow-up interview was structured around difficulties using ClimApp, if the functions felt valuable to them, and potential changes. Another question was whether the information provided was clear and relevant in addition to providing guidance on clothing and activity input.

2.4. Iteration 2 – Field test

In Iteration 2, a group of 38 first-time users (20 males, 18 females, age range 18–65 with an average age of 34,7) was recruited to use ClimApp in an outdoor cold environment of their choice. They were recruited through contact with companies, authorities, and advertisements on social media. The users were selected with the criteria that they were adults with either an outdoor occupation or an active outdoor lifestyle in winter conditions to merit being outdoor workers. The air temperature needed to be below 10 °C to ensure that ClimApp utilized the same thermal model (ISO 11079, 2007) for each participant to predict their required clothing insulation and the derived *ClimApp index*. The participants first completed tasks indoors like those of Iteration 1. Then they were asked to use ClimApp for a minimum of 60 min in outdoor exposure performing an activity of their choice. After the outdoor exposure, the participants responded to a web survey with questions regarding navigation, functionality, and usefulness. ClimApp is only used to predict thermal sensation, and the test participants were asked not to make any extraordinary decisions based on the ClimApp prediction. In the follow-up interview, which took place over the telephone, 10 participants answered questions about navigation, functionality, and usefulness. The questions covered whether or not it was easy to make use of the functions in the app, if the information provided was clear and how easy or difficult it was to navigate to a desired function. The interviewees were also asked if they believed ClimApp was missing any functions, or if something functioned in a way they did not expect, or if some functions proved useless to them. They were able to talk freely about their experiences and thoughts.

2.5. Analysis

The data were analyzed using a directed content analysis with activity theory as the guiding theoretical framework. This directed the analysis to capture all the relevant aspects of user interaction with ClimApp and their perception of using it (Hsieh and Shannon, 2005; Kaptelinin and Nardi, 2006; Kuutti, 1996). All available recordings from Iterations 1 and 2 were transcribed and coded including the free text answers from the survey using the *QSR Nvivo©* software. The codes emerging were grouped under several parental categories such as navigation, functionality, information clarity, and how they felt about it.

3. Results

The two iterations highlighted different issues concerning the usability of ClimApp. Here, we describe the results from the two iterations and the improvements made between them. The themes identified in the analysis are used as subheadings for each iteration to simplify the connection to the discussion.

3.1. Iteration 1 – Usability lab test

The lab test indicated several flaws in ClimApp that needed further attention. The participants understood most of the information ClimApp provided and appreciated its concept, yet parts of the information proved complicated or lacked explanations.

3.1.1. Custom location

In general, the participants were able to complete each task except *one* without major difficulties. The problematic function for almost every participant was to set a *custom location*. The participants struggled with this function in different ways. Initially, a few people attempted to navigate through the function by pressing the map needle on the *Dashboard* (Fig. 1a) as this seemed like the natural thing to do. However, doing so only updates the local weather forecast. One person stated:

> "I don't really understand how I should tell ClimApp where I'm located?" [While pressing the map needle on the *Dashboard*.]

When reaching the *custom location* panel, several steps are required to activate the function properly. The user must first activate the function with a slider, then set a map needle on the desired location on the map, and finally click a button. See Fig. 6a and c for an illustration.

The function demands the user to perform several actions that were not obvious to the users and several were surprised when it did not work. One person thought it was completed and relayed:

> "It's OK. Apparently they have the same weather as us!"

During the interview, the participants brought this up as the main criticism because they felt that it was easy to make mistakes and not know what went wrong.

> "Custom location felt very non-intuitive. I was very surprised when it didn't work!"

3.1.2. Indoor mode

Another function that surprised the participants was using the *indoor mode*, although they could find the function without major problems. The surprise was that the icon used to access the *indoor mode* is the house icon, the one commonly used as *Home* in many apps to return to the default screen:

> "Let's go here, *HOME*, and we will find the indoor mode!"

When asked to evaluate the prediction if a window was open in the room (Fig. 6b), a few users immediately pressed the window icon on the *Dashboard,* which only illustrates if a window is open and is not a button with connected functionality. These functions – *custom location* and *indoor mode* – both showed that the participant expected to navigate to the function using another pathway than what was intended.

> "It's annoying that you can't just click on it!" [The window icon on the *Dashboard*.]

3.1.3. Navigation

Another obvious navigation issue was the forecast panel (Fig. 1b). A few struggled initially with finding it on the *Dashboard* since it is quite small and positioned on the side of the display. The forecast panel also contains *detailed information* covering weather and personal input in raw numbers as well as infographics with *measures* to take when experiencing thermal stress. The participants struggled with navigating to the forecast panel and *detailed information* table. They also mentioned in the interview that they could not connect to the forecast panel.

> "Measures here were somewhat hidden!"

Most of the participants looked for a return button when accessing a panel other than the *Dashboard*. A few also pressed the hard-coded return button on the phone, which exits in ClimApp. This caused some annoyance.

> "Where's the return button? I'm used to pressing the phone's return button!"

3.1.4. Information level

A common feature in both the lab test and the interview was that for certain different functions, participants would have wanted more explanations or a help function. The initial reaction uttered by several participants when asked to evaluate their *thermal stress* was that they did not fully understand the definition. However, this seemed to be a passing matter as they progressed with the test. When accessing the forecast panel, the participants could choose either the *ClimApp index* or the *UTCI* to be visualized and it was obvious that the introduction of *UTCI* confused several participants. When tasked to let ClimApp know how they experienced their thermal sensation compared to the *prediction*, several participants exclaimed that they felt unsure how to submit the feedback using the *perception* function.

> "How do I submit this? Who knows?"

Several test participants were also uncertain about what the *acclimatized-to-heat* criteria were and wanted an explanation of this choice to determine whether to activate it. When selecting *clothing*, a few participants thought that the *fine-tuning* of their values was too complicated. Several thus suggested that advanced information and alternatives such as *fine-tuning* and the *detailed information* in the forecast panel should only be visible if the user entered an "expert mode", and that the initial "easy mode" should be leaner.

> "The recommendations by ClimApp were easy to understand but, for example, I had no idea what to do with all the detailed information! Such as about solar radiation; that was a lot! Since it was there, I felt like I could not fully use the app. Maybe if you include an easy mode and an advanced mode that you can toggle between. That way you don't have to get confused when you can't absorb all the information."

For other aspects such as the *activity* and *clothing selection* (Fig. 1c), the participants felt that more details and more options were needed. A few chose the wrong level when tasked to evaluate *thermal comfort* for a specific clothing type and activity.

3.2. Changes made in ClimApp between iterations 1 and 2

Several issues that some or most of the users experienced were brought up in Iteration 1. The initial experience was a lack of explanations when attempting to use ClimApp for the first time. To deal with this issue, a *tutorial* was added to the quick access bar at the bottom of ClimApp that explains: weather input (Fig. 5c), the *ClimApp index* and thermal stress (Fig. 5a), where to enter input such as *clothing, activity* and *personal info*, *acclimatization to heat*, the *forecast* graph, and *detailed information*. An info box was implemented to explain *heat acclimatization*. The *indoor mode* was moved from the quick access bar to the *custom location* panel to reduce the number of panels (Fig. 6c-d). A *thermostat* info box was implemented to explain how to interpret and input the value. The forecast panel access button was removed from the *Dashboard* and *forecast* was now integrated with the *Dashboard* by scrolling down (Fig. 5b). Activating *custom location* was updated so the user had to complete each step (activate function, set pin on map, press "set location" button) before being able to set the location due to problems in Iteration 1. The infographics for *measures* were removed because this took too much space and parts are now integrated with the advice given on the *Dashboard* (Fig. 5a).

In Iteration 2, the *custom location* panel (Fig. 6a) was redesigned to include the *indoor mode* by toggling between *outdoor mode* and *indoor mode* on the top of the panel (Fig. 6c). To access the map where the desired *custom location* should be put, the updated *custom location* in Iteration 2 requires the user to activate the function by sliding a bar (Fig. 6c), which was not needed in the previous interface design (Fig. 6a). The *indoor mode* (Fig. 6d) in Iteration 2 also includes more explanatory text to help the user understand the input parameters. Iteration 1 only presented the buttons for data input (Fig. 6b).

The quick access bar at the bottom was redesigned to include the tutorial function to the furthest right instead of the *indoor mode*

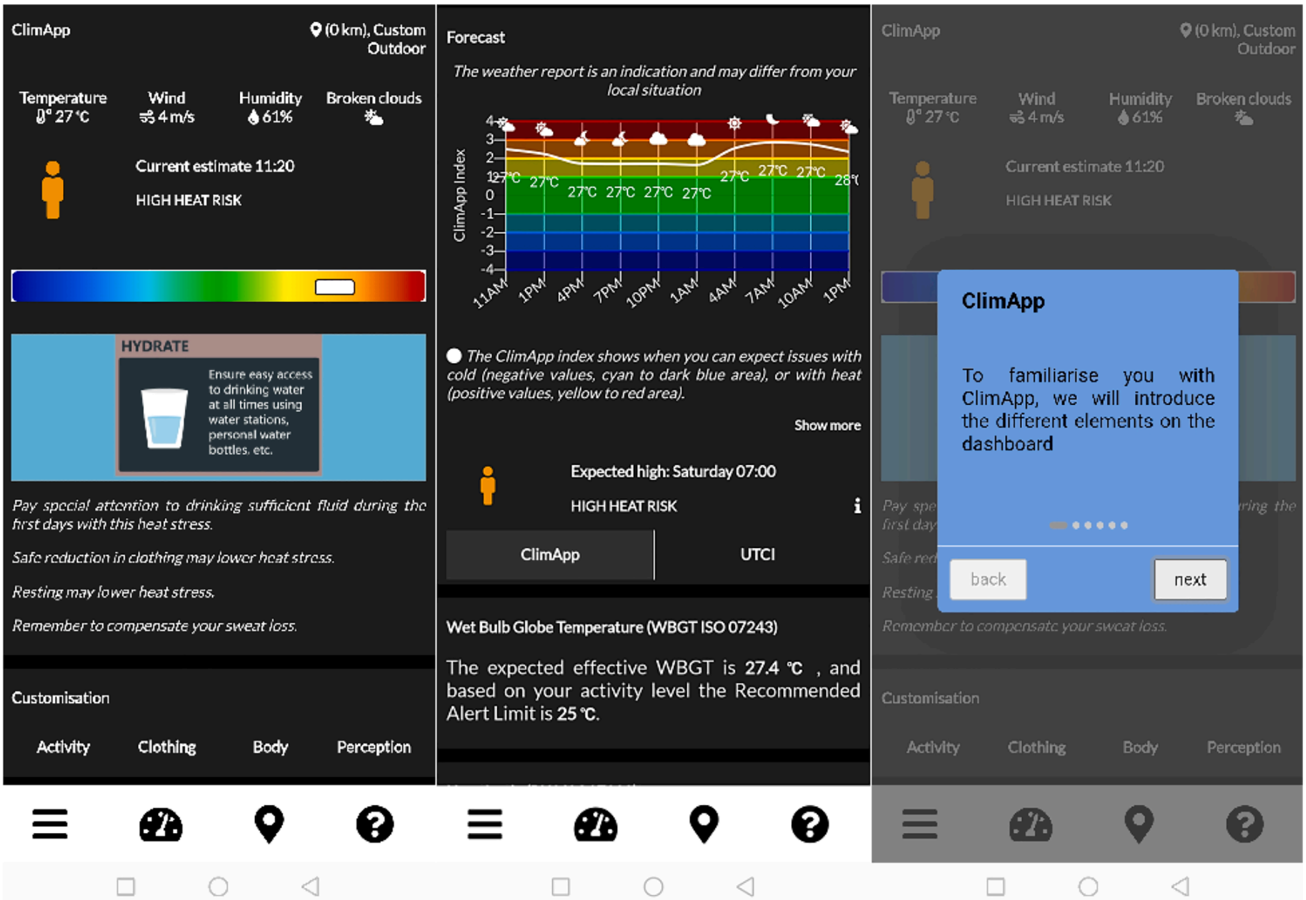

Fig. 5. (a–c) Updated version of ClimApp used in Iteration 2. The screens show the Swedish version with text translated to English for illustrative purposes The *Dashboard* (5a) is now updated to include infographics and includes the *forecast graph* by scrolling down (5b). The tutorial is accessed the first time using ClimApp and can be re-accessed any time by pressing the question mark on the bottom panel to the right (5c).

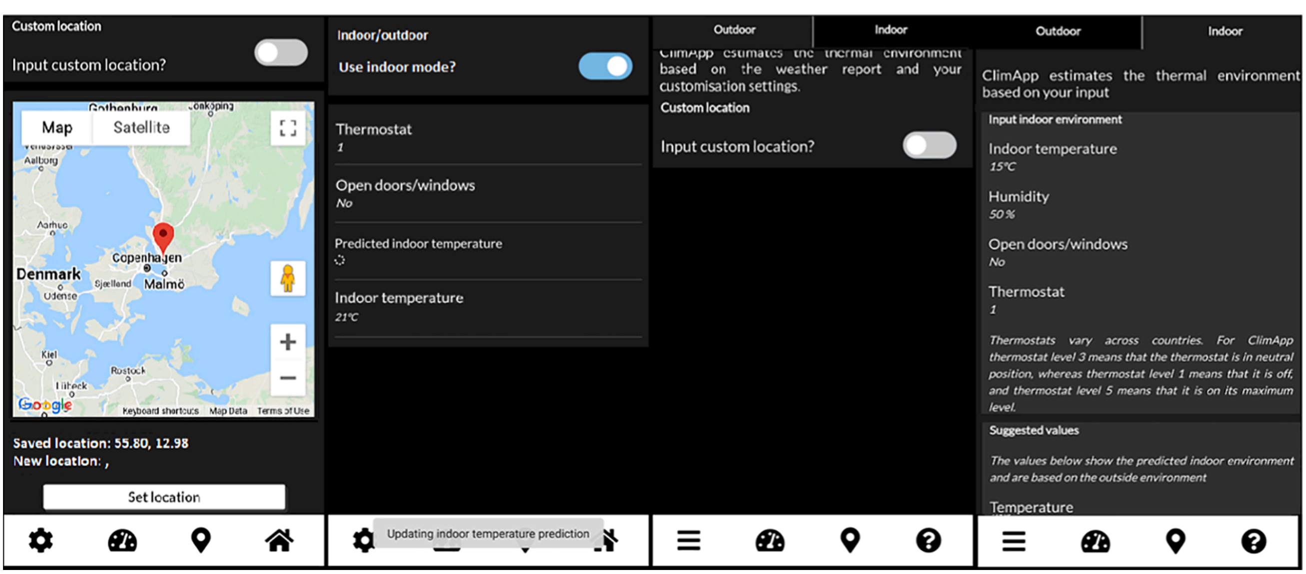

Fig. 6. (a–d) The difference of the *custom location* and *indoor mode* panels between the two iterations. The screens show the Swedish version with text translated to English for illustrative purposes Iteration 1's *custom location* (6a) and *indoor mode* (6b) were merged into the same panel in Iteration 2 (6c-d) by toggling a button at the top of the panel. The *custom location* is not accessible before activating the function by sliding the bar (6c), and the *indoor mode* contains explanations to assist the user (6d).

(Iteration 1) and uses a question mark as an icon. The icon for settings was changed from a cogwheel in Iteration 2 to three horizontal bars. The changes can be seen in Fig. 6a–d.

3.3. Iteration 2 – field test

Iteration 2 investigated what issues the participants experienced and whether ClimApp provided logical navigation and functionality. Iteration 2 focused more on functionalities and if the participants deemed ClimApp usable in outdoor environments during wintertime.

3.3.1. Physical activity and clothing level

The function that most participants mentioned in their survey was the *clothing level*. Being able to choose this level is something they felt was very important when dealing with cold environments.

> "Good that it gave me food for thought, because it is easy to underestimate how cold it will get!"

Iteration 2 took place during the summer when the focus was primarily on heat stress by avoiding overdressing and performing labor activities that were too intensive.

> "I often have difficulties knowing how much clothing I should wear when doing something outside. It is great to get an idea of this using ClimApp!"

At the same time, the participants felt that the *clothing level* and *activity level* choices were too few and not sufficiently explained (Fig. 1c). While the issue also came up in Iteration 1, this was more profoundly exclaimed during Iteration 2 where participants used ClimApp in the cold where clothing is more important.

> "… the only thing was this … like … how do you interpret the clothing levels? I think I got it right but it is a little rough!"

The lack of details made some participants feel uncertain about which level to select. The unit *clo,* which stands for *clothing insulation,* and the function to fine-tune the clothing properties were confusing and the participants were unsure if they were the right audience. The follow-up interview further emphasized that the participants felt that there were too few clothing choices to be used for outdoor winter exposure and that more activity levels would be helpful. A few participants felt that the static choices hindered them too much as their common activities were dynamic.

> "I'm outdoors guiding my clients. I found it a little difficult to find. I'm out with them doing some kind of sports activity and it's difficult to find the correct activity level for these activities!"

Based on the garments the users filled in in the questionnaire survey, and calculating the insulation according to the insulation summation equation in ISO 9920 (ISO 9920, 2007), 20 participants (52.6%) failed to choose the correct clothing level, each within an error margin of one level. On the contrary, only one participant (2.6%) entered the wrong activity level.

3.3.2. Navigation

Navigation was brought up during the interviews and several questions resulting in low scores on the survey were related to this function (Table 1, questions 1 and 7). The main problems participants experienced were finding the *indoor mode* and pressing the wrong button for their intended purpose. When prompted to use the *custom location*, participants explained that they attempted to press the map needle in the top right corner of the *Dashboard* which instead refreshed the local weather forecast with no effect on the *custom location* (Fig. 1a).

Table 1
The web-based survey statements. Each statement had two positive responses, two negative responses, and one neutral response from which to choose. For each response listed in Table 1, the number of participants who responded and the percentage of participants (in parentheses) are included. The median score is presented in the last column with a chi-square test result in brackets, the significance symbols are interpreted as; *** for $p \leq 0{,}001$, ** for $P \leq 0{,}01$, * for $P \leq 0{,}05$, - for $P \approx 0{,}05$ and ns for $P > 0{,}05$.

Statement	Strongly disagree	Partly disagree	Neither agree nor disagree	Partly agree	Strongly agree	Median agree or disagree (Significance)
1. It was easy to orient myself in ClimApp.	3 (7.9%)	5 (13.2%)	5 (13.2%)	21 (55.3%)	4 (10.5%)	Agree(**)
2. I understood what ClimApp's prediction of thermal stress meant.	1 (2.6%)	3 (7.9%)	4 (10.5%)	16 (42.1%)	14 (36.8%)	Agree(***)
3. I understood what the different levels for clothing meant.	0 (0.0%)	4 (10.5%)	1 (2.6%)	27 (71.1%)	6 (15.8%)	Agree(***)
4. I understood what the different levels for activity meant.	0 (0.0%)	0 (0.0%)	2 (5.3%)	22 (57.9%)	14 (36.8%)	Agree(***)
5. I believe I received sufficient information on what the functions in ClimApp did in order to use ClimApp.	0 (0.0%)	3 (7.9%)	9 (23.7%)	13 (34.2%)	13 (34.2%)	Agree(***)
6. I want to be able to make more detailed choices and receive more detailed information from ClimApp. (Neither agree nor disagree means that current level is desirable.)	1 (2.6%)	5 (13.2%)	12 (31.6%)	15 (39.5%)	5 (13.2%)	Agree(**)
7. I quickly found the function I was looking for.	2 (5.3%)	9 (23.7%)	5 (13.2%)	16 (42.1%)	6 (15.8%)	Agree(-)
8. I found and used forecast without any problems.	0 (0.0)	6 (15.8%)	0 (0.0%)	11 (28.9%)	21 (55.3%)	Agree(***)
9. I found and changed activity and clothing levels without any problems.	1 (2.6%)	2 (5.3%)	0 (0.0%)	13 (34.2%)	22 (57.9%)	Agree(***)
10. I found and used the indoor mode without any problems.	4 (10.5%)	9 (23.7%)	7 (18.4%)	9 (23.7%)	9 (23.7%)	Neither agree nor disagree(ns)
11. I found and used custom location without any problems.	1 (2.6%)	6 (15.8%)	4 (10.5%)	12 (31.6%)	15 (39.5 %)	Agree(***)
12. I believe it was easy to find the advice and recommendations in ClimApp.	2 (5.3%)	3 (7.9%)	7 (18.4%)	16 (42.1%)	10 (26.3%)	Agree(***)
13. I believe it was easy to understand the advice and recommendations in ClimApp.	2 (5.3%)	1 (2.6%)	8 (21.1%)	13 (34.2%)	14 (36.8%)	Agree(***)
14. I can see myself using ClimApp on a daily basis.	0 (0.0%)	10 (26.3%)	12 (31.6%)	12 (31.6%)	4 (10.5%)	Neither agree nor disagree(ns)
15. I can see myself using ClimApp during extreme weather events.	0 (0.0%)	2 (5.3%)	8 (21.1%)	11 (28.9%)	17 (44.7%)	Agree(***)

"But spontaneously you wanted to press in the top right corner. It felt natural that you changed location there! But that just updated the forecast …"

One person also wanted to make use of the update prediction function but could not find it:

"A button to update the current estimate; sometimes I had to restart ClimApp to get a new estimate!"

3.3.3. Information level

The tutorial function (Fig. 5c) appeared to have a positive effect because very few participants in both the survey and the following interview mentioned that they did not understand its functions. In Iteration 1, the participants initially felt uncertain about what thermal stress meant. This was not an issue in Iteration 2 where 30 participants responded that they completely or partially understood what thermal stress was. The *detailed information* and *forecast graph* are also explained in further detail. Several participants mentioned that the information provided by fine-tuning and the *clo* unit (Fig. 1c) confused them because it introduced information they did not know how to interpret.

"It made me feel as if I don't understand it properly or is it just me that is slow?"

The participants disagreed when it came to the overall information presented on the *Dashboard* (Fig. 1a and a). Some thought it was clean and found it to be easy to get an overview; others found it too detailed with an overload of information. The participants were asked if they wanted more or less *detailed information* from ClimApp. There was a shift towards wanting more *detailed information* with a mean score of 3.47 where 3 is completely neutral (Table 1, question 6). However, when elaborated on in the interviews, the picture was different:

"Personally, I would like to see that the more complicated information that requires that you know stuff is moved to another panel. That the starting screen can be where you simply select the clothing and activity and ClimApp knows what the weather is and you get recommendations on what to consider!"

Several participants were confused by *UTCI* and felt that it was not sufficiently explained. They did not know how to interpret the index or why it was available next to the *ClimApp index*, and as a result experienced that they were lost, something mentioned in both the survey and interview and brought up as an unnecessary function. Several participants also failed to properly submit their *UTCI* prediction due to this confusion.

"Then I was, what is UTCI then? I asked my colleagues, but they didn't know. It wasn't until I pressed the question icon that I understood that 'aha, it's this'! I didn't absorb that information the first time when I read it."

3.3.4. Additional remarks

After the *clothing selection*, the function that most participants appreciated was the *forecast graph* as it provided them with a clear overview of the short-term thermal stress risk. This helped them plan for the day and provide them with early warnings of risks.

"It's good that it shows how the weather will change over time. Usually, I dress in the morning without considering what the weather will be like in the afternoon."

Participants suggested that more clothing recommendations based on the forecast could be added as a complement to the advice already provided by ClimApp. The *custom location* function was mentioned a few times as problematic but not to the same extent as in Iteration 1. The lingering issue with selecting the *custom location* was the integrated Google Maps, which is prone to mistakes since two fingers are needed to operate the very touch-sensitive map.

3.3.5. Questionnaire survey

The web-based survey consisted of statements covering the overall usability, the navigation, and the perceived ease of use of each function in ClimApp. The participants responded to the statements using a 5-scale Likert scale with the following range: Strongly disagree to Strongly agree with a neutral stand being Neither agree nor disagree. The median result and Chi-Square significance test are calculated by grouping the agreeing responds together and likewise the disagreeing responds. The median is presented for each statement with a Chi-Square significance test result in brackets.

In Table 1, the overall median result is Agree for most statements except for statement 10 and 14. Three statements returned a non-significant value indicating an even distribution, these being; "7. I quickly found the function I was looking for", "10. I found and used the indoor mode without any problems", and "14. I can see myself using ClimApp on a daily basis". A comparison of statements 14 and 15 show that the participants generally saw ClimApp as a tool more suitable for extreme weather events.

4. Discussion

This study investigated the usability of ClimApp over two iterations consisting of testing and development. Applying the lens of activity theory, it was clear that ClimApp, at least in part, made sense and was perceived as meaningful and useful for the participants (Kaptelinin and Nardi, 2006; Kuutti, 1996). Most notably, they emphasized the utility of getting customized feedback based on their physical activity and clothing. This shows that the concept of ClimApp is pertinent from the perspective of how the users frame their daily activities in the context of use. The concept, and at least part of the functionality of ClimApp, makes sense to them. Furthermore, the tool appears to be more useful during extreme weather, which is to be expected as ClimApp aims to assist the user when dealing with thermal (heat and cold) stress. Thus, the usability of ClimApp is tightly coupled to its context of use and this is in line with the overall idea behind ClimApp, which was to provide climate information to the users tailored to their context of use, rather than generic information that they need to interpret themselves.

The initial testing in the usability lab shed light upon several issues related to navigation. Yet, this showed that the concept of ClimApp is also feasible from an interaction perspective, since the participants were able to finish the test. The information learned from Iteration 1 allowed Iteration 2 to overcome several of the previous issues and barriers which caused confusion (Steinfeld and Maisel, 2012), primarily from the navigation aspect. Iteration 2 was tested in the field, allowing the users to experience ClimApp in its real context of use. This situated nature of the test resulted in more valid feedback in relation to its real context of use (Suchman and Suchman, 2007).

Several issues were improved in Iteration 2. When first starting ClimApp in Iteration 2, the user is greeted by a tutorial which explains the available functions on the *Dashboard*. These functions are the main components of assessing thermal stress. The initial reaction in Iteration 1 was that participants felt slightly overwhelmed and did not really know how to interpret functions such as thermal stress prediction. Thus, while the *learnability* of ClimApp appears to have increased somewhat between Iteration 1 and 2, parts of the problem remain (Rogers et al., 2011). Thus, there is a need to further overcome this barrier in order to be more inclusive. One way to do this would be to hide complex information that may alienate some of the users (Steinfeld and Maisel, 2012).

A few suggestions contradicted those of others: Some wished that all information was on one screen while others wanted even more separation. A possible solution would be to limit the visible information for first-time users who could easily feel overwhelmed or those who are not interested in supporting information. The users could then remove this limitation if they wanted to receive more *detailed information*, and then would be able to provide input that was more detailed. Such information could include microclimate input or customizing activities and clothing levels. This dilemma is a conflict of interest between scientific goals where the functionality of ClimApp provides a novel assessment tool. At the same time, it must provide a level of information that is acceptable for potential users who can include novices and experts. In the post-test interviews, participants stated that they did not feel they were the right audience, since the information and language used – concerning clothing levels, the *clo* unit, and the index *UTCI*, for example – made little sense to them. Thus ClimApp partly failed to speak the language of first-time users (Nielsen, 1994). This must be considered in future updates.

The navigation in ClimApp needs further attention to make it work seamlessly on an operational level. There were several situations during the usability lab test where the user made mistakes and had difficulties finding the desired function due to a lack of affordance. A common mistake was trying to return to the previous panel by pressing the hard-coded return button on the smartphone, which resulted in exiting ClimApp. The participants also looked for some sort of arrow indicating a return button but could not find one. The questionnaire survey results indicated that navigation remains an aspect for improvement (Table 1, Statement 7). Yet the interviewees barely mentioned the navigation as an issue after both tests. These types of issues indicate that ClimApp did not always correspond to the users' expectations: the interface broke with platform conventions and established new interface metaphors. An example of the latter was using the house icon as a metaphor for the *indoor mode* in Iteration 1, rather than its conventional use as a metaphor for *Home*. In this way the interface was not compatible with the users' mental models of how interaction with a smartphone works (Nielsen, 1994; Norman, 1990).

In Iteration 1, the main criticism was the *custom location*, which did not tolerate such mistakes or guide the user to avoid them. This indicates a lack of feedback from the system. The system's status was not made sufficiently visible to the users (Nielsen, 1994; Norman, 1990). Iteration 2 provided an update of the custom location function where the user must first activate it to set a new location. This helps users by forcing them to complete each step, which in turn reduces the number of ways mistakes can be made. When test participants attempted to change the location provided in Iteration 1, several exclaimed both during the test and in the follow-up interview that they would like to have entered the location in a search field to reduce the work required to set their *custom location*. This function could also make use of saved locations and have them ready for the user for either quick comparison or quick access. The information provided in the *custom location panel* is minimal and can be extended to explain the steps in text to avoid potential errors such as not pressing the final button "sätt plats/set location" (Fig. 1c).

The results indicated that the *indoor mode* needs further consideration as this was the function that received the highest percentage (34.2%) of disagreeing responses (Table 1, Statement 10). Currently, it shares a panel with the custom location but the participants seemed to struggle in finding it because the *Dashboard* did not show the user how to switch between indoor and *outdoor mode* (Norman, 1990). One way to solve this is by changing or highlighting the icon that dictates the panel contents. When assessing the *indoor mode*, users are able to "inform" ClimApp if a window is open or not in the room where they are located. An icon visualizes whether a window is open or closed on the *Dashboard*, but several participants felt that this icon should have served as a button to let the user select *open window* or *closed window*. Similarly when interviewed, several participants explained how they initially pressed the map needle icon in the top right corner of the *Dashboard* when they wanted to change the *custom location*, yet this only updated the weather forecast. This button could be repurposed to act as a shortcut to the forecast panel and a new button using a generic refresh icon could be integrated with the weather forecast data.

One of the main functions in ClimApp that appeared to be very relevant from the participants' perspective was to select *activity level* and especially *clothing level*. However, the levels available were perceived to be too few and included too little information, even though they are partly based on clothing ensembles in the existing international standard, ISO 7243 (2017), which are commonly used in occupational settings in the heat (ISO 7243, 2017). However, many outdoor workers experience both heat and cold stress and they do not always dress according to these standardized clothing levels since they are too niched and cannot easily be translated to their own clothing. Moreover, the fact that many participants unknowingly selected the wrong clothing and activity level indicates that the alternatives provided did not always correspond to the users' understanding of these factors. To cater to a wider group of users, the information provided can be updated with clothing sets more commonly used in cold climates.

ClimApp provides personalization by allowing users to enter anthropometric data such as weight and height; yet, it leaves much room for further improvement in terms of disability and medical history, for instance.

This study gathered data from both a usability lab test and a field test including observation and questionnaire survey data and interview data. While the lab provides a controlled experimental setting, the conditions of the field test provide more validity. The usability lab test offered insight on operational behavior (Kaptelinin and Nardi, 2006) and how the users interpreted the existing interface, including the visibility of functions, navigation, the use of constraints and affordances (Norman, 1990). When applied in the field, the participants provided the researchers with more situated experiences that allowed a more immersive analysis of usability in relation to the intended real context of use and to the real life activities of the users (Kaptelinin and Nardi, 2006; Suchman and Suchman, 2007). Together, the two approaches applied here provide a good foundation to both study operational level interaction (how the users operate the interface), and the feasibility and usability of ClimApp in its real context of use.

The field test was performed remotely due to the ongoing pandemic. Initially the researcher would have presented ClimApp for companies, let workers test ClimApp and return for follow-up interviews. The pandemic led to difficulties in recruiting companies as their other priorities took the overhand. The study thus shifted from focusing on workers to a wider range of participants from a larger geographical area than originally planned. This limitation led to the user group shifting from outdoor workers to those who frequently spend their time outdoors either in their occupational or their recreational settings. This limitation shifts the research target group slightly from the worker group but still keeps it within those who frequently experience coldoutdoor conditions. The main research focus in this study is the design process of the app through user testing which is less affected whether the user is primarily working outdoors or if the user is simply frequently performing activities outdoors and still require climate services. The combination of a usability lab test and field test reduced the limitations of both test forms. The usability lab test focused on reliability and low-level cognition so they would not be major issues when usability and validity were tested in the field.

5. Conclusions

ClimApp is perceived as being usable in an applied context and offers functoriality appreciated by the users. ClimApp was designed based on user feedback at different stages and the functionality connected to the different thermal models. Several aspects of ClimApp were improved after two iterations, one of them being the navigation, which is likely a result of decreasing the number of panels ClimApp used. The users were introduced to ClimApp with a tutorial that explained several functions that had been difficult to understand in the previous version. Several usability aspects of ClimApp were identified that were in need of further improvement, especially navigation and the level of information provided in general. By personalizing the information flow and increasing the clothing and activity choices, ClimApp can likely be perceived as being even more useful.

Author contributions

JE, CR and CG conceived and designed the study. JE performed the tests and interviews. BK assisted and updated the software. JE and CR analyzed the data. JE and CR drafted the manuscript. CG and JT critically reviewed the manuscript. CG coordinated the ClimApp project. CG and JT obtained funding. All authors approved the submission of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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