ROBOTS IN ASSISTED
LIVING ENVIRONMENTS

UNOBTRUSIVE, EFFICIENT, RELIABLE AND MODULAR SOLUTIONS FOR INDEPENDENT AGEING

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Abstract

This deliverable is the RADIO Graphical User Interface for the end-users and installation and calibration tools to be used by installation technicians. The demonstrator of the end-user GUI has also undergone extensive formal evaluation, which is also reported here.

History and Contributors

Ver	Date	Description	Contributors
01	7 Nov 2016	Methodological background (Section 3).	TWG
02	22 Nov 2016	Intermediate version of the end-user interface, porting Web app to Android app (Section 2).	NCSR-D
03	16 Jan 2017	User experience expert review of the end-user interface (Section 3.6).	TWG, NCSR-D
04	20 Jan 2017	Technician's interface: Motion detection calibration (Section 4.1).	TWG
05	7 Mar 2017	Final end-user interface (Sections 2 and 3.5), addressing expert review comments. Given for end-user evaluation.	NCSR-D, S&C
06	10 Mar 2017	Technician's interface: Acoustic event recognition calibration (Section 4.2).	NCSR-D
07	12 Apr 2017	End-user evaluation results (Section 3.7).	TWG
08	19 April 2017	Internal peer review.	FZ
Fin	20 April 2017	Addressing peer review comments, final preparations and submission.	NCSR-D

Abbreviations and Acronyms

ADL	Activities of daily living
GUI	Graphical User Interface
MQTT	Message Queuing Telemetry Transport is a standard publish/subscribe-based messaging protocol
ROS	Robot Operating System, the robotics software framework assumed as the basis for development in RADIO.
UI	User Interfaces

Executive Summary

This deliverable is the RADIO Graphical User Interface for the end-users and installation and calibration tools to be used by installation technicians. The demonstrator of the end-user GUI has also undergone extensive formal evaluation with volunteers, which is also reported here.

The findings of the formal evaluation are that users recognized icons after a very limited number of fixations in other icons, meaning that at a very early stage of their interaction experience they recognize and recall the correct icon. No user clicked on a ‘wrong’ icon and users also reacted as expected when they were shown the confirmation message. The data collected by the eye-tracker have confirmed icon memorability and recognizability, readability and understandability of text messages, and size suitability of confirmation messages.

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1 INTRODUCTION

1.1 Purpose and Scope

This deliverable comprises the demonstrators of the primary users' interface to the RADIO Home functionalities: https://github.com/RADIO-PROJECT-EU/RADIO_user_android_app
and of the installation and calibration tools that are used by technicians to install RADIO:

- Motion analysis (Section 4.1): https://github.com/RADIO-PROJECT-EU/motion_analysis
- AUROS (Section 4.2): https://github.com/RADIO-PROJECT-EU/rrac_ui

The evaluation of the primary user's interface was originally outside the scope of this deliverable. The only relevant evaluation foreseen was the usability evaluation (in the context of the clinical partners' pilot studies) of the system as a whole (not of the user interfaces per se). However, the scope of this deliverable has been extended with respect to the original workplan to also report the usability study of the primary users' interface.

1.2 Approach

This deliverable is prepared within *Task 5.2 Design and development of user interfaces*. The unified smart home/robot *end-user interface*, offering simple and intuitive control over all comfort and assistance aspects of the RADIO system. This will be used on mobile devices (smartphones, tablets). The first version of the UI (D5.4) has undergone expert evaluation and has been improved based on these comments. The final version has undergone end-user evaluation.

1.3 Relation to other Work Packages and Deliverables

This deliverable is informed of *D6.9 User evaluation report I*. D6.9 provides requirements for the Graphical User Interface (GUI) of the end-user. This deliverable is in form of report setting the requirements for the first version of the RADIO end-user GUI. It will be superseded by D5.5 User Interface II that will include a) a report listing the final requirements for all GUIs prescribed in RADIO, b) user manuals for all GUI and c) GUI software.

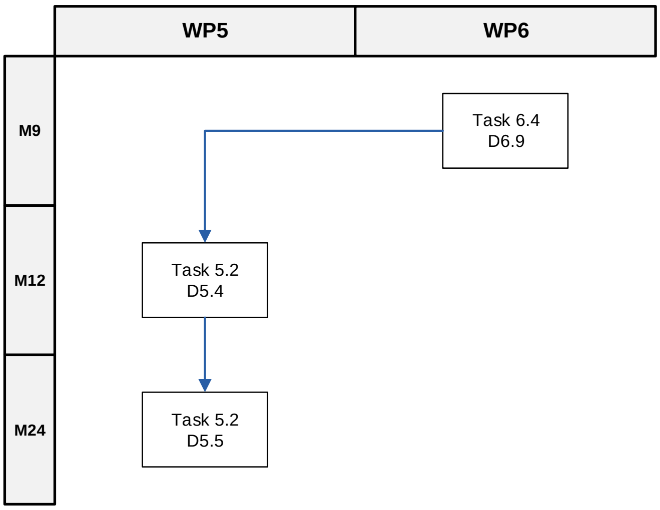


Figure 1: Relation to other Work Packages and Deliverables

2 RADIO END-USER INTERFACE TECHNICAL DETAILS

2.1 Radio Android application

The RADIO primary end-user interface was change from a Web app to an Android app. The main reason for the migration of the RADIO users' GUI from a web application to an Android application, was the ability of the Android application to effectively run hardware-intensive operations, like constantly polling for updates from the RADIO eco-system. In addition to running the application to a more optimized platform, the Android application offered the advantage of running a ROS node on the device itself, without the need of bridging protocols (see next paragraph).

2.2 User Interface - Robot communication

In the previous protocol a REST API along with a web server were running on the main controller, with the mobile device working as a client. The current architecture assigns to the mobile device a more active role by running more operations on it and freeing some resources from the main controller which does not have to run any of the previous services except of a small script that consumes messages coming from the mobile device. Switching to an Android application changed dramatically the communication between the UI and the robot, while at the same time, allowed less operations to be run on the main controller.

2.3 Home Automation

The graphical user interface for the smart home functionality was extended to include the new sensors and actuators to be used in the FHAG pilot. Figure 2 is a screenshot of the tab named as ‘Devices’ that show a list of all sensors installed for the FHAG pilot. This list can be ordered by name, area, status, type, battery level or last date communication. The state ‘offline’ means that the sensor does not communicate data to the gate, probably because its battery has run out.

It can be seen that there are two Multisensor 4’s motion sensors, one installed on the wall and the other one under the bed. This sensor captures motion data that can be used to identify some ADLs in combination with other data. Also, this sensor provides temperature changes, the level of light in the room and the humidity ranging. Pressure sensors to identify bed, sofa and chair occupancy, open/close cabinets and doors sensors, and sensors for controlling energy consumption were also included. The diagram shows the level of the battery of each sensor. The combination of these sensors by using rules enables to identify different ADLs (cf. Section 4, D3.5).

The tab ‘Control’ acts directly on the devices listed. Figure 3 shows the actuators installed for the FHAG pilot: lights, appliances and blinds control.

The application enControl supports a new functionality called ‘scenes’ that enables the communication and interaction between devices with a single button. Figure 4 shows 3 scenes: Time to Sleep, Leaving and Watch TV. ‘Time to Sleep’ set the house to bed. All the lights and TV go off. When the button ‘Leaving’ is pushed, every light in the house turns off and devices are powered down. The scene ‘Watch TV’ set the house to watch TV by closing blinds to 70%, turning all lights off and turning on the TV. Figures 5-7 show how the scenes can be defined by using ‘blockly’ technology, i.e., dragging and dropping blocks of actions.

Figure 2. Screenshot of EnControl tab 'Devices'

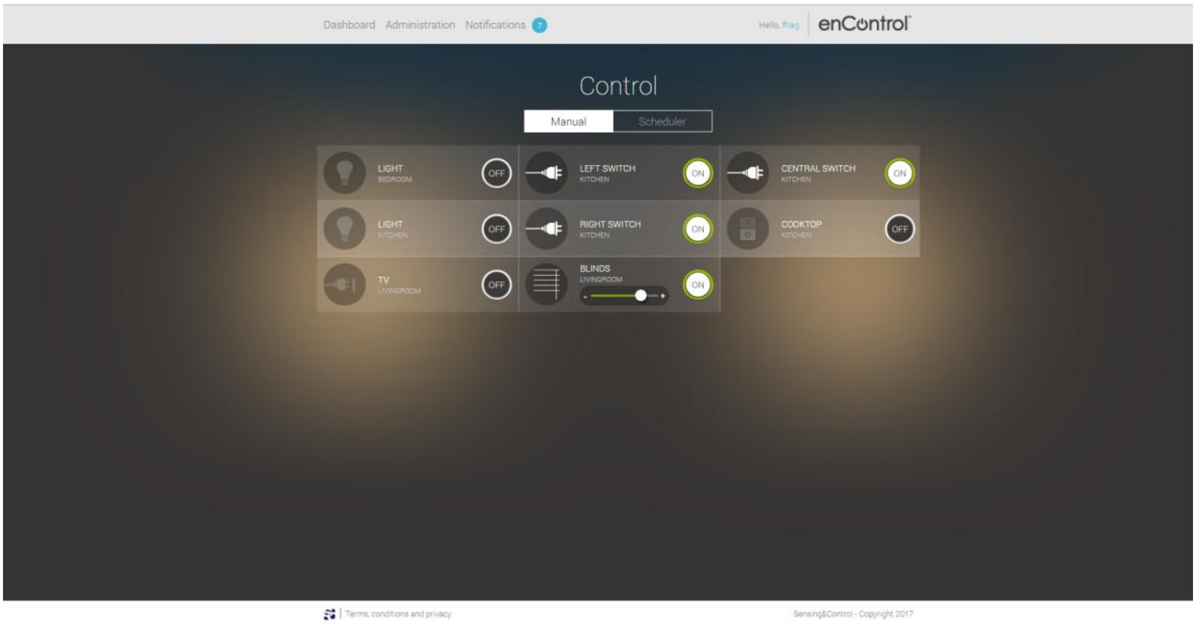


Figure 3. Screenshots of actuators installed at FHAG premises.

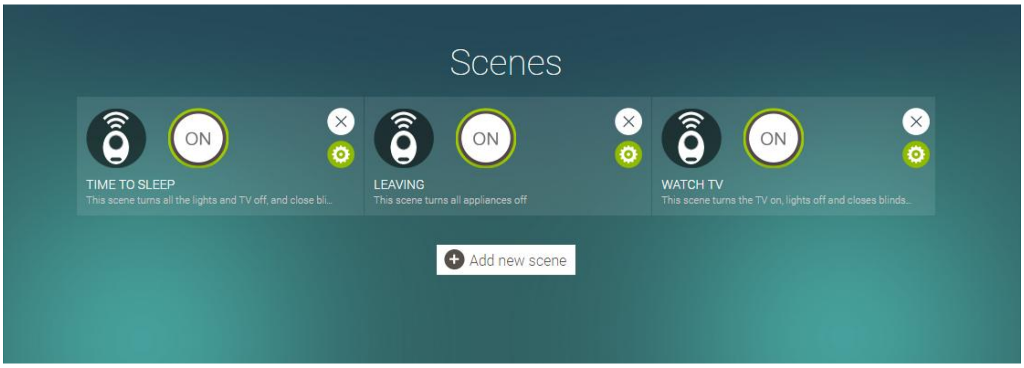
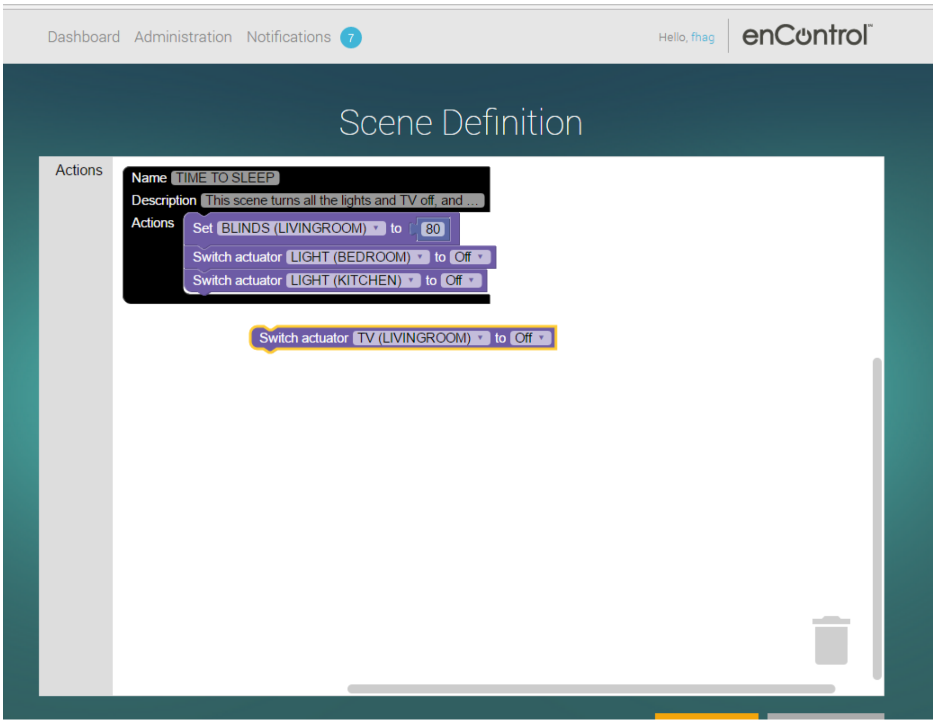


Figure 4. Screenshots of EnControl 'Scenes' functionality.



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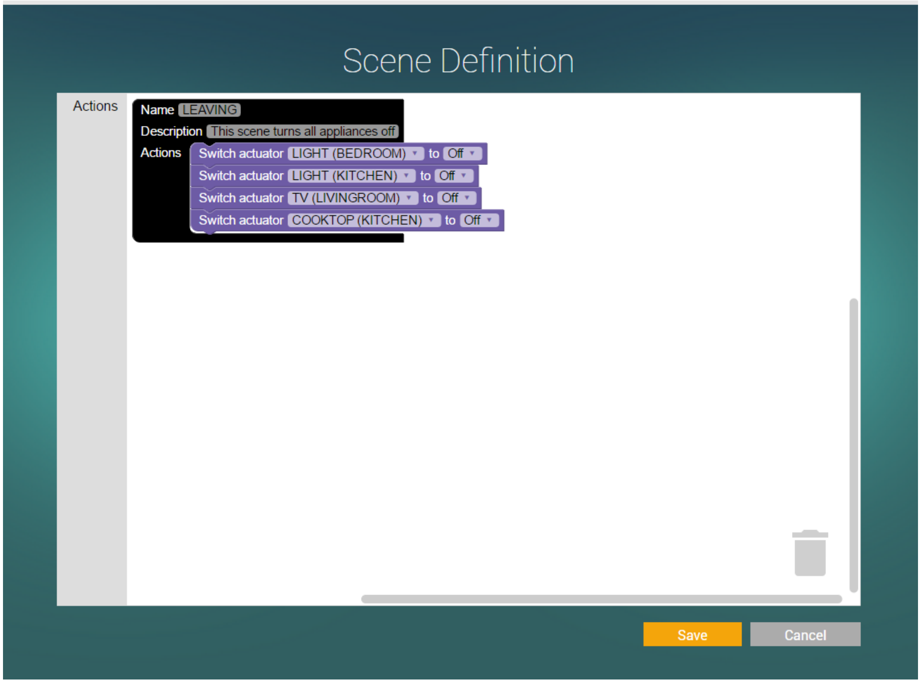


Figure 6. Screenshots of Scene definition: Leaving.

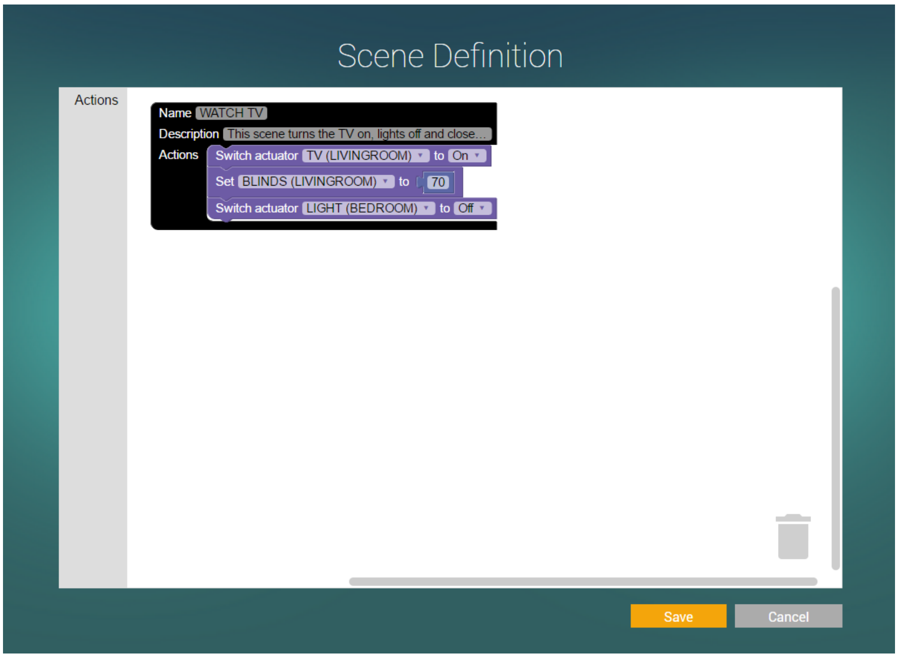


Figure 7. Screenshots of Scene definition: Watch TV.

3 RADIO END-USER INTERFACE USABILITY EVALUATION

Section 2 reports the usability study of the RADIO primary end-user interface. Specifically, Section 3.1 presents the background; it describes characteristics of aging and how theses affect the use of touch devices and the overall usage of computers. Section 3.3 goes through the design guidelines that must be followed for the elderly users, resulting in a Guideline Checklist presented in Section 3.4. RADIO primary users' GUI and its flow is presented in Section 3.5 (both for tablet and smart phone). The expert evaluation of the GUI is reported in Section 3.6. Based on the GUI result from expert evaluation, RADIO GUI usability study was run. The methods, study group, scenarios and data collected are presented in Section 3.7.

3.1 Background

The usability of a computer system describes the quality of how well a user is able to access the provided functionality. This quality is influenced by the factors whether the user can accomplish a certain intended task efficiently, effectively and satisfyingly. Five important attributes of usability are given by Nielsen [1994]:

Learnability: The system should be easy to learn for a user.

Efficiency: The system should allow user to reach an intended goal within a reasonable amount of time (i.e., the productivity of the system should be at a high level).

Memorability: The system should be easy to remember. A user who has not used the system over a long period of time should relearn to use the system with minimal effort.

Errors: The system should prevent the user from making errors and offer the user the opportunity to easily recover from them (if occurring nevertheless). Fatal errors must not occur.

Satisfaction: The system should be pleasant to use. Frustration, fatigue or dissatisfaction should not be induced. Thus, the aim of developing a user-friendly computer system is to fulfill these aspects as far as possible.

Usability guidelines lead developers towards such a user-friendly system by giving an overview and a sense for issues which affect humans in using a computer system. Since age-related impairments influence the way people use computer systems, the five aspects named above have to be considered from a different point of view. As an example, a system which is easy to learn for a twenty-year old is not automatically easy to learn for a 68-year old as well. Hence, this system would be less user friendly to the elderly. Physical and cognitive impairments which often occur with advancing age influence the way of fulfilling usability aspects.

3.2 Characteristics of Aging related to use of GUIs

In order to elaborate and understand specific usability guidelines especially for the elderly it is necessary to understand how age influences the way people think, act, react and move and how a user-friendly system can be developed despite the presence of age-related impairments. This paragraph gives an overview of the age-related declines in physical and cognitive capabilities. Figure 8 illustrates these issues at a glance. Based on this, Section 3.3 describes how such declines influence the development of applications for the elderly in detail and how these can be compensated.

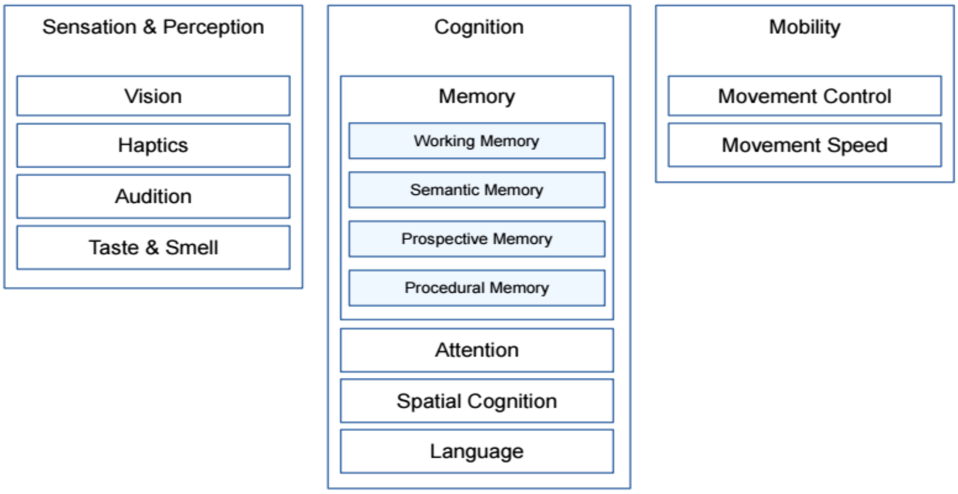


Figure 8. Overview of Age-Related Declines Categorized by Sensation & Perception, Cognition and Mobility

3.2.1 Sensation and Perception

Recognizing an object or a thing in general requires the ability of sensing physical stimuli (e.g., hearing a noise) on the one hand and the interpretation of these signals on the other hand (e.g., identifying a noise as human voice) [Fisk et al., 2009]. With advancing age changes in sensory capability concerning vision, haptics, audition, taste and smell may occur. Although it is possible that the ability to distinguish different tastes and smells decreases, this is not of concern when using tablet-applications and therefore not described in detail within this work. A very common impairment coming with age is the ***diminishing ability to focus objects*** at low distance (called presbyopia). Due to the stiffening of the lens in the eye, the lens is not able to adjust itself anymore in order to display a sharp image onto the retina. Additionally, when the lens becomes more yellow with advancing age, ***color discrimination*** for the short wavelength end of the spectrum (i.e., violet, blue and green shades) becomes more difficult. Hence, warm colors (like yellow or red shades) can be discerned more easily than cool ones. Next to visual impairments caused by the lens, the pupil affects the visual acuity as well. On the one hand, the pupil becomes smaller and therefore less light can enter the eye. Thus, the elderly people require a ***higher illumination in order to see sharply***. On the other hand, the process of dilating and contracting the pupil becomes slower, which is why adapting it to changes of illumination takes more time. As a result, the elderly population is more sensitive to glare. Furthermore, the ***contrast sensitivity decreases***. Age related changes in the neural circuitry of the retina and the brain cause a diminished capability to detect contrast. In addition, the visual field (i.e., the area wherein visual targets can be identified and discriminated without moving the eye or the head itself) narrows. ***Peripheral visual targets*** are therefore more ***likely missed*** by the elderly [Farage et al., 2012, Fisk et al., 2009, Sardegna et al., 2002].

Concerning haptics, the elderly people more commonly have ***problems in sensing and perceiving touches or pressure*** especially on the hands and feet. This causes more difficulties in recognizing when a contact is made to a surface or movable objects are changed in their position (e.g., pressing a hardware button). Moreover, ***impairments in vibration sensation*** make it difficult to sense high frequency vibrations (60 Hz and above), while sensing low frequencies is less affected. These declines in touch, pressure and vibration sensation can already become apparent within the fifties [Farage et al., 2012, Fisk et al., 2009].

Similar to vibration signals, high frequency ***auditory signals*** (2000 Hz and above) are ***less perceptible*** for the elderly (in particular men) as well. This causes the effect, that words with high-pitched consonants (e.g., “ch”, “sh”) are harder to understand. Moreover, a ***higher sound intensity*** (i.e., volume) is needed by older people with hearing impairments (called presbycusis) from which already 60% of people aged 55 or above are affected. Often, for people above age 60 conversational speech is becoming harder to understand. Because the capability of distinguishing different concurrent sounds from each other and processing gaps between dynamic sound diminishes, speech recognition and discriminating speech from background noise is difficult for persons affected [Farage et al., 2012].

3.2.2 Cognition

Cognitive functions such as memory, attention or spatial cognition are affected differently by age-related changes. The following descriptions of these cognitive functions are based on the literature from Fisk et al. [2009] and Farage et al. [2012]. As depicted in Figure 8, four different areas concerning Memory exist:

Working memory, semantic memory, prospective memory and procedural memory. Working memory (also called "short-term memory") is the part of memory which temporarily keeps currently used information active and therefore accessible. The ***amount of information*** (i.e., the capacity of working memory) ***and the period of time it is accessible decreases*** with age.

Semantic memory (also called "long-term memory") refers to the capability of storing and remembering knowledge. Although the elderly need more time to access this knowledge, it is normally not getting lost with advancing age (as long as a person does not suffer from diseases like Alzheimer's).

Prospective memory is the ability to remember doing something in the future. It is differentiated between time-based (e.g., remembering to take a medication at a certain time) and event-based (e.g., remembering taking a medication when the alarm clock rings) memory. Time-based future actions are generally more often forgotten by the elderly than event-based ones.

Procedural memory describes the knowledge of how certain actions are carried out. This knowledge concerning well-known and practiced behaviors or activities (e.g., driving a car) remains intact. Acquiring completely new or minimally changed procedures is becoming harder to internalize for the elderly.

Besides memory, another cognitive function affected with advancing age is the ***attention***. Focusing on a certain stimulus or event and processing its information requires attention and the ability to ignore competing stimuli. Since this ability declines with advancing age, ***switching attention between different sources of information is highly demanding*** for the elderly and processing these information takes more time.

Research showed a ***decline in spatial cognition*** as well. Locating objects within a three-dimensional space and developing a three-dimensional image in mind based on external cues becomes more difficult (e.g., mapping a two-dimensional coordinate on a map onto the three-dimensional space in the real world).

Moreover, there is a ***difference in understanding written and spoken language*** between older and younger people. Due to the minimized working memory capacity, processing and producing syntactically complex language is challenging especially for the elderly. When information is presented (written or spoken), drawing inferences (i.e., connecting this information) and understanding their intention is difficult for older people as well. Therefore, elderly people often have problems recognizing and understanding, for example, sarcasm or ironic expressions.

3.2.3 Mobility

With advancing age physical as well as psychological changes influence the way people are able to move and to control their movements. Due to the declining muscle strength and flexibility of the body, older people are more restricted in their range of body movements. Moreover, ***body movements become more error-prone***, since perceptive abilities diminish and transferring signals from the brain to perform a movement becomes less precise. Compared to younger people, the elderly people take more time in carrying out similar movements (on average 1,5 to 2 times longer) [Fisk et al., 2009, Farage et al., 2012].

3.2.4 Touch Devices for the Elderly

Input devices in general can be divided into two categories: **direct** and **indirect** [Wood, 2005]. Direct input devices offer the possibility to directly interact with the desired object. Hence, touch devices like tablets are direct input devices, since a button for example can simply be touched to carry out an action. Indirect input devices translate a body movement into data which is required to interact with a system. A computer mouse, for example, is such an indirect input device. In order to click a button on the screen, the user has to move the mouse and click a hardware button on it. Therefore, the interaction with the system takes place indirectly by using the mouse. Compared to direct input devices, indirect ones require more complex hand-eye coordination. To reach an intended point on the screen with a computer mouse, its movement using the hand has to be mapped onto the movement of the cursor on the screen. Additionally, different spatial information has to be processed as well. When the user moves the computer mouse towards him- or herself on the tablet, it moves downwards on the screen (i.e., spatial information from a three-dimensional space have to be mapped onto a two-dimensional display). Estimating and controlling the virtual distance the cursor is moved when the mouse is moved physically requires more attention and manual dexterity on the one hand. On the other hand, this way of interaction allows a very precise positioning of the cursor. Although indirect input devices are more efficient and accurate for experienced users, for novices these interaction methods can be more difficult to learn. Since the elderly show declines in movement control and spatial cognition, moving a mouse and coordinating these motions can be more demanding for them. [Wood, 2005, McLaughlin et al., 2009]

By contrast, touch devices (i.e., direct input devices) require less hand-eye coordination, are more easy to learn and faster to use for people of all ages [Shneiderman, 1991]. These lower cognitive demands are especially beneficial for the elderly [McLaughlin et al., 2009]. But, it has to be considered as well that working with direct input devices causes arm fatigue more quickly and the hand may cover the screen and, therefore, interface elements may be not visible at first sight or are activated accidentally. Moreover, certain tasks or control elements which require high accuracy are not suitable for touch devices, since less precise inputs can be made. As an example, for modifying discrete values a slider control (requires precision) is more suitable for indirect input devices, while on direct devices simple “Up”- and “Down”-buttons are easier and faster to use [McLaughlin et al., 2009]. Thus, in order to make full use of the beneficial characteristics and compensate negative effects of touch devices, interfaces have to be designed taking these aspects into consideration.

In summary, with touch devices the elderly benefit from fast learnability, direct usage and less cognitive demands of touch devices. They offer novices the possibility to easily access device functionality and requires less training than indirect input devices. However, the sort of task, the interface design as well as the users’ experiences and capabilities, influence the suitability and effectiveness of touch devices.

3.2.5 Computer and device usage by the elderly population

Technology is in general less used by the elderly (older than 60 years) compared to younger people [Fisk et al., 2009]. This does not necessarily mean that older people generally wish to avoid new technologies. Fisk et al. [2009] showed that if older adults are conscious about the benefits of a certain technology, they also want to use it. Therefore, the most frequently used technologies concerning computer science are word processing programs, E-Mail and other communication programs as well as programs for information retrieval (i.e., browsers and search engines) [Morris et al., 2007]. There are also technologies which leave the elderly no other choice than to use them (e.g., a train ticket kiosk). As many older people feel frustrated in using them, this may be due to the lack of age appropriate design [Fisk et al., 2009]. In fact, common reasons for the elderly for not using computers or the internet is thinking that it is not suitable for older people, too difficult or not useful [Morris et al., 2007]. Therefore, “*the barrier is not age, but the respondents’ idea that older people cannot or do not use computers*” [Morris et al., 2007]. In order to develop applications for the elderly, an age appropriate design and making the applications benefits clear helps to gain a better understanding and acceptance. In this way, the application is seen as a supportive tool than as a useless obstacle an elderly is afraid to use.

3.3 Design Guidelines for the Elderly

To design user interfaces in general many aspects have to be considered (e.g., the choice of colors, interactive design or navigation structure). Realizing such design aspects regarding tablet-applications for older people, common age-related changes have to be considered. This section lists the 58 design guidelines collected from the current research in the Human Computer Interaction domain and provides an overall classification of the identified guidelines in seven discrete groups [Blendinger, 2015]:

1. Design
2. Layout
3. Language and Wording
4. Icons, Graphics and Multimedia
5. Interaction
6. User Support and Training
7. Personalization

The RADIO UI will be evaluated against this set of UI design guidelines.

3.3.1 Design

The term “Design” in this report refers to how the choice of certain colors or typefaces can influence the visual perception of applications for older people. When interfaces are designed in consideration of age-related visual changes like in visual acuity or color perception, working with these interfaces can be facilitated for older users. Hence, readability and distinguishing certain information on screen can be enhanced when taking such age-related changes into account. ***Design is studied in terms of selection of appropriate colors, color contrasts and typeface***

Colors: Colors can transport information or evoke certain moods and therefore can be widely used in interface design. However, age-related changes in color perception cause a reduced ability to discern colors especially in the short wavelength end of the spectrum (i.e., blue-tones). This is due to the diminished amount of incoming light reaching the receptors in the back of the eye (cf. Section 3.2.2). Moreover, with increasing age the pupil is less able to dilate as widely as possible and the lens becomes yellowed [Fisk et al., 2009]. The latter absorbs and scatters parts of the blue light which makes it difficult to distinguish differences in short wavelength hues. Red and Yellow light can pass the lens unimpeded and objects appear with a warm, reddish glow [Sardegna et al., 2002]. Therefore, especially violet, blue and green tones become less noticeable and appear faded while bright, warm colors (i.e., yellow to red) are much easier to discriminate [Farage et al., 2012, Fisk et al., 2009]. This visual change is of great concern when colors in user interfaces are related to a certain information like grouping elements or signaling events (e.g., warnings). For decorative or plain display purposes of information the color contrast is more important than the explicit choice of warm colors. In other words, when the color carries no information it does not matter if the users finally perceives the intended color. Hence authors recommend choosing colors of the long-wavelength end and to avoid blue-tones for important information [Farage et al., 2012, Fisk et al., 2009, Campbell, 2015, Loureiro and Rodrigues, 2014]. This leads to the following guideline:

Use colors of the long wavelength end of the spectrum if the color carries information – avoid blue especially.

Furthermore, using a large variety of colors in interfaces increases the need of constant refocusing. This tires the eye more quickly [Kurniawan and Zaphiris, 2005, Boustani, 2010]. This means:

Colors should be used conservatively. Use colors to carry important and relevant information (e.g., warnings, grouping elements etc.)

Especially regarding the use of touch devices, Caprani et al. [2012] pointed out the problem of large dark or black colored areas in applications which highlight fingerprints and increase glare or reflections.

An elderly eye is less able to recover quickly from glare or bright lights due to the smaller and less adaptive pupil and opaqued lens [Sardegna et al., 2002, page 6]. Therefore:

Keep in mind that dark background colors increase glare and highlight fingerprints. The choice of appropriate colors also plays an important role when displaying text.

To increase readability Fisk et al. [2009] as well as Holt [2000] suggest to avoid colored (such as black text on blue background) and patterned background. On the one hand, this increases the contrast and therefore the ability to distinguish long text (cf. next paragraph). On the other hand, it prevents text in the foreground to be distorted by a pattern in the background, even when the contrast of foreground and background is sufficient.

Avoid colored and patterned backgrounds for text display areas.

When using colors, the color contrast is an important aspect to be considered as well. The higher the contrast between colors, the better these colors can be distinguished and perceived. This also influences older users when dealing with a tablet-application. The next paragraph discusses this topic in more detail.

Contrast: With increasing age beside the diminished perception of certain colors, the contrast between two colors becomes less noticeable as well. The contrast sensitivity decreases when age-related changes in the neural circuitry of the retina and the brain occur which controls the ability to detect and recognize contrast [Sardegna et al., 2002]. This is especially important when text is displayed on screens or directly adjacent colors have to be distinguished. Hence authors recommend to keep color contrast high [Caprani et al., 2012] [Fisk et al., 2009]. For displaying text Fisk et al. [2009] and Farage et al. [2012] recommend to use black text on white background or vice versa, since the highest contrast possible is reached. A more precise indication of how contrast ratio can be calculated and which values indicate a high, respectively a “good” color contrast are provided by the World Wide Web Consortium (W3C) [W3C, 2015]. The Web Content Accessibility Guidelines (WCAG) 2.0 (presented by the W3C) cover several recommendations to make web content more accessible [W3C, 2008]. These guidelines contain a formula to calculate the contrast ratio of two colors, which can be found in Appendix A. In addition, it is suggested that “the visual presentation of text and images of text has a contrast ratio of at least 7:1” [W3C, 2008]. For large text (e.g., headlines) and text that is part of a logo or has pure decoration purpose a contrast ratio of at least 4,5:1 is recommended. These contrast ratio values also consider to avoid the combination of colors that cannot be distinguished by color blind users (e.g., red and green or blue and yellow). Several online calculators indicating if two colors provide a proper color contrast use this formula provided by W3C [2008]. Because this Web Design related recommendation does not have to be adapted for touch interfaces, the following general guideline can be derived:

To ensure legibility the color contrast ratio of text smaller than 18 pt should be at least 7:1 or 4,5:1 for large text or decorative text (following the formula provided by W3C [2008]).

Typeface: With increasing age the ability to sharply focus objects at low distance decreases (called Presbyopia) [Fisk et al., 2009]. Since older people tend to need more time reading text and instructions on screens [Chadwick-Dias et al., 2002] special requirements for displaying text on screens have to be considered in general. Using sans serif font types for text display on screens is known to be easier to read than serif font types [Holt, 2000] [Nischelwitzer et al., 2007]. Authors therefore recommend to use sans serif font types such as Arial or Verdana on computer screens [Holt, 2000] [Kurniawan and Zaphiris, 2005]. Nischelwitzer et al. [2007] found in their study, in which a mobile health application was designed and developed, that elderly users preferred the use of sans serif font types on mobile devices as well. For designing a tablet-application this means:

Use sans serif font types (e.g., Verdana or Arial).

Holt [2000] cautions against using several font styles, since "italics make words appear wobbly, underlining makes them blur", "condensed type squeezes letters together" and too bold font types are "too heavy to distinguish". Decorative or fancy font types are generally not recommended for the elderly [Kurniawan and Zaphiris, 2005, Loureiro and Rodrigues, 2014, Fisk et al., 2009] and should be used for headings, if at all [Holt, 2000]. Furthermore, though uppercase text attracts attention, reading is slowed down compared to normal text. Hence, uppercase should be used sparsely like for highlighting key material [Fisk et al., 2009]. Each of these font variations cause difficulties in reading and therefore are not recommended for interface design for the elderly.

Avoid decorative, italic, underlined and condensed font styles. Use bold font types and uppercase text only for highlighting key terms.

3.3.2 Layout

Apart from the selection of appropriate style information like color or typeface, the question how content should be arranged and organized arises. This especially focuses on a better perception of content like buttons or text for elderly users. Due to arising motor and visual impairments with increasing age, reading text and reaching targets on touch screens can become more difficult. Such impairments are compensated by applying a sufficient size to touch targets and textual content, which altogether improves elderly users in using touch applications.

Size and Spacing: Concerning older people, it is important to choose the size of some interface elements (e.g., buttons or texts) conscientiously. Authors often propose to provide large interface elements as well as more space between them to ensure that the information on the screen is perceived and distinguished entirely and correctly by elderly users [Kurniawan and Zaphiris, 2005, Loureiro and Rodrigues, 2014, Kobayashi et al., 2011, Caprani et al., 2012]. Though this is a very simple way to make an application "age friendly", it can cause problems on small screens as less information can be displayed per view. Furthermore, the question arises how the term "large" should be quantified properly. In this section specific suggestions for button- and font-sizes are discussed as well as recommendations for proper spacing between buttons and within text.

It is generally known that older adults, compared to younger adults, take longer to make similar movements which also are less precise [Fisk et al., 2009]. The fact that older adults are more error-prone in movement control indicates that reaching a button on touch screens becomes more difficult with increasing age, especially if the target to hit is quite small. The most obvious way to compensate the diminished precision is to increase the size of interactive targets on touch screens. Moreover, larger targets can be detected more easily by users with impaired vision. In fact, it is generally accepted that elderly need more time and mental effort for performing a pointing task, when buttons are reduced in their size [Caprani et al., 2012].

Increasing the targets size hastily, frequently causes problems regarding the available space on small screens. This strategy moreover does not even increase the pointing accuracy of the elderly significantly. This has been shown by Jin et al. [2007] who determined the optimal size and spacing of buttons on touch screen interfaces. In fact, touching an isolated button (which has no adjacent buttons) on a touch screen was not considerably affected by manual dexterity. As a result, increasing the size of such isolated buttons has no measurable impact on pointing accuracy. Jin et al. [2007] propose a size of 11,43 mm square for such isolated buttons. When buttons are arranged in rows of adjacent buttons (e.g., on a keyboard), they are suggested to be slightly larger to ensure higher accuracy (16,51 to 19,05 mm square). In addition, the majority of the subjects in this study (26 older adults aged from 53 to 84 years) subjectively preferred button sizes of about 16,51 to 19,05 mm square, which were assessed to be "large, but not too large" [Jin et al., 2007]. Subjects with a high manual dexterity preferred relatively smaller buttons and less spacing between them. Additionally, they were more accurately and quickly in touching target buttons. For subjects with less manual dexterity vice versa. However, 11,43 mm square should be the minimum button size. The button sizes proposed by Jin et al. [2007] are illustrated in **Error! Reference source not found.** and their usage is summarized in **Error! Reference source not found.**.

Table 1. Button Sizes Recommended by Jin et al. [2007].

Size	Usage
$11{,}43^2$ mm^2	Minimum size for separate/isolated buttons and when a slower reaction time of around 1400 ms is acceptable.
$16{,}51^2$ mm^2	For limited screen space and buttons used in rows of adjacent buttons.
$19{,}05^2$ mm^2	Recommended button size for faster response performance and higher accuracy. This button size is also the preferred one by the elderly users.

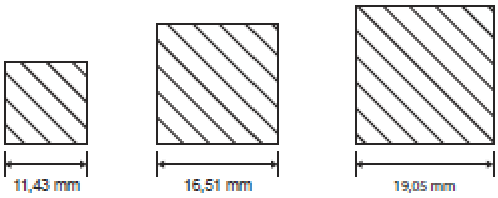


Figure 9. Button Sizes Suggested by Jin et al. [2007]

Hence, choosing a proper button size depends on the available space on the screen and the level of movement control of the user. Buttons do not need to be larger than 19,05 mm square. However, when they are smaller than 11,43 mm square they cannot be accurately reached by the elderly any more. These recommendations were basis to establish the following general guideline:

Buttons, clickable icons and labels should range in size between 11,43 mm square minimum and 19,05 mm square maximum. Adjacent buttons used in rows (e.g., keypad) should be at least 16,51 mm square.

The level of manual dexterity furthermore influences how accurate adjacent buttons, arranged in rows (e.g., software keyboards or keypads), can be handled. A proper amount of space between the buttons ensures that less errors through interaction (i.e., touching the wrong button) occur and less corrective inputs actions have to be made. Jin et al. [2007] therefore propose different spacing depending on the manual dexterity of the user. A button spacing of 3,17 to 6,35 mm is sufficient for people who are not affected by motor impairments. However, a button spacing of 6,35 mm to 12,7 mm leads to sufficient accuracy for users who suffer from such impairments. Spacing smaller than 3,17 mm or larger than 12,7 mm increases either the inaccuracy or the time needed for searching and finger movement. These recommendations of Jin et al. [2007] regarding button spacing lead to guideline:

The spacing between adjacent buttons in a row should reach from 3,17 mm to 12,7 mm maximum.

Reading characteristics of textual content is particularly influenced by the size of its characters (i.e., font size). On computer screens (unlike in print sector) the font size is generally measured in DTP-Point1 (pt), whereby 1 pt matches approximately 0.3527 mm which is 1/72 inch [Black, 1990].

Although several studies recommend to use a font size of 12 to 14 pt to accommodate elderly users, these recommendations are either made for large screens or print sector [Holt, 2000, Kurniawan and Zaphiris, 2005, Fisk et al., 2009]. Darroch et al. [2005] investigated the effect of varying font sizes between 2 and 16 points on reading text on small screens and compared the results of younger subjects to the ones of older subjects. On the one hand, reading very small text (i.e., font size 2-4 pt) unsurprisingly was found to be very discomforting for both older and younger users. On the other hand, when font size is too large (e.g., 14 to 16 pt depending on screen size) a single line contains less characters. This causes higher reading effort as every line break requires additional time searching for the corresponding start of the new line. The older subjects preferred font sizes between 9 and 12 pt which were slightly larger than the ones preferred by the younger group (i.e., 9 to 11 pt). All in all, a larger font size does not result in a better readability.

In fact, choosing an appropriate font size depends on the screen size and resolution of the target device as well as on the visual acuity of the user. A font size of 9 pt can be read well by users with high or normal visual acuity and on small screens, while font size 14 pt suites best on large screens. Due to these dependencies, it can be helpful for the user when the application provides an opportunity to customize the font size. Guideline LAY 1.3 summarizes these findings:

Font sizes for multiple lined text (i.e., primary text) should range between 9 pt and 14 pt and depend on screen size and the visual acuity of the user

Line height (in typography called leading) is the amount of space between the baselines in successive lines of text within a paragraph. Single spacing defines a line height that is 20% larger than the font size of a paragraph [Bringhurst, 2012]. Holt [2000] and Boustani [2010] recommend a line spacing from 1.5-lines up to double spacing, due to the narrowing field of view (cf. next paragraph). Though it slows down the reader due to the increased moving distance for the eye between the lines, the text appears less compact and each line becomes better distinguishable from another. [Holt, 2000].

Line spacing up to double spacing increases readability of text.

Because changing just one of the two factors (i.e., font size and line spacing) influences the appearance of the entire text, they affect the reading characteristics of text in a major way. However, the legibility of text does not depend on the font size and line spacing alone. Other layout issues like the amount of characters per line or text justification (as mentioned previously) have to be taken into account as well.

Text Layout: Another factor which influences the reading characteristics of a text is the amount of characters per line. In print and web-design it is a common recommendation to display 60-75 characters per line [Bringhurst, 2012]. The number of characters fitting into a single line are determined by the size of the target display in combination with the font size.

Keep text lines short in length: The amount of characters per line for primary text should range between 60 and 75.

When the font size of a paragraph is increased and thus the screen size is no longer sufficient to display the entire text at once, content often becomes scrollable. In fact, such a scrollable text mostly causes more problems for the elderly than reading a text with a slightly smaller font size [Nischelwitzer et al., 2007]. Thus, longer paragraphs should be either displayed more compact by decreasing font size slightly or it should be considered to divide it into several pages to avoid text-scrolling. Thus, the following guideline is defined:

Avoid the need of scrolling to read a text. Rather consider to decrease the font size or line spacing.

The problems which occur for elderly users when content in general (i.e., not solely text) is scrollable are discussed in Section 3.3.5 in more detail. Just like scrolling, moving text of any type (e.g., horizontally or vertically) impairs its readability as well. Such movements (e.g., automatic scrolling text) are difficult to process and cause confusion especially for elderly users [Fisk et al., 2009, Kurniawan and Zaphiris, 2005]. Thus, text should always be displayed static.

The justification of text indicates the way the words are placed within a line. Text can be left, right, fully justified or centered. Centered text can be used for headings but should not be used for longer paragraphs. Reading fully justified text (i.e., the words are spread equally over the lines) can be uncomfortable, due to the large variation of space between the words. To ensure that text is displayed in a readable way and in a familiar layout, left justified text should be used. [Holt, 2000, Kurniawan and Zaphiris, 2005].

Multiple line text should be left justified. Paragraphs and topics are often indicated by headlines and thus need to be apparent and distinguishable.

When they are at least 6 pt larger than the primary text, headings can be discerned better [Holt, 2000]. Designers, therefore, should consider the following guideline:

Provide clear and large headings.

Content Structure: Another issue concerning the layout of an application is the question about which content or information should be displayed where and in which way. Possible visual impairments can influence the perception of content on the screen as well as an age-related decline of attention and working memory.

The diminished ability to perceive colors and presbyopia have already been discussed. Another factor which is often impaired with increasing age is the narrowing field of view. This describes the area wherein visual targets can be perceived and discriminated from the environment without moving the eye. With increasing age this field of view impairs and especially distinguishing peripheral visual targets becomes more difficult. Hence, to process their environment older adults need a higher degree of attentiveness and thoroughness. [Farage et al., 2012]

When designing applications for the elderly, scanning a screen for certain content should be facilitated as well as recognizing any displayed information. This can be reached by aligning key information in the central visual field and when it can be discriminated easily [Farage et al., 2012, Kurniawan and Zaphiris, 2005]. In addition, the importance of information can be highlighted (and therefore recognized better) by a specific emphasizing design (e.g., different color or size) or by displaying it isolated from other content to catch the user's attention.

Attention, which can be described as "the capacity to maintain focus on a particular stimulus" [Farage et al., 2012], is affected by changes with age as well. Older adults increasingly have difficulties in moving their attention from one thing to another and are also less able to ignore competing information [Farage et al., 2012]. This especially makes it difficult for elderly to visually search for things. Such searching tasks in applications (e.g., "Where can I find the home-button?") can be enhanced by simply reducing the total amount of simultaneously displayed information. A minimum of non-relevant information keeps the content layout simple and "tidy" on the one hand, on the other hand elderly users can focus on the content they are looking for and are not distracted by rapid motion [Farage et al., 2012, Kurniawan and Zaphiris, 2005]. Tullis [2007] found that the older adults in their study tend to read more text (on web sites) even when it was not relevant for completing a task. Especially avoiding irrelevant text on screens can help the user to focus on their intended task or goal or to find certain information. That is, when designing an application, the narrowing peripheral vision and changed attention in older age can be compensated by considering the following guideline:

Simplicity of visual perception is key: Avoid visual clutter, distracting visual stimuli and non-relevant information due to the declining visual field.

Furthermore, the decline of working memory capacity with increasing age is of great concern regarding the layout of information as well. Working memory (also called short-term memory) includes information that has recently been obtained and which is currently used in mind. Our working memory is neither able to memorize a large amount of information nor to memorize it for a long time [Fisk et al., 2009]. Both factors decrease with age [Farage et al., 2012]. While the working memory capacity of young adults covers about 7 chunks of information [Farage et al., 2012], only 5 chunks or less can be processed by the elderly [Nischelwitzer et al., 2007]. This limitation can be compensated by organizing information within groups of around 5 information blocks which in turn can be arranged with additional (but in total about 5 per superior information group) distinct information groups. When the attentional focus stays within one of the information groups, only the chunks within this group have to be processed. In brief, this means:

Minimize working memory demands: Keep the number of information blocks presented or processed at once limited to around 5.

Through these guidelines the positioning of elements within the same view can be optimized. Since applications do commonly consist of several views, it is important that the user recognizes similar elements and functions throughout the entire application. Keeping this in mind the application should be consistent in design and functionality.

Consistency: In user interface design the term consistency and its importance was coined by Ben Shneiderman [Shneiderman and Plaisant, 2005] and Jakob Nielsen [Nielsen, 1995] who established general rules and heuristics for enhancing usability of user interfaces. A consistent design refers to each interface element and interaction method within the application. This includes the positioning and design (e.g., regarding typography or colors) of elements (e.g., of warnings or buttons), the terms that are used, the actions that are caused by similar interactions as well as the interaction sequences for reaching a similar goal. Each element (e.g., a button or an icon) and interaction (e.g., clicking a button to open a menu) should stay the same throughout the application, so the user is able recognize similar elements and functions better. Furthermore, involving actions or conventions, that are learned and established within other systems (e.g., using “OK” and “Cancel” buttons in dialogs) or the real world (e.g., using traffic signs), can help to elaborate a consistent application [Shneiderman and Plaisant, 2005]. A consistent design assists the user in relying on previously learned procedures and conventions. Thus, the result of interactions is more predictable which facilitates using an application.

Within applications for elderly users, consistency plays an even greater role. Every application requires a certain amount of training to memorize how it is organized and actions are performed. This knowledge about how to perform previously learned activities and procedures is called Procedural Memory [Fisk et al., 2009]. Though older adults have more difficulties in learning new procedures, the knowledge of already internalized activities (e.g., the knowledge how to multiply two numbers) stays intact and is easier to access than to inhibit [Fisk et al., 2009]. Through a consistent design less new processes or actions have to be learned whereby procedural memory is supported. This is reached by not suppressing already internalized knowledge about performing certain actions. This knowledge can be used to accomplish similar procedures within other systems. For example, if a user of a regular PC has learned to close a window or dialog with a button in the upper right corner, dialogs in tablet applications should not be closed with a button in the upper left corner.

In addition, older people tend to rely more on external cues to gain information from memory, and, therefore, suffer more mental effort than younger when expectations (i.e., learned processes) are not met by consistent design [Fisk et al., 2009]. The mental process that is linked to this cue could not meet the user's expectation (which he/she learned previously) and therefore cause confusion. The next guideline summarizes these findings:

Consistent design is even more important for the elderly than it is for younger people. Therefore, the location of elements and functions should remain the same across views and similar functions should act the same way throughout the application.

The less mental effort it costs a user to understand the application, the higher the acceptance to use it. Due to the strong correlation between consistent design and mental effort for the elderly, consistency is highly significant for the design process. However, understanding an application also depends on the internal organization of the content and the quality of the menu structure to reach it. Guidelines for developing such menu structures are proposed in the following paragraph.

Navigation and Menu Structure: An application always grants the user access to a specific set of information. To control and oversee this information, an underlying internal structure is required to present the information in a simple way. This internal structure is displayed to the user through a menu, an interface element with which functions and views are accessible. The design and structure of a menu affects the users understanding of his interactions and the possibilities of the application. Thus, it influences the way he/she navigates through the application and interacts with it. Especially elderly users can be supported by providing an appropriate menu structure with well-considered menu items. Tullis [2007] found that elderly users spend more time comparing and contrasting menu items to which would suite their intended action best. When such menu items are grouped into categories with labels which are unambiguously and whose differences are apparent, navigating and interacting with the application can be simplified. For a better distinction of certain menu groups (e.g., main menu and secondary menu) Caprani et al. [2012] suggest to differentiate these by their shape and style additionally. This results in:

Group information and actions into meaningful and clearly worded categories. The difference between the items should be apparent.

Beside the grouping and labeling of menu items, it is also important to be able to identify the existing navigation menus as such. Navigation cues (e.g., breadcrumbs[1], “next”- and “previous”-buttons, menu bars) help the user to find a route through the application and/or show the current location within the application. By displaying such cues clearly visible especially elderly are supported in managing and navigating through the application [Kurniawan and Zaphiris, 2005].

An additional important issue regarding navigation cues is to keep them consistent in design as well as in behavior (cf. previous paragraph) [Farage et al., 2012]. When the current view of an application changes, previously used navigation cues should stay at the same position and have the same function as the user has learned before. The following two guidelines summarize these findings:

Provide a clear and consistent navigation by displaying precise navigation cues and actions that are readily visible and accessible.

The current location in the application should be obvious to the user all the time.

Menu structures can be organized in broad or deep hierarchies. In broad hierarchies more nodes are allocated per level than in deep hierarchies. Hence, one level of a broad menu structure can contain a large amount of nodes, where a node of such hierarchies corresponds to a menu option. If the same overall amount of menu options is distributed on more levels with less options per level, it is called a deep hierarchy. Information in a deep hierarchy on the one hand can be organized more clearly due to the increasing number of subcategories. Because the labeling of each subcategory delivers more information about its content, the description of the content itself becomes more precise. On the other hand, with more subcategories more decisions need to be made to reach the desired information. Therefore, it can be more difficult for the user to find a route through such deep hierarchies. Especially older adults more frequently need to head back to the previous level or have problems of losing orientation in such deep hierarchy structures [Fisk et al., 2009]. This causes a high demand on working memory which is also known to decline within age. In other words:

Avoid deep hierarchies in menu structures hence the user does not get lost in the application.

The amount of interim steps which have to be made to reach a certain goal also affects the success of the user. To achieve such a goal, actions and commands are selected sequentially by the user (i.e., step by step). If anywhere in this sequence an error occurs (e.g., touching the wrong button), the user may

[1] “Breadcrumbs show each level of hierarchy leading to the current page, from the top of the application all the way down. In a sense, they show a single linear »slice« of the overall map of the site or app” [Tidwell, 2010]

lose orientation and has to start over again. The probability of success increases when the number of steps in the procedure decreases. Because in most cases the number of steps cannot be reduced to only a single one (not only due to the lack of space), a trade-off between the number of steps in the procedure and the number of control elements (i.e., buttons) has to be made. Especially for older adults this is important because “when it comes to tasks with significant memory demands, older adults are more likely than younger ones to commit errors in reproducing a long sequence. Hence, minimizing the number of steps in a procedure can be particularly helpful to older users.” [Fisk et al., 2009].

Furthermore, through minimizing the number of steps to accomplish a task, the load of procedural memory as well as working memory is decreased. When less steps (no matter if they are already accomplished or still remaining) have to be kept in mind, less errors occur while performing the entire sequence of steps. This leads to following guidelines:

Minimize the number of steps to complete a task as well as the number of control-elements to increase the probability of successfully completing the task.

“Don’t force the user to keep information in mind for too long to accomplish a single task.” [Fisk et al., 2009]

In summary, layout issues in application design cover a wide field. Choosing a proper size of content elements is as important as structuring the information logically, simply and consistently.

3.3.3 Language and Wording

Using a proper language in applications influences the way elderly users interact with them. Studies in the field of web design showed that older people tend to be more cautious in clicking on links or buttons, since it is not always clear to them what action will be caused [Chadwick-Dias et al., 2002, Tullis, 2007, Nielsen, 2013]. By labeling interactive elements using the active voice (e.g., “Save Password” instead of “OK”), the consequences which follow on an action can be made more clearly and foreseeable to the user. Furthermore, the elderly tend to feel uncomfortable in trying new things [Nielsen, 2013]. A positive phrasing (e.g., “You have successfully saved your password.”) confirms the user in using the application more confidently. Such positive phrasing is also important regarding error messages. Since the elderly were found to be “twice as likely to give up on a task” than younger adults [Nielsen, 2013], it is important to reinforce the intention of the user when an error occurs. Formulating such error messages positively can motivate the user to try again. The guideline therefore is:

Language should be simple and clear. In addition, it should use active voicing and positive phrasing.

Older adults tend to have more problems comprehending language when connections between concepts have to be made, which are not explicitly shown [Fisk et al., 2009]. Textual cues (e.g., labels) support the user to understand and recognize the current state of the application and define every possible change of state precisely. This state information is indicated more clearly, when such textual cues are expressed with familiar terms. Hence, the use of an application can be facilitated when ambiguous terms are avoided and less inferences have to be made by the user.

In particular, terminology which is very familiar and obvious among application developers like “Touch”, is not always well known to elderly users, particularly for non-native English speakers [Nischelwitzer et al., 2007]. However, technical terms cannot be avoided in every application (e.g., healthcare applications). This can be compensated by providing a glossary [Holt, 2000]. Furthermore, Campbell [2015] reminds developers to consider if phrasing assumes that the user is at a certain stage of life or certain age. These findings are summarized in the guideline:

Phrasing assuming prior knowledge (e.g., technical terms) or a certain (especially young) age of the user should be avoided. Provide a glossary if technical terms are necessary

In summary, when developing applications for the elderly, language is the key to make an application more accessible. It offers the opportunity for older users to understand applications and to use them more confident.

3.3.4 Icons, Graphics and Multimedia

Icons or graphics convey information about functionality without using words. When the meaning of an icon or symbol is familiar to the user (e.g., a house leads to the “Home”-view) the intended context can be recognized quickly, possibly more quickly than through reading a text message or label [Fisk et al., 2009]. To make sure if the intended meaning is also understood properly, Farage et al. [2012] propose to test these icons with elderly people. This possibility of supplying information without the need of text leads to the following guideline:

Well-designed or familiar symbols and icons can be more effective ways to convey information than text messages.

This guideline, however, also includes that not each control element needs to be accompanied with an icon or graphic. This is only useful in cases when a pictorial representation leads to better and faster understanding than a textual message would do. Vice versa, adding a label or text message to icons will help to avoid misunderstanding the underlying action or compensates diminished visual capacity. [Holt, 2000]

Where possible provide a label or text for icons or illustrated instructions.

3.3.5 Interaction

There is a huge variety in providing interactive methods for the user to attain or entering certain information. Though many different types of interaction methods are established and well known, the question rises if these are also suitable for older users. This section covers whether and in which way interacting with touch applications changes within age and how these changes should be considered in interaction design.

Gestures: Since Apple's iPhone was introduced in 2009, several interactive gestures for multi-touch devices became commonly known by users and associated with certain actions (Figure 10). However, nowadays similar gestures for certain actions are used by devices with other operating systems like Android or Windows as well. Although the same gesture patterns are used by iOS as well as Android and Windows as well, the functionality between the systems differs. To give a brief overview, Table 2 compares the presented gestures with their associated system related functions. Some of these gestures are combined with the same functionality independently from the operating system. For example, the Double Touch or Pinch zoom gesture is used to zoom into content by each of these operating systems. However, others are used for different system related actions like the Long Touch gesture.

In addition, Figure 10 shows that these core gestures only consist of a few different interaction patterns (simple touches and strokes) although a large variety of gestures are possible. The question arises whether these common gestures are suitable for older users or whether other more meaningful gestures should be provided.

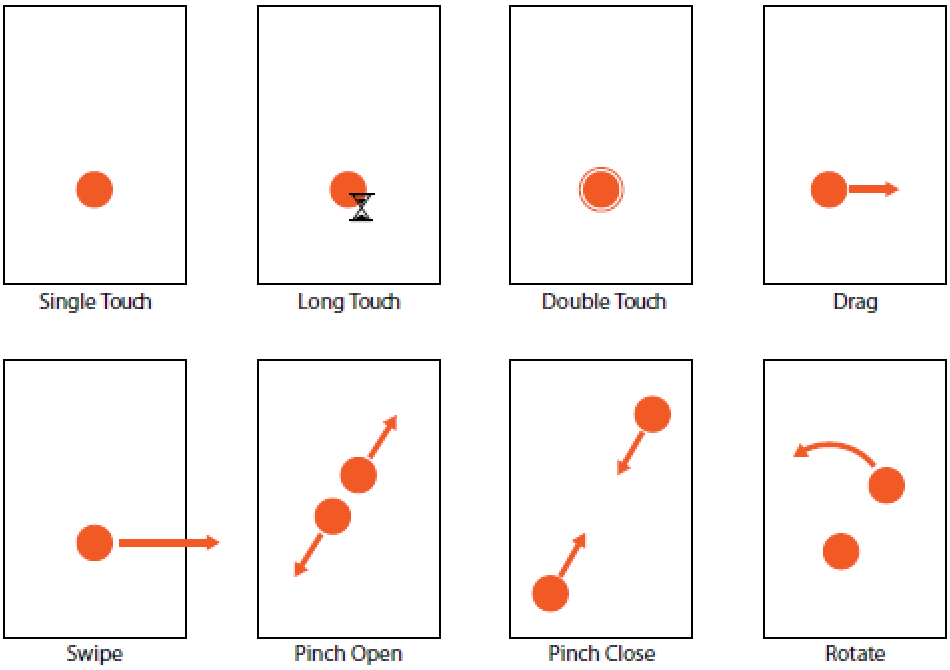


Figure 10. Common gestures on touch devices

Table 2. Comparison of standard gestures used by common operating systems

Comparison of Android [Android 2015a], iOS [Apple Inc., 2014], and Windows [Microsoft Corporation, 2015].

Gesture	**iOS**	**Android**	**Windows**
Single Touch	Selecting an item or triggering a functionality		
Long Touch	Displaying a magnified view for cursor pointing	Selecting multiple items and interacting with them via a displayed contextual action bar	Opening a context menu
Double Touch	Zooming into content		
Drag	Scrolling content or dragging an element	Moving between views and for precise scrolling content within one screen	
Swipe	Scrolling content quickly or moving between screens		
Pinch Open	Zooming into content		
Pinch Close	Zooming out of content		

The interaction patterns listed in Figure 10 and Table *2* do not cover all possible and especially practical gesture interactions at all. A gesture may consist of a single touch up to several strokes including one or more fingers or even hands. The complexity to perform and recognize a certain gesture mainly decides whether it is suitable for a certain use case. For example, drawing the letter “O” on the screen to open a certain file is easy to handle. However, it can be recognized by the application either as the letter “O”, a zero or encircling an object and therefore may leads to misinterpretation. It is possible that gestures which are well known and easy to perform by younger people, may be judged by older users as hard to execute or not suitable for a specific task.

To analyze whether a gesture is practical and suitable for older users, a classification of all gestures is required considering the infinite number of possible gestures. Therefore, Stößel [2012] collected 568 different gestures and analyzed how many fingers, number of segments (a continuous movement of the finger without lifting it off) and number of strokes (movement of the finger from one resting point on the surface to another) were needed for its execution. As a result, Stößel [2012] provides following gesture classification:

- **Indexical gestures:** The gesture consists of a mere positioning of the finger on a certain screen object or region. A simple tap is the predominant indexical gesture.
- **Manipulative gestures:** Screen objects or regions are manipulated with the help of movement patterns such as repeated tapping, long presses, dragging movements, swift swipe or flick movements, spreading or pinching movements, encircling or boxing screen objects etc.
- **Alphanumeric gestures:** These gestures consisted of one or more letters or numbers which were drawn with the finger on the screen. In few cases, even whole words were drawn.
- **Iconic gestures:** Drawings that result in the depiction of real world objects. Common iconic gestures were arrows, but also crosses, houses, magnifying glass, ear, loudspeaker, houses, scissors and other objects were schematically drawn on the screen.
- **Symbolic gestures:** A sign that was neither an iconic object depiction, nor an alphanumeric character, which counted as an extra subset category. Examples comprise e.g. a minus sign, plus sign, bracket, question mark etc.
- **Combined:** When a gesture consisted of separate parts which stem from different categories, they were counted as combined. In most cases, these gestures contained a manipulative and an iconic or symbolic segment.

There are two factors which mainly decide whether a gesture is suitable for older people or not. On the one hand, this is the complexity of a gesture structure, on the other hand, the process of memorizing and finding the gestures and the action it causes. The latter is important to consider when cognitive changes occur with age. Forgetting the functionality behind a gesture is more frequently the cause of an error than insufficient manual dexterity to perform the gesture [Stößel, 2012]. Also the lack of visual clues for typical functions (e.g., zooming through a Pinch gesture – cf. Figure 10) affects that gestures are unknown to the user [Kobayashi et al., 2011]. By providing such clues, adequate instructions and training opportunities, older adults may remember and perform gestures better. Thus:

Instructions, training opportunities and clear visual clues facilitate memorizing and familiarizing gestural actions.

In addition, due to age-related impairments in movement control (cf. Section 3.2) it is recommended to keep movement tasks in general simple and discrete rather than complex [Farage et al., 2012]. Therefore, because of their simplicity, Indexical and Manipulative gestures are frequently recommended and overall rated to be more suitable than symbolic or iconic gestures [Stößel, 2012, Loureiro and Rodrigues, 2014, Motti et al., 2013]. Besides, the more of such simple gestures are used, the less different gesture patterns have to be memorized and the less time is needed for remembering and executing gestures as well as completing tasks. For this reason, the following guideline implies:

"Prefer indexical and manipulative gestures over symbolic and iconic gestures" (following the gesture categorization by Stößel [2012]).

Even though Iconic and Symbolic gestures are more complex to perform, Stößel and Blessing [2010] found that elderly users more likely accept such gestures than younger adults. In addition, more difficult gestures are indeed performed slower but not less accurate by the elderly compared to younger adults [Stößel, 2012]. Hence, it is not generally necessary to avoid complex gesture interactions, but more complex ones can be handled by older adults effectively as well [Stößel et al., 2010, Motti et al., 2013]. The higher acceptance of these more complex gestures by older people can be explained with the similarity of these gestures to real world signs and objects. This familiarity is significantly more important to older users compared to younger ones [Stößel, 2012]. For example, drawing a check mark to confirm an action is indeed less efficient than pressing an "OK" button, but might be rated more suitable for certain use cases by elderly users. Stößel [2012] therefore provides following guideline:

"Favor familiarity of a gesture pattern over its execution efficiency" [Stößel, 2012]

Alphanumeric gestures, however, are in general not recommended by Stößel [2012]. For older people it is difficult to "make the association between the [...] letter and the connected command". Sufficient repetition and training is needed to internalize such gestures and thus are more practical as shortcuts for experienced users than for novices. This means:

"Avoid alphanumerical gestures." [Stößel, 2012]

Although indexical and manipulative gestures are the easiest ones to perform, understand and remember, this does not mean that more complex gestures should be avoided in general. In fact, manipulative gestures exist which seem easy to perform on the first sight (based on the required number of fingers, segments and strokes) but actually are not suitable for older users. Studies have shown that especially scrolling (through dragging the content), drag and drop and double touch operations cause difficulties for older users [Nischelwitzer et al., 2007, Kurniawan and Zaphiris, 2005, Caprani et al., 2012, Wacharamanotham et al., 2011, Findlater et al., 2013, Al-Razgan et al., 2012].

The problem regarding scrollable or automatic scrolling text was mentioned already in Section 3.2. One issue is the loss of the current line and thus the orientation within the text [Nischelwitzer et al., 2007]. As scrolling operation on touch screens mainly consist of dragging the content up- or downwards, it is necessary that during this action the finger does not loose contact to the surface. On resistive touch screens constant pressure is needed additionally. Especially for people with age-related impaired manual dexterity or imprecision (e.g., caused by a tremor) this is problematic [Leonardi et al., 2010, Wacharamanotham et al., 2011]. Such scrolling operations are avoided by dividing content into several views which can be accessed through swiping or pagination controls (e.g., "Next" or "Previous"-buttons) [Caprani et al., 2012, Dahn et al., 2014].

Another important issue regarding scrolling operations is reported by Stößel [2012]. For example, performing a dragging gesture downwards to scroll, could be either interpreted as dragging the content downwards (i.e., scrolling upwards) or as dragging the window frame downwards (i.e., scrolling downwards). This affects confusion depending on prior experiences or metaphors the user associates with the corresponding gesture. Thus, the following guideline cautions against using scrolling. Alternative methods should be used instead.

Turning over pages (like through "Next"- and "Previous"-buttons or swiping) should be preferred to scrolling up or down.

Similar to scrolling operations, drag and drop operations are difficult to handle for older people as well. With advancing age performing drag operations by constantly touching the surface becomes more difficult. Drag operations are therefore very demanding for older people and have to be repeated several times until they are internalized [Leonardi et al., 2010]. Thus, authors caution against using drag and drop operations [Findlater et al., 2013, Al-Razgan et al., 2012, Murata and Iwase, 2005]. For the same reason, it is also possible that the Long Touch gesture (cf. Figure 10) becomes difficult to perform as well, though this has to be further investigated. In fact, a Long Touch gesture is hard to separate from a Double Touch if the user is trembling. This can also be of concern, when buttons are at the same position on two successive views. The button on the successive view may be activated unintentionally, when these views change too fast. In order to prevent such erroneous inputs, Double Touch gestures should be avoided [Caprani et al., 2012]. These findings are briefly summarized in the following guideline:

Avoid drag and drop operations and double touch gestures

If double touch gestures are inevitable, the movement speed of the elderly needs to be considered as well. In general, elderly users tend to be 1.3 to 2 times slower compared to younger adults when performing similar movements, [Fisk et al., 2009, Stößel, 2012]. Thus Stößel [2012] proposes the following guideline for time-based gestural interactions:

"Accommodate for slower gesture execution for time-critical events (e.g. multitap latencies). Movement is slowed by 1.3 compared with younger users." [Stößel, 2012]

Other gesture types which have been investigated by Stößel [2012] are curved gestures, for example a rotation gesture. Such gestures are reported to be "particularly difficult" by the older users. Thus:

"Employ curved gestures sparsely." [Stößel, 2012]

Besides Stößels categorization listed above, touch interactions can be differentiated by the number of contact areas which are needed to carry out the gesture. While single touch interactions require just one finger (e.g., Touch or Swipe), multi-touch interactions are performed by using at least two fingers of one or both hands (e.g., Pinch Open).

The question arises whether there is a difference between younger and older adults in performing and subjectively rating single- and multi-touch gestures. In fact, Stößel [2012] investigated, single-touch gestures are indeed preferred by older adults over multi-touch gestures and additionally are performed less accurate. On the one hand, the size of the hidden surface through the hand is larger when two or more fingers are used. Hence, more concentration effort is needed to visualize the missing parts additionally to the visible surface. On the other hand, performing multi-touch gestures requires more manual dexterity than single-touch gestures, so older adults are rather affected by fatigue. [Lepicard and Vigouroux, 2012]

Multi-touch gestures are not recommended for older users.

Comparing the findings of this section with the gestures illustrated in Figure 10, one can say that some of these commonly used gestures are not suitable for older users. Especially the zoom operations (i.e., Double Touch and Pinch Open/Close) may be difficult to handle, since these gestures are not executable accurately with motor impairments like a tremor. In addition, gestures containing stroke movements (e.g., Drag, Swipe or Rotate) should be avoided for the same reason. Since simplicity in executing gestures is as important for older people as memorizing them, not just the Single Touch gesture, but also iconic or symbolic gestures are suitable as well. Concerning the latter, sufficient training opportunities and cues must not be neglected.

Data entry: Entering data is an essential form of interaction especially for applications which acquire, process or communicate data such as medical, financial or simple messaging applications. Currently, software keyboards and keypads are provided to enter textual or numerical data on tablet devices. Particularly for older users it becomes difficult to complete major data entry tasks with such software keyboards within an adequate time and a minimum of mental and physical effort. Rising motor impairments like diminishing pointing accuracy lead to a slow input speed while cognitive impairments like less capacity of the working memory require more concentration to complete such tasks [Farage et al., 2012, Fisk et al., 2009]. As a consequence, if data entry is essential to an application, entry sequences (e.g., forms) and data entry task in general should be reduced an essential minimum. Apart from that, entering data can be accelerated as well as simplified by providing other options like selecting predefined values or providing buttons or sliders to increment or decrement values [Caprani et al., 2012].

Keep data entry tasks to a minimum.

Choosing a most suitable input option for textual data depends on the text length on the one hand and on the user experience in using a certain keyboard layout on the other hand. Users who are experienced in using a standard QWERTY-layout on physical keyboards are able to cope with the use of a software keyboard with the same keyboard layout much faster and therefore have less problems entering longer texts. Moreover, the more experience a user has using the QWERTY-layout, the more words per minute can be entered. Novices in turn may search longer for letters on a QWERTY-layout than on an alphabetically ordered keyboard layout. Such an alphabetically ordered keyboard as well as a minimum of text entry tasks should be preferred for users with less typing experience. [Fisk et al., 2009, Nicolau and Jorge, 2012]

Although several other keyboard layouts exist (e.g., Dvorak or Neo), the QWERTY-layout is the most established. Thus, the following guideline recommends to provide a QWERTY layout for experienced users instead of other layouts. Additionally, the assignment of the keys on a QWERTY-keyboard (which is optimized for the English language) slightly differs in other countries. Characters which are less often in other languages are swapped or replaced with more frequent ones. In Germany, for instance, the QWERTZ-layout is used, in France and Belgium AZERTY-layout. Consequently, an application should provide the country-related layout of the English QWERTY-keyboard.

Regarding long textual data entry tasks on software keyboards, a country-related QWERTY-layout for experienced users should be preferred. For novices an alphabetic layout and short input sequences may be used.

Due to space constraints on small screens, the key shape and key layout of a software QWERTY-keyboard differs from a physical keyboard. Keys like backspace and shift which sometimes are placed at different positions and often are not textually labeled have to be searched extensively [Kobayashi et al., 2011]. Nicolau and Jorge [2012] investigated the input speed and accuracy of older people using QWERTY-layout software keyboards on touch devices. To facilitate text entry tasks for older users they propose to display keys wider than taller to prevent input errors by touching a neighboring letter. Moreover, providing a language based error correction simplifies entering text for older users. The most common errors occurred by simply forgetting to enter single letters. The mental effort to correct such errors is reduced when correctly spelled words are suggested.

The keys of a software keyboard to enter textual data should be wider than taller and provide a language based error correction.

The lack of haptic buttons on virtual keyboards makes it difficult for experienced users to use the ten-finger typing system. Moreover, the input field is possibly hidden by the keyboard as well as the inputting arm fatigues more quickly [Caprani et al., 2012]. Since numeric input tasks are short in length and displaying the software keypad requires less space, special hardware keypads for such tasks are not necessary. Therefore:

A hardware keyboard facilitates the entry of long text sequences.

Software keyboards are preferable for small data input activities, especially for numeric data.

For people with significant visual impairments a voice recognition can be taken into consideration. Although it provides a high input speed, an error correction within such systems is difficult and ambient noises may interfere with the user's voice [Fisk et al., 2009]. In general, different typing experiences, typing behavior and personal preferences influence which input option suites best. Thus, the opportunity to choose among a virtual or hardware keyboard as well as an alphabetical or QWERTY-layout should be provided. [Nicolau and Jorge, 2012]

Feedback: When humans interact with computer systems, it is important that the system informs the user about the current system state. Whenever an action is performed by the user, its success or failure has to be communicated by the system. On touch device applications such feedback is possible through visual, tactile or auditory signals as well as through a combination of them. To ensure that especially older users can sense and interpret this signals properly, several age-related sensory changes have to be considered. With increasing age, several impairments in visual perception can occur. The color perception can be affected as well as peripheral vision and visual acuity. Guidelines to accommodate visual content for such impairments (e.g., using proper colors) have already been suggested in previous sections. Since visual feedback (while pressing buttons, performing gestures, receiving messages etc.) is omnipresent in touch applications, these guidelines have to be taken into consideration when visual feedback is developed.

A common problem regarding touch interaction is the so called “fat finger problem”. Because of the large contact area of the fingertip and the occlusion of the target by the finger, the intended target is possibly not be reached accurately and therefore missed [Holz and Baudisch, 2010]. Moreover, several models exist to detect a discrete coordinate which is nearest to the intended target [Holz and Baudisch, 2010, 2011]. Regarding older users who are affected by a tremor, reaching an intended target on the surface becomes even more difficult. Visual feedback, which indicates the perceived touch coordinate, helps older people to reach their intended target [Kobayashi et al., 2011]. Thus:

Support the user by indicating the touch location with visual feedback.

At present, tactile feedback on touch devices is only possible through vibration signals. Due to the fact that the surface of these devices is plain, other haptic elements (like tangible buttons) and therefore tactile feedback opportunities are not possible yet. As mentioned earlier, with age the vibration receptors within the skin and muscles to detect high frequency vibration (60 Hz and above) become less sensitive while sensing the low frequency vibrations (such as 25 Hz) is less impaired [Fisk et al., 2009]. For vibrotactile feedback within touch applications this means:

Use low frequency vibration (25 - 60 Hz) for vibrotactile feedback.

Similar to haptics, hearing losses within age mainly affect high frequency (2000 Hz and above) contrary to low frequency sounds. In previous sections guidelines have been provided to accommodate these auditory changes concerning verbal information. As an example, male voices are better noticed than female because of the low frequency voice. The same applies to non-verbal auditory information. Low frequency sound signals should be used to convey feedback information; i.e., between 500 and 2000 Hz. However, high frequency sound signals (2000 Hz and above) can be perceived and localized better when the duration of these sounds is increased.

Another frequently occurring hearing problem is presbycusis, the diminishing ability to perceive low intensity sounds (i.e., quiet sounds). While younger people are able to perceive sounds below 3 dB (a whisper is around 8 dB loud), the individual threshold increases with age, which is why about 60% of people aged 55 or above already have some sort of hearing impairment. An individual threshold exceeding 35 dB results in severe hearing impairments. It is therefore recommended to provide sound signals with a volume of at least 60 dB (a normal conversation is about 50 to 60 dB). [Farage et al., 2012, Fisk et al., 2009] The following guideline briefly summarizes these findings:

Auditory feedback should provide a volume of at least 60 dB and a sound-frequency of 500 - 2000 Hz. If high frequencies have to be used the duration (at least 500 ms) should be increased.

However, providing feedback on touch devices is not restricted to one type at a time (i.e., unimodal feedback). Different cues (auditory, tactile or visual) can be combined, which is called multi-modal feedback. In fact, providing tactile feedback solely may cause rather distraction than support [Motti et al., 2013]. In general, perceiving redundant feedback signals through different sensory channels enhances the performance of older users. Through providing multi-modal feedback possible impairments of one sensory channel may be compensated when simultaneously another one is stimulated. [Lee et al., 2009, Jacko et al., 2003, Fisk et al., 2009, Farage et al., 2012]

Multi-modal (combining audio, visual and/or tactile signals) feedback should be favored over uni-modal feedback. Especially tactile and visual feedback should not be used solely

Feedback is used to inform the user that a previous command has to be repeated or more succeeding ones can be performed. The elderly tend to process information more slowly and take between 1,5 and 2 times longer to respond than young people. Application developers therefore should generally assume that older users perform any succeeding actions within a longer time interval. This means pop-up menus or messages, for example, should either be displayed with ample duration or must be closed explicitly by the user. [Fisk et al., 2009, Kurniawan and Zaphiris, 2005]

Provide ample time to process information and to make a physical response.

Developers of any computer system must assume that both the user and the system are prone to errors. Irrespective of whether these errors are caused by the system or the user, clearly informing the user about the cause and consequences of the error is essential for successfully recovering from it. For older users the wording of error messages is especially important, as they are more likely to give up on a task they find difficult to perform as compared to younger users. This means, a simple language as well as avoiding technical terms is also a fundamental issue regarding error messages. Moreover, to prevent older users from simply overlooking error messages, they should not vary in their placement or appear inconspicuous. [Fisk et al., 2009, Nielsen, 2013] Briefly summarized this means:

Provide error messages that are informative about the error occurred, the consequences and how to recover from it. Error messages should always appear at the same location.

3.3.6 User Support and Training

Learning and understanding how to use new applications is essential for their successful handling. Even if the functionality of applications is provided as intuitively as possible, problems like open questions or misunderstandings may arise. Therefore, several methods are available to assist people when confronted with new applications and their functionality. Next to providing a manual, tutorials or an online help, users also can be supported in person. Especially older users rely more on the availability and comprehensibility of supportive material than the younger. Older people may suffer from cognitive changes, have doubts about their ability to learn or tend to avoid getting into new learning situations. Therefore, more help and interactive training is needed within this age group [Fisk et al., 2009]. This section covers how older users should be assisted in becoming acquainted with applications.

In general, an application should provide supportive material which is accessible at any point in time. This prevents users from getting lost within the application or reaching a point where heading back or further actions are unclear. As an example, a “Help”-button should be provided which is displayed at the same position on every application view

User support must be accessible at any time and any location within the application. The user should not get into a situation where he is left on his own.

The way how user-supportive and learning material is provided and organized depends on its complexity. However, when multiple sources of such material (e.g., a printed in combination with a online manual) are provided, high mental effort is needed to combine the information from one source with another. Thus, to solve a problem or answer a question, the user should refer to as few sources as possible [Fisk et al., 2009].

“Provide only one source of learning material (e.g., manual, tutorial) if possible.” [Fisk et al., 2009]

The functionality of an application can be introduced by providing an initial training (e.g., step-by-step walkthrough). Depending on the level of the user’s prior knowledge, such a training needs to be more or less precise regarding its information content. As an example, an e-mail client may explain the term “e-mail” to a novice before introducing more specific functionality like sending and receiving e-mails. Thus Dahn et al. [2014] suggest:

“Consider to provide the user a choice between a more comprehensive or more restricted initial training with regards to its information content.”

Furthermore, when application features are initially presented, the slower pace of older people to process information should be considered. This implies that sufficient time and opportunities should be provided to practice or repeat a single training step. Additionally, next training steps should be triggered by the user instead of time based events [Campbell, 2015, Fisk et al., 2009].

“Introducing application features gradually over time can be useful to prevent cognitive overload.” [Campbell, 2015]

In summary, being able to practice any functionality of touch applications is crucial for the elderly. Studies show that in combination with sufficient training opportunities even more complex gestures like multi-touch gestures can be used successfully although they are not recommended for elderly users [Kobayashi et al., 2011].

3.3.7 Personalizing Application Interfaces

With increasing age declines in perceptual, cognitive and psychomotor abilities occur. This means neither that older adults show all of these declines in general nor that they occur at a certain age. While some abilities may be impaired at a certain age, other may remain intact depending on the person concerned. This is the reason why the individual capabilities vary much more among older than younger age groups. [Fisk et al., 2009] Due to these variances of individual capabilities, it is important to compensate age-related impairments when designing applications for the elderly, as much as possible. At the same time, unnecessary adaptations which may disrupt the usability of applications should be avoided. For example, to older people without hearing impairments a loud acoustic feedback may be annoying. An application which offers a number of adjustable factors, allows to be customized to individual needs and preferences.

Adjusting certain factors of a user interface (e.g., the font size) to personal needs is important for the elderly.

The specific factors which should be adjustable by the user vary with the provided functionality of the application. For example, when an application requires reading long texts, different font sizes should be offered. Additionally, the size of graphics or buttons should be modifiable when these are essential for user interactions. The following guideline summarizes several other factors, which are recommended by different authors to be adjustable [Loureiro and Rodrigues, 2014, Dahn et al., 2014, Darroch et al., 2005]:

Consider to make some of the following factors adjustable:

- *the size of font, graphics or targets*
- *the combination of audio, tactile and visual feedback*
- *the way data is entered (software or physical keyboard)*
- *the range of application functionalities*
- *style information like background images or colors*

If too many of these factors can be modified by the user, customizing the application possibly becomes too complicated on the one hand. On the other hand, the less possibilities an application provides for personalization, the more restrictions regarding individual preferences have to be accepted by the user. Thus, a balance between simplicity and personal needs has to be made.

3.3.8 Summary

Thoughout Section 3, 58 literature based guidelines were elaborated, discussed and grouped into seven different guideline categories. Due to the fact that these guidelines cover a large amount of possible use cases, developing senior-friendly applications rarely requires the realization of every single guideline.

In fact, the use case and scope of function of an application influences which guidelines are reasonable to be brought into practice.

This may also mean, that in some cases it makes sense to concentrate on applying just a few of these guidelines. Moreover, depending on the use case and available development resources (i.e., time, money and personnel) the cost-benefit factor of a guideline differs. The implementation effort of some guidelines is not worth the benefit it brings for a better usability of an application interface. As an example, an application to access data within a complex information structure (e.g., a search engine) requires more concentration on a good menu structure than on the design of appropriate and meaningful icons. In this framework, the guidelines listed will be further evaluated with respect to the actual application at hand and they will be used by the evaluators as an exhaustive list that in many cases will refer to guidelines not applicable in the specific application case (not applicable guidelines will be marked respectively).

3.4 UI Guidelines for multi-touch devices CheckList

	GUIDELINE
1	DESIGN: Color
1.1	Use colors of the long wavelength end of the spectrum (i.e., warm colors like red or yellow) if the color carries information – avoid blue especially
1.2	Colors should be used conservatively. Use colors to carry important and relevant information (e.g., warnings, grouping elements).
1.3	Keep in mind that dark background colors increase glare and highlight fingerprints.
1.4	Avoid colored and patterned backgrounds for text display areas.
	DESIGN: Contrast
1.5	To ensure legibility the color contrast ratio of text smaller than 18 pt should be at least 7:1 or 4,5:1 for large text or decorative text
	DESIGN: Typeface
1.6	Use sans serif font types (e.g., Verdana or Arial).
1.7	Avoid decorative, italic, underlined and condensed font styles. Use bold font types and uppercase text only for highlighting key terms.
2	LAYOUT: Size and Spacing
2.1	Buttons, clickable icons and labels should range in size between 11,43 mm square minimum and 19,05 mm square maximum. Adjacent buttons used in rows (e.g., keypad) should be at least 16,51 mm square
2.2	The spacing between adjacent buttons in a row should reach from 3,17 mm to 12,7 mm maximum
2.3	Font sizes for multiple line text (i.e., primary text) should range between 9 pt and 14 pt and depend on screen size and the visual acuity of the user
2.4	A 1.5 line spacing up to double spacing increases readability of text.
	LAYOUT: Text Layout
2.5	Keep text lines short in length: The amount of characters per line for primary text should range between 60 and 75.

2.6	Avoid the need of scrolling to read a text. Rather consider to decrease the font size or line spacing.
2.7	Avoid moving text like automatic scrolling.
2.8	Multiple line text should be left justified.
2.9	Provide clear and large headings
	LAYOUT: Content Structure
2.10	Simplicity of visual perception is key: Avoid visual clutter, distracting visual stimuli and non-relevant information due to the declining visual field
2.11	Minimize working memory demands: Keep the number of information blocks presented or processed at once limited to around 5
	LAYOUT: Consistency
2.12	Consistent design is even more important for the elderly than it is for younger people. Therefore, the location of items and functions should remain the same across views and similar functions should act the same way throughout the application
	LAYOUT: Navigation and Menu Structure
2.13	Group information and actions into meaningful and clearly worded categories. The difference between the options should be apparent.
2.14	Provide a clear and consistent navigation by displaying precise navigation cues and actions that are readily visible and accessible.
2.15	The current location in the application should be obvious to the user all the time.
2.16	Avoid deep hierarchies in menu structures hence the user does not get lost in the application.
2.17	Minimize the number of steps to complete a task as well as the number of control-elements to increase the probability of successfully completing the task.
2.18	Don’t force the user to keep information in mind for too long to accomplish a single task.
3	LANGUAGE AND WORDING
3.1	Language should be simple and clear. In addition, it should use active voicing and positive phrasing.
3.2	Phrasing assuming prior knowledge (e.g., technical terms) or a certain (especially young) age of the user should be avoided. Provide a glossary if technical terms are necessary
4	ICONS, GRAPHICS AND MULTIMEDIA
4.1	Well designed or familiar symbols and icons can be more effective ways to convey information than text messages.

4.2	Where possible provide a label or text for icons or illustrated instructions.
4.3	Speech rate of verbal information should be kept to 140 words per minute or less, male voices should be preferred to female voices and synthesized speech should be as natural as possible.
4.4	Consider providing parallel visual and auditory presentation of language (i.e., subtitles or a text-to-speech function)
4.5	Limit your sounds to one at a time; for example, speech over music may be hard to distinguish.
5	INTERACTION: Gestures
5.1	Instructions, training opportunities and clear visual clues facilitate memorizing and familiarizing gestural actions
5.2	Prefer indexical and manipulative gestures over symbolic and iconic gestures
5.3	Favor familiarity of a gesture pattern over its execution efficiency
5.4	Avoid alphanumerical gestures (e.g., drawing an “C” for “copy file”)
5.5	Turning over pages (like through “Next”- and “Previous”-buttons or swiping) should be preferred to scrolling up or down
5.6	Avoid drag and drop operations and double touch gestures.
5.7	Accommodate for slower gesture execution for time-critical events (e.g. multi-tap latencies). Movement is slowed by 1,3 compared with younger users
5.8	Employ curved gestures sparsely
5.9	Multi-touch gestures are not recommended for older users
	INTERACTION: Data Entry
5.10	Keep data entry tasks to a minimum
5.11	Regarding long textual data entry tasks on software keyboards, a country-related QWERTY-layout for experienced users should be preferred. For novices an alphabetic layout and short input sequences may be used.
5.12	The keys of a software keyboard to enter textual data should be wider than taller and provide a language based error correction
5.13	A hardware keyboard facilitates the entry of long text sequences
5.14	Software keyboards are preferable for small data input activities, especially for numeric data
	INTERACTION: Feedback

5.15	Support the user by indicating the touch location with visual feedback
5.16	Use low frequency vibration (25 - 60 Hz) for vibrotactile feedback
5.17	Auditory feedback should provide a volume of at least 60 dB and a sound-frequency of 500 - 2000 Hz. If high frequencies have to be used the duration (at least 500 ms) should be increased.
5.18	Multi-modal (combining audio, visual and/or tactile signals) feedback should be favored over unimodal feedback. Especially tactile and visual feedback should not be used solely
5.19	Provide ample time to process information and to make a physical response.
5.20	Provide error messages that are informative about the error occurred, the consequences and how to recover from it. Error messages should always appear at the same location
6	USER SUPPORT AND TRAINING
6.1	User support must be accessible at any time and any location within the application. The user should not get in a situation where he is left on his own.
6.2	Provide only one source of learning material (e.g., manual, tutorial) if possible.
6.3	Consider to provide the user a choice between a more comprehensive or more restricted initial training with regards to its information content
6.4	Introducing product features gradually over time can be useful to prevent cognitive overload
7	PERSONALIZATION
7.1	Adjusting certain factors of an user interface (e.g., the font size) to personal needs is important for the elderly
7.2	Consider to make some of the following factors adjustable: - the size of font, graphics or targets - the combination of audio, tactile and visual feedback - the way data is entered (software or physical keyboard) - the range of application functionalities - style information like background images or colors

3.5 The RADIO UI

3.5.1 The tablet UI

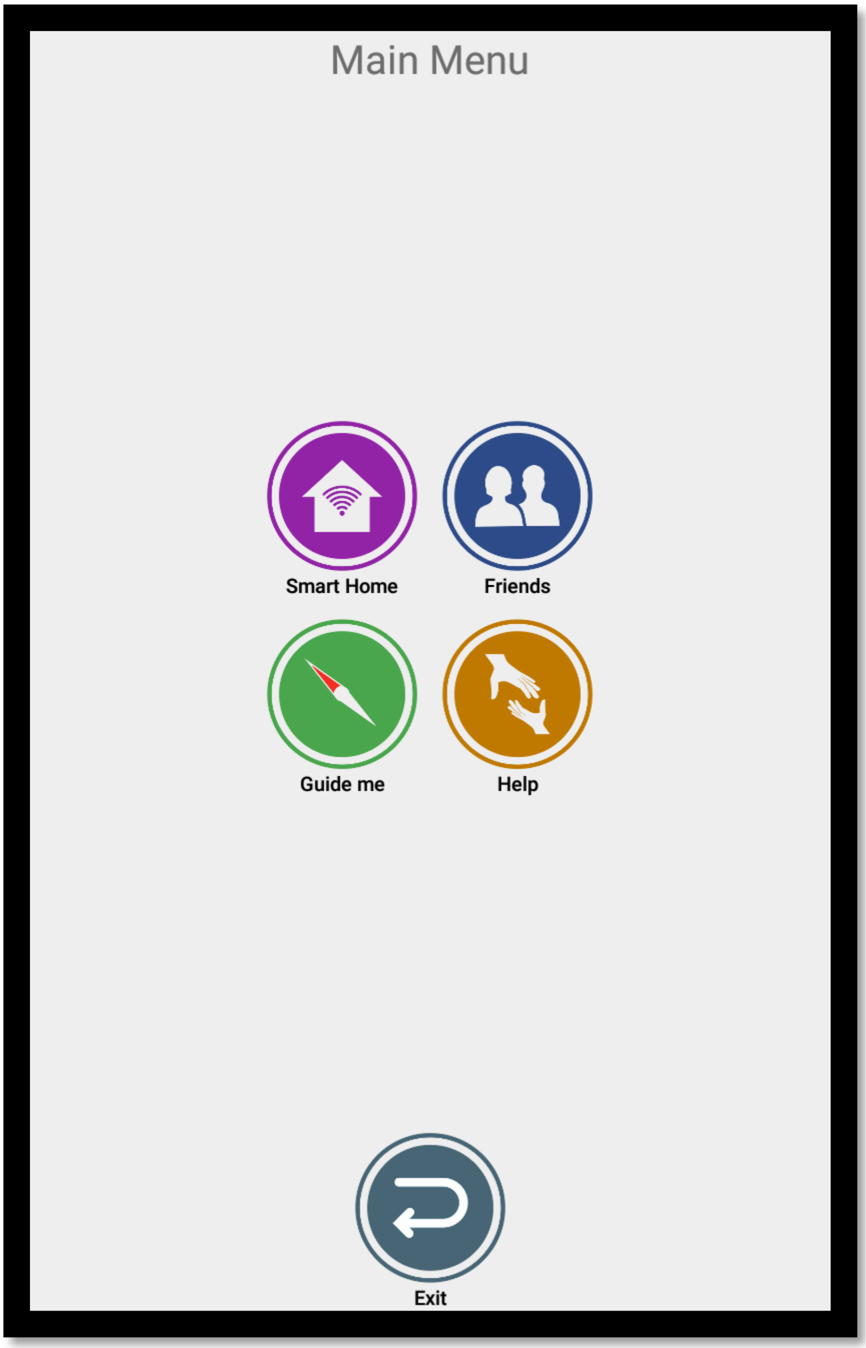


Figure 11. The RADIO Main Menu screen

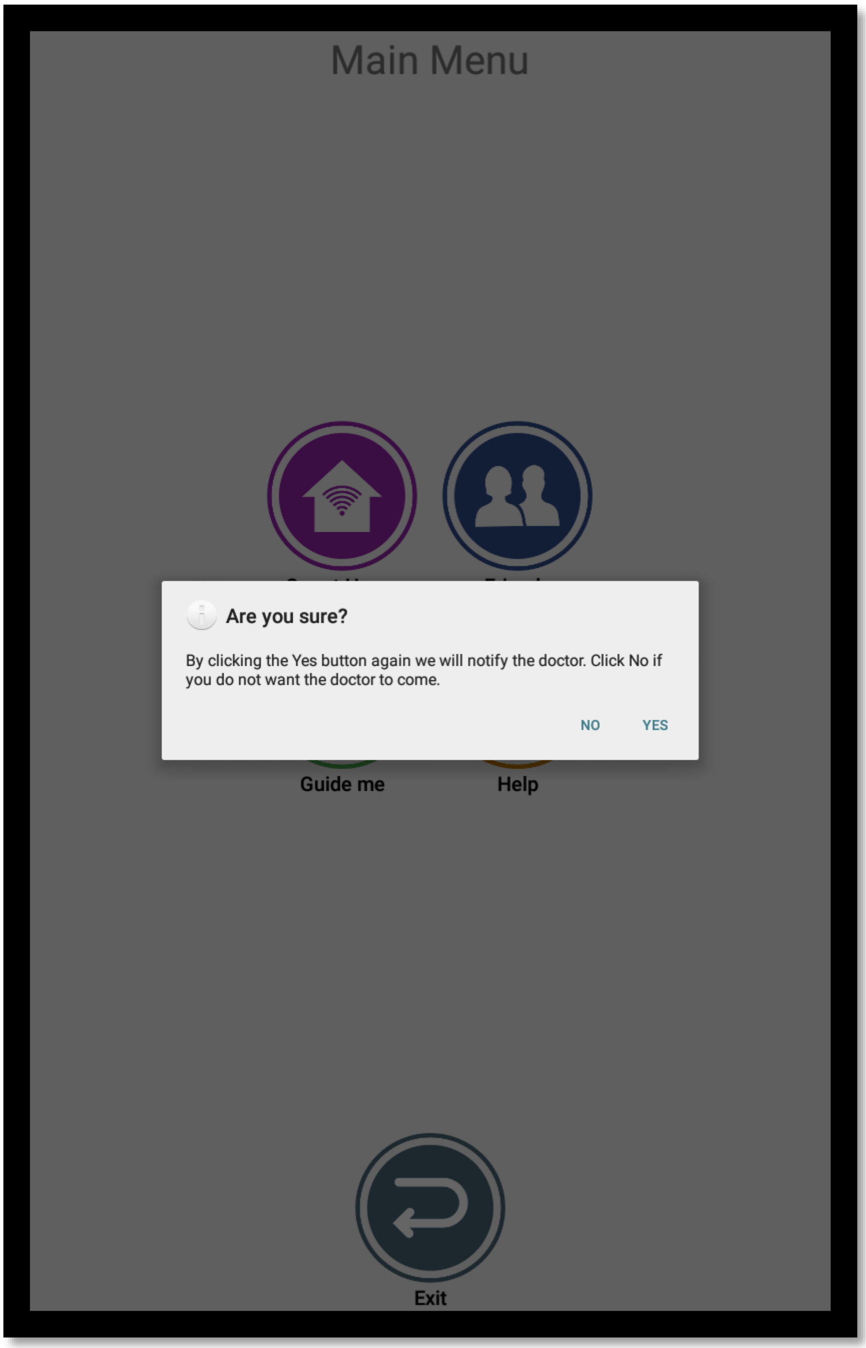


Figure 12. The RADIO confirmation message when the user clicks on the Help icon

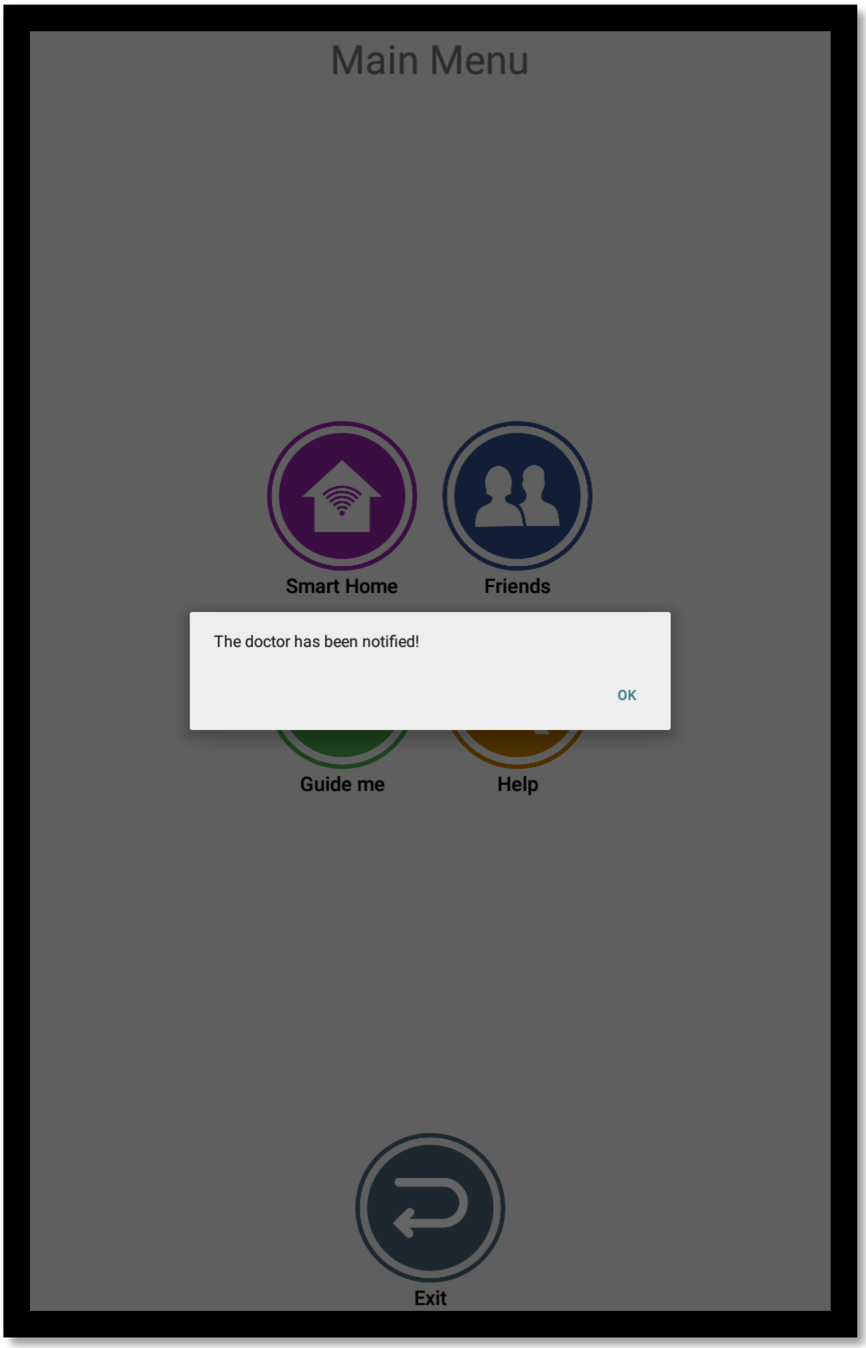


Figure 13. The RADIO notification message when the user clicks YES on the confirmation message (Help icon clicked)

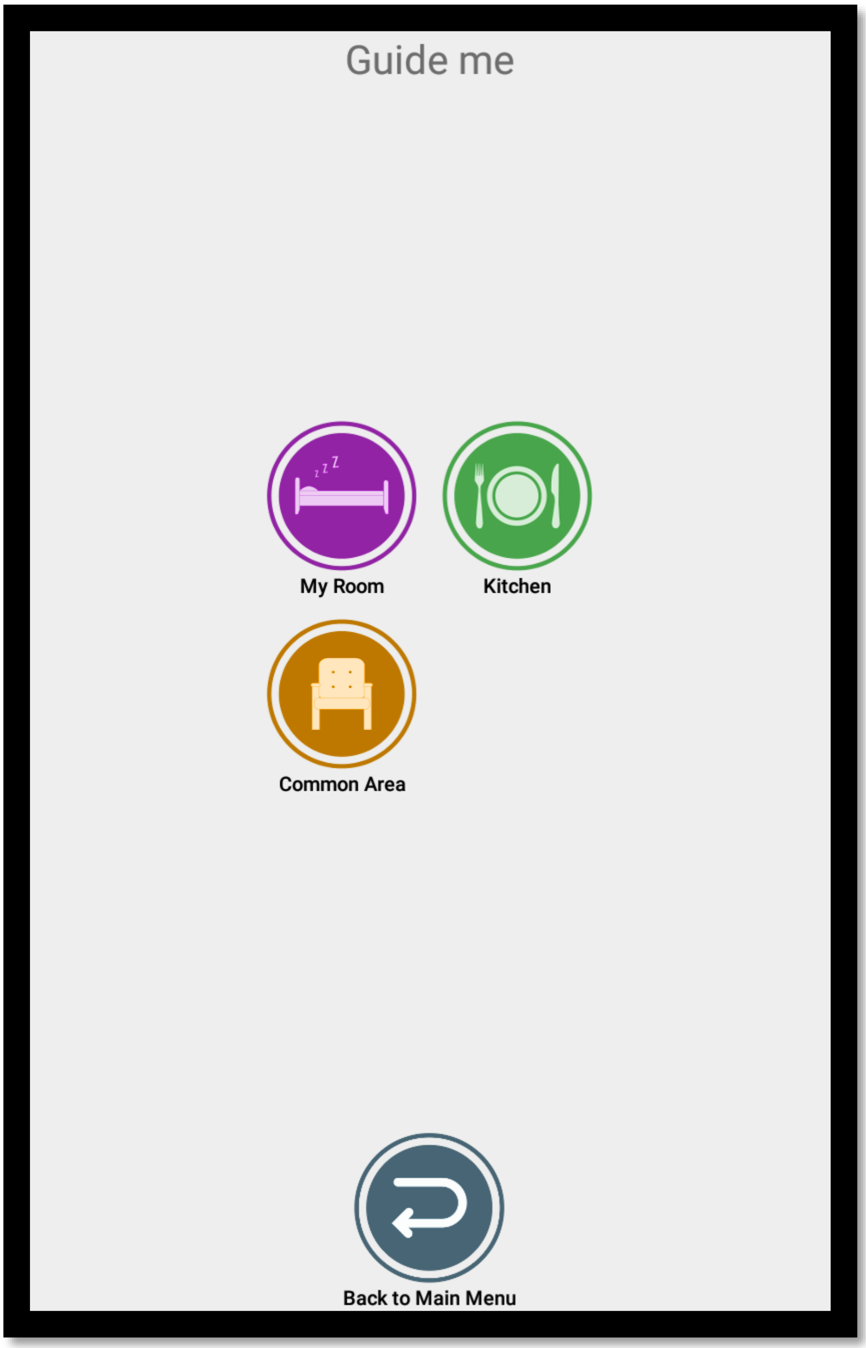


Figure 14. The RADIO Guide me screen (opens when the user clicks the 'Guide me' icon on the Main Menu screen)

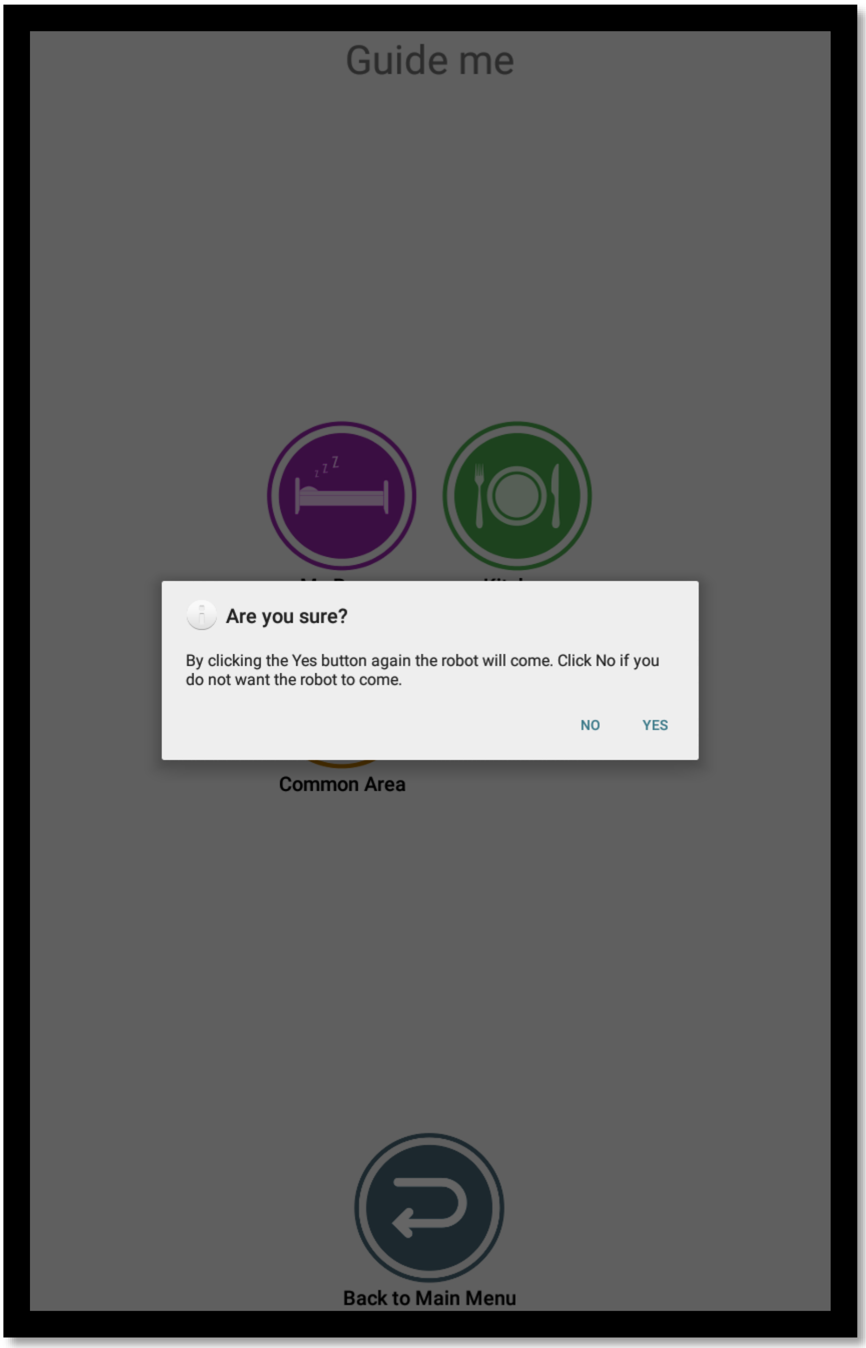


Figure 15. The RADIO confirmation message when the user clicks on any of the 3 available icons (Bedroom, Kitchen or Common Area)

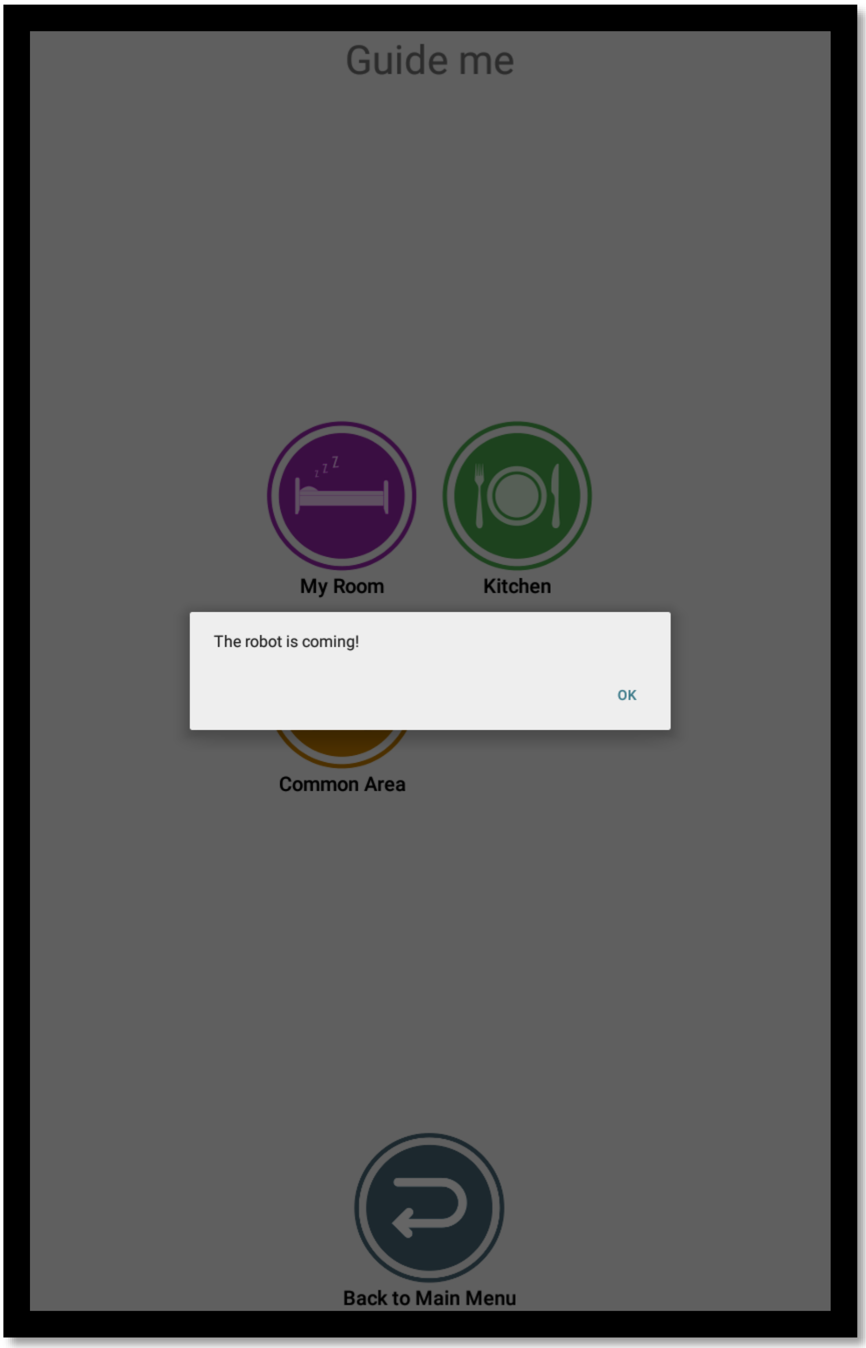


Figure 16. The RADIO notification message when the user clicks YES on the confirmation message (Bedroom, Kitchen or Common Area icon clicked)

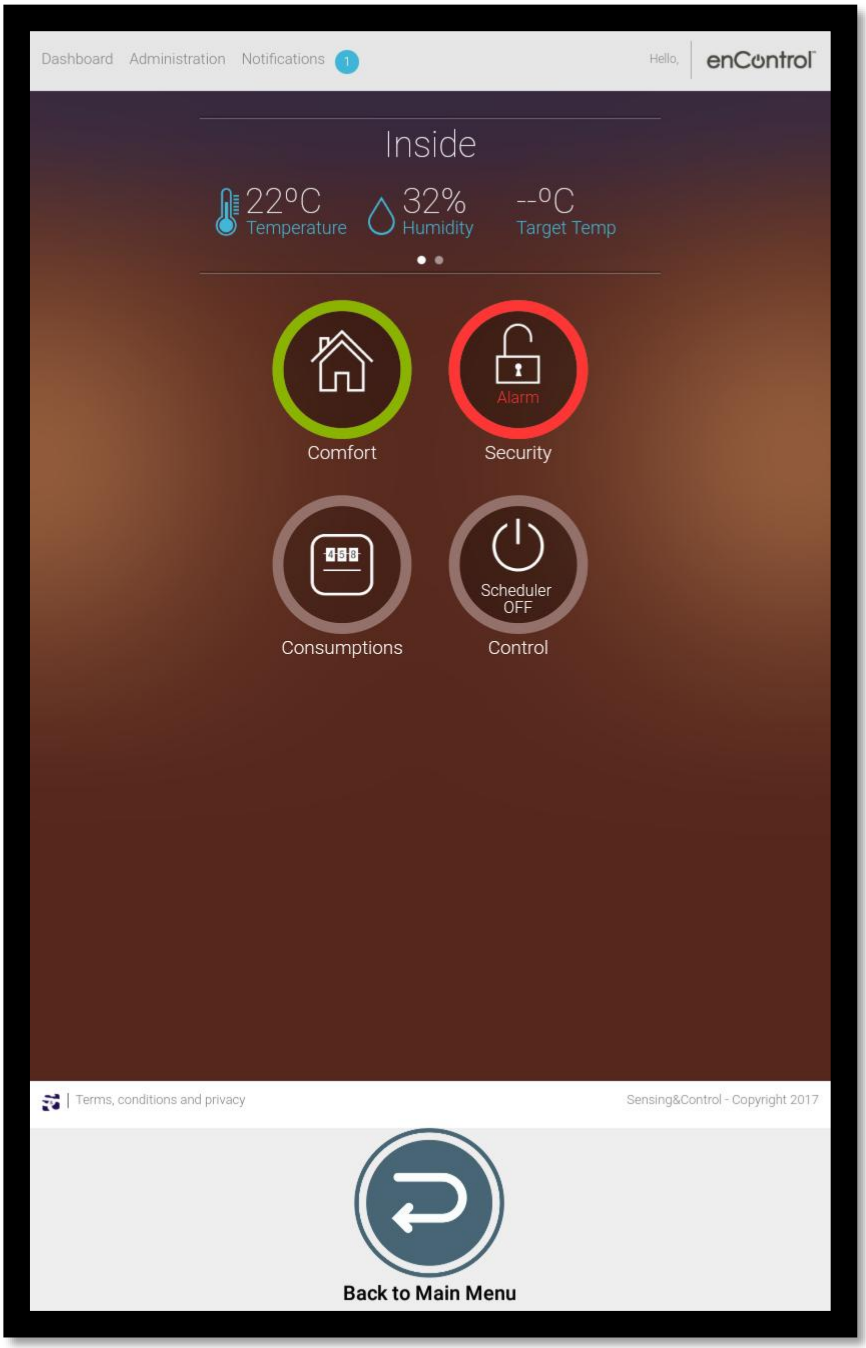


Figure 17. . The EnControl Smart Home dashboard screen (opens when the user clicks the 'Smart Home' icon on the Main Menu screen)

Figure 18. The Facebook page (opens when the user clicks the 'Friends' icon on the Main Menu screen)

3.5.2 The smartphone UI

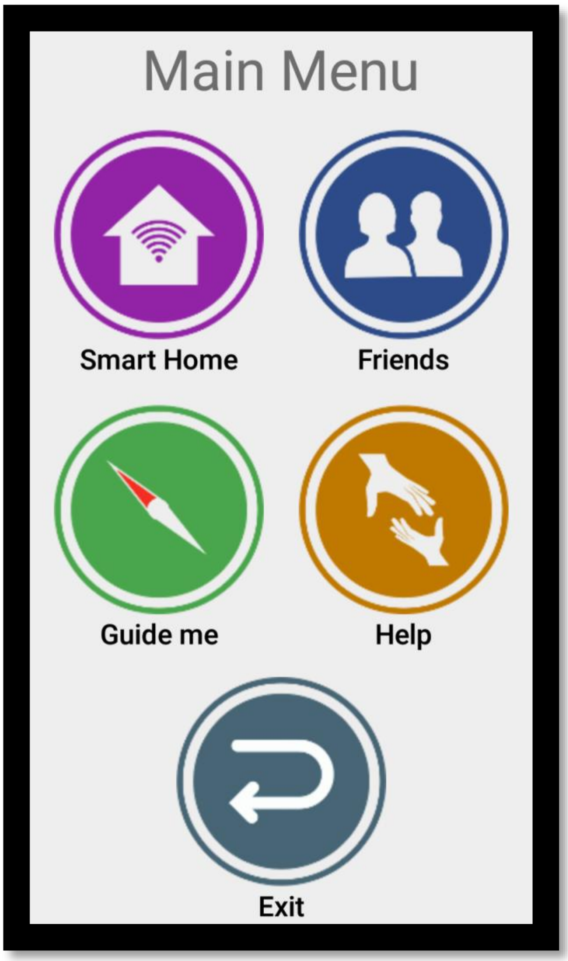


Figure 19. The RADIO Main Menu screen – smartphone version

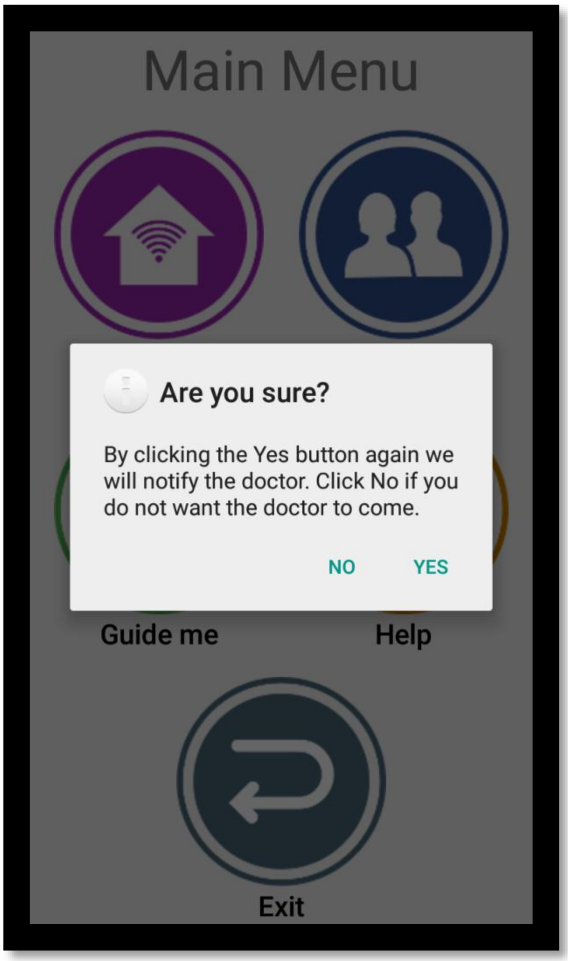


Figure 20. The RADIO confirmation message when the user clicks on the Help icon – smartphone version

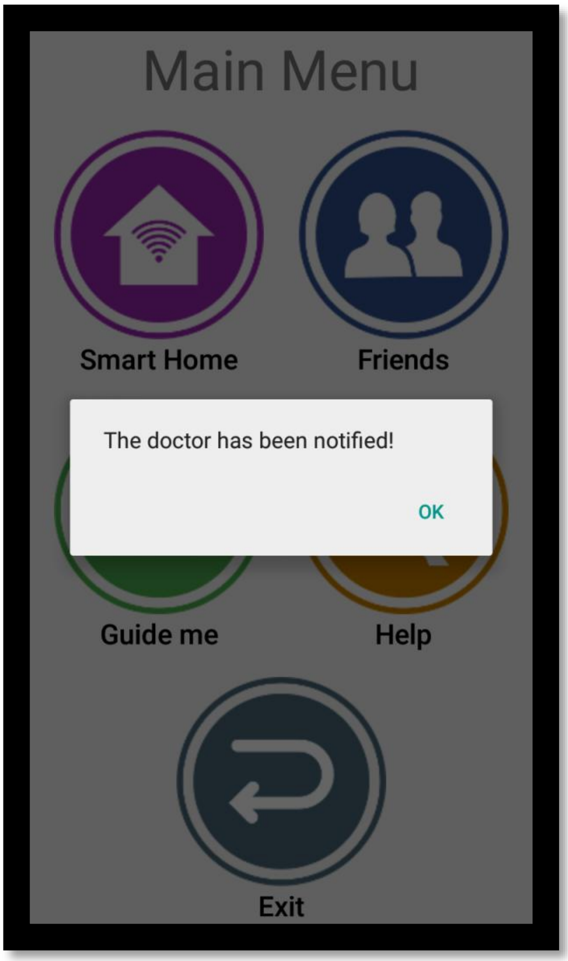


Figure 21. The RADIO notification message when the user clicks YES on the confirmation message (Help icon clicked) – smartphone version

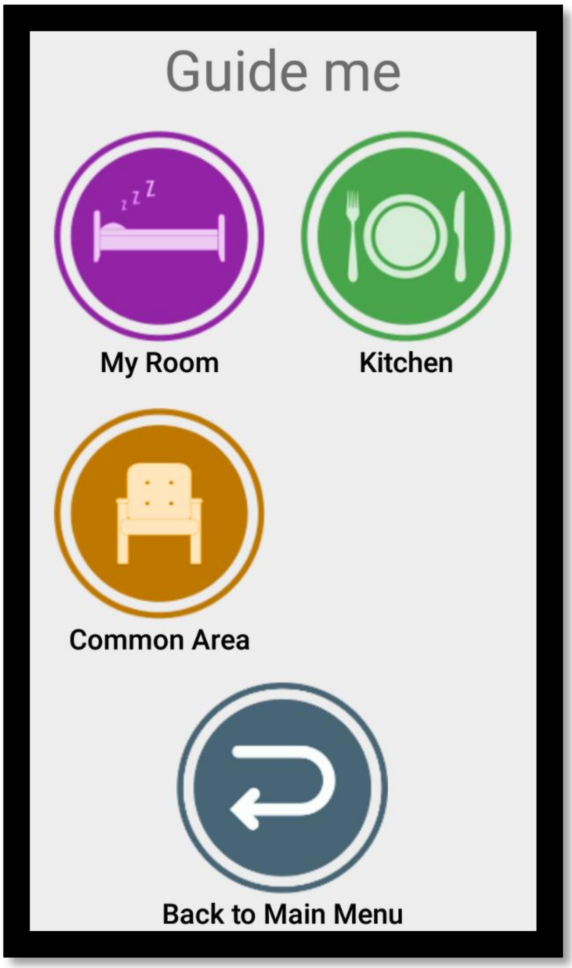


Figure 22. The RADIO Guide me screen (opens when the user clicks the 'Guide me' icon on the Main Menu screen) – smartphone version

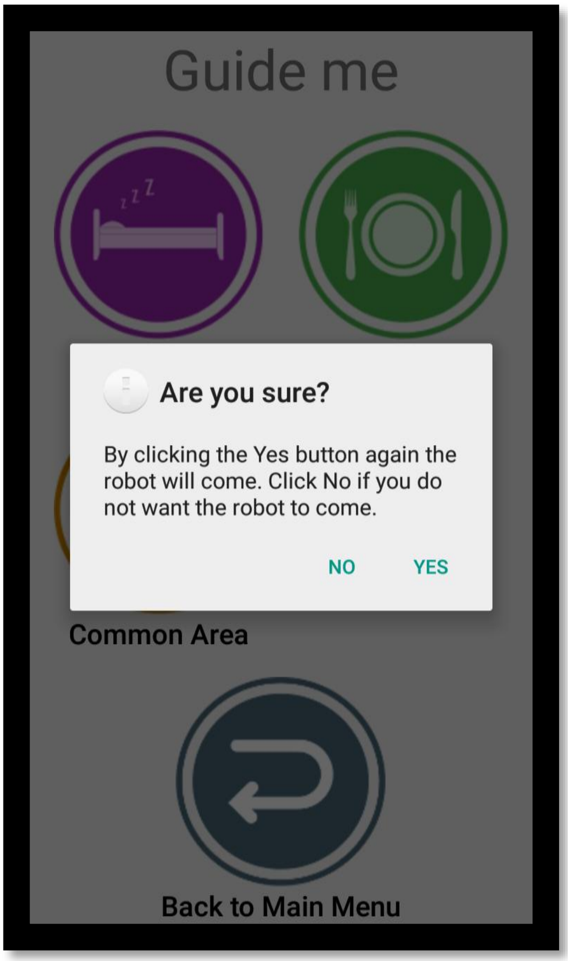


Figure 23. The RADIO confirmation message when the user clicks on any of the 3 available icons (Bedroom, Kitchen or Common Area) – smartphone version

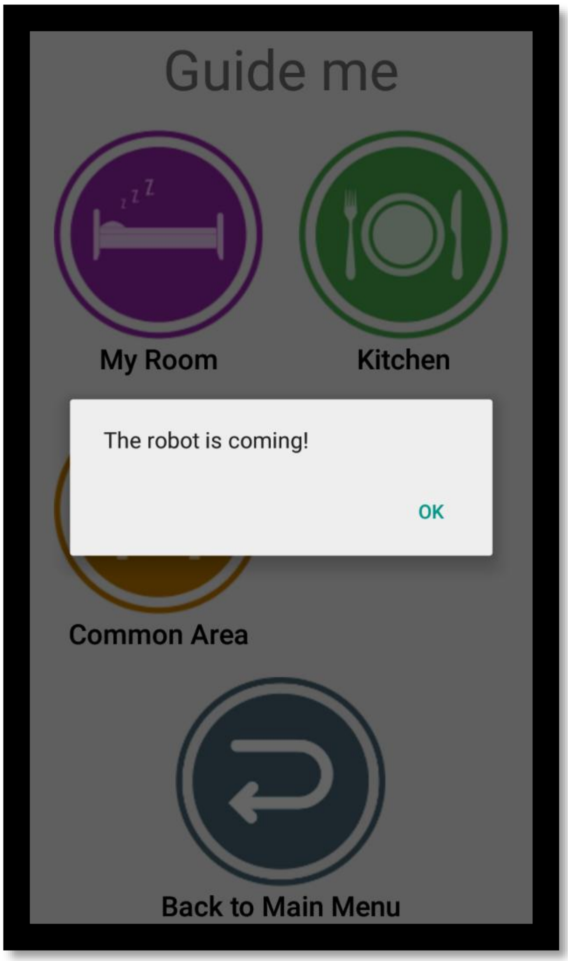


Figure 24. The RADIO notification message when the user clicks YES on the confirmation message (Bedroom, Kitchen or Common Area icon clicked) – smartphone version

3.6 Expert Evaluation

The list of collected UI guidelines was presented in Section 3.4. Here we apply this checklist to the RADIO GUI.

Symbols meaning:

● YES (the guideline is well-applied)

◐ YES but not fully (the guideline is applied to a degree, could be improved)

○ NO (the guideline is violated; improvements are required)

	GUIDELINE	Applied	Comment
1	**DESIGN: Color**		
1.1	Use colors of the long wavelength end of the spectrum (i.e., warm colors like red or yellow) if the color carries information – avoid blue especially	●	Color is used on icons (one color per each icon) for distinguishing reasons and when it is used on text it is confined to a shade of green. Blue is avoided as an information carrying color and it is only used on the Friends icon which corresponds to the Facebook brand color identity (as a hint to the application this icon opens).
1.2	Colors should be used conservatively. Use colors to carry important and relevant information (e.g., warnings, grouping elements).	●	Colors have been used in icons to provide distinguishability and in a monochrome fashion to avoid color pollution and overload.
1.3	Keep in mind that dark background colors increase glare and highlight fingerprints.	●	Background in native application screens is white.
1.4	Avoid colored and patterned backgrounds for text display areas.	●	All text display areas have a white background.
	DESIGN: Contrast		
1.5	To ensure legibility the color contrast ratio of text smaller than 18 pt should be at least 7:1 or 4,5:1 for large text or decorative text	●	Color contrast ratio for text in button labels is 20.47:1 and for text on screen titles (larger text) is 6.62:1
	DESIGN: Typeface		

1.6	Use sans serif font types (e.g., Verdana or Arial).	●	All texts in the application are in a sans-serif font.
1.7	Avoid decorative, italic, underlined and condensed font styles. Use bold font types and uppercase text only for highlighting key terms.	●	Bold, italic or otherwise decorated font formatting has been avoided throughout the application.
2	**LAYOUT: Size and Spacing**		
2.1	Buttons, clickable icons and labels should range in size between 11,43 mm square minimum and 19,05 mm square maximum. Adjacent buttons used in rows (e.g., keypad) should be at least 16,51 mm square	●	Both metric ranges are respected in all buttons, icons and labels.
2.2	The spacing between adjacent buttons in a row should reach from 3,17 mm to 12,7 mm maximum	●	Icon spacing conforms to the guideline.
2.3	Font sizes for multiple line text (i.e., primary text) should range between 9 pt and 14 pt and depend on screen size and the visual acuity of the user	●	Multiline text is used only in informative messages and messages for action verification. Text size in these messages is between 9 and 14 pt.
2.4	A 1.5 line spacing up to double spacing increases readability of text.	●	Text in informative text messages (the only case where text wraps in many lines) is readable but a 1.5 line spacing could improve its readability even more.
	LAYOUT: Text Layout		
2.5	Keep text lines short in length: The amount of characters per line for primary text should range between 60 and 75.	●	Text lines' length conforms to the guideline.
2.6	Avoid the need of scrolling to read a text. Rather consider to decrease the font size or line spacing.	●	No scrolling is required.
2.7	Avoid moving text like automatic scrolling.	●	No scrolling is required.
2.8	Multiple line text should be left justified.	●	Text alignment conforms to the guideline.

2.9	Provide clear and large headings	●	All screens have a large and clear heading indicating the current position in the application.
	LAYOUT: Content Structure		
2.10	Simplicity of visual perception is key: Avoid visual clutter, distracting visual stimuli and non-relevant information due to the declining visual field	●	Visual elements are kept to a minimum, there are no decorative elements, screens have enough white space (especially in the tablet version) and visual elements are used to represent clickable icons of the application.
2.11	Minimize working memory demands: Keep the number of information blocks presented or processed at once limited to around 5	●	In all native application screens available options are kept to a maximum of 5.
	LAYOUT: Consistency		
2.12	Consistent design is even more important for the elderly than it is for younger people. Therefore, the location of items and functions should remain the same across views and similar functions should act the same way throughout the application	●	Consistency is respected and kept in all screens (same buttons have the same behavior, representation and positioning, text in message screens keep consistent phrasing and options)
	LAYOUT: Navigation and Menu Structure		
2.13	Group information and actions into meaningful and clearly worded categories. The difference between the options should be apparent.	●	Options are coded into different colors and icons are large and contain a distinguishing graphic. Grouping is not applicable as options are limited to 5 (maximum).
2.14	Provide a clear and consistent navigation by displaying precise navigation cues and actions that are readily visible and accessible.	●	Each screen has a clear title and an option for returning to the previous one.
2.15	The current location in the application should be obvious to the user all the time.	●	Each screen has a clear title.
2.16	Avoid deep hierarchies in menu structures hence the user does not get lost in the application.	●	The application has a very simple and shallow structure, which ensures that in no point the user might feel disoriented or lost.

2.17	Minimize the number of steps to complete a task as well as the number of control-elements to increase the probability of successfully completing the task.	●	All tasks can be accomplished in a sequence of 3 clicks (provided that the user makes no mistakes).
2.18	Don't force the user to keep information in mind for too long to accomplish a single task.	●	The user does not need to remember any information to accomplish a task (just to have in mind the task itself).
3	**LANGUAGE AND WORDING**		
3.1	Language should be simple and clear. In addition, it should use active voicing and positive phrasing.	●	Language is simple without any technical references. It uses active voicing and positive phrasing.
3.2	Phrasing assuming prior knowledge (e.g., technical terms) or a certain (especially young) age of the user should be avoided. Provide a glossary if technical terms are necessary	●	Language is simple without any technical references. No need to provide a glossary.
4	**ICONS, GRAPHICS AND MULTIMEDIA**		
4.1	Well-designed or familiar symbols and icons can be more effective ways to convey information than text messages.	●	Icons have a representative and distinguishing graphic seniors are familiar with.
4.2	Where possible provide a label or text for icons or illustrated instructions.	●	All icons are accompanied by a textual label.
4.3	*Speech rate of verbal information should be kept to 140 words per minute or less, male voices should be preferred to female voices and synthesized speech should be as natural as possible.*	*Non Applicable*	*The application does not support speech.*
4.4	*Consider providing parallel visual and auditory presentation of language (i.e., subtitles or a text-to-speech function)*	*Non Applicable*	*The application does not support speech.*

4.5	Limit your sounds to one at a time; for example, speech over music may be hard to distinguish.	●	Sounds are restricted to system sounds that act as feedback when an action needs confirmation.
5	***INTERACTION: Gestures***		
5.1	*Instructions, training opportunities and clear visual clues facilitate memorizing and familiarizing gestural actions*	*Non Applicable*	*System functionality does not require instructions and training, it is a simple interface that is to be treated as a walk-up-and-use application.*
5.2	*Prefer indexical and manipulative gestures over symbolic and iconic gestures*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.3	*Favor familiarity of a gesture pattern over its execution efficiency*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.4	*Avoid alphanumerical gestures (e.g., drawing an "C" for "copy file")*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.5	*Turning over pages (like through "Next"- and "Previous"-buttons or swiping) should be preferred to scrolling up or down*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.6	*Avoid drag and drop operations and double touch gestures.*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.7	*Accommodate for slower gesture execution for time-critical events (e.g. multitap latencies). Movement is slowed by 1,3 compared with younger users*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.8	*Employ curved gestures sparsely*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
5.9	*Multi-touch gestures are not recommended for older users*	*Non Applicable*	*No gestures are required for interacting with the application (just clicking on icons)*
	INTERACTION: Data Entry[2]		

[2] The native application screens require no data entry (the application is connected to a dashboard app and Facebook but the evaluation of those UIs is not part of this report).

5.10	*Keep data entry tasks to a minimum*	*Non Applicable*	*No data entry required for interacting with the application*
5.11	*Regarding long textual data entry tasks on software keyboards, a country-related QWERTY-layout for experienced users should be preferred. For novices an alphabetic layout and short input sequences may be used.*	*Non Applicable*	*No data entry required for interacting with the application*
5.12	*The keys of a software keyboard to enter textual data should be wider than taller and provide a language based error correction*	*Non Applicable*	*No data entry required for interacting with the application*
5.13	*A hardware keyboard facilitates the entry of long text sequences*	*Non Applicable*	*No data entry required for interacting with the application*
5.14	*Software keyboards are preferable for small data input activities, especially for numeric data*	*Non Applicable*	*No data entry required for interacting with the application*
	INTERACTION: Feedback		
5.15	Support the user by indicating the touch location with visual feedback	●	Touch locations are clearly indicated by large sized icons the users can simply click (tap) to activate.
5.16	*Use low frequency vibration (25 - 60 Hz) for vibrotactile feedback*	*Non Applicable*	*No vibration is used as a feedback mechanism*
5.17	Auditory feedback should provide a volume of at least 60 dB and a sound-frequency of 500 - 2000 Hz. If high frequencies have to be used the duration (at least 500 ms) should be increased.	●	Auditory feedback conforms to the guideline.
5.18	Multi-modal (combining audio, visual and/or tactile signals) feedback should be favored over unimodal feedback. Especially tactile and visual feedback should not be used solely	●	All visual feedback is used in combination with audio feedback.

5.19	Provide ample time to process information and to make a physical response.	●	There is no time limit for users to proceed with any action within the application.
5.20	Provide error messages that are informative about the error occurred, the consequences and how to recover from it. Error messages should always appear at the same location	●	Error messages appear the same way informative or verification messages appear (see Section 3.5), i.e. in a white panel in the center of the screen while graying-out the preceding screen.
6	USER SUPPORT AND TRAINING		
6.1	User support must be accessible at any time and any location within the application. The user should not get in a situation where he is left on his own.	*Non Applicable*	*System functionality does not require instructions and training, it is a simple interface that is to be treated as a walk-up-and-use application.*
6.2	Provide only one source of learning material (e.g., manual, tutorial) if possible.	*Non Applicable*	*No learning material is required for the application*
6.3	Consider to provide the user a choice between a more comprehensive or more restricted initial training with regards to its information content	*Non Applicable*	*No learning material is required for the application*
6.4	Introducing product features gradually over time can be useful to prevent cognitive overload	*Non Applicable*	*No additional features to be introduced gradually.*
7	PERSONALIZATION		
7.1	Adjusting certain factors of an user interface (e.g., the font size) to personal needs is important for the elderly	● (grey)	Font sizes are large enough. Nevertheless it would be good to allow for adjusting font sizes.
7.2	Consider to make some of the following factors adjustable: - the size of font, graphics or targets - the combination of audio, tactile and visual feedback - the way data is entered (software or physical keyboard)	●	See 7.1 comment. Visual and audio feedback are already combined. There is no need for data entry in all native application screens There is no additional functionality to be gradually introduced Style could be adjusted but allowing only predefined combinations to ensure contrast

	- the range of application functionalities - style information like background images or colors		guidelines are met. In this case though it is doubtful if the option for customizing the style justifies the extra effort seniors will have to put in order to manipulate an additional GUI feature.

From the above one concludes that the RADIO UI conforms to a high degree to the list of identified multi touch UI guidelines for elderly users. More specifically, excluding 21 of the 58 guidelines that were considered non-applicable to the context of the RADIO application (see respective rationale on the preceding table), 35 from the remaining 37 guidelines are well-applied and 2 are applied but there is merit for further improvement.

Summarizing the RADIO UI conformance with the usability guidelines checklist, the UI does not demonstrate any major or minor usability issues, but could be further enhanced if multiple line spacing is increased to 1.5 in text messages and if text sizes in general could be customizable to fit each user's needs (i.e. there is the option to adjust text sizes accordingly).

Another suggestion made by the evaluators is to unlock screen orientation so that the RADIO application can be used in landscape mode, too in the case of tablet devices. For smartphone usage, evaluators suggest to keep the screen locked to portrait orientation for better UI layout.

Moreover, evaluators suggested increasing the spacing between screen contents and screen borders, as headings are placed too close to the top border of the screen and the labels of the "Back to Main Manu" and "Exit" buttons are too close to the bottom border of the screen.

3.7 User Testing

3.7.1 Eye-tracking

Eye tracking is a methodology that helps researchers understand visual attention. With eye tracking, we can detect where users look at a point in time, how long they look at something, and the path their eyes follow. Eye tracking has been applied to numerous fields including human factors, cognitive psychology, marketing, and the broad field of human–computer interaction. In user experience research, eye tracking helps researchers understand the complete user experience, even that which users cannot describe [Romano Bergstrom and Schall, 2014]. Most modern eye trackers rely on a method called corneal reflection to detect and track the location of the eye as it moves. Corneal reflection uses a light source to illuminate the eye, which then causes a reflection that is detected by a high-resolution camera. The image captured by the camera is then used to identify the reflection of the light source on the cornea and in the pupil. Advanced image processing algorithms are then used to establish the point of gaze related to the eye and the stimuli.

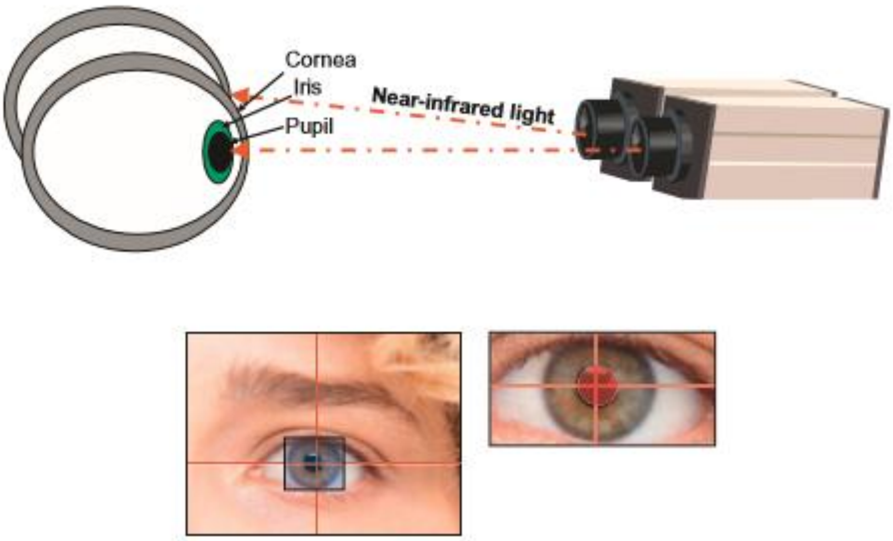


Figure 25. Eye-tracking technology

This process is divided into fixation and saccades. A fixation is the pause of the eye movement on a specific area of the visual field. These pauses are often extremely brief, as the eye continually performs saccades. Saccades are rapid movements of the eye from one fixation to another to help the eye piece together a complete scene of what an individual looks at.

The eye trackers that UX professionals use today come with software suites that instantaneously produce visualizations of the eye-tracking data and automate a significant amount of tasks that previously took weeks to analyze manually. The output from these software packages help to highlight where the user looked, the length of time they looked there, and the gaze pattern their eyes followed. Some of the most commonly used visualizations include the heat map and gaze plot.

- A **heatmap** is a visualization that uses different colors to show the amount of fixations participants made or for how long they fixated areas. Heat maps are color coded: red is typically used to indicate a relatively high number of fixations or duration and green the least, with varying levels in between. An area with no color on a heat map signifies that the participants may not have fixated on the area. This does not necessarily mean they did not see anything—they may have looked there for a short period or may have only registered peripherally, but it may have not been detectable by the eye tracker.

- **Gaze plots** are a visual representation of fixations and saccades for a particular time frame. In most software applications, fixations are represented by dots, and saccades are lines connecting the dots. Fixations are typically numbered to show the order of the fixations and can vary in size to illustrate the duration of the fixation.

In the current study, eye-tracking has been used as a supportive means for validating icon recognizability and text readability as users are asked to performed specific tasks using the RADIO UI. The equipment used comprised:

- **Tobii Glasses:** allow capturing free eye movement and fixation not just on a specific screen but anywhere in the surrounding environment a user chooses to look at. Data gathered by the eye-tracking glasses are much richer and can provide insights on what distracts users for how long and how fast.
- **Tobii T60 Eye Tracker:** integrated in a 17-inch TFT monitor, the eye tracking system allows for a large degree of head movement, providing a distraction-free test environment that ensures natural behavior, and therefore valid results. The eye tracking technology's high level of accuracy and precision ensures that the research results are reliable.
- **Tobii X60/X120 Mobile Device Testing Solution:** Allows eye tracking during natural interaction with smart phones, tablet computers or other devices or objects of similar size (up to 5 or 10 inches display). The device depending on its size can be mounted either on the provided small device mount or on the large device mount. These mounts allow for smooth rotation of devices between landscape and portrait modes. The setup also allows for free hand movement testing where the device is not mounted but instead the participant holds it in his hands and leans against the setup's relevant surface.

Figure 26. Tobii Glasses and Tobii T60 Eye Tracker

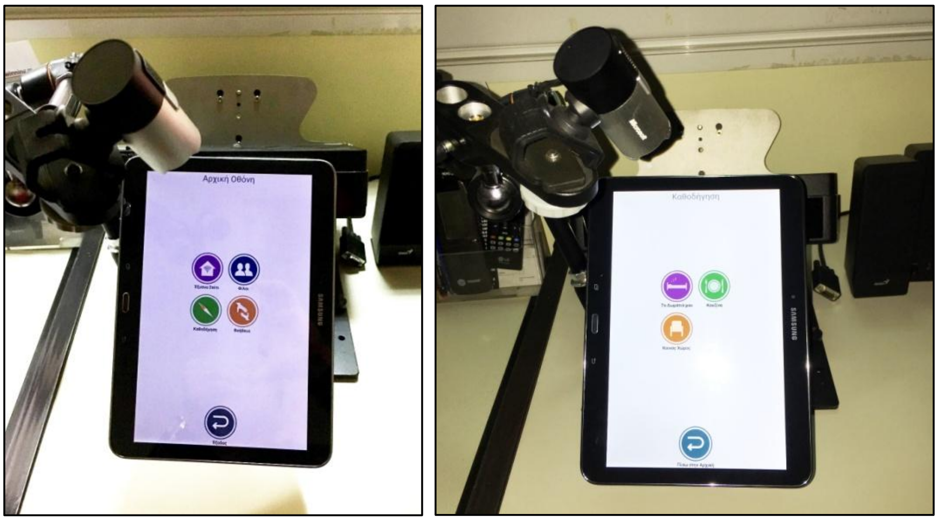


Figure 27. Tobii eye-tracker mounted on a mobile device stand

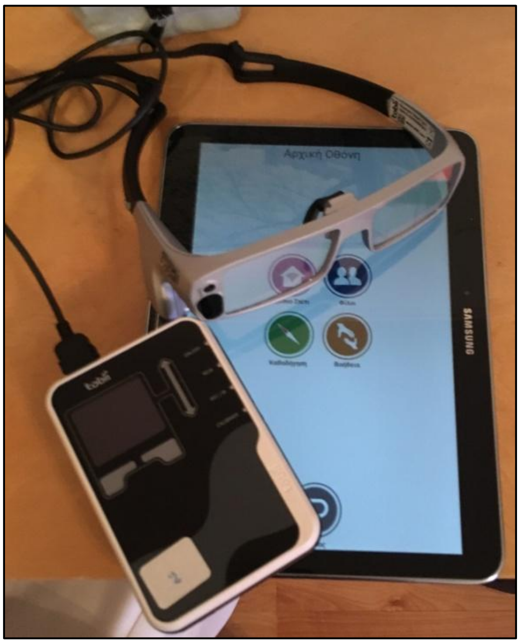


Figure 28. Tobii eye-tracking glasses used for RADIO UI evaluation

Collected data were processed by the Tobii studio software, a platform for stimuli presentation, recording, observation, visualization, and analysis of eye tracking data. The software allows processing of large amounts of information for meaningful interpretation. More specifically, Tobii studio allows for designing eye-tracking usability studies, running test sessions, observing subjects remotely, visualizing the results, and analyzing statistics. It integrates a variety of data, besides eye tracking, to include stimuli presentation and subject behavior, which gives researchers a complete view of behavior. The software automatically synchronizes all of the data into one file.

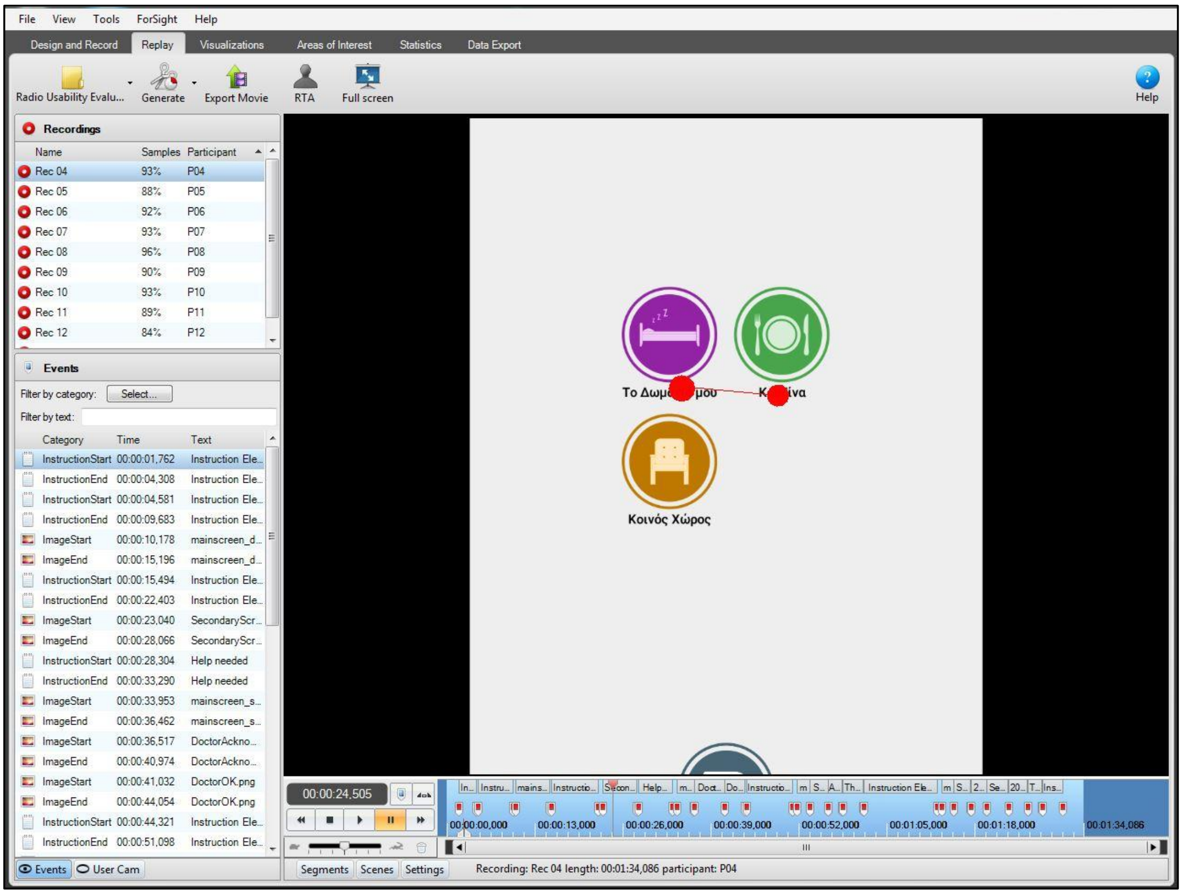


Figure 29. Tobii Studio screenshot from the RADIO UI evaluation

Replay of eye tracking videos with the gaze point of the subject overlayed enables in-depth qualitative analysis and sharing of highlights. Tobii studio also generates overview of the data for a more detailed quantitative analysis and interpretation by using the calculation of eye tracking and click metrics based on AOI's (Areas Of Interest), as well as versatile tables and charts. Raw or filtered eye tracking data can be exported for further analysis and significance testing in Excel, SPSS, MATLAB, and other statistical software suites. In addition, adjustable fixation filters are available for eye movement classifications.

User testing sessions were video recorded using a SONY HXR-NX30E wide 10x optical video camera (Figure 30) and photographs were taken using a Canon EOS50D camera with an extra zoom lens EF24-70MM 1:2,8 (Figure 31).

Figure 30. SONY HXR-NX30E wide 10x optical

Figure 31. Canon EOS50D camera with an extra zoom lens EF24-70MM 1:2,8

3.7.2 Methodology

For the purposes of user testing a series of 10 home visits were scheduled. In every visit two usability experts were present moderating the tests and specialized personnel from Frontida Zois were overlooking the process. The test was performed at the premises of the elderly at a preselected date and time according to the preferences of each user.

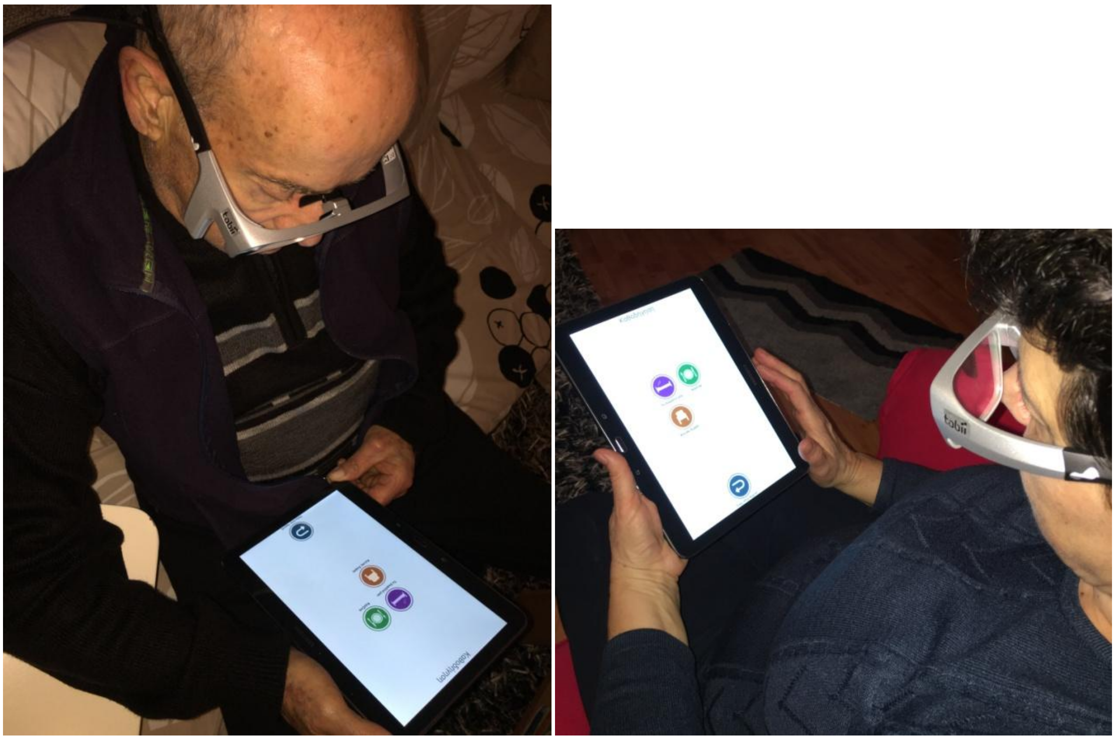


Figure 32. User testing participants using Tobii glasses

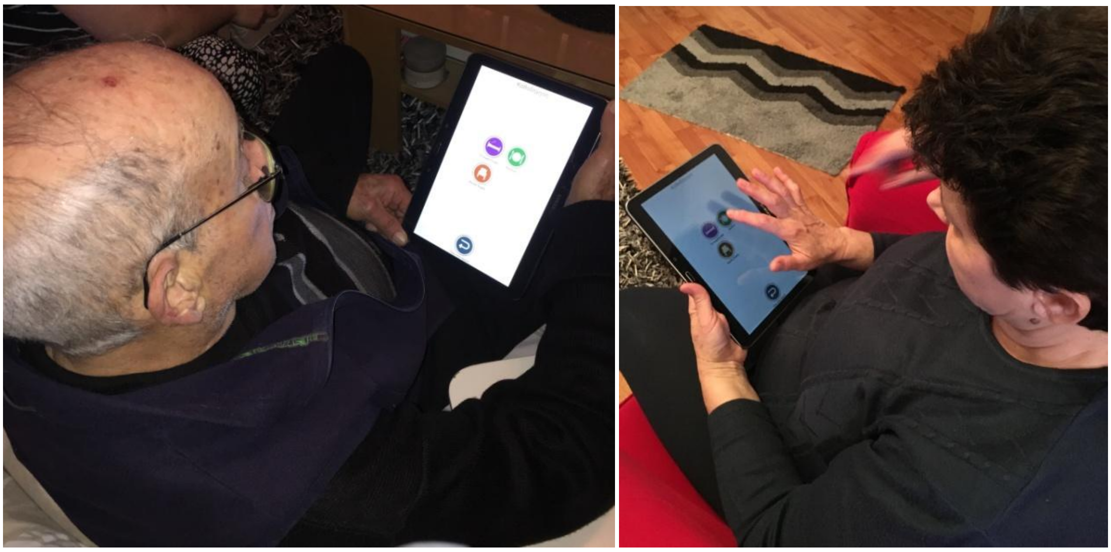


Figure 33. User testing participants while interacting with the RADIO application on a tablet

Users were initially informed about the RADIO project aims and expected results and then they were informed about the experiment process and the estimated duration. It was specifically specified that the test was not about their ability to use correctly the RADIO application but to help us evaluate whether the application has been correctly designed and they can use it easily and effectively to obtain their everyday tasks without stress.

Each user was then asked to sign off a consensus form (see Appendix I) giving us permission to video record the test session and take photos. Next, users were asked to provide us with the following information: age, sex, previous experience with tablets/smartphones/PCs. Each user was asked just to observe the Main Menu screen and then the Guide Me screen in order to get familiar with the screen contents and layout and then the user was asked to perform the scenarios presented in the next section.

3.7.3 User sample

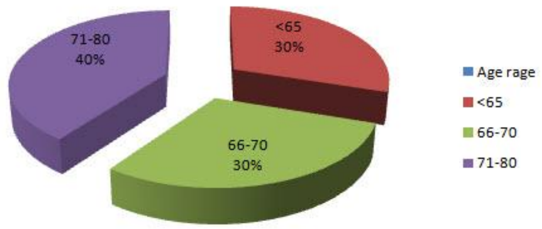


Figure 34. User sample ages

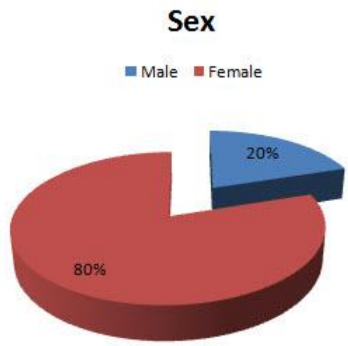


Figure 35. User sample sex

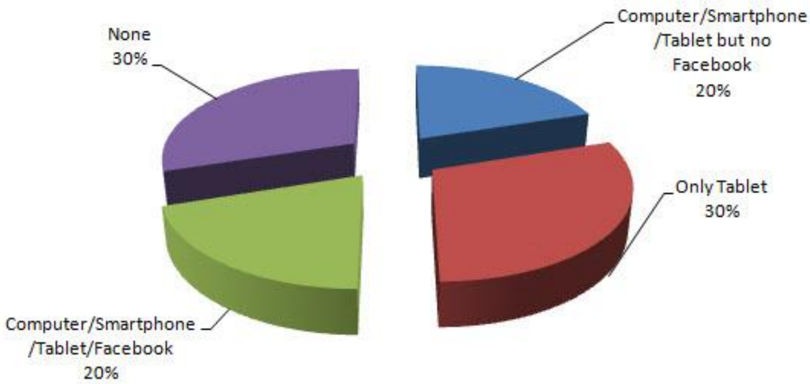


Figure 36. Previous usage experience with tablets/smartphones/PCs

3.7.4 Scenarios

Each user was asked to perform three scenarios in the following order (Table 3). The second column of the table describes the purpose of defining the corresponding scenario:

Table 3. User test scenarios

	Scenario description	Rationale
1	[the user is at the Main Menu screen]: Click the appropriate icon to call the doctor and confirm your action when asked to.	• Assess 'Help' icon recognizability • Assess readability and understandability of confirmation text message • Assess size suitability of confirmation message options ('No', 'Yes', 'OK')
2	[the user is at the Main Menu screen]: Call the robot to guide you to the Kitchen and confirm your action when asked to.	• Assess 'Guide me' icon recognizability • Assess 'Kitchen' icon recognizability • Assess size suitability of confirmation message options ('No', 'Yes', 'OK')
3	[the user is at the Main Menu screen]: Call the robot to guide you to the Common Area, cancel your selection when asked to confirm it and then ask the robot to guide you to the bedroom (and confirm when asked to).	• Assess 'Guide me' icon memorability • Assess 'Common Area' icon recognizability • Assess readability and understandability of confirmation text message • Assess readability and understandability of cancelation text message • Assess 'My Room' icon recognizability • Assess size suitability of confirmation message options ('No', 'Yes', 'OK')

After collecting all data previously described, they were analyzed to provide descriptive statistics regarding the test and qualitative information about the RADIO application evaluation.

3.7.5 Collected data

As previously mentioned, before executing specific scenarios users were asked to observe the two main screens (Main Menu and Guide Me) to get an idea of screen contents and layout without having yet specified any tasks.

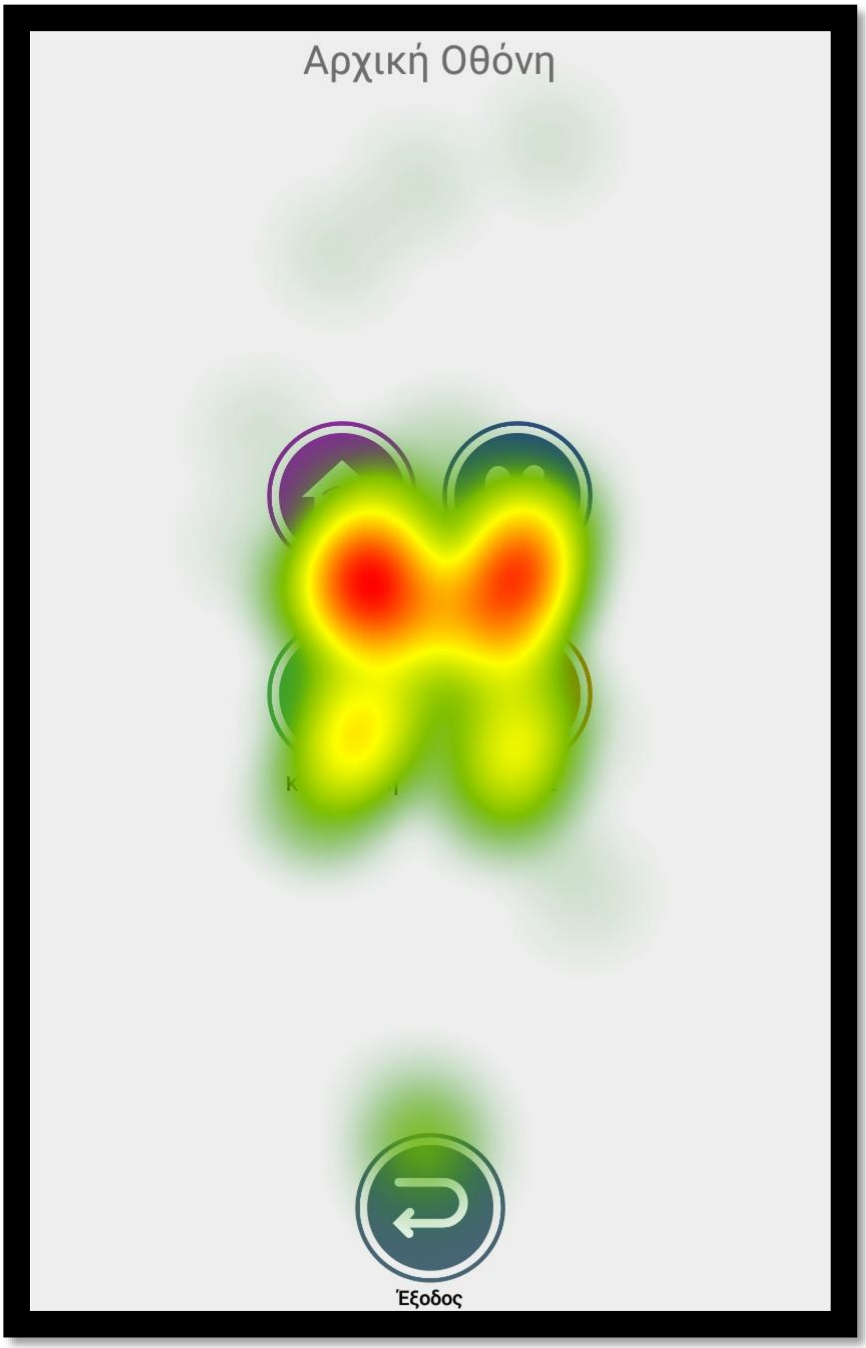


Figure 37. Heatmap of the Main Menu screen (gaze data from all users)

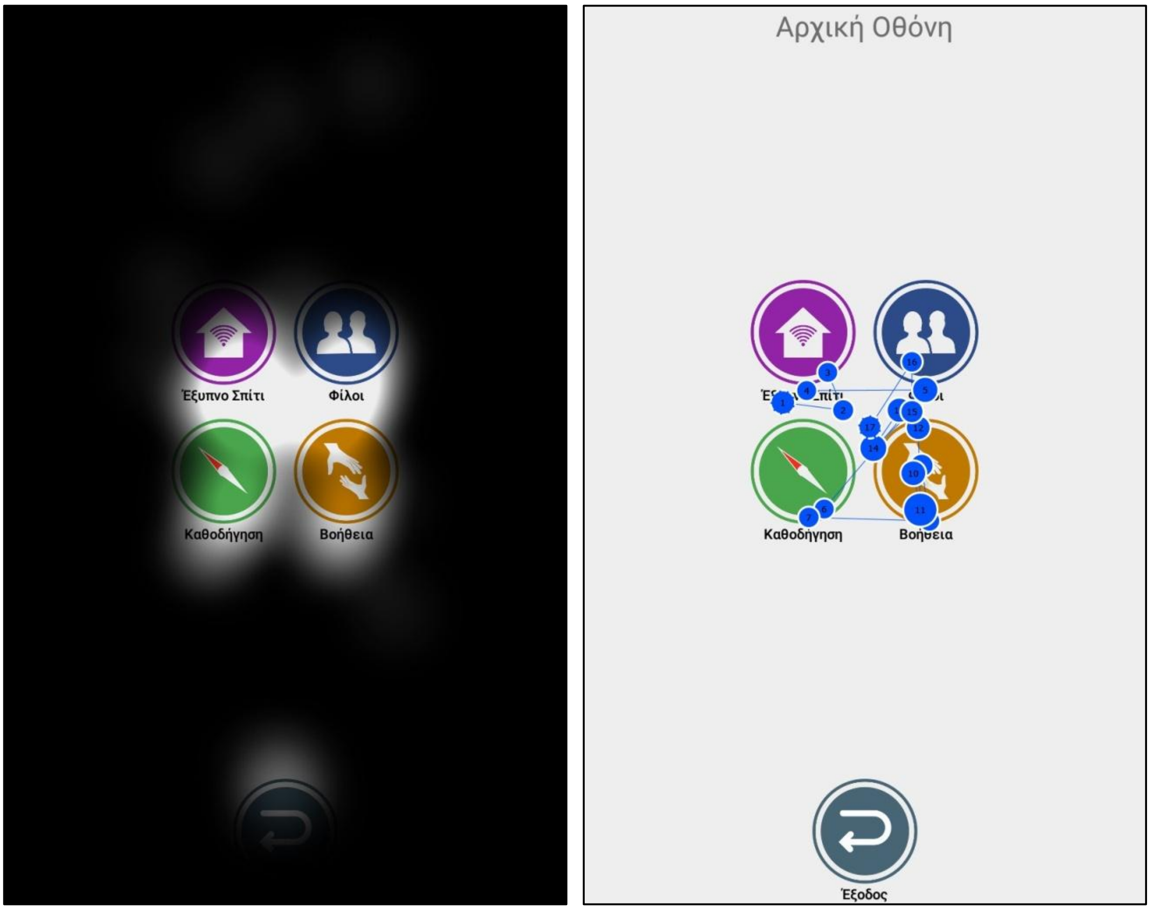


Figure 38. Main Menu screen Gaze Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user)

From the Gaze opacity one can observe that all centrally located icons gathered the visual attention of users. The Heatmap revealed that the first line icons (purple and blue) were noticed more by users which can be justified by their position and color. Western world reading pattern (from left to right and from top to bottom) explains the sequence of eye-fixations on the gaze plot.

Users were also asked to observe the Guide Me screen.

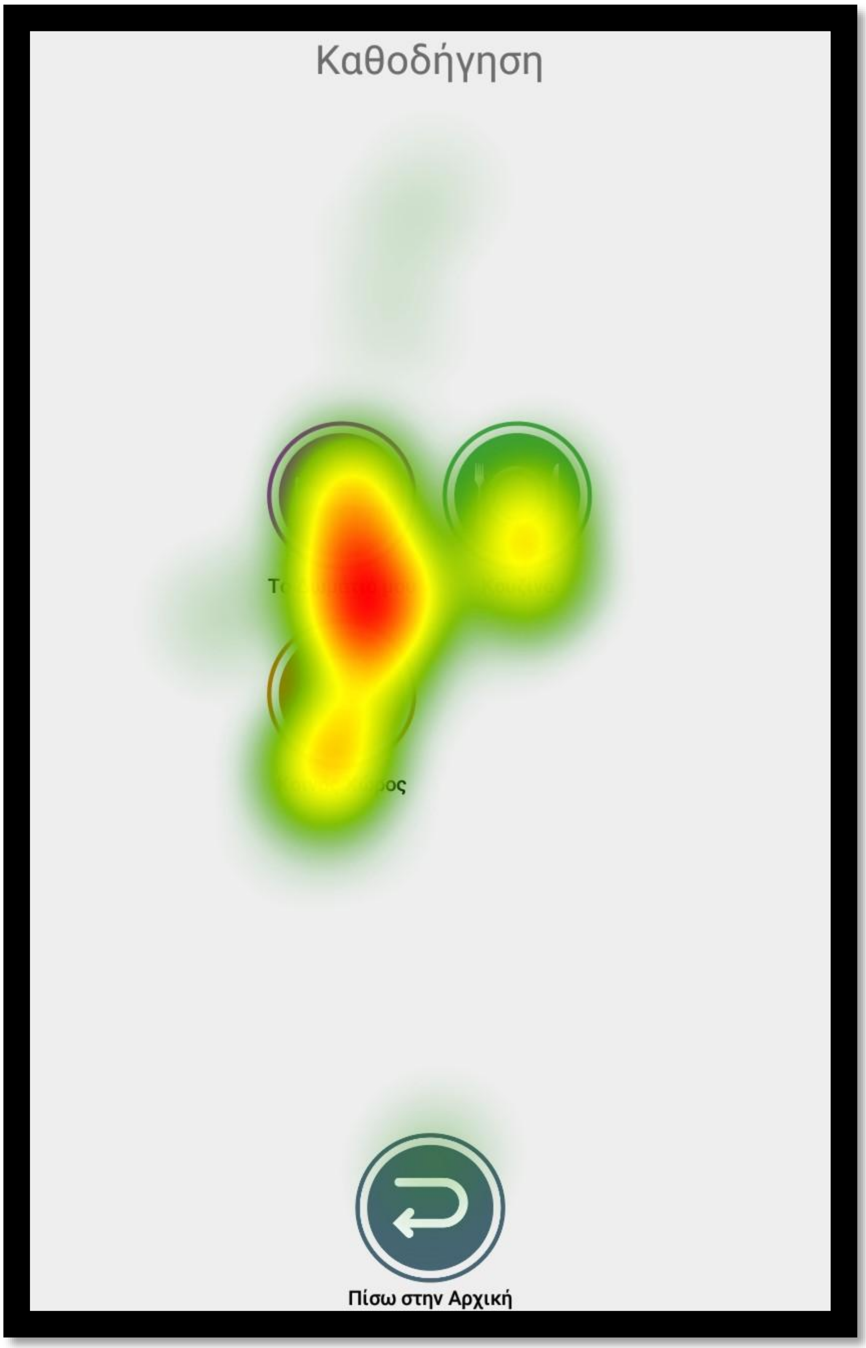


Figure 39. Heatmap of the Guide Me screen (gaze data from all users)

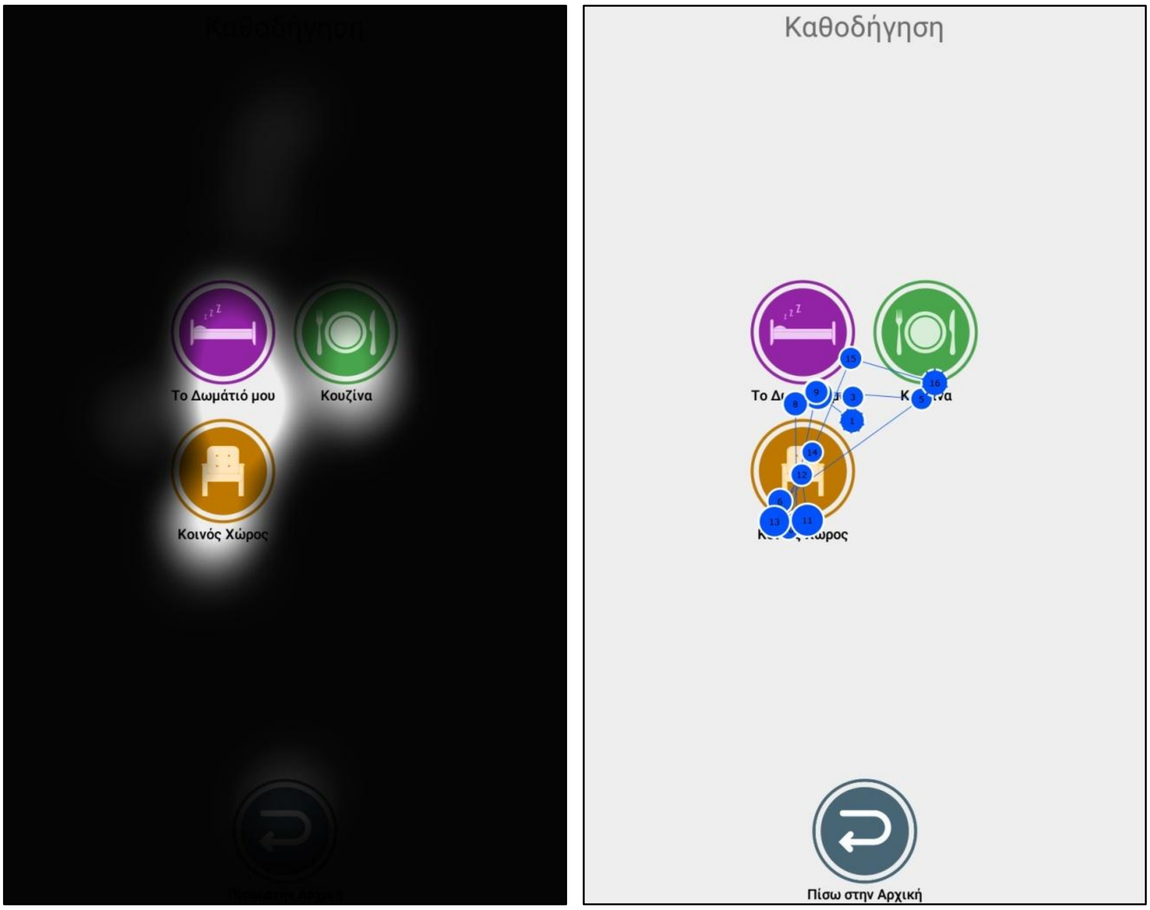


Figure 40. Guide Me screen Gaze Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user)

The same observations as before also apply in this case. The icon on the left topmost position is more noticed by users but they also gaze on the other two icons. Again users seem not to notice the headings which is rather an indication that icons have a predominant role and that users will only look for headings in case they lose their direction (this is something to be examined during the scenarios).

In scenario 1, users were asked to (a) click the appropriate icon to call the doctor and (b) confirm their action when asked to.

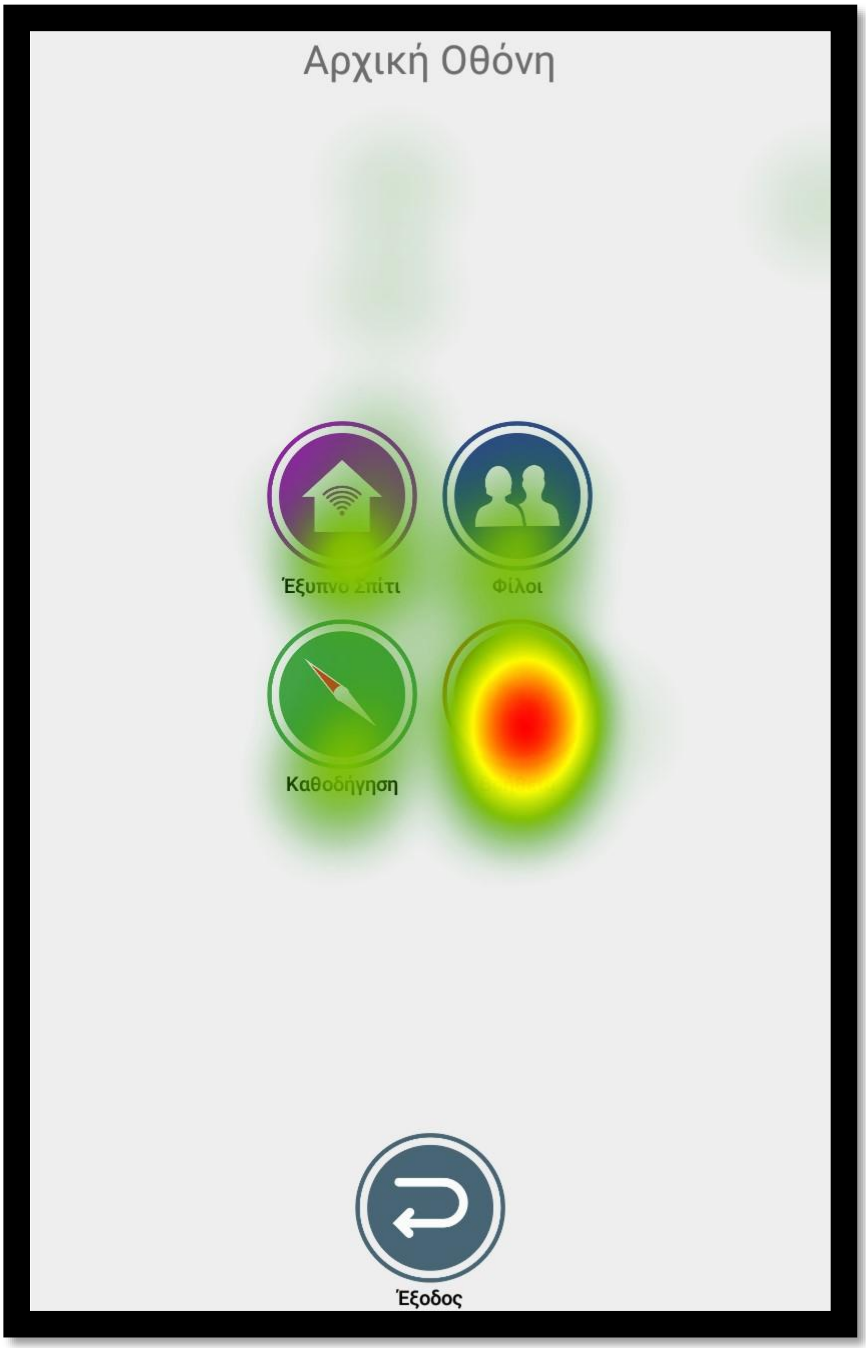


Figure 41. Heatmap of step 1, scenario 1 (click on button to call the doctor), gaze data from all users

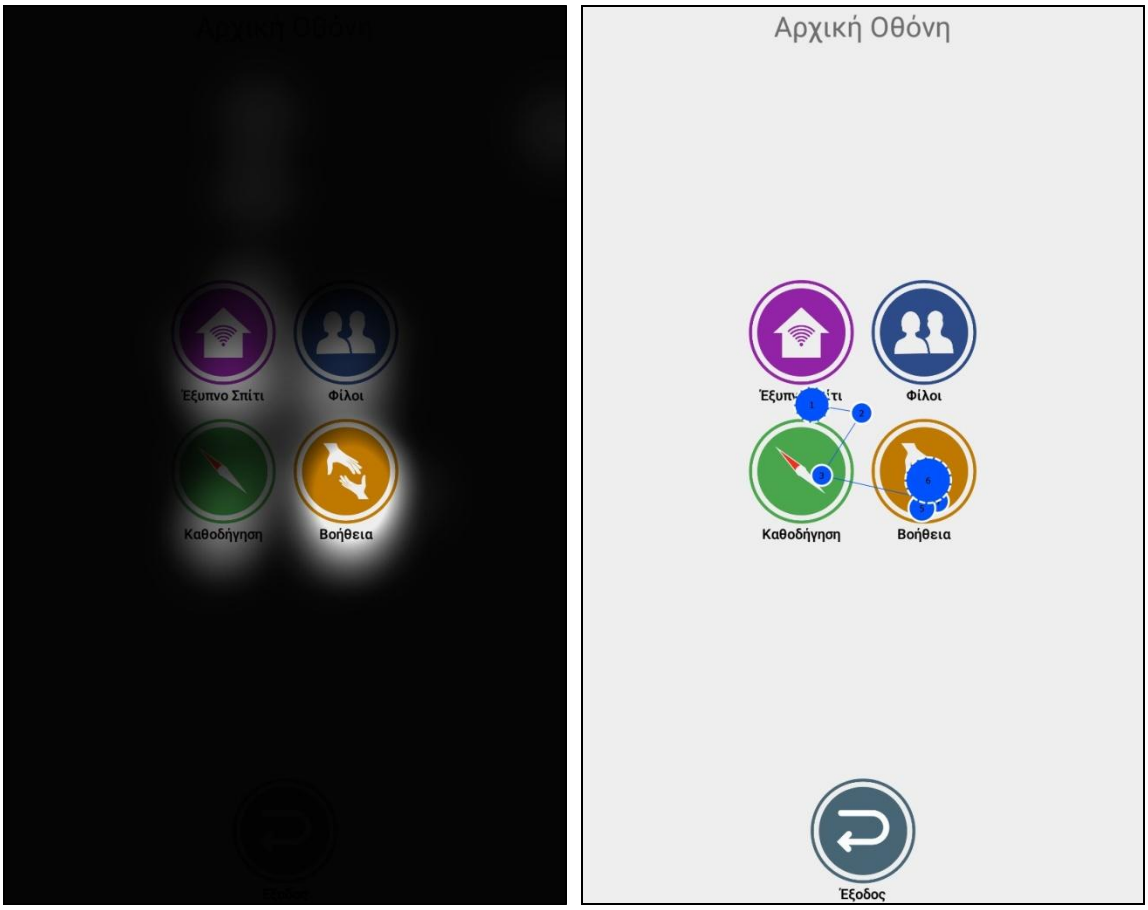


Figure 42. Gaze Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 1, scenario 1 (click on button to call the doctor)

Figure 43. Heatmap of step 2, scenario 1 (confirm that you want to call the doctor), gaze data from all users

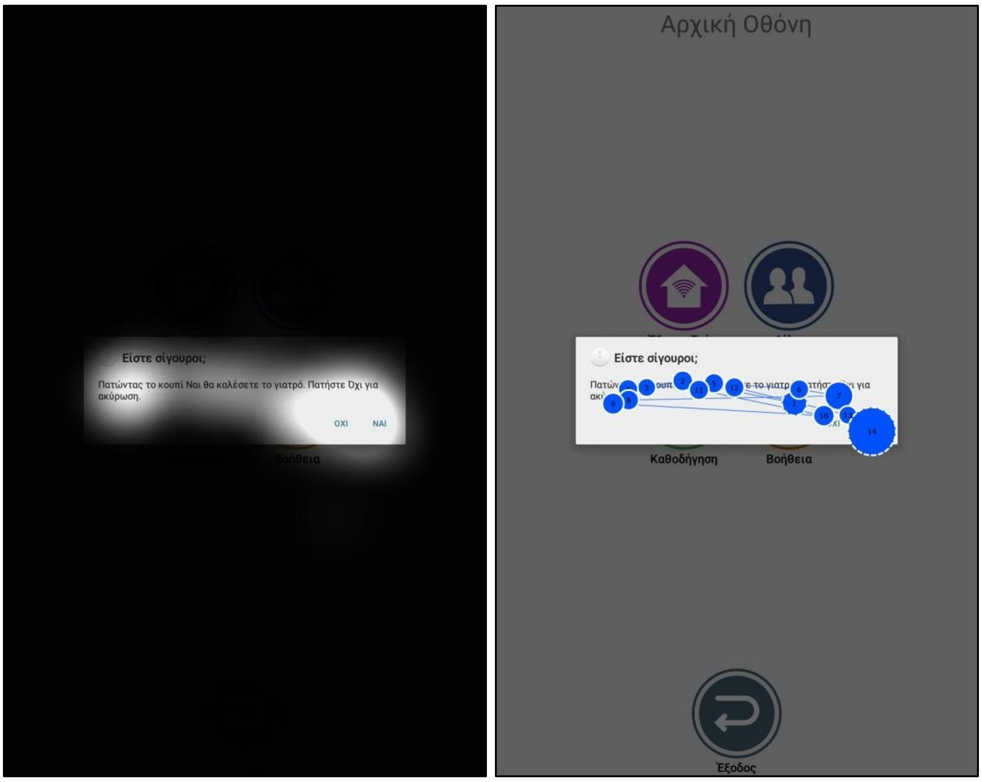


Figure 44. Gaze Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 2, scenario 1 (confirm that you want to call the doctor)

Figure 45. Heatmap of step 3, scenario 1 (close final confirmation message), gaze data from all users

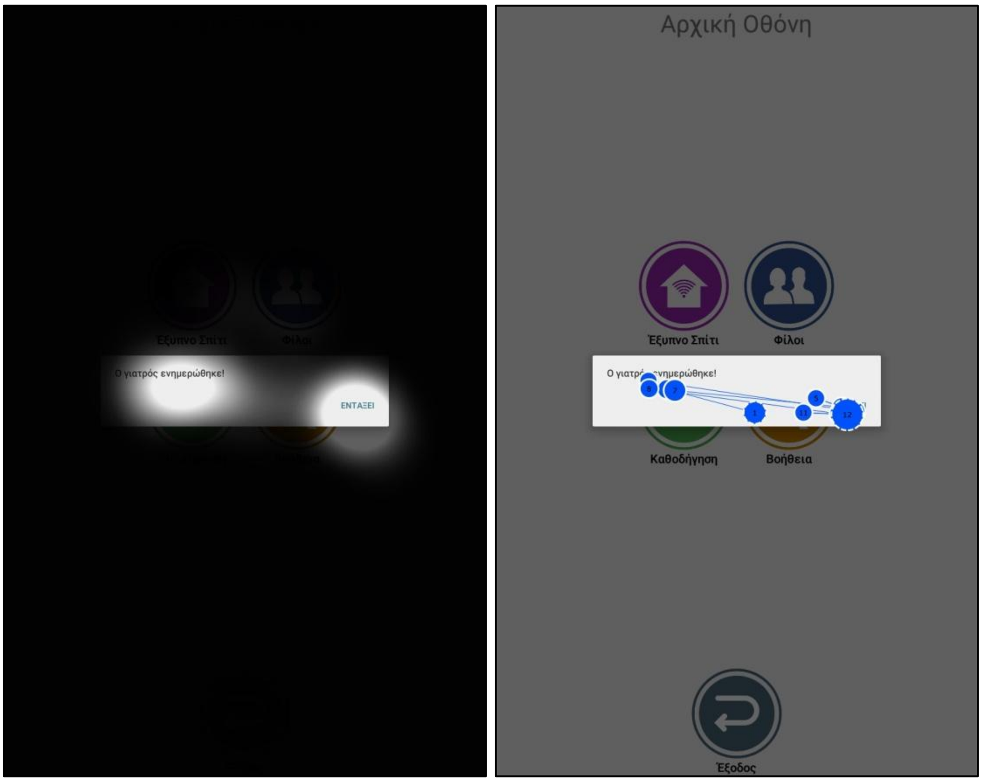


Figure 46. Gaze Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 3, scenario 1 (close final confirmation message)

Users have recognized the correct icon after observing all icons, no user clicked on a 'wrong' icon and users also reacted as expected when they were shown the confirmation message (read the text and the options and selected the one indicated by the scenario). Thus eye-tracking data have confirmed:

- 'Help' icon recognizability
- Readability and understandability of confirmation text message
- Size suitability of confirmation messages options ('No', 'Yes' and 'OK')

In scenario 2, users were asked to (a) call the robot, (b)to guide them to the Kitchen and (c) confirm the action when asked to.

Figure 47. Heatmap of step 1, scenario 2 (call the robot to guide you to the kitchen), gaze data from all users

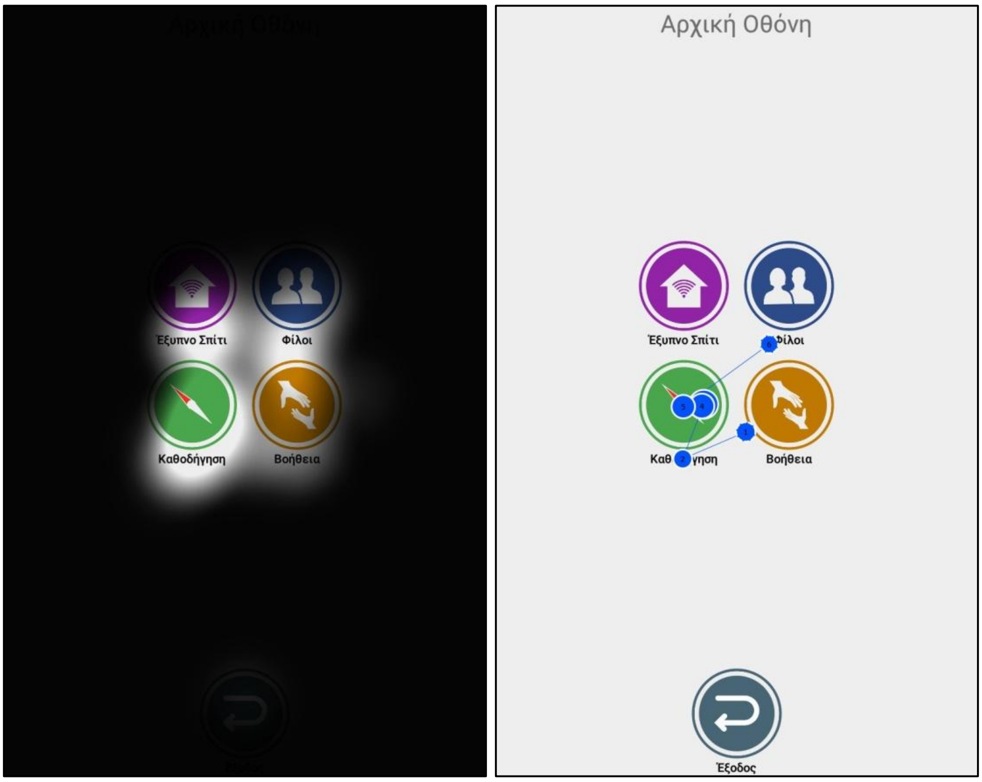


Figure 48. Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 1, scenario 2 (call the robot to guide them to the kitchen)

Figure 49. Heatmap of step 2, scenario 2 (select the kitchen), gaze data from all users

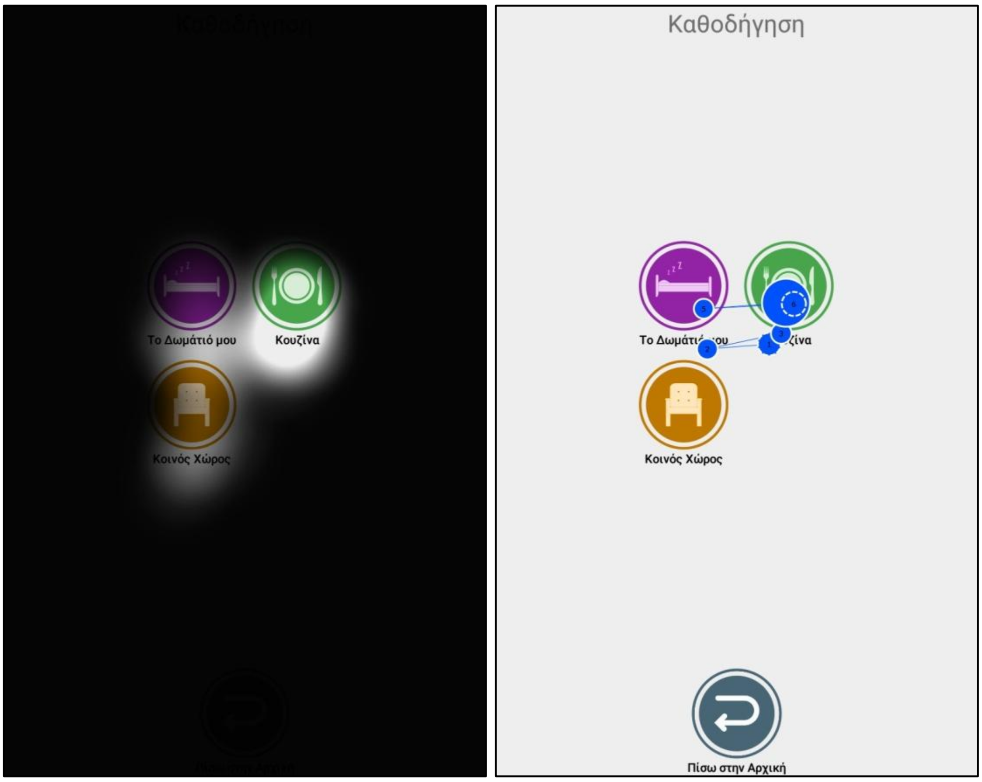


Figure 50. Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 2, scenario 2 (select the kitchen)

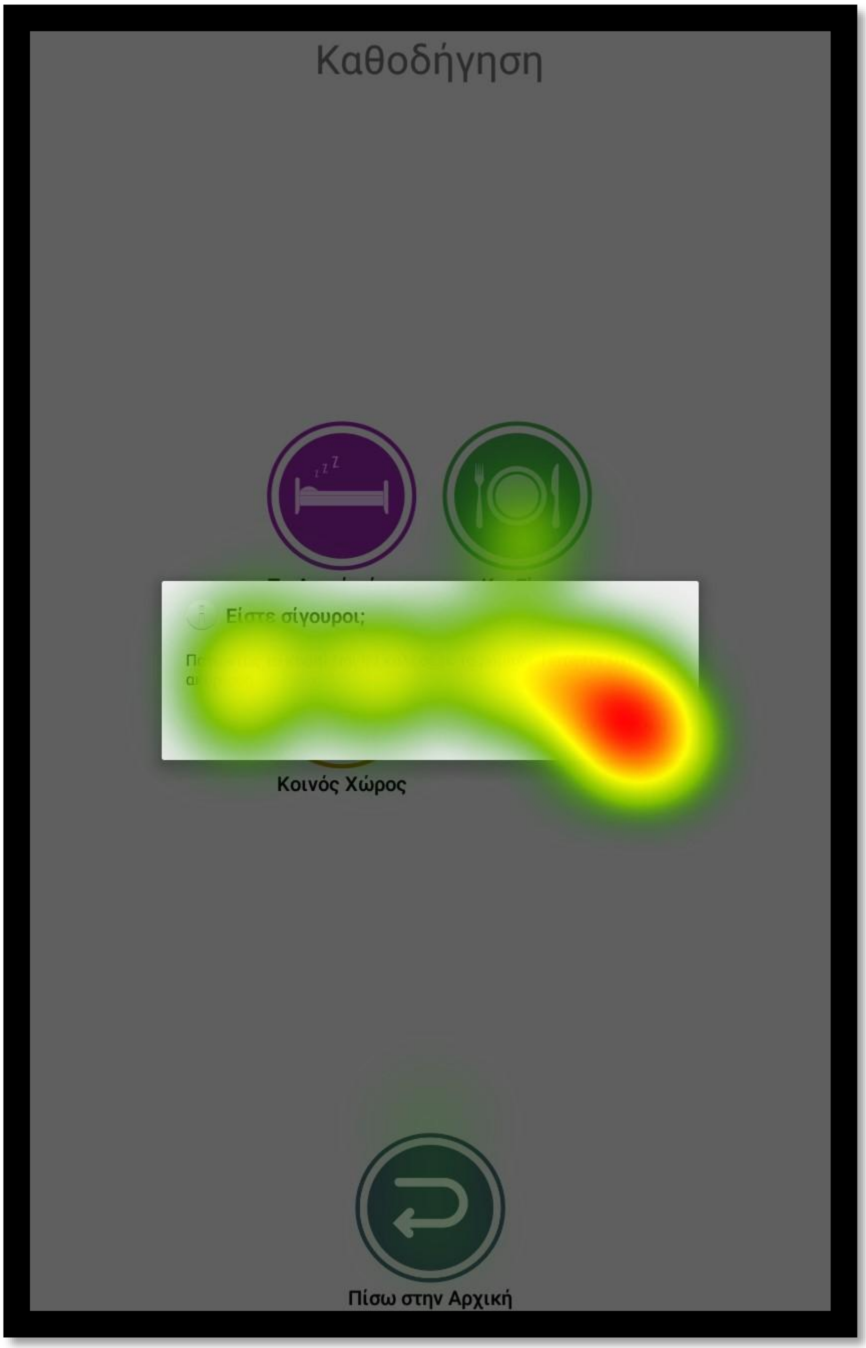


Figure 51. . Heatmap of step 3, scenario 2 (confirm calling the robot), gaze data from all users

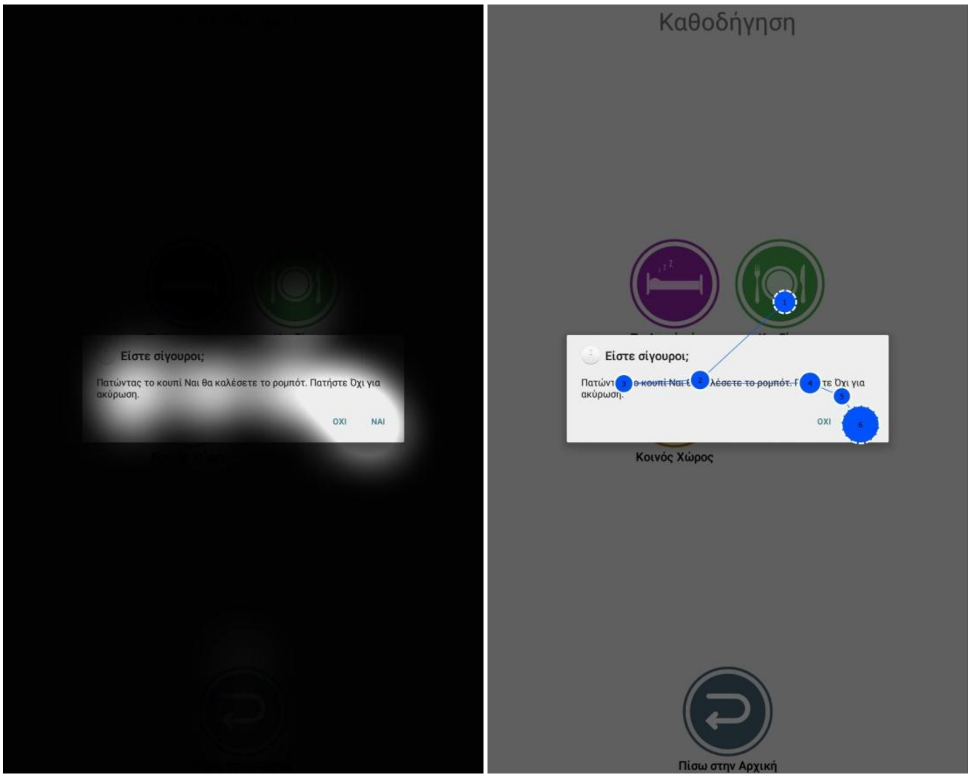


Figure 52. Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 3, scenario 2 (confirm calling the robot)

Figure 53. Heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 4, scenario 2 (close final confirmation message)

Users have recognized the 'Guide me' icon after observing a limited set of icons. That means that at a very early stage of their interaction experience, they recognize and recall the correct icon. In the second screen the 'Kitchen' icon was easily located and selected by all users. No user clicked on a 'wrong' icon and users also reacted as expected when they were shown the confirmation message (read the text and the options and selected the one indicated by the scenario). Thus data collected by the eye-tracker have confirmed:

- 'Guide me' icon recognizability
- 'Kitchen' icon recognizability
- Size suitability of confirmation messages options ('No', 'Yes' and 'OK')

In scenario 3, users were asked to (a) call the robot to guide them to the Common Area, (b) cancel their selection when asked to confirm it, (c) ask the robot to guide them to the bedroom and (d) confirm when asked.

Eye tracking data for step 1 resembled closely the visualization in Figure 47 and Figure 48. Seniors fixated longer on the Guide Me icon and that was their final selection (click). Next, users were should select the Common Area icon. The next two figures confirm that users fixated and finally clicked on the requested icon.

Figure 54. Heatmap of step 2, scenario 3 (select the Common Area), gaze data from all users

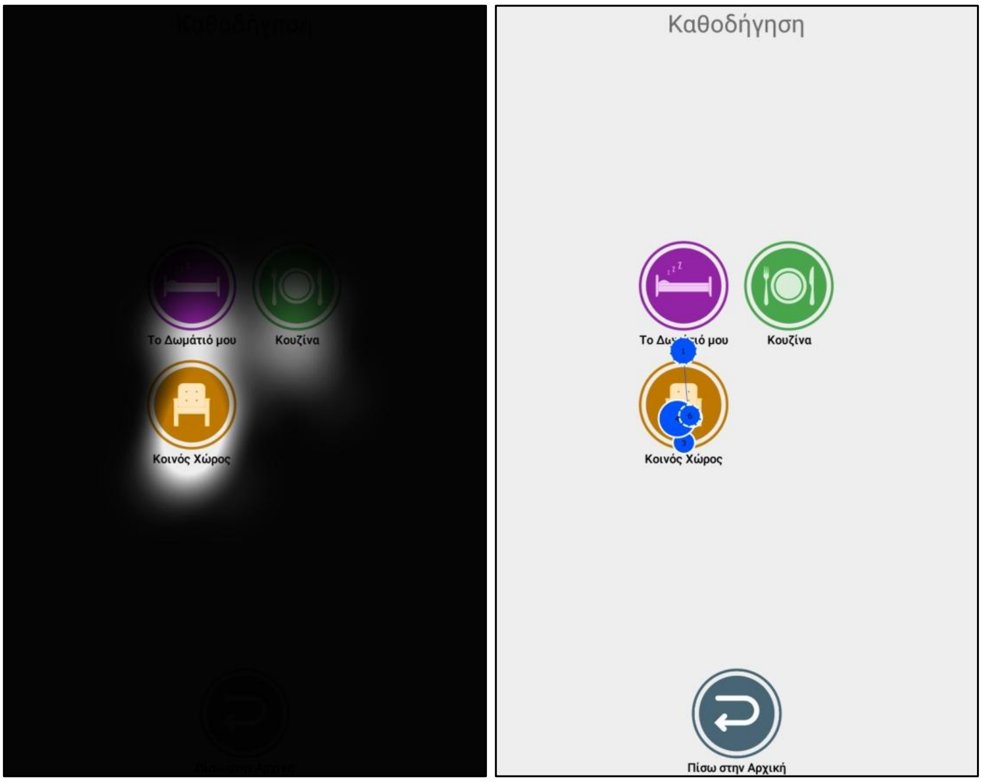


Figure 55. Opacity heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 2, scenario 3 (select the Common Area)

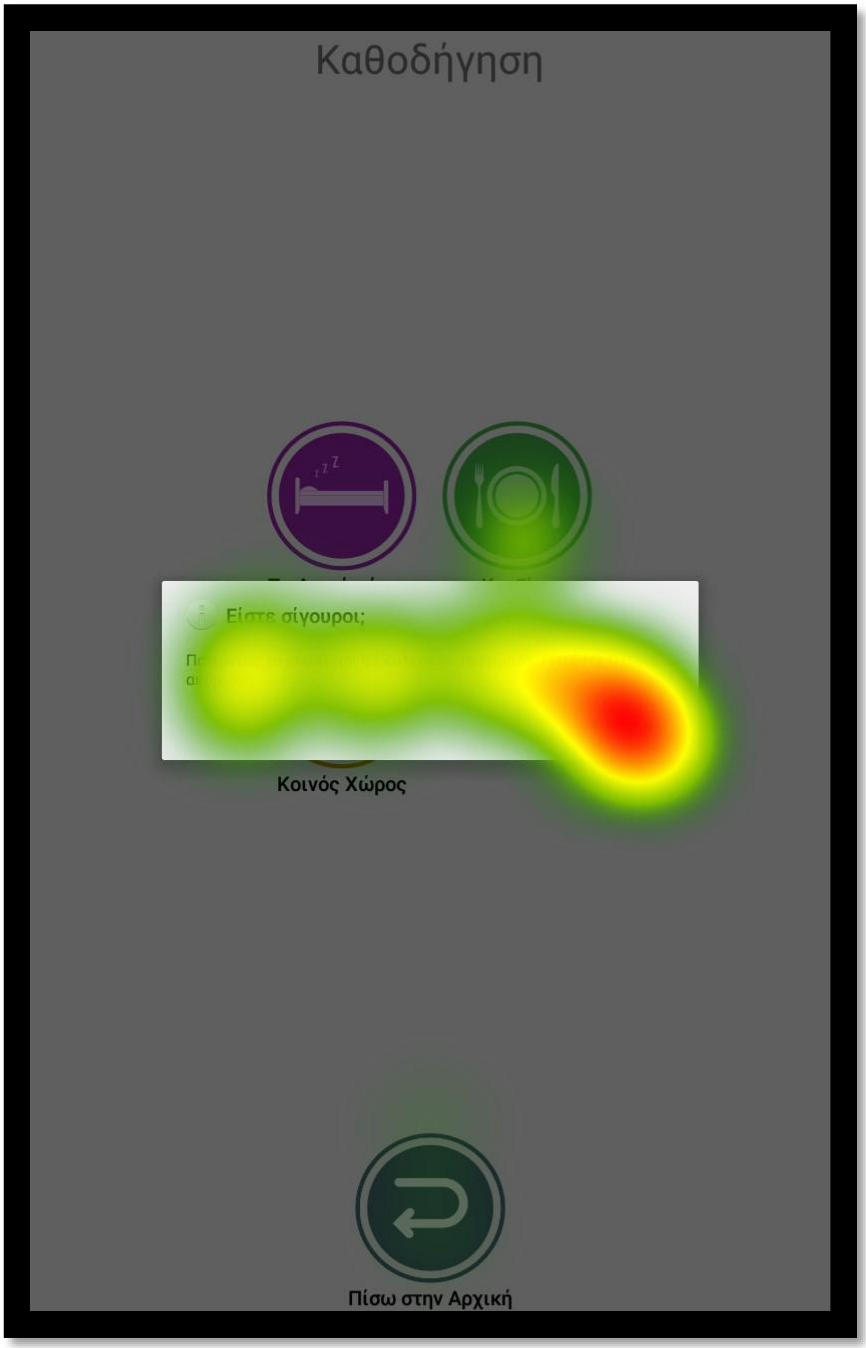


Figure 56. Heatmap of step 3, scenario 3 (cancel the selection of Common Area), gaze data from all users

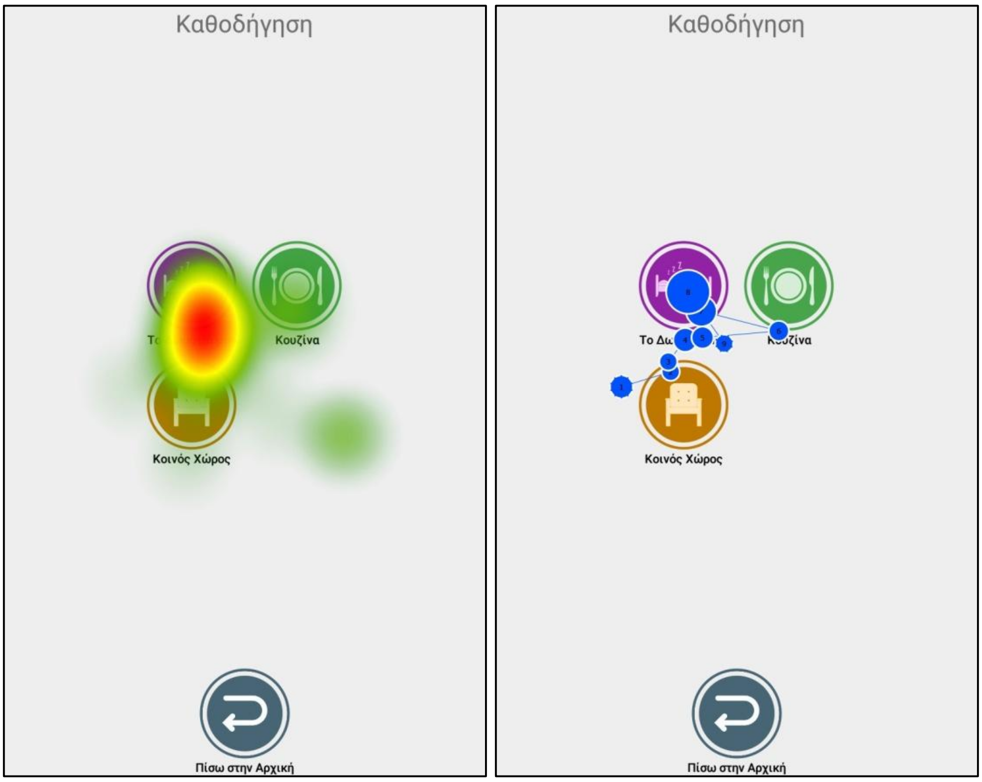


Figure 57. Heatmap (gaze data from all users) and Gaze plot (indicatively, one user) of step 4, scenario 3 (select the bedroom)

Users seem to be very familiar with the main screen of RADIO. The 'Guide me' icon was easily selected. Users have recognized the 'Common Room' icon after a very limited number of fixations in other icons. That means that at a very early stage of their interaction experience, they recognize and recall the correct icon. Quite similar is the case with the 'My Room' icon, although users seem to spend more time looking around (the number of fixations is bigger than the previous two cases). But no user clicked on a 'wrong' icon and users also reacted as expected when they were shown the confirmation message (read the text and the options and selected the one indicated by the scenario). Thus data collected by the eye-tracker have confirmed:

- 'Guide me' icon memorability
- 'Common Area' icon recognizability
- Readability and understandability of confirmation text message
- Readability and understandability of cancelation text message
- 'My Room' icon recognizability
- Size suitability of confirmation messages options ('No', 'Yes' and 'OK')

4 TECHNICIAN'S INTERFACE

4.1 Motion Analysis Area Configuration Component

The motion analysis system works more accurately if it is calibrated to each different environment, taking into account furniture positions. During calibration, the technician uses a GUI to adjust the thresholds that define the areas of interest, such as the threshold beyond which detecting motion signals that the end user has gotten out of bed. Methodological details about visual event recognition are in D3.4, Section 4. Here we present the GUI that is used at installation time to calibrate the system without requiring any specialized knowledge of machine learning techniques.

The configuration GUI has the command menu side-by-side with the camera view, with the current thresholds superimposed on the live video (Figure 58). The technician can use menu commands to move and resize all thresholds. For example, to move the horizontal line higher (effectively representing the threshold beyond which a person is considered to be standing up) the technician pressed the corresponding key in the help menu and the result of each keystroke is immediately visualized on the right (Figure 59). Besides translation, the areas of interest that are defined by bounding boxes can also be resized (Figure 60).

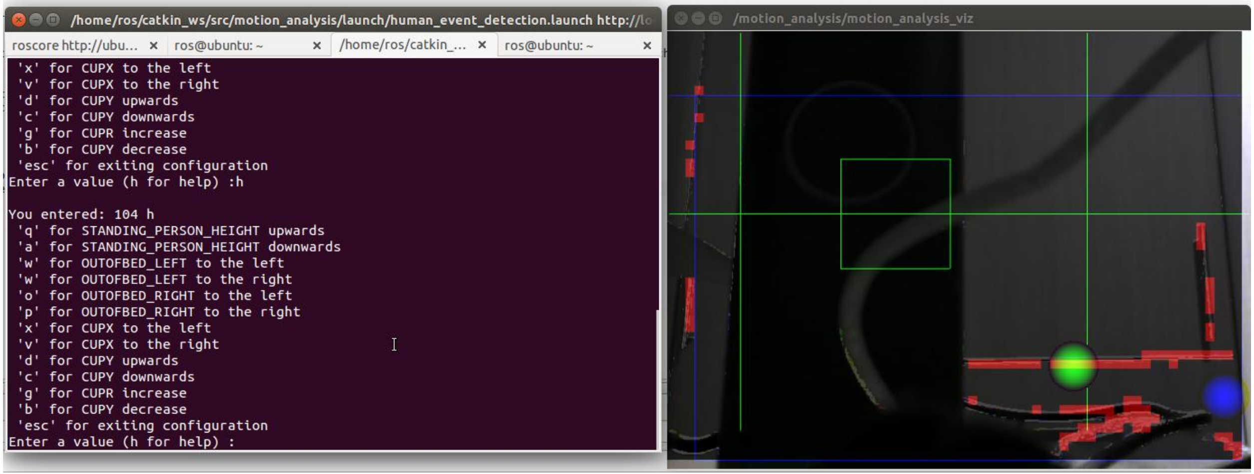


Figure 58: Help and user input menu (left) and visualization of the current thresholds (right).

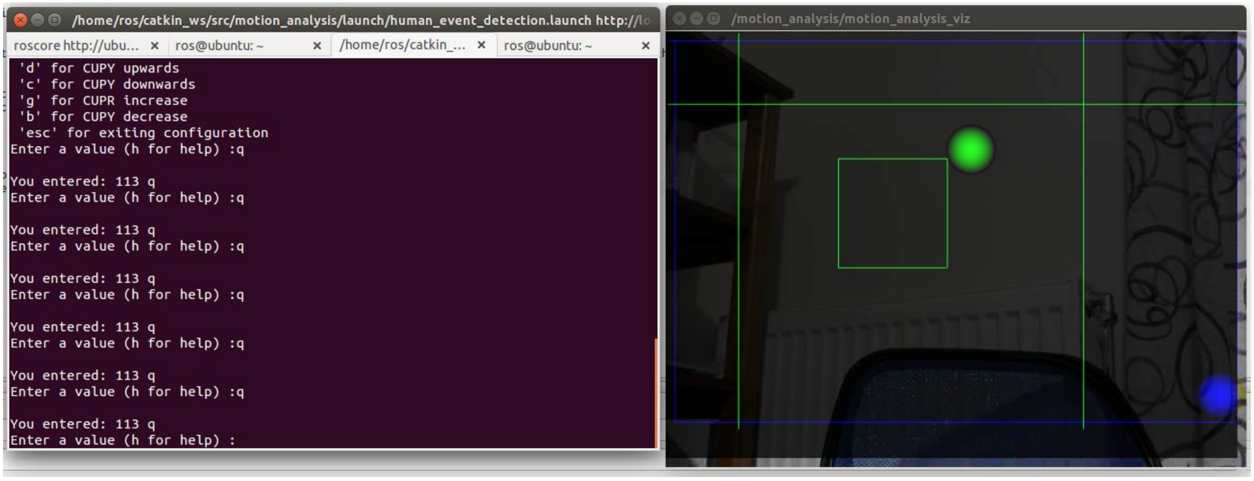


Figure 59: Current thresholds are dynamically visualized as soon as adjusted by the menu.

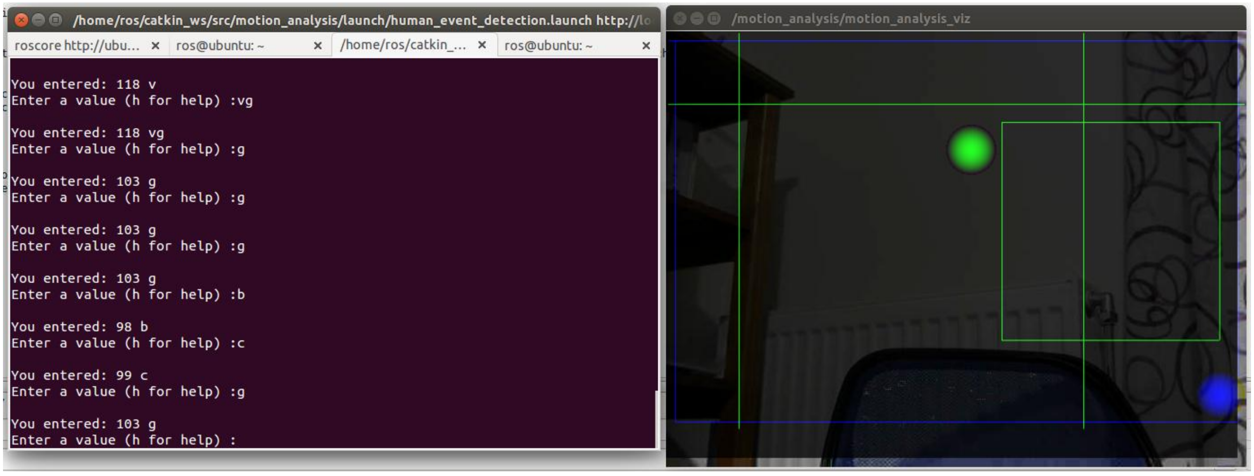


Figure 60: Areas of interest defined by bounding boxes can be translated and resized.

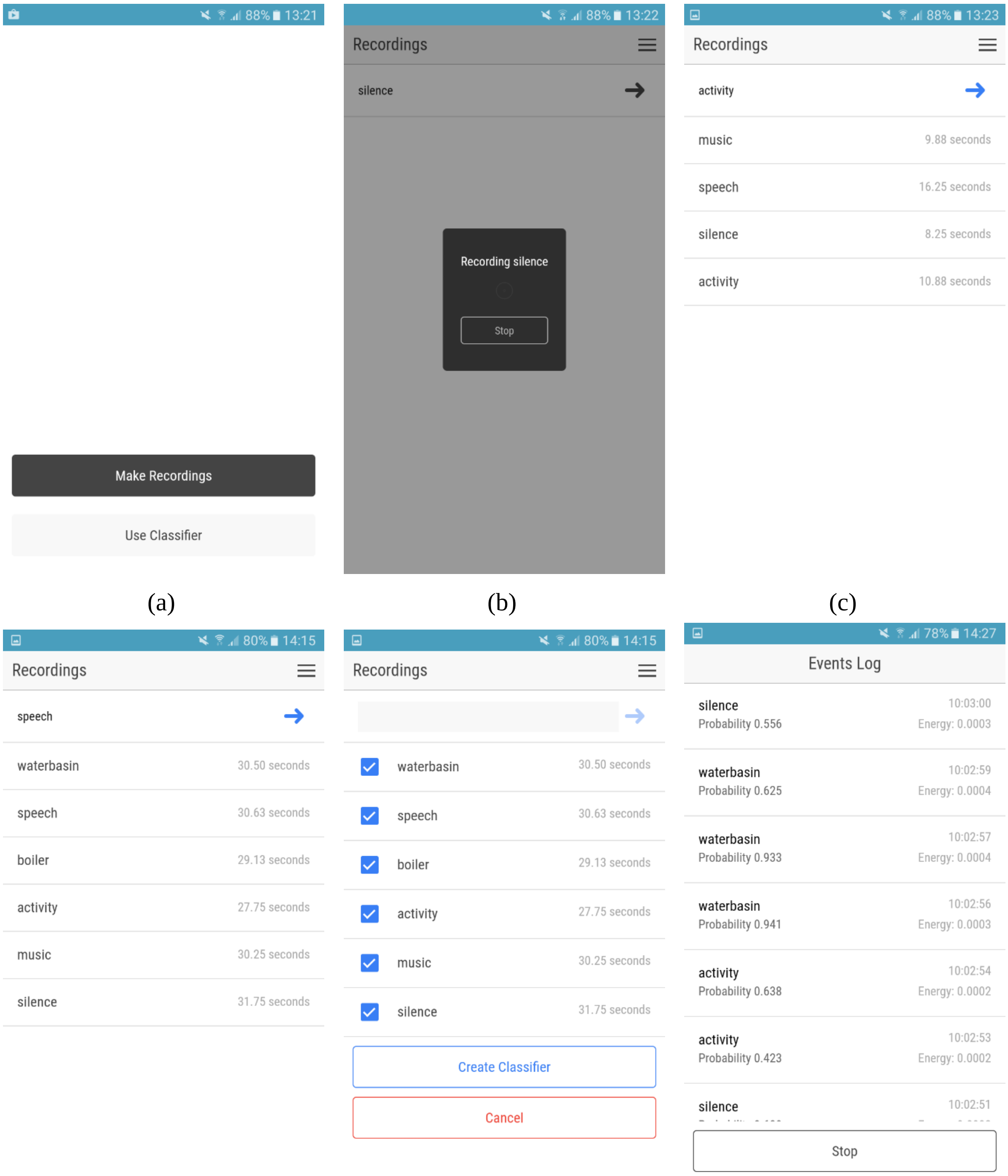
The full motion detection system is executing during calibration, so that the technician can directly test the effect of the changes they make. Once satisfied, the technician saves the thresholds. The system comes with default positions that are used as the starting point for the tool, and can also be left unaltered.

4.2 Acoustic Classification Configuration

The acoustic recognition system works more accurately if it is calibrated to each different acoustic environment. During calibration, the technician uses a GUI to have the system record low-level events and to label these recordings with events. The system them uses these annotated examples to re-train its model so that it better represents the new environment. Methodological details about AUROS, the acoustic event recognizer, are in D3.5, Section 3. Here we present the GUI that is used at installation time to calibrate the system without requiring any specialized knowledge of machine learning techniques.

The GUI is implemented as an Android app. Communication between the mobile app and AUROS is through MQTT. When AUROS is used on the robot, the Main Controller bridges between MQTT and ROS; when AUROS is used as a fixed sensor, it is embedded in a RasberryPI device and communication is directly over MQTT.

An example of screenshots of such a calibration session is shown in Figure 58. The first step is to name the event that will be recorded and then mark the start and end point of the recording (Figures 61a and 61b). The GUI shows the accumulated duration for each event (Figures 61c and 61d). When at least 20sec of recordings for each category have been accumulated, the app activates the “Create Classifier” button (Figure 61e). This notifies AUROS to re-train the acoustic classifier. Once training is completed, the technician can test the resulting recognizer on new sounds (Figure 61f). The technician can add more samples and re-train or, if satisfied, finalize the procedure.



(d) (e) (f)

Figure 61: Characteristic screenshots from the acoustic calibration tool.

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APPENDIX I

Consensus form (in Greek)

Αντίγραφο Συμμετέχοντα

Δήλωση συγκατάθεσης

Αριθμός συμμετέχοντα:_____

Δηλώνω υπεύθυνα ότι έχω διαβάσει τη δήλωση συγκατάθεσης. Η φύση, ο σκοπός και οι πιθανές επιπτώσεις της διαδικασίας μου έχουν εξηγηθεί επαρκώς. Γνωρίζω ότι έχω δικαίωμα να εγκαταλείψω τη διαδικασία οποιαδήποτε στιγμή. Γνωρίζω επίσης ότι διατηρώ το δικαίωμα αναίρεσης της συγκατάθεσής μου αφού δω το οπτικοακουστικό υλικό που με αφορά.

Δηλώνω ότι συμφωνώ στη συμμετοχή της παρούσας συλλογής δεδομένων.

Πάτρα, __ / __ / 2017

____

Υπογραφή

____

Ονοματεπώνυμο [με κεφαλαία]

____

Υπογραφή Υπεύθυνου για το πείραμα

Δρ. Σπυρίδων Συρμακέσης

ΤΕΙ Δυτικής Ελλάδας

Φύλλο: άρρεν □ θήλυ □

Ηλικία : ετών

Χρησιμοποιώ: ☐ Κινητό ☐ Ταμπλέτα ☐ Υπολογιστή ☐ Facebook

Έχετε ενημερωθεί για την διαδικασία;	ΝΑΙ	ΟΧΙ
Είχατε την ευκαιρία να απευθύνετε διευκρινιστικές ερωτήσεις;	ΝΑΙ	ΟΧΙ
Λάβατε ικανοποιητικές απαντήσεις στις ερωτήσεις σας;	ΝΑΙ	ΟΧΙ
Λάβατε επαρκείς πληροφορίες για τη διαδικασία;	ΝΑΙ	ΟΧΙ
Από ποιόν ενημερωθήκατε;	Όνομα	
Γνωρίσετε ότι έχετε το δικαίωμα να: Αποχωρήσετε οποιαδήποτε στιγμή πριν ή κατά τη διάρκεια της διαδικασία, χωρίς να αιτιολογήσετε τους λόγους της απόφασής σας; Αναιρέσετε τη συγκατάθεσή σας αφού δείτε το οπτικοακουστικό υλικό που σας αφορά;	ΝΑΙ	ΟΧΙ

Επιθυμείτε να αναφέρεστε ονομαστικά στις ευχαριστίες;

- ΟΧΙ
- ΝΑΙ, να αναφέρομαι ως:

____

(όνομα με λατινικούς χαρακτήρες),

____

(φορέας, URL, ή άλλος προσδιορισμός στην αγγλική)