IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 26 February 2025, accepted 8 April 2025. Date of publication 00 xxxx 0000, date of current version 00 xxxx 0000.

Digital Object Identifier 10.1109/ACCESS.2025.3559726

Designing Inclusive Smartwatch Interfaces: Guidelines for Enhancing Usability and Adoption Among Older Adults

RUI P. DUARTE[1], VALTER N. N. ALVES[1], AND MICKAEL MOTA[2]
[1]Research Center in Digital Services, Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal
[2]Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal

Corresponding author: Rui P. Duarte (pduarte@estgv.ipv.pt)

This work was supported in part by the National Funds through the FCT-Foundation for Science and Technology, I.P., within the Scope of the Project under Grant UIDB/05583/2020; and in part by the Research Centre in Digital Services (CISeD) and the Instituto Politécnico de Viseu under Project PIDI/CISED/2023/011.

ABSTRACT Aging introduces sensory, motor, and cognitive challenges and limited familiarity with digital interfaces, often hindering older adults' adoption of new technologies. Smartwatches, with their compact size and health monitoring features, promise to improve older adults' quality of life. However, their small screens and complex interfaces create significant usability barriers. While guidelines for mobile and web interfaces exist, frameworks for smartwatch design still need to be explored. This study addresses this gap by proposing smartwatch-specific design guidelines for older adults. Through an analysis of user challenges, existing design principles, and smartwatch constraints, the research formulates actionable recommendations to enhance usability and user experience. The contributions include identifying key obstacles older adults face with smartwatches, evaluating the applicability of established guidelines, creating tailored design principles for small screens, and developing a design system that balances simplicity, usability, and functionality. These contributions aim to facilitate smartwatch adoption and improve the inclusivity of digital technologies for older adults.

INDEX TERMS Design guidelines, human-computer interaction, smartwatch, older adults.

I. INTRODUCTION

Aging makes learning and using new technologies more complex and is accompanied by changes in vision, hearing, coordination, and memory [1]. In addition, most older people have little experience and familiarity with digital interfaces and the design elements that make them up [2]. Based on these challenges, it is relevant that interface design meets the needs of this target public and enables their inclusion.

The complexity of using portable devices presents a significant barrier, often causing many older adults to reject these technologies [3]. To address this issue, the literature provides guidelines for designing mobile applications and websites [2], [4], [5]. However, researchers have not yet developed guidelines for designing smartwatch interfaces. Smartwatches hold potential relevance for older adults as wearable devices that track user activity, including sleep and heart rate. They offer immediate feedback on vital signs, deliver real-time health information, and support healthcare needs. As such, smartwatches could become essential tools for improving the quality of life for older adults [6], [7], [8], [9].

Smartwatches are computerized wristwatches with functions that go beyond simply displaying the time. They are equipped with touch screens and numerous sensors to give the user valuable information. Since these devices are watches, their size is limited, meaning users must interact with small screens. This constraint imposes a rigorous and careful use of the space available on the interface. Standard screen sizes on these devices are between 1 and 2 inches. For example,

The associate editor coordinating the review of this manuscript and approving it for publication was Adamu Murtala Zungeru.

Apple Watch SE (44 *mm*): 1.78'', Galaxy Watch 7 (40 *mm*): 1.31'', and Garmin Venu 2 (45 *mm*): 1.3''. By way of comparison, some of today's standard smartphone sizes are between 6.1 and 6.7 inches (e.g., iPhone 15:6.1'', Samsung Galaxy S24:6.2'', Google Pixel 8 Pro: 6.7''). Smartwatches have recently gained popularity as a non-intrusive solution for monitoring daily activities. They are widely used and have given rise to various remote health monitoring applications, most centered on assisting autonomy at home [6], [7].

They can provide several essential functionalities that could save lives, such as detecting a fall, enabling real-time monitoring of vital signs (e.g., heart rate or body temperature), and locating the wearer, which can be very important in the case of a person with cognitive impairment [10]. This device can also be very effective as a reminder to take medication or keep appointments [11], [12], [13]. Smartwatches offer several advantages over traditional monitoring devices. Their compact size enables comfortable, all-day wear without inconvenience, making them particularly suitable for older adults who may find larger devices cumbersome [10]. Their portability also makes smartwatches appealing for monitoring daily activities, especially for older adults who are frequently on the move. Additionally, smartwatches are simple to use and require no special clothing or accessories. They can be worn like a regular watch and do not disrupt daily activities. Smartwatches are unlikely to feel intrusive for many older adults, as they are accustomed to wearing conventional watches [14], [15]. Consequently, smartwatches can be seamlessly integrated into daily routines, offering a discreet monitoring solution for those who prefer not to feel constantly observed [16].

According to the United Nations Organisation [17], the number of people aged 65 years or older worldwide is projected to more than double by 2050, rising from 761 million (2021) to 1.6 billion, and one in six people in the world will be over age 65 [18]. It is, therefore, important not to exclude that population group from using new technologies. One of the critical factors in the acceptance of technology is the usability of its interface. The complexity of an interface often leads to rejection, which is also the case with older people [2], [19].

Usability sets are compromised by different factors, one of which is age. Indeed, the difficulties associated with age are numerous, including those related to sensory issues. The most affected senses are audition, vision, and touch. Estimations indicate that around 40% of individuals experience hearing loss significant enough to impede social interaction and environmental safety by age 65. In addition, loss of sensitivity to high-frequencies in sound is a common occurrence in auditory decline [20]. Moreover, visual impairments are also more pronounced in older adults, especially concerning dark adaptation, the extent of the visual field, visual processing speed, and perceptual flexibility [1]. Movement control is also affected by aging due to illnesses: seniors need more time to respond to tasks since their moves are less precise [21]. At the cognition level, the difficulties encountered include loss of attention and memory problems [1], [22].

In addition, the fact that many older adults are less familiar with new technologies than other user groups creates a lack of familiarity that prevents them from finding their way around the interface using their existing knowledge to act in an unfamiliar field. Interaction designers, therefore, need to consider these difficulties to create solutions that allow for positive user experiences. In this work, we consider older adults to be people over 65, although, in other works, other ages are considered [23], [24].

Interaction design concerns how people interact with technology, creating user experiences [25]. Designers and developers need to focus on the user and not the system. Two contexts are important to achieve good interface design: User Interface (UI) and User Experience (UX). Users interact with applications through the user interface (UI), while user experience (UX) reflects their overall perceptions of the product. UX can encompass a wide range of factors, focusing on usability components and the emotional impact on the user. A positive UX encourages users to accept the interface and tolerate minor faults, whereas a negative UX often discourages continued use. Effective UX includes all elements that enable users to perform tasks that meet their needs within a specific context. Conceptual metaphors align the interface with the user's natural tendency to learn through analogy. These metaphors, created using conceptual models, enable users to draw on familiar knowledge when interacting with an unfamiliar domain [26].

Researchers are developing design guidelines to create smartwatch interfaces tailored to the needs of older adults, providing clear guidance for application development on these devices. This work is based, first and foremost, on a study of the needs and difficulties of older people concerning interaction with digital interfaces. Secondly, it identifies guidelines created for this audience on other devices. Finally, it draws on the specifications of smartwatches for that purpose. The aim is to cross-reference these data to determine design guidelines for the target audience that are realistically usable on this device. This study explores a current gap in the literature. It aims to enable the creation of interfaces that meet the needs of older adults, easing their use of smartwatches [27], [28].

Three main research questions are defined:

- *(RQ1)*: What challenges and impediments do elderly individuals encounter when engaging with digital interfaces, particularly on smartwatches?
- *(RQ2)*: How do existing interface design guidelines tailored for older adults, developed initially for alternate devices, align with the design prerequisites and usability considerations inherent to smartwatches?
- *(RQ3)*: How can interface design guidelines for smartwatches balance constraints specific to the device and the necessity to provide diverse functionalities to agree with the multifaceted needs of elderly users?

The main contribution of this work is to propose design guidelines for smartwatch interfaces that enhance the user experience for older adults by addressing their specific usability challenges. This involves identifying the difficulties they encounter in interacting with digital interfaces, analyzing existing design guidelines developed for other devices, and adapting them to the context of smartwatches. The proposed guidelines will be transformed into practical recommendations and translated into interface components organized within a design system. To achieve this, the work is divided into specific objectives: examining the obstacles older adults encounter with digital and smartwatch interfaces (*O1*), analyzing the relevance of existing guidelines across devices (*O2*), creating smartwatch-specific guidelines that account for user needs and the constraints of small screens (*O3*), and developing a generic design system that balances simplicity, usability, and functionality to meet the diverse requirements of older adults (*O4*).

The remainder of this paper is organized as follows. Section II presents the theoretical framework supporting the work of this paper. Section III focuses on the methodology used to filter and identify guidelines. Section IV starts by presenting the process of defining the 21 guidelines, followed by a description of them and their applications to the design of smartwatch interfaces. Section V concludes the paper, providing perspectives for future work and limitations.

II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This section presents the theoretical framework of the study. The first section presents relevant concepts, followed by the use of smartwatches and the challenges that older adults face. Finally, the related work is presented.

A. MAIN CONCEPTS

Interaction design aims to create products that enable users to achieve their objectives in the best possible way. It focuses on the dialogue between users and technology, optimizing interaction to improve the interface or product's appeal. Interaction design is essential for shaping the user experience during interaction, so it is a practice that influences not only the effectiveness and ease of use of a product but also user satisfaction and emotion. The role of interaction designers is to define the architecture, functionalities, and interactions of digital devices, taking into account users' emotional and cognitive aspects and the context of the environment in which users interact. They aim to create a harmonious relationship with users by creating simple and meaningful experiences [29]. Users interact with applications through the **User interface** (UI). This includes all the components that enable users to carry out tasks that cover the user's requirements in the context of use. The primary objective of a user interface is to allow efficient and easy interaction between the user and the system [30].

User experience (UX) pertains to how users perceive a product, encompassing a variety of perspectives. The measurement of UX focuses on both the usability elements and the emotional impact on the user during interface interactions. A positive impact fosters user acceptance and tolerance for faults, whereas a negative impact indicates that the interface is unlikely to be utilized [31], [32]. Design principles are fundamental concepts and considerations that designers apply to create functional designs, improve usability, and make effective design decisions. Hierarchy, for example, is one of these principles, suggesting that interface elements should be arranged according to a visual hierarchy and that the most critical information should be emphasized [33].

Application Design guidelines are recommendations to guarantee consistency and best practices when designing products, applications, or websites. Guidelines give designers a structured framework to ensure the final product is user-friendly and easy to use. Guidelines can encompass various aspects such as typography, colors, navigation, and layout. Furthermore, these guidelines can assist designers in steering clear of common errors, improving usability, guaranteeing consistency, and ensuring that their designs cater to the users' accessibility needs [34].

B. SMARTWATCHES

A smartwatch is a wearable device that combines the functions of a traditional wristwatch with advanced features found in smartphones. It operates via a touchscreen, often with a few side buttons, and connects to paired smartphones via Bluetooth to collect data. Many models also have Wi-Fi connectivity, and some advanced models feature LTE, enabling independent operation for calls, messages, and apps. Smartwatches provide quick and convenient access to information, especially when using a smartphone is impractical or impossible [35]. These devices are designed to be lightweight, achieved not only through their small size but also due to the materials used in their construction, such as polymer, aluminum, and titanium [36]. Their lightness allows for all-day wear without feeling bulky on the wrist.

Smartwatches share similarities with smartphones regarding hardware and software, including components such as working memory, storage memory, processors, and operating systems. The most commonly used operating systems for smartwatches are Android Wear and Apple Watch OS. Additionally, they feature wireless connectivity via Bluetooth or Wi-Fi, and most devices use an LCD or OLED touchscreen and are powered by rechargeable lithium-ion batteries, much like smartphones [37].

Smartwatch manufacturers offer various essential functions and health applications that utilize sensors to collect data traditionally reserved for medical or sports equipment. These sensors can measure sleep, blood oxygen saturation, and heart rate [38], [39], [40]. Conventional text input through a keyboard is particularly challenging on these small devices.

As a result, manufacturers often promote alternative input methods, such as dictation or AI-suggested responses, as seen in Samsung Galaxy [41].

Smartwatches may include various sensors, such as GPS for geo-location, which are essential for weather updates, distance traveled, and assisted navigation. They also feature movement sensors, including accelerometers and gyroscopes, which help save battery life by turning the display on or off depending on wrist movements. Pedometers are used to track physical activity, including steps and routes. Other sensors include barometers and thermometers for weather data and NFC for contactless payments. More recent models also incorporate health sensors, such as infrared sensors for pulse and blood oxygen levels and electrical sensors for electrocardiogram (ECG) measurements [10], [42], [43].

Studies have highlighted the use of smartwatches in various applications, such as fall detection [7], [44], real-time activity monitoring [10], [45], and the analysis of health data related to the cardiovascular system, blood pressure [9], [46], [47], stress levels [48], and posture [49]. These devices are also employed for daily assistance in areas such as medication adherence [50] and support for individuals with cognitive difficulties [6].

Several unique features of smartwatches stand out compared to other devices in daily use, such as smartphones, tablets, or computers. The distinctive characteristics identified in this study include their small screen size, wrist-worn form factor, lightweight construction, minimal physical buttons, alternative input methods (which reduce the need for a keyboard), discreet design (resembling traditional watches), and an extensive range of sensors.

C. CHALLENGES FOR OLDER ADULTS

As individuals age, they undergo many changes encompassing various aspects of their physical, cognitive, emotional, and perceptual abilities. These age-related changes can significantly impact daily lives, health, and overall quality of life. Understanding the nature of these changes is crucial for developing effective strategies to improve interface design and address the specific needs of older individuals.

1) VISUAL

An initial indication of aging manifests as near-focus impairment or presbyopia. This condition arises when the crystalline lens in the eyes becomes stiffer and, therefore, less flexible. As a result, the lens has difficulty focusing on close objects, leading to blurred vision [51]. This age-related change becomes noticeable around age 40 and progressively worsens over time. It can be managed effectively with corrective lenses such as reading glasses, which help to counteract the loss of flexibility in the eye's lens, enabling adults to see up close [1], [2], [21], [52]. Another standard change accompanying aging is a decline in visual acuity. This decrease, known as diminished visual acuity, is prevalent among older adults and reduces the clarity of vision, causing objects to appear less distinct. A common cause is cataracts, which lead to opacification of the natural eye lens, leading to blurred or hazy vision. Other causes include diseases affecting the retina, such as macular degeneration, which makes it difficult to perceive fine detail and causes objects to appear distorted or blurred, and diabetes. Visual field narrowing can also affect older adults, reducing peripheral vision, meaning that the ability to see objects or movements outside the central field of vision is compromised [1], [52].

Age-related changes in the lens and retina can cause a natural decrease in color perception. This alteration can manifest itself as difficulty in perceiving specific colors accurately. There tends to be a decline in color perception within the violet-blue-green range of the spectrum. As a result, the colors yellow and red are more easily distinguished. Thus, older individuals typically find it easier to perceive and differentiate bright, warm colors compared to cooler ones [1], [52]. In addition, the ability to detect contrast often diminishes with age. This decline can be attributed to various factors, including changes in the eye lens, retina, and visual processing pathways. Thus, older adults may have difficulty distinguishing objects from their background, especially in low-light conditions or environments with poor contrast. There is, therefore, a need to increase contrast to make it easier to distinguish between elements [1], [51], [52], [53].

Older people also adapt more slowly to changes in illumination, especially when adapting to darker conditions. Indeed, light perception decreases since fewer photoreceptor rods are in the eye. For example, individuals with this problem may take longer to adapt to light conditions when moving from a bright to a dark environment. Thus, greater levels of illumination and enhanced contrast are required for improved clarity [1], [2], [52]. Moreover, the pupil becomes smaller with age, and less light can enter the eye, implying that more illumination is necessary for sharp vision. Also, older adults are more sensitive to glare, i.e., vision is impaired by direct and reflected light. Alterations to the vitreous humor or the presence of cataracts can cause light to be scattered inside the eye, causing this difficulty. Consequently, adequate lighting is essential to minimize glare and optimize visual clarity [1], [2], [52].

2) HEARING

Auditory sharpness frequently diminishes as a natural part of the aging process. In fact, during aging, cellular atrophy occurs in the cochlea, which is the primary detector of incoming auditory signals and other components of the hearing sensory system [21]. This decline, known as presbycusis, usually includes progressive hearing loss deteriorating over time, difficulty hearing high-frequency sounds, and ringing or whistling in the ears commonly known as tinnitus [1], [2], [20], [21]. As a result, sound perception and voice recognition are significantly impaired, particularly for low-intensity sounds, which appear to be silenced. In addition, older adults have difficulty identifying the location of a sound, even more so when they have only one ear. Stimuli to one ear can, therefore, cause disorientation. Using both ears when possible is relevant to localizing sound [1].

Regarding auditory attention, older adults have difficulty disregarding competing information reaching the ears. This difficulty affects the differentiation of speech from background noise and speech recognition. Furthermore, understanding distinct sounds at fast rates is an additional difficulty, as recall diminishes as the rate of speech increases. This decline can also affect performance in multitasking environments [1], [2], [21], [52].

3) COGNITION/MEMORY CHANGES

Cognitive aging losses are related to a reduced capacity for executive functions such as attention, memory, decision-making, comprehension, and spatial cognition. At the neural level, these changes are linked to the fact that the prefrontal cortex, a brain region associated with executive function, experiences a significant reduction in tissue volume with advancing age compared to many other brain structures [21]. The decrease in attention, the capacity to maintain focus on a particular stimulus, implies that it takes longer to shift attention, and older adults may struggle to suppress irrelevant information. Understanding information quickly, making timely decisions, and managing several simultaneous tasks is a challenge [1], [2], [51], [53].

Issues with working memory, the active memory of what is currently perceived or thought about, although it might not impact simple procedures, compromise the recall of multiple instructions and information. Older adults may experience information overload and difficulty multitasking because they are less able to retain large amounts of information in their working memory [1], [2], [51], [52]. Regarding future memory, recalling planned actions and remembering tasks scheduled at specific times can be more difficult for older people than remembering event-related tasks. For example, it may be more challenging to remember to take a medicine at a specific time than to remember when a particular event occurs, such as a sound or visual reminder [1], [21]. Procedural memory encompasses the retention of skills and tasks learned in the past. This encompasses well-practiced routines almost unconsciously, like driving, which generally remain largely intact in older individuals. While older people can transfer old skills to new contexts and learn new skills, the process may require more time, a slower pace, and increased opportunities for practice and repetition to achieve proficiency [1].

Language comprehension is also affected as individuals age, making it more challenging for older adults to understand verbal and written information and make inferences. Specifically, subtlety, irony, and unfamiliar context can hinder the ability to conclude [1], [54].

Lastly, concerning spatial cognition, the mental manipulation of spatial information becomes more challenging as individuals age, adversely affecting performance in computer tasks and the ability to orient based on cues mentally. Reduced capacity for executive functions such as attention, memory, decision-making, comprehension, and spatial cognition can all negatively influence the use of interfaces [2], [52].

4) MOTIVATION

A significant correlation exists between confidence and willingness to adopt technologies [55]. Barriers such as limited digital skills, negative feelings associated with previous technology failures, and computer anxiety can significantly hinder the adoption and use of digital technology [24]. Lack of familiarity with technology and computer-related anxiety can prevent users from perceiving the ease of use and usefulness of technology, reducing their desire to use it [55], [56]. Insufficient confidence can pose a significant barrier to successful usage and even the initial attempt to utilize technology [57].

D. TECHNOLOGY ADOPTION AMONG OLDER ADULTS

Numerous technologies have the potential to significantly improve the quality of life for older adults in various domains, including health monitoring, home automation, social connectivity, cognitive and mental support, and mobility. Technological advances can benefit older adults by promoting their independence and improving their daily lives despite the difficulties associated with old age. There is a notable disparity in technology adoption rates between older and younger populations, with older adults less likely to adopt new technologies [58], [59]; this prevents them from taking advantage of the potential benefits, which might suggest that this audience is not interested in using technology. Still, studies have been carried out on the acceptability and use of technology by older adults, concluding that older people can be interested in learning how to use it. Participants in these studies came from various social and geographical backgrounds and had different cognitive abilities and knowledge of technology. These disparities did not impact the results obtained by the researchers, regardless of the technology tested. Participants expressed strong interest in using mobile applications to track their health observations and symptoms. Participants emphasized the benefits of mobile health apps that offer enhanced interactivity, individualized health monitoring, and personalized medication information [60]. Older adults also expressed an interest in using a communication application [61]. As other research indicates, older people recognize the benefits of digital technology, and most are keen to learn how to use it effectively [23], [62]. Overall, older adults are motivated by learning to use new technologies that can help them improve their quality of life and maintain their independence [63].

1) DAILY USAGE

Older people can not only be interested in technology but also be able to embrace it and use it daily. Many areas and devices have been reviewed by researchers, such as technology-based exercise, which had an excellent utilization rate and could offer a sustainable way to promote physical activity and prevent falls among older adults [64]. Concerning the use of mobile technologies for medication adherence, older people may be committed users, as mobile applications are perceived as valuable tools for taking medication [60]. In addition, a device such as a wristwatch enabling monitoring health conditions can also have a high take-up rate and can be adopted for long periods [65]. Finally, it should be noted that in these studies, the personal situation of the participants had no significant impact on their willingness to learn to use the technology. However, preconceived ideas about aging and technology can negatively affect their confidence and motivation.

2) PERCEIVED VALUE AND IMPACT

Factors such as perceived value and impact on quality of life significantly influence the decision to adopt new technologies [66], [67]. The fact that technology is deemed useful and can positively impact daily life is a factor contributing to its adoption. On the other hand, older adults are reluctant to use technologies they do not see as offering any benefits. Evidence for a direct link between perceived usefulness and technology adoption has been found across various technologies [68].

3) SUPPORT AND TRAINING

Support and training before and during the use of technology are also important factors to consider. Older people are often less familiar with and confident about new technologies than younger people. Also, technologies requiring much effort to learn or use are generally unappreciated. Given the lack of experience with technology, proper coaching and appropriate support are essential [68]. Older people prefer to be trained before using a new technology, and training should be targeted at this audience rather than generic. Training programs, including written manuals and face-to-face training, can be more effective if designed to account for low technological literacy, lack of confidence in new technology, and age-related difficulties. [61], [63], [68]. In addition, individuals within the social circles of older adults, including family and friends, can play a crucial role in adopting technology products [66]. Typically, younger individuals, such as grandsons or sons, act as intermediaries between the device and the user, enabling the user to develop habits and cues thanks to their guidance and encouragement [61], [68].

4) PRIVACY

Personal privacy violations and data privacy concerns are also important in technology adoption. Older adults still have suspicions about new technology, even those accustomed to using computers or smpartphones [53], [60], [63]. Older adults prioritize data privacy concerns but will be open to sacrificing some privacy as long as the technology proves beneficial to them [66], such as utilizing remote monitoring and sharing data with healthcare professionals if it can aid in identifying emerging health issues [65].

5) EASE OF USE

Not surprisingly, a critical factor in technology adoption is ease of use. This characteristic refers to how users can use a technology effectively and satisfactorily. That implies enabling users to perform their tasks accurately in a reasonable time, making learning and understanding the technology easier and minimizing errors and, therefore, user frustration. Older people can be apprehensive about technology because of concerns and frustrations about ease of use, which may inhibit their desire to adopt it. In this context, usability can be the source of user satisfaction [69]. This audience, therefore, generally chooses to adopt the technology that is easiest for them to use [61], [65], [68]. For example, when several health monitoring devices are offered to this audience, the device most frequently used during research is the simplest to use [65]. Thus, for example, older adults who find an application valuable and easy to use are likelier to adopt the technology and integrate it into their daily lives [61].

6) EMOTIONAL RESONANCE

Technology should be designed with emotional considerations in mind. A product's ability to connect the user to something they feel is a significant part of its appeal [68]. Those affective benefits should also be evident to older adults. While many older adults can feel lonely, one way of playing on the emotional level can be to bring the user closer to their family. For example, a device with features that make it easier to communicate and share experiences with the family or one that allows features to be personalized with characteristics that are dear to the user (e.g., being able to use, in an application, a voice message recorded by a person close to the user), may imply greater motivation on the part of this audience [70]. The cost of a technology can also have an impact on its adoption. Indeed, high cost can drive older people away from using technology [68], as they may tend to focus on its cost rather than its benefits [71]. For example, research has shown that the perceived expense of smartwatches negatively influences the intention of users across all age groups to utilize wearable technology [35].

7) INDEPENDENT LIVING

The desire for independence significantly influences technology adoption among older adults [66]. Older adults want to remain independent for as long as possible, even when age-related changes make daily life more difficult.

Technologies that help older adults to remain independent, allow them to control their functions, and do not emphasize aging or frailty are more likely to be adopted and used by this audience [68]. Technologies that enhance or support independent living are especially appealing, enabling older adults to manage their daily activities, health, and social interactions with minimal reliance on others. Independence-enhancing products can significantly improve older people's receptiveness to new technologies. This need to remain independent is also crucial in terms of technology design. A device designed for this audience, which, due to its appearance or mode of operation, could make its user appear dependent, fragile, or in need of assistance, may discourage older adults from using it due to the possibility of being stigmatized. It is preferable to embed or integrate features into everyday items commonly used by people of all ages instead of designing specific devices dedicated to a single function [68]. Connected watches, for example, seem to meet this need. They offer a host of features for this audience while at the same time being commonly used by all types of users, and therefore do not reflect a targeted audience that fights against stigmatization [6], [14], [15], [16].

E. RELATED WORK

According to the literature, several sets of guidance for designing applications for older adults mainly focus on Web and mobile aspects. However, guidelines still need to be developed for smartwatch devices, making the development of guidelines for designing smartwatch interfaces an innovative initiative in this field.

Mustaquim et al. [72] conducted a study on the impact of Universal Design (UD) principles on accessibility issues for elderly adults, involving 31 participants from an elderly care home. Universal Design is defined as designing products and environments that people of all ages and abilities use without needing adaptation. The study aimed to explore how existing UD principles influence accessibility for older adults in their daily lives. An empirical investigation was conducted with a closed group of older adults using assistive technologies and other systems designed for them. The findings indicated that UD principles had a limited impact on supporting accessibility, and participants identified additional factors, particularly social considerations, that UD did not address. This highlights the inadequacy of current design principles in defining accessibility for older adults.

In a related study, Iancu and Iancu [2] reviewed solutions for mobile technology design for older adults, driven by the idea that improving design can lead to greater technology acceptance and use among this demographic. The review examines older adults' cognitive and physical characteristics, emphasizing key factors to consider when designing technology for them. It also discusses the features that devices intended for older adults should have and provides an overview of current market offerings. This review contributes by discussing the role of design in the technology acceptance process, addressing the technological and personal challenges older adults face, and offering a structured approach to designing technology that meets their needs. Additionally, it evaluates the existing technology supply tailored to older adults in the market.

Similarly, Gomez-Hernandez et al. [4] systematically reviewed the literature on mobile app design for older adults based on usability testing. Their review, which analyzed studies published between 2010 and 2021, identified 27 design guidelines derived from usability tests with individuals over 60. Two key principles emerged as particularly significant: simplifying the design and increasing the size and spacing of interactive controls. These guidelines, categorized into five groups with subcategories, provide valuable insights for developing mobile apps that address the needs of older adults, ensuring the design is both user-friendly and effective for this demographic.

Patsoule and Koutsabasis [5] presented a case study on redesigning a tourist web portal to make it more senior-friendly. The redesign process involved several stages. First, they established seven principles and 45 guidelines for web design tailored to older adults. Next, the original website underwent a heuristic evaluation based on these principles and guidelines. The third stage involved redesigning the website into an interactive online prototype and conducting a comparative summative usability evaluation with 12 older users, followed by post hoc interviews and questionnaires. The results demonstrated that the redesigned website was significantly more usable and acceptable to older users than the original version.

Additionally, a study on the design of mobile health applications for older adults was conducted [73]. Given the lack of existing guidelines for designing applications specifically for this user group, the researchers aimed to derive guidelines from usability tests to help designers create health applications that older adults could effectively use. They evaluated three healthcare applications through cognitive walkthroughs, heuristic analysis, and user testing to achieve this. These evaluations revealed several design issues that could hinder usability for older adults, including poor navigation, small button sizes, and inadequate data visualizations. Based on these findings, the authors developed a set of nine guidelines to enhance the usability of mHealth applications for older users, addressing their cognitive, perceptual, physical, and motivational needs.

Other researchers [74] presented the design and evaluation process of a mobile application user interface aimed at promoting exercise and preventing falls among older adults. The interface was developed iteratively, with each version refined based on feedback from usability testing. Each testing session identified user difficulties, which informed subsequent design improvements that were re-evaluated to enhance usability. After completing three iterations of design and testing, the authors provided general recommendations for designing mobile interfaces targeted at older adults based on the insights gained throughout the process.

Nurgalieva et al. [75] conducted a systematic literature review on design guidelines for touchscreen applications targeted at older adults. Their review analyzed 52 research articles to identify, classify, and evaluate design guidelines derived from research in this area. The findings resulted in a taxonomy-based literature analysis, which led to a comprehensive list of design guidelines that can be applied when developing inclusive touchscreen applications for older users.

Similarly, Farage et al. [1] presented a comprehensive analysis of age-related changes and their impact on daily life, classifying them into five categories: visual function, hearing, touch and temperature perception, mobility and balance, and memory and cognition. For each category, the authors proposed specific design guidelines to address the challenges posed by these changes. These guidelines aim to design products, communication materials, and physical environments that are better suited to meet the needs of older adults, helping designers consider age-related factors in their work.

In another study, Lewis and Neider [21] proposed recommendations for the design of wearable devices for older adults, motivated by the idea that digital wearable technologies can assist in addressing age-related challenges, particularly in areas such as health and well-being. These wearable devices, worn on the wrist, head, or attached to clothing, allow users to interact with them via tactile or vocal means without requiring physical handling. The authors assessed older adults' cognitive, physical, and sensory abilities and provided 23 design recommendations tailored to this demographic. These recommendations focus on enhancing the usability of wearable devices, which can monitor environmental conditions and provide personalized information through various sensors.

The studies mentioned above provide valuable guidelines for designing interfaces that address the needs of older adults across various devices, such as mobile applications and websites. While many of these guidelines apply to smartwatches (e.g., ensuring high contrast between foreground and background colors), some may pose usability challenges. Smartwatches differ significantly from traditional smartphones, tablets, or computers, primarily due to their smaller size and reduced screen area. This limited screen space necessitates careful space management in the interface to ensure readability and usability.

Specific guidelines, such as "Large screen with large icons/buttons", "Avoid location", "Controls close to the edge of the screen", and "Designers should avoid scrolling", may be complex to implement effectively on smartwatches. These design recommendations, suited to larger screens, must align with the constraints posed by the small display sizes of wearable devices. As a result, the significant differences between the form factors of smartwatches and other devices suggest that the guidelines developed in previous works are not directly applicable to smartwatch interface design for older adults.

III. METHODOLOGY

Developing interface design guidelines for smartwatch applications that support older adults requires several key steps. The process workflow is summarized in Figure 1. A review of the existing scientific literature is required. Firstly, it is crucial to understand the difficulties older adults face since age-related changes in visual, auditory, perceptual, motor, and cognitive abilities, coupled with a lack of experience with digital interfaces, are critical factors in understanding the needs of older people and adapting interfaces accordingly. Secondly, it is necessary to examine the guidelines found in the scientific literature. Various guidelines exist in the literature for designing interfaces geared toward different devices and users. Therefore, most of the existing guidelines in the literature must be analyzed for several devices, making it possible to establish common points between them, which will provide important indicators for the proposition of guidelines in the case of smartwatch interfaces. As part of this project, it is necessary to summarize and group the guidelines found in the literature into a list to satisfy the previous point.

The methodology for obtaining the proposed guidelines consists of eight stages, described chronologically in Figure 2.

We identified 161 guidelines from seven studies under the specified search conditions, which we refer to in this work as "reference guidelines". We organized these guidelines in a table that lists the guideline number, authors, domain, description, explanatory text, reformulated guideline, and reference. Next, we reformatted several guidelines as needed to ensure compatibility with other guidelines for the later stages of the study.

Third, we created a Miro file to facilitate team brainstorming. The reference guidelines were then classified and grouped into subcategories based on similarity. Next, we analyzed these categorized guidelines in light of the specific constraints of smartwatch features, comparing them to identify any potential contradictions. This step allowed us to filter the guidelines based on their compatibility with smartwatches.

Next, the analysis of similarities between the prepared and filtered reference guidelines led to their synthesis into "proposed guidelines". Finally, recognizing that the initial classification – assigning a single class to each guideline – was not suitable for this project, we switched to a multiple-criteria classification, where each guideline could belong to several classes.

Once we determined the proposed guidelines, we created summary cards for each, enabling quick and easy review. We also added two new sheets to the Excel file. The first is called "Guidelines Overview". It summarizes the analysis results for each reference guideline, making it easy to see which reference guidelines led to which proposed guidelines and which were filtered out. The second sheet is titled "List of Proposed Guidelines". It includes detailed information on the

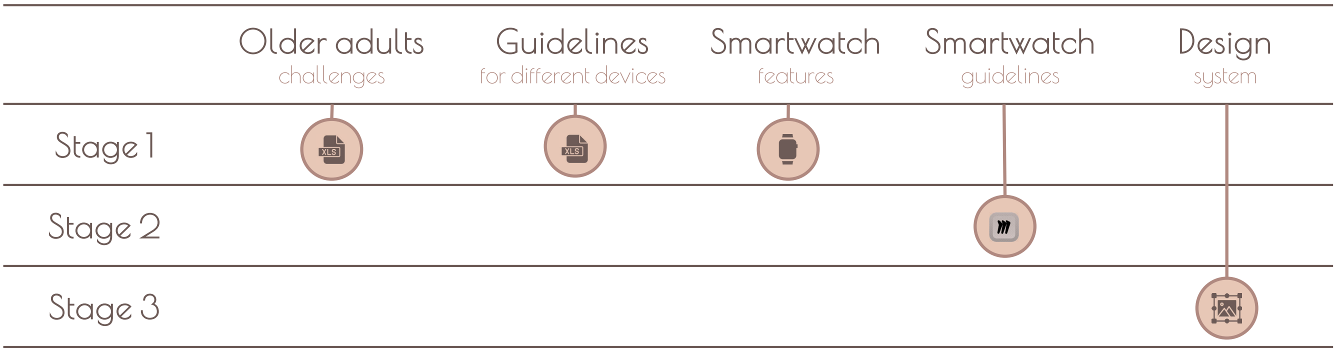


FIGURE 1. Process workflow.

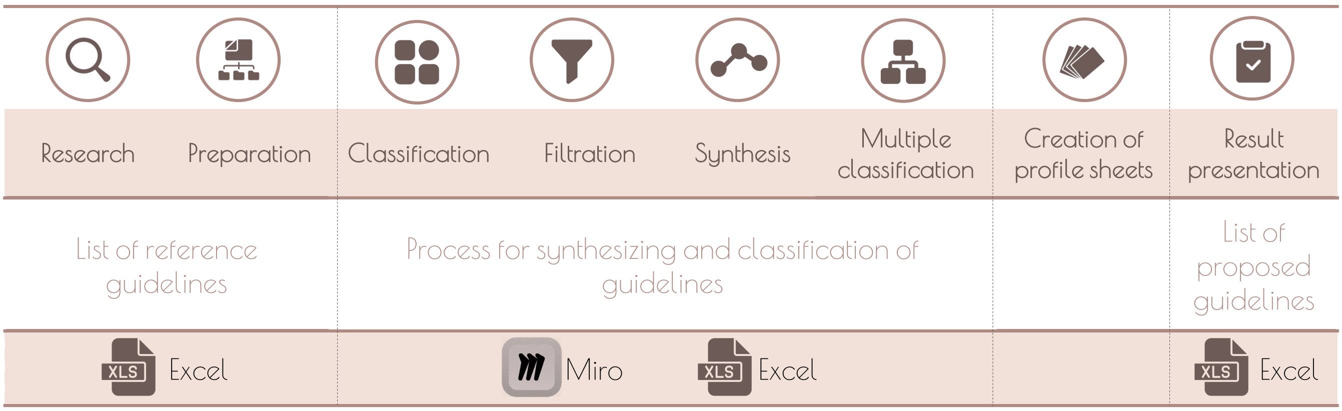


FIGURE 2. Stages of the process leading to the proposed guidelines.

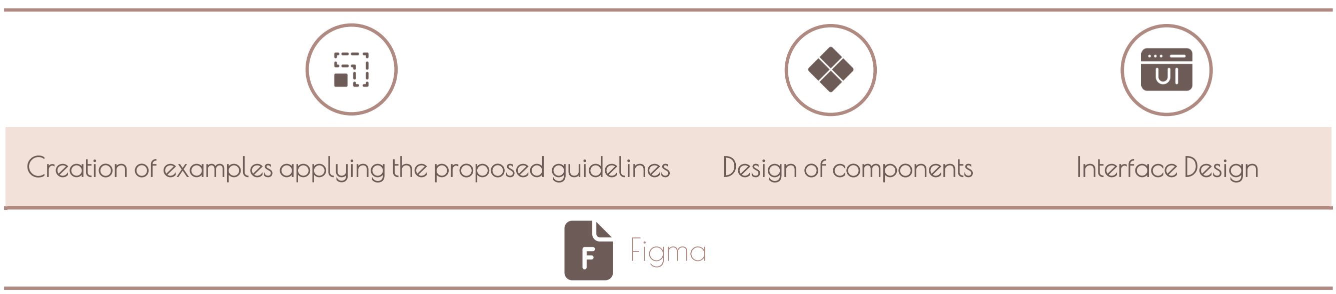


FIGURE 3. Stages to create the design system.

proposed guidelines, such as their domains of origin, titles, synopses, explanatory texts, and classifications.

The previous step provides a framework for developing a design system using Figma software, which comprises generic components and concrete examples of applying the proposed guidelines. This set of design elements could make it easier to understand and use these guidelines in other works involving the design of smartwatch interfaces for this target audience. The stages in the development of this part of the work are described in Figure 3.

Firstly, we considered possible concrete cases in which the guidelines should be applied. After this, we selected several examples to illustrate their use. Next, we implemented the components for the interfaces designed in the previous stage, such as buttons, lists, text, and colors. Finally, we created the suggested interfaces by applying the proposed guidelines to these components.

IV. SPECIFICATION OF GUIDELINES

This section details the work to propose smartwatch interface design guidelines for older adults.

A. PREPARING AND FILTERING

As described in the methodology chapter, we created a list of reference guidelines to organize the guidelines found in the literature. This list initially included four columns: *Number*, *Author*, *Domain*, and *Guideline*. We used the *Number* column to assign an identification index to each guideline. In contrast, the *Author* column lists the authors' names to make it easy to trace each guideline's source. The *Domain* column indicates

TABLE 1. Examples of the initial analysis for the list of reference guidelines.

#	Author	Domain	Guideline	Explanation
1	Iancu & Iancu [2]	Mobile	**Large screen** with **large icons/buttons**	The screens should be large enough to incorporate icons of at least 9.6 millimeters diagonally (or 11 millimeters if a mouse is used)
3	Iancu & Iancu [2]	Mobile	**Space between interface elements** that function in a sequence manner should be around 0.2 cm, and the space between unrelated buttons should be around 1 cm apart in the diagonal.	The space between interface elements that function in a sequence manner should be around 0.2 cm, the space between unrelated buttons should be around 1 cm apart in the diagonal
...	...	...	...	...
54	Gomez-Hernandez et al. [4]	Mobile	**Minimize** the use of **keyboard**	
55	Gomez-Hernandez et al. [4]	Mobile	Consider **reducing touch sensitivity** (A high sensitivity to touch produces involuntary taps on the screen by a certain number of older users)	A high sensitivity to touch produces involuntary taps on the screen by a certain number of older users. Designers should consider how high control sensitivity is and reduce it if there is a risk of involuntary taps by older users. Thus, these users can move their hands over the screen without fear of accidentally tapping on the controls.
56	Gomez-Hernandez et al. [4]	Mobile	Provide **multisensory feedback** (multisensory feedback will increase the probability that messages will get to users correctly)	Because older users may experience perception limitations, multisensory feedback will increase the probability that messages will get to users correctly. In this manner, we provide multiple options to users with limitations in hearing or vision.
57	Gomez-Hernandez et al. [4]	Mobile	Show **clear feedback** after control tapping, as subtle feedback might not be noticed (Older users may not notice subtle changes in the color of a pressed button, and they have a higher risk of tapping outside the target)	Limitations in perception may lead the user to miss subtle feedback; therefore, feedback should be clear and always provided to respond to an explicit user action, such as control tapping. Older users may not notice subtle changes in the color of a pressed button and have a higher risk of tapping outside the target. Therefore, provide bolder interaction feedback anytime the tap has occurred so that the user is aware of having tapped a control.
58	Gomez-Hernandez et al. [4]	Mobile	Do **not rely on vibration** as the primary way of providing **feedback**	Designers should not consider vibration and tactile feedback as the only means of conveying information because older users may not notice it. Current mobile phones provide weak vibration motors, but this could change.
59	Gomez-Hernandez et al. [4]	Mobile	**Increase** response **time** for feedback information, and time-outs (Long time-outs in input interaction modes allow users time to interpret the screen and decide on their next action)	Long time-outs in input interaction modes allow users time to interpret the screen and decide on their next action. In this regard, the time for feedback information on the screen should be long enough for users to process, such as in the case of pop-up messages.
...	...	...	...	...
126	Lewis & Neider [21]	Wearable	Tasks requiring fine-motor control should allow for easy recovery from errors	Designers should nearly always account for some difficulty in movement when considering older adult users. Given that many devices require fine, coordinated motor actions, such as gesture or button selection for interaction, this change warrants particular consideration.
127	Lewis & Neider [21]	Wearable	Guard against activation of nontarget controls	—
128	Lewis & Neider [21]	Wearable	Limit need for tactile feedback in device interactions	Additionally, older adults are less sensitive to tactile feedback or touch-based stimuli, which are imperative for interacting with technology. An alternative to using interfaces that require fine motor control is using voice-commanded technology.
...	...	...	...	...

the specific area or device type adequate for the proposed guideline. Finally, the *Guideline* column displays either the original title of each guideline or, if unavailable, an excerpt from the text where the guideline was derived. We later added a fifth column, *Explanation*, as shown in Table 1, to provide a more detailed description of each guideline. In this column, we included the authors' original explanations when available. If no description was available, we left the cell blank.

With the reference guidelines listed, we began our analysis. In our research, we encountered certain design recommendations for our target audience that were labeled as guidelines but were written as descriptive texts. We extracted these texts, placed them in the *Explanation* column, and summarized their key points into short sentences to serve as titles. This approach ensured compatibility with the other guidelines. For example, we based reference guideline 57 on the sentence, *"Show clear feedback after control tapping, as subtle feedback might not be noticed"*, which we reformulated as *"Show clear feedback after control tapping"*.

We applied a similar approach to guidelines containing measurements specific to other devices, such as recommended icon sizes, fonts, and spacing, as these dimensions – originally designed for larger devices – may not suit smartwatches. For instance, reference guideline #3, *"Space between interface elements that function sequentially should be around 0.2 cm, the space between unrelated buttons should be around 1 cm apart in the diagonal"* describes spacing intended for mobile applications and websites. Since this spacing may not work well on smaller screens like smartwatches, we reworded the guideline to keep its primary intent: related interface elements should be closer together. In contrast, unrelated elements should have more space between them. The beige cells of the *"Reformulated Guideline"* column in the List of reference guidelines describe the new titles resulting from the reformulation of the original texts.

During the analysis of the guidelines, other modifications were introduced. Some guidelines were composed of several parts dealing with different subjects, so dividing them to have one clear objective per reference guideline was preferable. As shown in Table 2, the reference guideline #6, *"Need for use of text and pictures for representing the functions of the buttons. And increased visibility for frequent and important actions"*, has been split into two separate guidelines: *"Need for use of text and pictures for representing the functions of the buttons"* and *"Frequent and important actions should have increased visibility"*, and reference guideline 6 is denoted with "—" since it is no longer a guideline (due to its decomposition into other guidelines). The gray cells in the list of reference guidelines represent this type of intervention. In total, 9 reference guidelines were decomposed, giving rise to 21 new guidelines.

In addition, in some cases, we merged reference guidelines that suggested the same kind of intervention in different contexts. For example, Patsoule and Koutsabasis's [5] guidelines *"Assistance should be provided in the execution of an operation"*, *"Assistance should be provided while performing an incorrect action"*, *"Assistance should be provided while searching"*, and *"Assistance should be provided while completing forms"* (numbered as #93, #94, #95, and #96), were merged into *"Assistance should be provided while using the interface"*, which replaces the previous guidelines. This guideline merger operation is represented by the green lines in the list of reference guidelines, as shown in Table 3, and involved 11 reference guidelines, which merge into 2.

Additionally, reference guidelines with ambiguous titles that did not convey their objectives – and lacked explanatory text – were labeled as *"Unclear"* and excluded from further use in this work. These guidelines were grouped in the *"Unclear"* cluster within the process for synthesizing and classifying the guidelines, marked in orange in the List of reference guidelines, as shown in Table 4.

The preparation phase involves several key steps: reformulating guidelines, splitting any single guideline that covers multiple topics into separate guidelines, consolidating similar guidelines from the same source, and identifying and excluding unclear guidelines. After completing these steps, the list of reference guidelines is ready to be integrated into synthesizing and classifying. This approach allows grouping and analyzing commonalities among guidelines, presenting them in a simpler, more flexible, and intuitive format.

In line with several authors who have organized their guidelines into categories based on challenges faced by older adults [1], [2], [4], [21], we chose to group our guidelines similarly. Initially, we identified four main categories commonly used by these authors: Visual, Hearing, Motor, and Cognitive. Within each category, we created sub-categories to organize guidelines by theme further, as shown in the figure. The four categories are distinguished using a color code: Visual in orange, Hearing in blue, Motor in pink, and Cognitive in green.

After classifying the prepared reference guidelines synthesizing and classifying, we began evaluating their applicability to smartwatch interfaces. This involved filtering the guidelines based on this specific criterion. As a result, we found that some reference guidelines, while relevant to our target audience on other devices, did not apply to smartwatches. This outcome marked nine reference guidelines as *"Not applicable"* as shown in Table 5.

Reference guideline #1, from the mobile application and website domains, describes the need for a large screen in which icons also need to be large. However, smartwatch screens are small, so this guideline cannot be applied. Reference guideline #21, which describes the ergonomic requirements for a good grip on the device, is also not applicable to smartwatches since they are worn on the wrist and do not need to be held in the hand. Regarding reference guideline #19, while the use of double clicks is not even common in smartwatch interfaces, it seems very difficult to avoid scrolling given the small screen size of these devices. The same applies to reference guideline #31, where the

TABLE 2. Split of reference guidelines from the list of reference guidelines. Gray cells represent the decomposition of guidelines.

#	Author	Domain	Guideline	Reformulated Guideline
1	Iancu & Iancu [2]	Mobile Web	Large screen with large icons/buttons	Large screen with large icons and buttons
2	Iancu & Iancu [2]	Mobile Web	Font sizes bigger than 16 pixels and adjustable	Large and adjustable font sizes are required
3	Iancu & Iancu [2]	Mobile Web	Space between interface elements that function in a sequence manner should be around 0.2 cm, the space between unrelated buttons should be around 1 cm apart in the diagonal	Interface elements that function sequentially should have a smaller spacing than buttons that are not linked
—	Iancu & Iancu [2]	Mobile Web	Need for use of text and pictures for representing the functions of the buttons. And increased visibility for frequent and important actions	—
4	Iancu & Iancu [2]	Mobile Web	Need for use of text and pictures for representing the functions of the button	Need for use of text and pictures for representing the functions of the buttons
5	Iancu & Iancu [2]	Mobile Web	Increased visibility for frequent and important actions	Frequent and important actions should have increased visibility
—	Iancu & Iancu [2]	Mobile Web	The need for proper illumination in dim light and adjustable light and increased and adjustable contrast between the background and the text	—
6	Iancu & Iancu [2]	Mobile Web	The need for increased contrast between the background and the text	Increase the contrast between background and text
7	Iancu & Iancu [2]	Mobile Web	The need for proper illumination in dim light and adjustable light and adjustable contrast between the background and the text	Adequate lighting is required in low light conditions, as well as adjustable brightness and contrast between background and text
...	...	...	...	...

TABLE 3. Merge of reference guidelines from the list of reference guidelines. Light green represents the group of guidelines merged into the dark green guideline.

#	Author	Domain	Guideline	Reformulated Guideline
...	...	...	...	...
92	Patsoule & Koutsabasis [5]	Web	There should be an option to select ways of searching content according to user preferences	There should be an option to select ways of searching content according to user preferences
93	Patsoule & Koutsabasis [5]	Web	Assistance should be provided in the execution of an operation	**Assistance should be provided** to the user while using the application
94	Patsoule& Koutsabasis [5]	Web	Assistance should be provided while performing an incorrect action	
95	Patsoule & Koutsabasis [5]	Web	Assistance should be provided while searching	
96	Patsoule & Koutsabasis [5]	Web	Assistance should be provided while completing forms	
97	Patsoule & Koutsabasis [5]	Web	Major helping elements should be provided for inexperienced	Major **helping elements should be provided** for inexperienced
98	Patsoule & Koutsabasis [5]	Web	All elements of the site should be consistently displayed	Application **consistency** is **crucial**
99	Patsoule & Koutsabasis [5]	Web	There should be a layout consistency	
100	Patsoule & Koutsabasis [5]	Web	The conceptual organization of information should be consistent	
101	Patsoule & Koutsabasis [5]	Web	There should be navigation consistency	
102	Patsoule & Koutsabasis [5]	Web	The actions required should be consistent	
103	Patsoule & Koutsabasis [5]	Web	The design style and format should be consistent	
104	Patsoule & Koutsabasis [5]	Web	There should be terminology consistency	
...	...	...	...	...

TABLE 4. Unclear guidelines removed from the list of reference guidelines, marked in orange.

#	Author	Domain	Guideline	Reformulated Guideline
...	...	...	...	...
105	Patsoule & Koutsabasis [5]	Web	Efficient ways to perform any action should be provided	
106	Patsoule & Koutsabasis [5]	Web	The content should be presented in a diffuse spirit of friendliness	
107	Patsoule & Koutsabasis [5]	Web	The design should be predictable with regard to the way of performing actions	—
108	Patsoule & Koutsabasis [5]	Web	Any surprises in the design should be avoided	
109	Patsoule & Koutsabasis [5]	Web	The design should inspire trust	
...	...	...	...	...

small screen size means that static menus can be challenging or involve a limited number of functions. For reference guidelines #27 and #141, the screen's small size could make it difficult to exhibit the position or purpose of the task to the

TABLE 5. Not applicable guidelines removed from the list of reference guidelines.

#	Guideline	Reason
1	Large screen with large icons/buttons	Small screen size of smartwatches
19	Designers should avoid double click need and scrolling	Small screen size of smartwatches
21	Non-slippery materials and body design for grip support are needed	Smartwatches are designed to be worn
27	Indicate a permanent indication of the current position within the information space and task	Small screen size of smartwatches
31	Use simple and static menus	Small screen size of smartwatches
41	Avoid locating controls close to the edge of the screen	Small screen size of smartwatches
122	Be cautious about the positioning of interactive elements towards the edge of the screen	Small screen size of smartwatches
135	Make devices and displays adaptable to the user (e.g., adjustable display location)	Small screen size of smartwatches
144	Provide the user with the status of the steps or goals within broader tasks, such as showing the user the next action	Small screen size of smartwatches

user. Reference guidelines #41 and #122 are also removed because interactive elements must be located close to the edges of a small screen to maximize maximum space. Finally, for reference guideline #135, it seems very difficult to allow the user to adjust the location of the display on such small screens.

We also concluded that the characteristics of smartwatches already ensure some reference guidelines. We tagged those guidelines as *"Covered"* and left them without further consideration. That happened to four reference guidelines, presented in Table 6, relating to features compatible with smartwatches, such as the need for a lightweight device (e.g., reference guideline #23) and reduced use of keyboards (e.g., reference guideline #54 and #118), since these devices are lightweight and mobile and very rarely offer the use of a keyboard (e.g., calculator application). In addition, since smartwatches are compatible with and can be used by people who wear eyeglasses, reference guideline #136 was also tagged as *"Covered"*.

Finally, some reference guidelines have been identified as conflicting with others, as shown in Table 7. These include reference guideline #19, which suggests avoiding scrolling, whereas reference guideline #117 recommends its use. Since reference guideline #19 had already been tagged as *"Not applicable"*, it was not retained for further work. Reference guideline #29 suggests not providing alternative paths for a single task, such as being able to make calls from contacts and call history. This could contradict the principle of reference guidelines #26, #134, #140, and #146, which advocated reducing the number of steps for user tasks. Sometimes, not designing alternative paths can increase the number of steps for certain tasks. For example, if a user is in call history and wants to call a number in this list but can only do so from the contact application, the task the user wants to perform will take longer and will include more steps than if an alternative path had been devised from the initial interface. Finally, reference guideline #32 recommends using text and numbers rather than icons. However, reference guidelines #4, #44, #121, and #160 recommend combining icons and text. We have chosen to consider these latter and mark reference guideline #32 with the *"conflict"* label. Conflicts between reference guidelines are signaled in the corresponding proposed guideline profile sheet.

This filtering phase of the reference guidelines carried out in the process for synthesizing and classifying the guidelines is represented by labels of different colors, placed in the bottom-left corner of the respective guidelines: black for *"Not applicable"*; blue for *"Covered"*, and yellow for *"Conflict"*.

B. SYNTHESIS AND MULTIPLE CRITERIA CLASSIFICATION

After preparing, classifying, and filtering the reference guidelines, the reference guidelines were synthesized within each sub-category to produce a set of proposed guidelines. Each reference guideline contributed to the development of one or more proposed guidelines, and each proposed guideline is assigned an identification number. These numbers reflect a subjective ranking based on the perceived importance of each guideline. This ordering is intended to highlight the most critical guidelines first, ensuring their prominence, especially for readers who may not review the entire list. A "Motivational" label has been introduced to identify guidelines that have the potential to positively influence user motivation. This designation is based on insights gathered in Section II.

An issue was identified during the synthesis of the proposed guidelines. While the visual, hearing, motor, and cognitive categories – drawn from previous studies – were used consistently throughout this work, it became apparent that certain guidelines could belong to multiple categories rather than being confined to a single one, as suggested by those studies. For instance, reference guideline #47, *"Clearly show which elements are touchable"*, emphasizes visually distinguishing interactive elements from non-interactive ones to help users recognize and understand their function. This makes it relevant to both the cognitive and visual categories. Similarly, proposed guideline #13, *"Time shouldn't be a barrier"*, was initially categorized as *Cognitive* due to users requiring more time to interpret the interface. However, it also fits the *Motor* category, as aging-related declines in motor control may necessitate additional time for precise gestural interactions.

Furthermore, certain sub-categories were repeated across multiple classes. The *Feedback* sub-category appeared in

TABLE 6. Covered guidelines by native characteristics of smartwatches from the list of reference guidelines.

#	Guideline	Reason
23	The mobile devices should be light enough to carry everywhere without discomfort	Smartwatches are lightweight devices
54	Minimize the use of keyboard	Smartwatches rarely feature keyboards
118	The use of keyboard should be minimized	Smartwatches rarely feature keyboards
136	Design devices that accommodate eyeglasses	Smartwatches are compatible with eyeglasses

TABLE 7. Guidelines in conflict from the list of reference guidelines.

#	Guideline	Guidelines with which it conflicts
19	Designers should avoid double click need and scrolling	#117
29	Avoid alternative methods for a single task	#26, #134, #140, #146
32	Use text and number key rather than icon	#4, #44, #121, #160

TABLE 8. Changes in the classification of the proposed guidelines after switching to a multiple criteria classification. This table presents only the guidelines impacted by the change in classification.

Proposed Guideline	Initial classification	Multiple Criteria Classification				
		Visual	Motor	Hearing	Cognitive	Motivational
1	Visual	✓	✓			
2	Hearing			✓		✓
5	Motor		✓		✓	
6	Motor		✓		✓	
7	Motor	✓	✓	✓	✓	
8	Cognitive				✓	✓
9	Visual	✓			✓	
11	Visual	✓				✓
13	Cognitive		✓		✓	✓
14	Hearing	✓		✓		✓
18	Visual	✓			✓	
19	Cognitive				✓	✓
21	Cognitive				✓	✓

the *Hearing*, *Motor*, and *Cognitive* classes. In contrast, the *Customization* sub-category was found in both the *Visual* and *Hearing* classes. This overlap made it challenging to group reference guidelines addressing similar themes, as they were classified under different categories. For instance, reference guideline #13, *"A combination of sensorial warnings is suggested when an action is conducted"*, was placed in the *Feedback* sub-category within the *Motor* class. Meanwhile, reference guideline #69, *"There should be an appropriate form of feedback with a clear indication of any change that may happen"*, was also part of the *Feedback* sub-category but was categorized under the *Cognitive* class.

As a result, assigning each guideline to a single class restricted the practical synthesis of the reference guidelines. The classification system was revised to adopt a multi-criteria approach to address this limitation, enabling guidelines to be included in multiple classes when applicable. Additionally, the initial classification did not treat the motivational barrier as a distinct class; instead, it was indicated by a label for guidelines that addressed it. With this revision, the motivational barrier has been formally introduced as a fifth class, emphasizing its equal importance alongside the other challenges. Table 8 shows the changes in the classification of the proposed guidelines, made possible by the switch to multiple criteria classification.

The visual format used to represent the classes of guidelines has also been updated. Previously, the schema divided the guidelines into four main groups, with the color of each guideline indicating its class. This approach has now been replaced by labels that signal the multiple classes assigned to each guideline. From this stage onward, five classes have been considered: *Visual*, *Hearing*, *Motor*, *Cognitive*, and *Motivational*. Furthermore, each guideline now includes a dedicated profile sheet, designed to enhance comprehension and facilitate practical application. These profile sheets provide all the necessary information to understand and implement a guideline.

C. PROPOSED FINAL GUIDELINES

The set of the 21 proposed guidelines is described in Table 9, where the classification of each guideline is provided. Moreover, a design system was created to offer application examples, presenting screens that reflect good practices for each guideline.

TABLE 9. Proposed guidelines.

#	Title	Multiple Criteria Classification					Domain				Related Guidelines
		Visual	Hearing	Motor	Cognitive	Motivational	Mobile	Web	General	Wearable	
1	Provide large buttons and readable text	✓				✓	✓	✓	✓	✓	
2	Favor loud but adjustable sound		✓			✓	✓	✓	✓	✓	10,11
3	Ensure high contrast	✓					✓	✓	✓		
4	Be objective				✓		✓	✓			12,15,17
5	Avoid complex gestures			✓	✓		✓	✓	✓	✓	
6	Ensure distance between controls			✓	✓		✓	✓			
7	Use multisensory feedback	✓	✓	✓	✓		✓	✓		✓	12
8	Support corrections				✓	✓	✓	✓	✓		
9	When designing buttons, include both icons and text labels	✓			✓		✓		✓		18
10	When using sound, prefer low frequencies		✓				✓	✓	✓	✓	
11	Allow for customizations	✓				✓	✓	✓	✓	✓	
12	Avoid distractions				✓		✓	✓	✓	✓	
13	Avoid time-based interactions			✓	✓	✓	✓	✓		✓	
14	Integrate speech to complement output/input	✓	✓			✓	✓	✓	✓		2,11
15	Simplify task execution				✓		✓	✓	✓	✓	4,12
16	Use color effectively	✓					✓		✓		
17	Emphasize the most important information				✓		✓	✓			4
18	Use intuitive icons	✓			✓		✓		✓		
19	Support the sense of privacy				✓	✓	✓				
20	Use plain language				✓		✓		✓		
21	Offer assistance				✓	✓	✓	✓			

1) PROVIDE LARGE BUTTONS AND READABLE TEXT

Guideline #1 emphasizes that the text must be large and legible to reduce visual fatigue and enable faster reading times. First, the recommended fonts are Arial or Helvetica, while the handwritten or decorative fonts that could be difficult to read should be avoided. Secondly, the buttons on the interface should be large, round, or rectangular. Using large buttons and the wide spacing between interface elements proposed in guideline #6 could enable appropriate interaction for users with less precise movement control. This guideline could help combat reduced visual acuity, fatigue, and difficulty making precise gestures [1], [2], [4], [5], [21], [76], [77].

Figure 4 shows two examples of applying proposed guideline #1. The first three images refer to a medication management app interface interface. Large buttons are used, with a width of 190 *px* and a height of 50 *px*, to ensure they are visible and wide enough to prevent accidental pressure (1). On rectangular devices, the length of the buttons has been reduced so as not to infringe on the scroll indicator on the right of the interface (2).

2) FAVOR LOUD BUT ADJUSTABLE SOUND

Guideline #2 (depicted in Figure 5) suggests that the default sound setting must provide a higher sound level, ensuring an audible signal of at least 60 *dBs* (decibels). In addition, the sound volume should be easily customizable to accommodate various listening environments and user needs. This guideline could help combat impairments in sound perception and could play a motivating role in reducing our target audience's negative feelings and apprehensions about their ability to hear [1], [2], [21].

The interface depicted in Figure 5 presents a possible design for a volume control interface. It comprises a header title (1) reminding the user that they are adjusting the volume, a circular indicator (2) that allows the user to modify the volume by tapping on it while providing a visual representation of the sound level, and finally, at the center of this indicator, the sound level displayed as a percentage (3) to provide the user with the sound volume status in two different ways. Below the image in the first row, we present several applications for various devices of different sizes.

3) ENSURE HIGH CONTRAST

This guideline states that high contrast should be provided to improve visibility and legibility by making it easier for users to distinguish the different interface elements correctly. This need for high contrast between foreground and background elements applies to color, for example, by using black text on a white background, and brightness, for example, by combining a brighter element with a darker background. In addition, it's essential not to use background images, as they can make it difficult to distinguish the elements in the foreground. This guideline could help reduce the decline in contrast perception [1], [2], [4].

Figure 6 shows two examples of applying proposed guideline #3. It shows a step count tracking application interface, presenting the number of steps taken during the day. This interface uses white text on a black background (1), allowing a very high contrast of 21:1. In addition, the light yellow icon (2), in color #FAFFC3, combined with the black background also provides a high contrast of 20.16:1.

On the other hand, color inversion is also important. Therefore, using a white background with a dark blue headline and incorporating blue labels achieved a contrast of 21:1.

4) BE OBJECTIVE

This guideline focuses on the need to ensure clarity regarding the function of each interface element and consistency throughout the application to minimize the possibility of misinterpretation by the user. Users with cognitive difficulties may have difficulty distinguishing between interactive and non-interactive elements, so it is essential to differentiate these elements to avoid ambiguities during interaction. Also, the function of each interface element must be immediately apparent, and searching for information within the interface should require minimal effort [4], [5].

Figure 7 presents two examples of the proposed guideline #4. The first uses an interface based on the main menu of a sports activity tracking application. The headline is centered at the top of the page, in a large size so that it is easily recognizable (1). In addition, the buttons have a black background to distinguish them from the rest of the interface and show that they are interactive elements (2). The white text on the button and its icon make it easier to understand its function. Finally, the scroll indicator on the right of the interface and the partial display of the last button in the list highlight that it is possible to scroll down the interface (3).

The second interface represents an alert notification triggered when a fall is detected. The header includes an icon and the text "Fall detected" (4), which clearly and explicitly informs the user of the critical nature of the notification and its purpose to assist them. Two vertically arranged buttons maximize the use of the screen's width and are easy to identify (5). Each button features a short sentence describing its function and an accompanying icon. The "Help" button is highlighted in red (#D80D0D) to convey urgency and draw the user's attention. To maintain clarity, no additional elements have been included in the interface.

5) AVOID COMPLEX GESTURES

This guideline proposes that using gestural interaction as an input method does not have to rely on complex gestures or rapid sequences of movement such as double tap, pinch, or drag and drop. Interaction based on more complex gestures relies on familiarity with the technology, the ability to memorize these gestures, and reasonable control of movements, which could put users at a disadvantage. It is, therefore, recommendable to focus on minimal gesture functions such

FIGURE 4. Examples of application of guideline #1 in different devices.

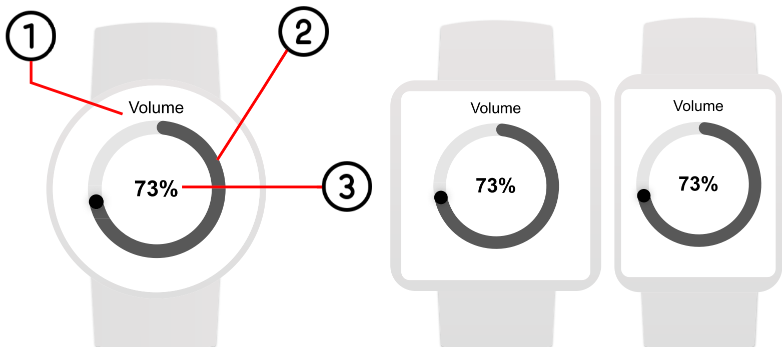


FIGURE 5. Examples of application of guideline #2. The square and rectangular images represent applications in devices with different screen sizes.

FIGURE 6. Examples of application of guideline #3 in different devices.

FIGURE 7. Examples of application of guideline #4 in different devices.

as single taps and scrolling when necessary. This guideline can benefit users with problems regarding coordination and precision of movement or memory difficulties [1], [2], [4], [21].

6) ENSURE DISTANCE BETWEEN CONTROLS

This guideline emphasizes the need for adequate spacing between the elements making up the interface. It is necessary to provide more space between interface elements to have

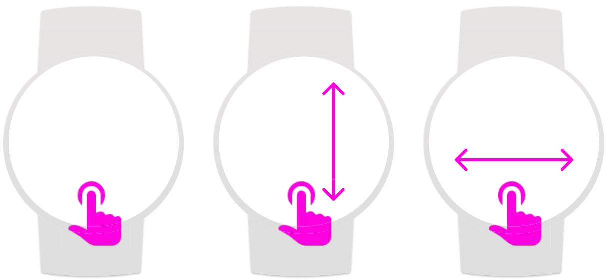


FIGURE 8. Examples of gestures in the context of guideline #5. From left to right: touch, swipe vertically, and swipe horizontally.

a straightforward interface and prevent accidental presses because motor limitations can significantly reduce the precision of movements. Also, smaller spacing should be used to group related elements together to help users understand the relationships between different components [2], [4], [5], [73].

The first three images in Figure 9 refer to an activity tracking application to show the suggested spacing between the elements. Significant spacing has been taken into account in all interfaces. The spacing between the header and the button list is wider to allow the user to identify the interface title (1). The spacing between each button is less pronounced (2) to emphasize that they are linked elements.

The following screens depict an interface for receiving a voice call. The interface features a prominent headline displaying the caller's icon, name, and two large buttons for answering or declining the call. The icon and the caller's name are placed close together (3), ensuring users can quickly associate these elements as related. The decision buttons are positioned at the bottom of the screen, with ample spacing between them and the header, visually emphasizing that a decision is required (4). Additionally, the buttons are spaced far enough apart to reduce the risk of targeting errors (5). For rectangular or square devices, the headers can be positioned higher in the interface to accommodate the flat top edges of such screens.

7) USE MULTISENSORY FEEDBACK

This guideline recommends combining sensory feedback in response to a specific user action. It is necessary not to consider only one means of returning information to the user, as users may have perceptual limitations, leading to missed feedback. For example, a user with reduced hearing acuity may not hear auditory feedback. Several types of feedback (visual, auditory, and tactile) will increase the likelihood of information reaching users correctly. This guideline could help users with vision or hearing problems or those less sensitive to tactile sensations. As well as those with attention problems, since feedback will indicate that an action has been completed [2], [4], [21].

Figure 10 illustrates suggestions for implementing this proposed guideline. First, the feedback is provided when a button is pressed. The example uses the main menu of a health data tracking application. When a button is activated, its color changes and its border is highlighted (1), providing visual feedback to inform the user of the action taken. Additionally, a sound is played (2), and haptic feedback is delivered through vibrations (3), ensuring a multi-sensory confirmation of the interaction.

Next, an example of user feedback is presented in a medication reminder application notification. A yellow background color (4) is used as visual feedback to draw the user's attention to the screen during the notification. Additionally, the notification is accompanied by a sound (5) and vibrations (6), providing multi-sensory feedback to ensure the user notices the reminder.

8) SUPPORT CORRECTIONS

Following this guideline, there is a need to ensure a secure way to exit from any screen and an option to rectify or cancel any action taken. For this, applications should be designed so that a main interface serves as a safe point of return for users. If the smartwatch doesn't have a physical button for going back, ensure that every interface includes a clear exit option to alleviate anxiety for older adults who may feel uncertain about navigating the application. An exit option encompasses any method to return to a previous safe state, such as a back or cancel button. This will reassure users, allowing them to retrace their steps and reduce the fear of getting lost in the application. This guideline could aid users less able to orient attention or inhibit irrelevant information, providing a rollback of an action taken. Also, it may serve as a motivator for users, as minimizing error impact contributes to ease of use [1], [4], [5], [21], [74], [78].

Figure 11 shows the suggested interfaces applying this proposed guideline. It refers to deleting a contact in a contact directory application. When the delete button is activated (1), a confirmation screen appears, enabling the confirmation of the operation or go back (2). It is important to note that large buttons can be used for rectangular or square smartwatches. In contrast, for round ones, applying medium buttons combines good spacing and sufficient size (3).

Next, the use case for a button to return to the application's main menu could be applied to smartwatches without a physical button to perform this action. The interface is a page displaying the user's heart rate; when the back button is pressed (4), the user returns to the application's main menu (5).

9) WHEN DESIGNING BUTTONS, INCLUDE BOTH ICONS AND TEXT LABELS

Concerning button design, this guideline suggests combining icons and text to help understand and remember the function of the buttons. The text should indicate the button's function so that users can quickly understand its purpose. This is particularly important for users who may not be familiar with

FIGURE 9. Examples of application of guideline #6 in different devices.

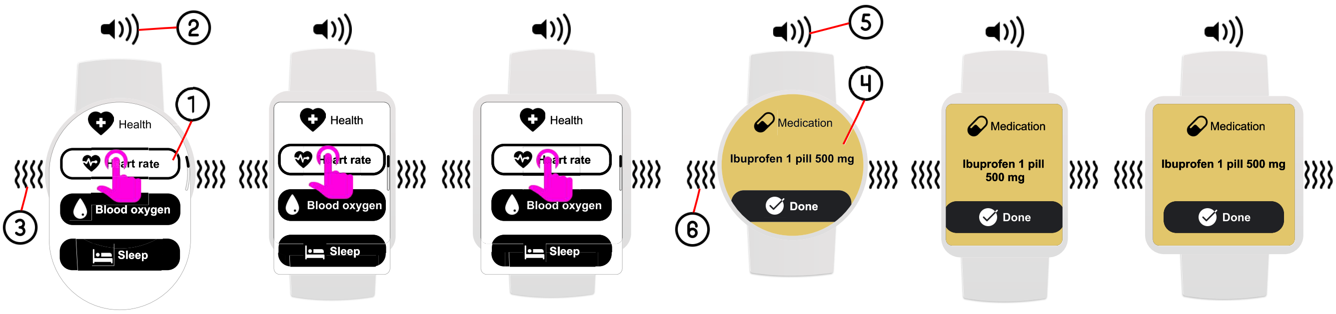


FIGURE 10. Examples of application of guideline #7. Two examples are presented in different devices.

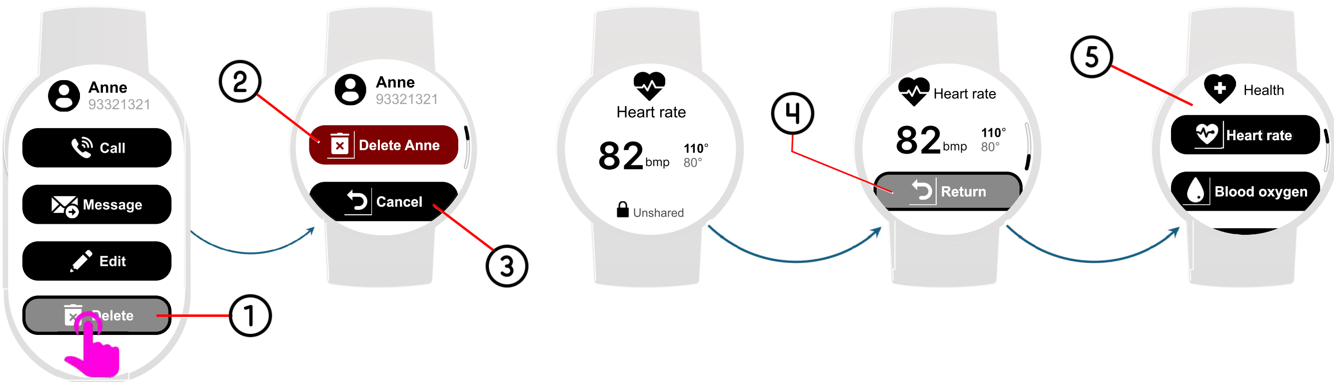


FIGURE 11. Examples of application of guideline #8. Two examples are presented in different devices.

specific icons. As for the icons, they provide a visual cue because they can be quickly recognized, which reinforces the text label and makes the button more intuitive [1], [4], [74], [79].

Figure 12 suggests two examples of applying this guideline. The first button, which allows users to see their heart rate by pressing it, combines the *Heart rate* label with an icon representing cardiac activity (1). The same applies to the second button, combining the *Blood oxygen* label with an icon representing a drop (2), stressing that this is health data relating to blood, and for the third one using the *Sleep* label along with an icon representing a person lying in bed (3).

Next, a notification interface reminds the user to drink water to keep hydrated. The button used to close this reminder also comprises a combination of an icon and text label. It uses a *Done* label and an icon representing a ticked box (4) to indicate to the user that this is a button for confirming the callback.

10) WHEN USING SOUND, PREFER LOW FREQUENCIES

In compliance with this guideline, avoiding high frequencies when using sounds is paramount. Age-related hearing loss is often characterized by difficulty hearing high-frequency sounds. So, High frequencies sound beyond 4,000 Hz should be avoided. To combat this barrier, low-frequency sounds between 500 Hz and 2000 Hz, should be preferred [1], [2], [21].

The interface shown in Figure 13 is a medication reminder notification in the form of an audio message, recognizable by the visual indicator in the center of the screen (1). This audio message should, therefore, have a frequency of less

FIGURE 12. Examples of application of guideline #9. Two examples are presented in different devices.

than 4000 Hz. The same applies to the audible notification emitted by this reminder. In addition, multisensory feedback can be used to help the user perceive this notification (2).

11) ALLOW FOR CUSTOMIZATIONS

Guideline #11 suggests that the user must customize the application to suit his needs. Users should be able to select alternative methods for presenting application elements, such as the size of text and icons, font style, light, contrast, and functionality. This could help users with declined visual acuity, light perception, or contrast detection. It could also increase motivation as users can choose the settings best suited to their situation [1], [2], [5], [21], [73].

Figure 14 presents an example of the implementation of the user's ability to personalize the interface. These interfaces represent the parameters of an application, allowing the user to change the size of the icons. When pressing the *Icon size* button in the display settings (1), a new page appears titled *Icon size*. Here, button icons are sized accordingly with corresponding options, offering a visual representation to the user (2). When the user chooses large icons, all the icons change to large (3).

12) AVOID DISTRACTIONS

This guideline states that any distraction should be avoided to assist users in maintaining concentration while using applications. Only display elements relevant to the current task, avoid unnecessary details or secondary functions that could divert attention, and avoid background noise. Users should be directed to the elements they must interact with to continue their task, such as the next important button. Also, reduce the number of colors, fonts, and visual effects to aid users with attention impairments [1], [4], [5], [21].

Figure 15 illustrates a notification interface reminding the user to hydrate. The interface features a prominent 60×60 *px* icon of a water droplet positioned at the top (1), followed by a short sentence directly below it, clearly stating the purpose of the notification (2). At the bottom, a large green button, spaced further from the text, draws attention as the *exit point* of the interface (3). The next screen displays the user's heart rate, structured similarly to the hydration reminder interface but without a button. Here, the focus is entirely on the heart rate, prominently shown in a large, bold 42 *px* Arial font (4).

13) AVOID TIME-BASED INTERACTIONS

From this guideline, there should be no time constraint for acting. Users can take longer to read and process information; making them feel confident with the interface and not rush them, increasing response time, time for feedback information, and time-outs are important. This extra time could benefit slower users or those with movement coordination problems, allowing them to interpret the interface correctly and decide their actions at their own pace. In addition, this could contribute to the user's perception of ease of use, which could increase motivation [2], [4], [21]. Figure 16 presents the suggestions for applying the proposed guideline #13. The first image highlights that the medication reminder notification interface does not impose any time constraints on the user. It is a notification that does not disappear after a certain time-out since it uses the *Done* button to be closed (1), letting users read and understand the interface at their own pace. In addition, the second image, related to the confirmation of contact deletion, does not impose any time constraints on the user, as it can only be closed by pressing either the *Delete* or *Cancel* button. This interface could be more suitable than a Pop-Up because it closes either after a time-out or by pressing a button to close it. However, since the space in a Pop-Up is limited, we have chosen not to consider this solution.

14) INTEGRATE SPEECH TO COMPLEMENT OUTPUT/INPUT

This guideline proposes integrating speech to complement output and input. To make the application easier to navigate and to enable the device to be used according to user preferences and needs, voice recognition and voice command technologies should be used. In addition, voice response technology can be beneficial for giving feedback to users or reading texts to them. A natural speech rhythm should be maintained with pauses at punctuation points while avoiding computer-generated voices. This may be suitable for users with visual problems. Also, coupled with the customization capability mentioned in guideline #11, this technology could imply increased user motivation when, for example, using a

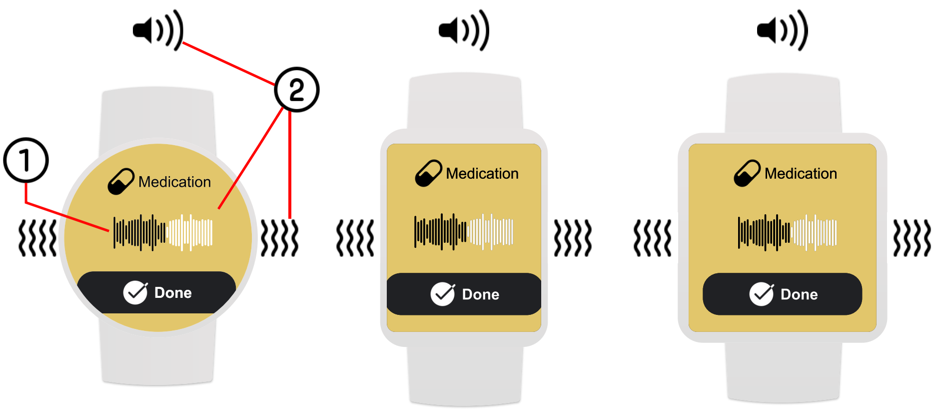


FIGURE 13. Examples of application of guideline #10 in different devices.

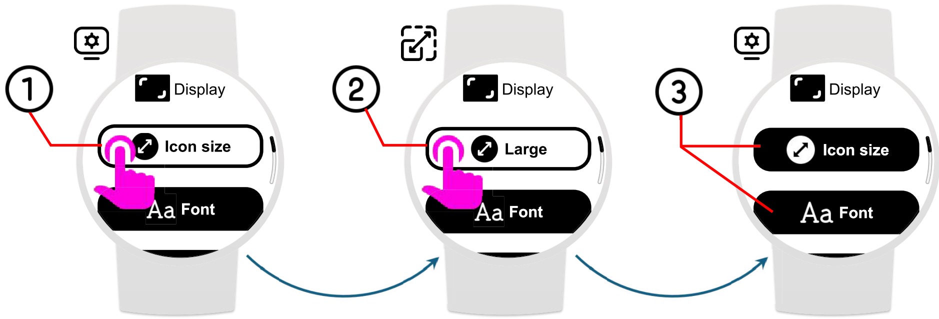


FIGURE 14. Example of application of guideline #11, with customizations in the interface.

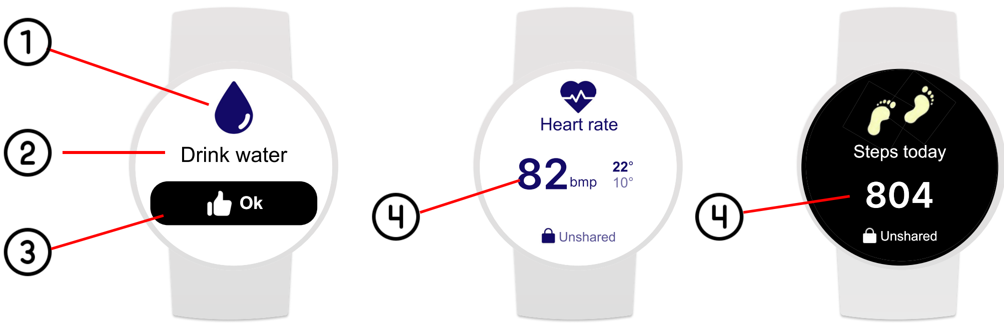


FIGURE 15. Example of application of guideline #12, with necessary elements on the interface.

message recorded by a familiar voice can have an emotional impact on the user [1], [2], [21].

Figure 17 shows the interface of a received message, proposing different input or output options for this case. In this interface, the user can read the message received or, by pressing the *Dictate* button (1), it can be read to him. In addition, to reply to the message, the user can use voice recognition to create a text message using speech after pressing the *Speak* button (2), or write its response using a keyboard by pressing the *Write* button (3).

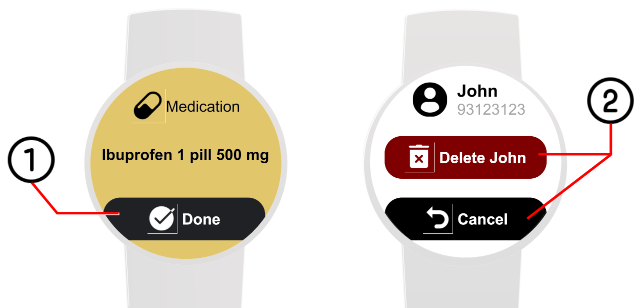


FIGURE 16. Examples of gestures in the context of guideline #13.

15) SIMPLIFY TASK EXECUTION

Regarding task execution, this guideline recommends reducing the number of pages and steps and minimizing time spent on the task. Steps include button selections and presses. If a task requires many steps, users can be lost by not remembering all of them. Then, tasks should be based on a few short, simple steps. For instance, using voice commands

FIGURE 17. Example of application of guideline #14, with necessary elements on the interface.

for interface navigation could simplify specific tasks. Brief and straightforward tasks could benefit users with memory problems [1], [2], [4], [21], [73].

Two examples of applying the proposed guideline 15 are provided in Figure 18. The first image uses the interface to show a message received in the previous guideline. Given that the user's task is to reply to this message, using speech to write his reply message (1) instead of writing it on a keyboard can reduce the time and effort needed to carry out this task.

The second image shows the interface for the actions that can be carried out with a contact. This interface allows calling this contact directly by pressing the *Call* button (2). If the user is on this interface and has set himself the task of calling this contact, pressing this button drastically reduces the number of steps involved in this task, as the fact that this action can be performed from this menu means that there is no need to go to another interface to complete this task.

16) USE COLOR EFFECTIVELY

Regarding color choices, this guideline suggests that the preferred colors to use are those with longer wavelengths, also known as warm colors, such as red, orange, and yellow. Shorter wavelength colors (cool colors), such as blue, green, and purple, should be avoided to help users with reduced color perception. However, if they are used, high levels of contrast will be needed to facilitate perceptibility. In addition, minimizing the number of colors used and using them consistently throughout the interface to represent different groups of options could help users quickly learn and recognize application patterns [1], [73].

In the interface for requesting help if a fall has been detected, shown in the first image of Figure 19, the red color (#D80D0D), which is a warm color, is used to draw users' attention to the button requesting for help (1); indeed the help button must be the first thing the user sees.

In the second and third images, a weather application interface is presented. The cool color blue (#130A67) is used in the background (2). However, it is combined with white

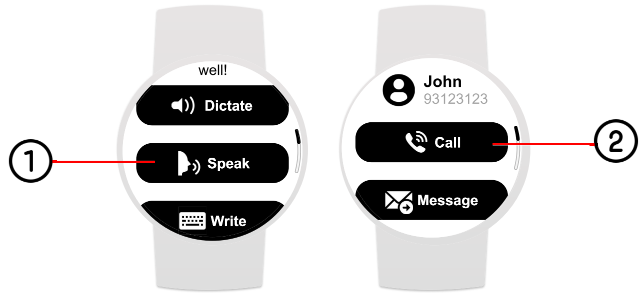


FIGURE 18. Example of application of guideline #15, with necessary elements on the interface.

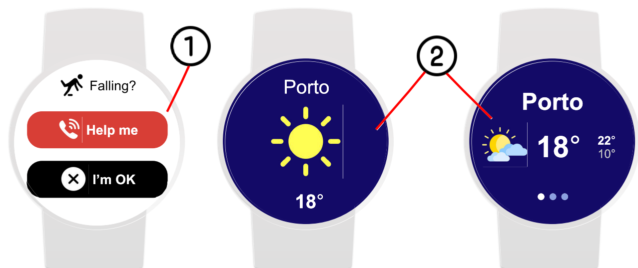


FIGURE 19. Example of application of guideline #16, with necessary elements on the interface.

(#FFFFFF) text and a yellow (#FFFD54) icon to ensure a high contrast level of 16.58:1 and 15.34:1, respectively.

17) EMPHASIZE THE MOST IMPORTANT INFORMATION

This guideline postulates that information should be presented hierarchically, where the most important information should be easily recognizable (using, for example, larger text, bold type, and color). The most frequently used actions should be easily accessible, for example, by placing them at the top of a list. This differentiation of important elements from others could help users who have difficulty focusing their attention [2], [5].

Figure 20 suggests two examples for applying proposed guideline #17. The first three images represent a voice call history consisting of a list of events, each representing a call

FIGURE 20. Example of application of guideline #17, with necessary elements on the interface.

already made or received. The names of contacts (1) who have called or been called are written in large Arial bold font aligned with the button, representing a previous call. At the side of the contact's name is an icon indicating whether or not the call has been missed, with the red icon indicating a missed call (2). Finally, other information, such as the date and time of the call (3), is displayed in smaller type and color next to the icon and below the contact name.

In the second group of images, an activity tracking application is used, where the most important information is the application header, located at the top of the screen (4). Secondly, the buttons are easily identifiable from the background. Also, the most frequently executed actions are located at the top of the list to make them more accessible to the user (5). In this case, the button for starting a sports session is at the top of the list, followed by the button for viewing physical activities already completed.

18) USE INTUITIVE ICONS

This guideline emphasizes using clear and easily understandable icons closely related to the functions they represent while avoiding using abstract icons. They should illustrate representations of the real world, such as a telephone icon for making a call. Complex icons with unnecessary embellishments should be avoided because they could be confusing [1], [4].

Figure 21 shows two suggestions for applying this guideline. The first image uses the user fall detection interface, where each button has a simple icon representing its function. In the case of the help button, the icon used is a telephone indicating a call for help (1), and in the case of the button representing that help is not required, a cross indicating refusal (2).

The second image uses the menu of actions that can be carried out for a contact; a telephone icon is used for the call button (3), a letter icon for the button allowing to send a message (4), a pencil symbolizing the edit button (5), and a bin with a cross for the delete button (6).

19) SUPPORT THE SENSE OF PRIVACY

Several considerations can be considered to support privacy. First, a clear distinction should be made between private and

FIGURE 21. Example of application of guideline #18, with necessary elements on the interface.

public information in the application so that the user is aware of this. Also, users need to be able to customize their data-sharing preferences. To help them in this task, step-by-step instructions for adjusting the privacy and sharing settings can be provided. Finally, it is advisable always to include a confirmation screen to request the user's consent before sharing data or when they make changes to sharing settings. Addressing data privacy concerns could reduce some older adults' fears and motivate them to use these devices [73].

Two examples of implementation of the proposed guideline #19 are illustrated in Figure 22. The first three images are related to the change in data sharing parameters for heart rate data. First, the user selects the application for which he wants to change these parameters (1). If data sharing regarding heart rate is enabled, it is written *Sharing Enabled*, and the button is red and allows the user to disable it (2) if data sharing is deactivated, it is written *Sharing Disabled*, and the button allows to activate it (3). When a data sharing parameter changes, a confirmation screen ensures that the user is informed of the change and accepts it (4). Large buttons for the confirmation screen can be chosen (5).

The fourth image emphasizes the distinction between private and public information within the application. Indeed, on the interface showing the user's heart rate, a visual element has been added to indicate that this data is not shared (6). This component consists of a closed padlock icon and the label *Unshared*, or an open padlock icon with *Shared* label.

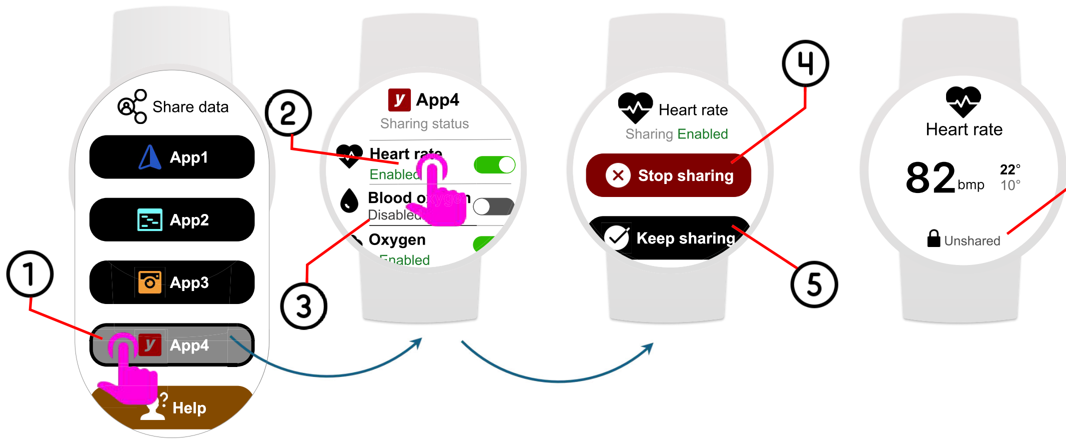


FIGURE 22. Example of application of guideline #19, with necessary elements on the interface.

20) USE PLAIN LANGUAGE

This guideline focuses on using simple and unambiguous language throughout the application. To accommodate users unfamiliar with technology, using technical terms in the UI should be avoided. Instead, language that aligns with the semantic field of older adults and the context in which the application is used could be employed. Simple, short messages and avoiding subtle or ironic language are also recommended. This approach could help users understand the interface [1], [4], [74].

Figure 23 presents two interfaces using plain language. Regarding the notification of a detected fall presented in the first image, a very short, unambiguous message is presented at the top of the interface (1). In addition, each button incorporates a short sentence (2), as opposed to simple words such as *yes* and *no*. This lets the user clearly understand the button's function without re-reading the notification's title.

The third and fourth images present the case of an interface requesting user authorization for an application to use his location. The subject of the notification is clearly expressed above the interface in a short sentence pointing out that this is a request regarding the share of the location. In addition, the user is reminded of the application's name, requesting to use his location (3) to minimize the possibility of making a mistake in his choice. Finally, the two buttons used to respond to this request are labeled *Allow* or *Deny* (4). This links each button to the request mentioned in the interface header.

21) OFFER ASSISTANCE

This guideline encourages to assist the user. When a user learns to use an application, initial training through video tutorials or face-to-face interaction is advised. Video tutorials on a smartphone or other device connected to the smartwatch could be beneficial, as the smartwatch's screens may not allow clear viewing of videos or animations. While using the application, provide users with helpful information that is easily identifiable (e.g., by using a specific color) and accessible from the application's home screen. Also, a point of contact (e.g., phone helpline) should be supplied to users needing more information. This guideline could support users in learning how to use the interface and play a motivational role by not leaving the user alone with it [4], [5], [73].

A suggestion for applying proposed guideline #21 is shown in Figure 24. This is the data-sharing settings menu, which includes a help button at the bottom of the list (1). This button should have a specific color. In this example, we have chosen brown to distinguish it from the others through the application. When the user presses it, an interface containing information about the menu appears to help the user (2); this interface also includes contact information (3), such as phone number and email, if the user requires more help.

D. BENCHMARKING

The following benchmark analysis evaluates the comprehensiveness of the smartwatch design guidelines (#1—#21) proposed in our work in addressing critical dimensions relevant to older adults, smartwatch-specific constraints, and general usability principles. This analysis builds on the limitations of the guidelines (G1—G8) proposed by Samaddar et al. [80] to identify key areas where the proposed guidelines provide broader and deeper coverage.

Table 10 evaluates how the proposed guidelines address the specific needs of older adults, including motor, visual, and hearing impairments, cognitive load, privacy concerns, and personalization. Older adults often face challenges such as reduced dexterity, sensory limitations, and difficulty adapting to complex interfaces. The table highlights how the proposed guidelines provide enhanced support compared to Samaddar et al. [80] guidelines by emphasizing cognitive simplicity (#4, #12, and #20), multisensory feedback (#2 and #7), and customization options (#11). This ensures a user-centered design approach that aligns with the requirements of older adults.

Table 11 assesses how well the proposed guidelines accommodate smartwatch-specific constraints, such as small screens, limited input methods, reliance on gestures, multimodal feedback, and battery life considerations. The

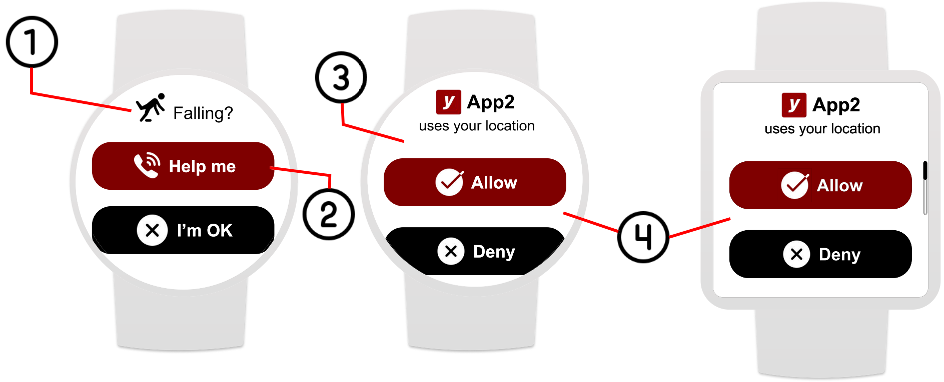


FIGURE 23. Example of application of guideline #20, with necessary elements on the interface.

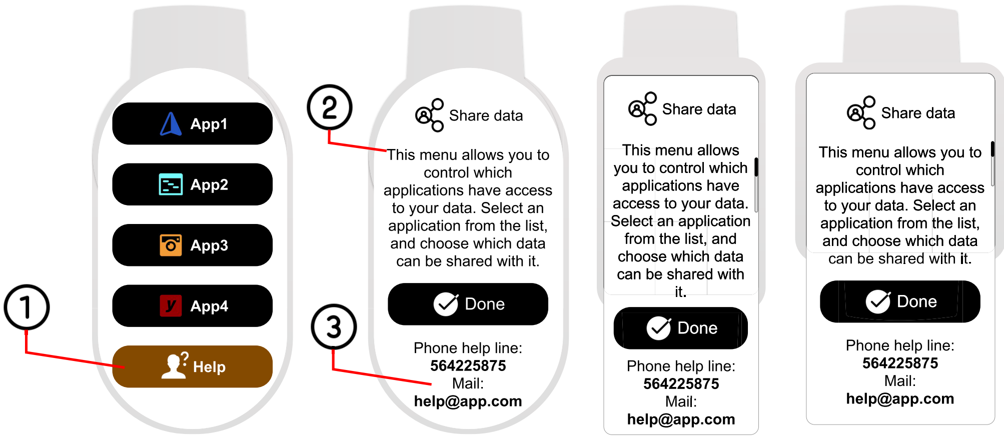


FIGURE 24. Example of application of guideline #21, with necessary elements on the interface.

TABLE 10. Comparison of guidelines based on the needs of older adults.

Criteria	Samaddar et al. [80] guidelines (G1 — G8)	Our guidelines (#1 – #21)	Coverage analysis for our guidelines
Motor impairments	G2, G3	#1, #6, #8	Provide stronger support through large buttons, error recovery, and spacing, which are crucial for motor impairments.
Visual impairments	G5, G7	#1, #3, #16	Build on readability by refining color usage, emphasizing key information, and improving overall contrast and font size.
Hearing impairments	Not addressed	#2, #7, #10	Explicitly address hearing needs, providing adjustable volume and multisensory feedback, absent in [80].
Cognitive load	G4, G6	#4, #12, #15, #20	Comprehensively targets cognitive simplicity by reducing clutter, using objective designs, and offering task simplification, which was not emphasized in [80].
Privacy concerns	Not addressed	#19	Adds privacy considerations, critical for older adults managing health data or sensitive information.
Personalization and adaptability	Not addressed	#11	Introduces customization options for fonts, themes, and controls, addressing a key gap in [80].

proposed guidelines demonstrate a detailed approach to addressing these challenges, particularly through features like large buttons (#1), intuitive input alternatives (#5, #9), and speech integration (#14). The guidelines also emphasize reducing gesture reliance (#15), ensuring usability on compact devices with enhanced feedback mechanisms (#2, #7), and supporting long-term use by considering battery-efficient features.

TABLE 11. Comparison of guidelines based on smartwatch characteristics.

Criteria	Samaddar et al. [80] guidelines (G1 — G8)	Our Guidelines (#1 – #21)	Coverage analysis for our guidelines
Small screen size	G3, G7	#1, #6	Explicitly address usability on small screens by including larger buttons, better control spacing, and improved font sizing.
Limited input methods	G1	#5, #9, #13	Offers more comprehensive solutions for input, including reducing gesture complexity, providing text/icons combinations, and removing time-based interaction.
Reliance on gestures	G1, G4	#5, #15	Go beyond authors guidelines by reducing gesture reliance through simpler design, combining icon/text labels, and emphasizing task simplicity.
Multimodal feedback	Not addressed	#2, #7, #14	Explicitly introduce multimodal feedback to address both sensory limitations (visual, auditory), essential for older users and the smartwatch format.
Battery life considerations	Not addressed	#14	Indirectly support battery efficiency by proposing speech integration to reduce reliance on visual touch-based input, thus saving power.

TABLE 12. Comparison of guidelines based on general design principles for older adults [81].

Criteria	Samaddar et al. [80] guidelines (G1 — G8)	Our Guidelines (#1 – #21)	Coverage analysis for our guidelines
Accessibility	G6, G8	#1, #3, #16, #20	Improve upon accessibility by including enhanced readability, multimodal options, and better color usage.
Error recovery	G2	#8, #21	Strengthen error recovery with explicit support, offering real-time assistance and feedback mechanisms to avoid user frustration.
Feedback and multimodality	Not addressed	#2, #7	Emphasize multisensory feedback, which is crucial for engaging users with different sensory impairments and providing diverse forms of feedback (sound, haptics, etc.).
Navigation and structure	G1, G5	#4, #9, #12, #15	Introduce clearer navigation strategies, including more explicit icon/text labeling, better task prioritization, and less reliance on gestures.
Task prioritization	G7	#16, #17	Provide refined prioritization using color, layout, and clear visual hierarchy to highlight important tasks.
Privacy and trust	Not addressed	#19	Strongly addresses privacy concerns, especially for older adults, where trust in data handling is critical.

Table 12 benchmarks the guidelines against general design principles for older adults [81], focusing on accessibility, error recovery, feedback mechanisms, navigation, task prioritization, and privacy. The guidelines extend usability coverage by introducing explicit strategies for clarity (#4), interface decluttering (#12), and intuitive interaction through plain language (#20). Additionally, they emphasize robust error recovery mechanisms (#8, #21), privacy considerations (#19), and efficient task prioritization (#16, #17). These features relate to universal design principles, ensuring usability for older adults.

In conclusion, the new guidelines (#1 —- #21) provide a holistic and detailed framework for designing smartwatch interfaces for older adults. They address previously overlooked dimensions such as hearing impairments, privacy, motivational aspects, multimodal feedback, and usability principles like error recovery and task prioritization. They expand the coverage and depth of considerations and ensure a more inclusive, practical, and user-friendly approach to the interface design of smartwatch applications for older adults.

V. CONCLUSION

Age-related difficulties can hinder interactions with interfaces, compromising user experience and potentially leading to a negative perception and rejection of technology among older users. Various studies have suggested guidelines for designing interfaces tailored to this target audience across different domains (e.g., mobile applications, Web, wearable devices) to address this issue. However, this subject has not been comprehensively investigated within the context of smartwatch interfaces despite the potential of such devices to be highly useful for older adults. Smartwatches can provide several important functionalities that can save lives, such as detecting a fall and allowing real-time monitoring of vital signs (e.g., heart rate, body temperature). Furthermore, these devices possess numerous advantages when compared to conventional monitoring devices, as they are non-intrusive and highly portable, seamlessly integrating into daily life.

Our objective was, therefore, to fill this gap in the literature by proposing a set of design guidelines for smartwatch interfaces for older adults. In this study, we reviewed the age-related challenges that can hinder interaction with interfaces, identifying five categories: visual impairments, hearing loss, motor difficulties, cognitive problems, and a possible loss of motivation, which can be linked to age-related challenges as well as to a poor or negative experience using technology (as addressed in RQ1). Subsequently, we systematically extracted design guidelines focused on our target audience but related to other domains, resulting in 175 reference guidelines. Then, we identified peculiar features of smartwatches (e.g., small screen size, wrist-worn devices) to assess the potential applicability of the extracted guidelines initially designed for other devices. The analysis of these guidelines included a preparation and filtering phase, in which guidelines were identified as covered by some inherent characteristics of smartwatches. In contrast, others did not apply to such devices when we could not find solutions for their implementation in smartwatch interfaces (RQ2). Then, we classified the guidelines based on the five categories of challenges identified and distilled them into 21 guidelines we propose for designing smartwatch interfaces for older adults. Finally, to provide tangible instantiations of the application of the guidelines, we created a design system that includes examples and suggestions on using several components suitable for reuse in future studies and developments (RQ3). Each example is presented and applied to representations of different smartwatch physical formats available on the market (round, rectangular, and square).

By proposing design guidelines for smartwatch interfaces for older adults, our work contributes to the research and development in this domain. However, we acknowledge, as a main limitation, that, due to time constraints, users were not involved in evaluating the quality of the proposals. As such, our work should be regarded as a starting point, bearing in mind that the guidelines we present need further testing for future work. To achieve this, the components and interfaces of the design system, or others created in line with the set of guidelines, could be evaluated through usability tests. During those tests, researchers would assign specific tasks to participants and observe their interactions, compiling a comprehensive record of all relevant information, such as errors, hesitations, misunderstandings, and successes. Furthermore, the tests could be recorded for subsequent analysis. The information gathered could provide insights for correcting, validating, or proposing other guidelines and interface examples. In addition, future work might also provide recommendations on specific measures for component sizes and spacing based on observations of the use of interfaces conceived according to the proposed guidelines. It would also be relevant to realize if a particular physical format of smartwatches should be recommended for this target audience.

REFERENCES

[1] M. A. Farage, K. W. Miller, F. Ajayi, and D. Hutchins, "Design principles to accommodate older adults," *Global J. Health Sci.*, vol. 4, no. 2, p. 2, Feb. 2012.

[2] I. Iancu and B. Iancu, "Designing mobile technology for elderly. A theoretical overview," *Technolog. Forecasting Social Change*, vol. 155, Jun. 2020, Art. no. 119977.

[3] S. Farivar, M. Abouzahra, and M. Ghasemaghaei, "Wearable device adoption among older adults: A mixed-methods study," *Int. J. Inf. Manage.*, vol. 55, Dec. 2020, Art. no. 102209.

[4] M. Gomez-Hernandez, X. Ferré, C. Moral, and E. Villalba-Mora, "Design guidelines of mobile apps for older adults: Systematic review and thematic analysis," *JMIR mHealth uHealth*, vol. 11, Sep. 2023, Art. no. e43186.

[5] E. Patsoule and P. Koutsabasis, "Redesigning websites for older adults: A case study," *Behav. Inf. Technol.*, vol. 33, no. 6, pp. 561–573, Jun. 2014.

[6] J. R. Thorpe, K. V. H. Rønn-Andersen, P. Bień, A. G. Özkil, B. H. Forchhammer, and A. M. Maier, "Pervasive assistive technology for people with dementia: A UCD case," *Healthcare Technol. Lett.*, vol. 3, no. 4, pp. 297–302, Dec. 2016.

[7] T. Vilarinho, B. Farshchian, D. G. Bajer, O. H. Dahl, I. Egge, S. S. Hegdal, A. Lønes, J. N. Slettevold, and S. M. Weggersen, "A combined smartphone and smartwatch fall detection system," in *Proc. IEEE Int. Conf. Comput. Inf. Technol., Ubiquitous Comput. Commun.; Dependable, Autonomic Secure Comput., Pervasive Intell. Comput.*, Oct. 2015, pp. 1443–1448.

[8] T.-C. Lu, C.-M. Fu, M. Ma, C.-C. Fang, and A. Turner, "Healthcare applications of smart watches," *Appl. Clin. Informat.*, vol. 7, no. 3, pp. 850–869, 2016.

[9] F. V. Lima, V. Kadiyala, A. Huang, K. Agusala, D. Cho, A. M. Freeman, and R. Druz, "At the crossroads! Time to start taking smartwatches seriously," *Amer. J. Cardiol.*, vol. 179, pp. 96–101, Sep. 2022.

[10] C. E. King and M. Sarrafzadeh, "A survey of smartwatches in remote health monitoring," *J. Healthcare Informat. Res.*, vol. 2, nos. 1–2, pp. 1–24, Jun. 2018.

[11] LiveConnect24. (2023). *What are the Benefits of a Smartwatch*. WebPage. Accessed: Jan. 23, 2023. [Online]. Available: https://www.lifeconnect24.co.uk/blog/benefits-of-smartwatch/

[12] *The Benefits of Smartwatches for Seniors*, WebPage, AccessibleHome-Care, Coral Springs, FL, USA, 2022.

[13] E. Frederic and L. Christian, "Supporting elderly homecare with smartwatches: Advantages and drawbacks," in *e-Health–For Continuity of Care*. Amsterdam, The Netherlands: IOS Press, 2014, pp. 667–671.

[14] T. M. Manini, T. Mendoza, M. Battula, A. Davoudi, M. Kheirkhahan, M. E. Young, E. Weber, R. B. Fillingim, and P. Rashidi, "Perception of older adults toward smartwatch technology for assessing pain and related patient-reported outcomes: Pilot study," *JMIR mHealth uHealth*, vol. 7, no. 3, Mar. 2019, Art. no. e10044.

[15] D. Vargemidis, K. Gerling, V. V. Abeele, L. Geurts, and K. Spiel, "Irrelevant gadgets or a source of worry: Exploring wearable activity trackers with older adults," *ACM Trans. Accessible Comput.*, vol. 14, no. 3, pp. 1–28, Sep. 2021.

[16] E. Y. Ding, M. CastañedaAvila, K.-V. Tran, J. Mehawej, A. Filippaios, T. Paul, E. M. Otabil, K. Noorishirazi, D. Han, J. S. Saczynski, B. Barton, K. M. Mazor, K. Chon, and D. D. McManus, "Usability of a smartwatch for atrial fibrillation detection in older adults after stroke," *Cardiovascular Digit. Health J.*, vol. 3, no. 3, pp. 126–135, Jun. 2022.

[17] *World Social Report 2023: Leaving no one Behind in an Ageing World*, WebPage, United Nation Organisation, New York, NY, USA, Nov. 2023.

[18] *Global Issues Ageing*, WebPage, United Nation Organisation, New York, NY, USA, 2024.

[19] A. Kuerbis, A. Mulliken, F. Muench, A. A. Moore, and D. Gardner, ‘‘Older adults and mobile technology: Factors that enhance and inhibit utilization in the context of behavioral health,’’ *Mental Health Addiction Res.*, vol. 2, no. 2, pp. 1–11, 2017, doi: doi: 10.15761/MHAR.1000136.

[20] A. D. Fisk, S. J. Czaja, W. A. Rogers, N. Charness, and J. Sharit, *Designing for Older Adults: Principles and Creative Human Factors Approaches*. Boca Raton, FL, USA: CRC Press, 2020.

[21] J. E. Lewis and M. B. Neider, ‘‘Designing wearable technology for an aging population,’’ *Ergonom. Design: Quart. Human Factors Appl.*, vol. 25, no. 3, pp. 4–10, Jul. 2017.

[22] N. Charness and W. R. Boot, ‘‘Aging and information technology use: Potential and barriers,’’ *Current Directions Psychol. Sci.*, vol. 18, no. 5, pp. 253–258, Oct. 2009.

[23] L. R. Betts, R. Hill, and S. E. Gardner, ‘‘‘There’s not enough knowledge out there’: Examining older adults’ perceptions of digital technology use and digital inclusion classes,’’ *J. Appl. Gerontol.*, vol. 38, no. 8, pp. 1147–1166, Aug. 2019.

[24] G. A. Wildenbos, M. W. M. Jaspers, M. P. Schijven, and L. W. Dusseljee-Peute, ‘‘Mobile health for older adult patients: Using an aging barriers framework to classify usability problems,’’ *Int. J. Med. Informat.*, vol. 124, pp. 68–77, Apr. 2019.

[25] J. Preece, H. Sharp, and Y. Rogers, *Interaction Design: Beyond Human-Computer Interaction*. Hoboken, NJ, USA: Wiley, 2015.

[26] M. G. Helander, *Handbook of Human-Computer Interaction*. Amsterdam, The Netherlands: Elsevier, 2014.

[27] J. Chung, H. R. Brakey, B. Reeder, O. Myers, and G. Demiris, ‘‘Community-dwelling older adults’ acceptance of smartwatches for health and location tracking,’’ *Int. J. Older People Nursing*, vol. 18, no. 1, Jan. 2023, Art. no. e12490.

[28] A. Seifert, A. Schlomann, C. Rietz, and H. R. Schelling, ‘‘The use of mobile devices for physical activity tracking in older adults’ everyday life,’’ *Digit. HEALTH*, vol. 3, Jan. 2017, Art. no. 2055207617740088.

[29] K. Huang, ‘‘Challenges in human-computer interaction design for mobile devices,’’ in *Proc. World Congr. Eng. Comput. Sci.*, Jan. 2009, pp. 1–6.

[30] M. H. Miraz, M. Ali, and P. S. Excell, ‘‘Adaptive user interfaces and universal usability through plasticity of user interface design,’’ *Comput. Sci. Rev.*, vol. 40, May 2021, Art. no. 100363.

[31] C. Rusu, V. Rusu, S. Roncagliolo, and C. González, ‘‘Usability and user experience: What should we care about?’’ *Int. J. Inf. Technol. Syst. Approach*, vol. 8, no. 2, pp. 1–12, Jul. 2015.

[32] *The Definition of User Experience (UX)*, WebPage, Norman and Nielsen, Dover, DE, USA, 1998.

[33] *Design Principles*, WebPage, Interaction Design Foundation, Aarhus, Denmark, 2016.

[34] *What are Design Guidelines*, WebPage, Geeksforgeeks, Noida, India, 2024.

[35] K. J. Kim and D.-H. Shin, ‘‘An acceptance model for smart watches: Implications for the adoption of future wearable technology,’’ *Internet Res.*, vol. 25, no. 4, pp. 527–541, Aug. 2015.

[36] S. Luo, ‘‘Smartwatch materials decoded! WebPage,’’ Tech. Rep., 2023.

[37] M. Dehghani and K. J. Kim, ‘‘The effects of design, size, and uniqueness of smartwatches: Perspectives from current versus potential users,’’ *Behaviour Inf. Technol.*, vol. 38, no. 11, pp. 1143–1153, Nov. 2019.

[38] A. Provazza and B. Lutkevich, ‘‘What is a smartwatch? WebPage,’’ Tech. Rep., 2022.

[39] *What Does a Smartwatch Do*, WebPage, SamsungGroup, Suwon-si, South Korea, Aug. 2024.

[40] A. Islam, A. Bezerianos, B. Lee, T. Blascheck, and P. Isenberg, ‘‘Visualizing information on watch faces: A survey with smartwatch users,’’ in *Proc. IEEE Visualizat. Conf. (VIS)*, Oct. 2020, pp. 156–160.

[41] *Galaxy Watch7 LTE (44mm)*, WebPage, Samsung Group, Suwon-si, South Korea, Sep. 2024.

[42] *Types of Sensors in Smartwatches, Fitness Trackers and Bands*, WebPage, Engineering Product Design, Aug. 2024.

[43] A. Kamišalić, I. Fister, M. Turkanović, and S. Karakatič, ‘‘Sensors and functionalities of non-invasive wrist-wearable devices: A review,’’ *Sensors*, vol. 18, no. 6, p. 1714, May 2018.

[44] T. R. Mauldin, M. E. Canby, V. Metsis, A. H. H. Ngu, and C. C. Rivera, ‘‘SmartFall: A smartwatch-based fall detection system using deep learning,’’ *Sensors*, vol. 18, no. 10, p. 3363, Oct. 2018.

[45] Y. Karnati, R. R. K. Reddy, A. Thakkar, M. McConnell, T. Mendoza, M. Mardini, T. Manini, and S. Ranka, ‘‘A smartwatch-based framework for real-time and online assessment and mobility monitoring,’’ *Innov. Aging*, vol. 4, no. 1, p. 798, Dec. 2020.

[46] S. T. Himi, N. T. Monalisa, M. Whaiduzzaman, A. Barros, and M. S. Uddin, ‘‘MedAi: A smartwatch-based application framework for the prediction of common diseases using machine learning,’’ *IEEE Access*, vol. 11, pp. 12342–12359, 2023.

[47] S. B. Bhanvadia, M. S. Brar, A. Delavar, K. Tavakoli, B. R. Saseendrakumar, R. N. Weinreb, L. M. Zangwill, and S. L. Baxter, ‘‘Assessing usability of smartwatch digital health devices for home blood pressure monitoring among glaucoma patients,’’ *Informatics*, vol. 9, no. 4, p. 79, Oct. 2022.

[48] P. Siirtola, ‘‘Continuous stress detection using the sensors of commercial smartwatch,’’ in *Proc. Adjunct ACM Int. Joint Conf. Pervasive Ubiquitous Comput. ACM Int. Symp. Wearable Comput.*, New York, NY, USA, Sep. 2019, pp. 1198–1201.

[49] N. S. Erdem, C. Ersoy, and C. Tunca, ‘‘Gait analysis using smartwatches,’’ in *Proc. IEEE 30th Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC Workshops)*, Sep. 2019, pp. 1–6.

[50] H. Kalantarian, N. Alshurafa, E. Nemati, T. Le, and M. Sarrafzadeh, ‘‘A smartwatch-based medication adherence system,’’ in *Proc. IEEE 12th Int. Conf. Wearable Implant. Body Sensor Netw. (BSN)*, Jun. 2015, pp. 1–6.

[51] T. T. Cota, L. Ishitani, and N. Vieira, ‘‘Mobile game design for the elderly: A study with focus on the motivation to play,’’ *Comput. Hum. Behav.*, vol. 51, pp. 96–105, Oct. 2015.

[52] G. A. Wildenbos, L. Peute, and M. Jaspers, ‘‘Aging barriers influencing mobile health usability for older adults: A literature based framework (MOLD-U.S.),’’ *Int. J. Med. Informat.*, vol. 114, pp. 66–75, Jun. 2018.

[53] C. Li, J. Neugroschl, C. W. Zhu, A. Aloysi, C. A. Schimming, D. Cai, H. Grossman, J. Martin, M. Sewell, M. Loizos, X. Zeng, and M. Sano, ‘‘Design considerations for mobile health applications targeting older adults,’’ *J. Alzheimer’s Disease*, vol. 79, no. 1, pp. 1–8, Jan. 2021.

[54] K. D. Federmeier, M. Kutas, and R. Schul, ‘‘Age-related and individual differences in the use of prediction during language comprehension,’’ *Brain Lang.*, vol. 115, no. 3, pp. 149–161, Dec. 2010.

[55] R. W. Berkowsky, J. Sharit, and S. J. Czaja, ‘‘Factors predicting decisions about technology adoption among older adults,’’ *Innov. Aging*, vol. 1, no. 3, Nov. 2017, Art. no. igy002.

[56] F. Ferreira-Brito, S. Alves, T. Guerreiro, O. Santos, C. Caneiras, L. Carriço, and A. Verdelho, ‘‘Digital health and patient adherence: A qualitative study in older adults,’’ *Digit. HEALTH*, vol. 10, Jan. 2024, Art. no. 20552076231223805.

[57] A. Siren and S. G. Knudsen, ‘‘Older adults and emerging digital service delivery: A mixed methods study on information and communications technology use, skills, and attitudes,’’ *J. Aging Social Policy*, vol. 29, no. 1, pp. 35–50, Jan. 2017.

[58] T. N. Friemel, ‘‘The digital divide has grown old: Determinants of a digital divide among seniors,’’ *New Media Soc.*, vol. 18, no. 2, pp. 313–331, Feb. 2016.

[59] M. Anderson and A. Perrin, ‘‘Tech adoption climbs among older adults,’’ in *Pew Research Center: Internet, Science & Tech*. Washington, DC, USA: United States of America, 2017.

[60] L. G. Park, F. Ng, J. K Shim, A. Elnaggar, and O. Villero, ‘‘Perceptions and experiences of using mobile technology for medication adherence among older adults with coronary heart disease: A qualitative study,’’ *Digit. HEALTH*, vol. 6, Jan. 2020, Art. no. 2055207620926844.

[61] B. B. Neves and G. Mead, ‘‘Digital technology and older people: Towards a sociological approach to technology adoption in later life,’’ *Sociology*, vol. 55, no. 5, pp. 888–905, Oct. 2021.

[62] B. Barbosa Neves, R. Franz, R. Judges, C. Beermann, and R. Baecker, ‘‘Can digital technology enhance social connectedness among older adults? A feasibility study,’’ *J. Appl. Gerontol.*, vol. 38, no. 1, pp. 49–72, Jan. 2019.

[63] M. Heinz, P. Martin, J. A. Margrett, M. H. Yearns, W. D. Franke, H.-I. Yang, J. Wong, and C. K. Chang, ‘‘Perceptions of technology among older adults,’’ *J. Gerontolog. Nursing*, vol. 39, no. 1, pp. 42–51, Dec. 2012.

[64] T. Valenzuela, Y. Okubo, A. Woodbury, S. R. Lord, and K. Delbaere, ‘‘Adherence to technology-based exercise programs in older adults: A systematic review,’’ *J. Geriatric Phys. Therapy*, vol. 41, no. 1, pp. 49–61, 2018.

[65] J. Evans, A. Papadopoulos, C. T. Silvers, N. Charness, W. R. Boot, L. Schlachta-Fairchild, C. Crump, M. Martinez, and C. B. Ent, ‘‘Remote health monitoring for older adults and those with heart failure: Adherence and system usability,’’ *Telemedicine e-Health*, vol. 22, no. 6, pp. 480–488, Jun. 2016.

[66] S. T. M. Peek, E. J. M. Wouters, J. van Hoof, K. G. Luijkx, H. R. Boeije, and H. J. M. Vrijhoef, ''Factors influencing acceptance of technology for aging in place: A systematic review,'' *Int. J. Med. Informat.*, vol. 83, no. 4, pp. 235–248, Apr. 2014.

[67] J. Moxley, J. Sharit, and S. J. Czaja, ''The factors influencing older Adults' decisions surrounding adoption of technology: Quantitative experimental study,'' *JMIR Aging*, vol. 5, no. 4, Nov. 2022, Art. no. e39890.

[68] C. Lee and J. F. Coughlin, ''PERSPECTIVE: Older adults' adoption of technology: An integrated approach to identifying determinants and barriers,'' *J. Product Innov. Manage.*, vol. 32, no. 5, pp. 747–759, Sep. 2015.

[69] H. Hawley-Hague, E. Boulton, A. Hall, K. Pfeiffer, and C. Todd, ''Older adults' perceptions of technologies aimed at falls prevention, detection or monitoring: A systematic review,'' *Int. J. Med. Informat.*, vol. 83, no. 6, pp. 416–426, Jun. 2014.

[70] M. D. Rodríguez, V. M. Gonzalez, J. Favela, and P. C. Santana, ''Home-based communication system for older adults and their remote family,'' *Comput. Hum. Behav.*, vol. 25, no. 3, pp. 609–618, May 2009.

[71] I. Gambo, M. V. Bueno-Delgado, K. Mooses, F. J. M. Muñoz, R. Zviel-Girshin, A. Andrushevich, M. Mrissa, A. Landowska, and K. Taveter, ''Technology adoption review for ageing well: Analysis of technical solutions,'' *Frontiers Public Health*, vol. 11, Sep. 2023, Art. no. 1169192.

[72] M. M. Mustaquim, ''A study of universal design in everyday life of elderly adults,'' *Proc. Comput. Sci.*, vol. 67, pp. 57–66, Jan. 2015.

[73] S. A. Morey, R. E. Stuck, A. W. Chong, L. H. Barg-Walkow, T. L. Mitzner, and W. A. Rogers, ''Mobile health apps: Improving usability for older adult users,'' *Ergonom. Des., Quart. Hum. Factors Appl.*, vol. 27, no. 4, pp. 4–13, Oct. 2019.

[74] A. C. D. Barros, R. Leitão, and J. Ribeiro, ''Design and evaluation of a mobile user interface for older adults: Navigation, interaction and visual design recommendations,'' *Proc. Comput. Sci.*, vol. 27, pp. 369–378, Jan. 2014.

[75] L. Nurgalieva, J. J. J. Laconich, M. Baez, F. Casati, and M. Marchese, ''A systematic literature review of research-derived touchscreen design guidelines for older adults,'' *IEEE Access*, vol. 7, pp. 22035–22058, 2019.

[76] G. Hou and Y. Hu, ''Designing combinations of pictogram and text size for icons: Effects of text size, pictogram size, and familiarity on older adults' visual search performance,'' *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 65, no. 8, pp. 1577–1595, Dec. 2023.

[77] G. Hou, U. Anicetus, and J. He, ''How to design font size for older adults: A systematic literature review with a mobile device,'' *Frontiers Psychol.*, vol. 13, Aug. 2022, Art. no. 931646.

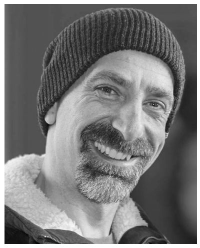
[78] J. Nielsen, *Ten Usability Heuristics*. Dover, CA, USA: Nielsen Norman Group, 2005.

[79] H. Huang, M. Yang, C. Yang, and T. Lv, ''User performance effects with graphical icons and training for elderly novice users: A case study on automatic teller machines,'' *Appl. Ergonom.*, vol. 78, pp. 62–69, Jul. 2019.

[80] S. Samaddar and H. Petrie, ''C.A.R.E: Designing a smartwatch app for older people,'' in *Proc. 36th Int. BCS Hum.-Comput. Interact. Conf.*, 2023, pp. 66–75.

[81] M. F. Story, ''Principles of universal design,'' in *Universal Design Handbook*. New York, NY, USA: McGraw-Hill Construction Media, Feb. 2001.

RUI P. DUARTE received the B.S. degree in applied mathematics from the University of Coimbra, Portugal, the M.S. degree in computational methods from the University of Porto, Portugal, and the Ph.D. degree in informatics engineering from the University of Beira Interior, Portugal. He is currently an Associate Professor of computer science with the Polytechnic Institute of Viseu, Portugal. He is the Director of the M.Sc. in Informatics Engineering and Information Systems and a member of the Coordination Team of the Research Center in Digital Services (CISeD), Polytechnic Institute of Viseu, where he also is a researcher and coordinates several research projects. He also is working in the field of emotional design for older adults. His research interests include human–computer interaction and computer graphics.



VALTER N. N. ALVES received the degree in informatics engineering, the M.Sc. degree in information systems and technologies, and the Ph.D. degree in information science and technology from the Faculty of Sciences and Technology, University of Coimbra, specializing in human–computer interaction, with the thesis ''Sound design guidance as a contribution towards the empowerment of indie game developers.'' He is currently an Associate Professor of computer science with the Informatics Department, Polytechnic Institute of Viseu, Portugal, where he has worked, since 1997. He teaches courses in areas, including interaction design, multimedia, and graphic design. He is the Director of the Degree in Multimedia Design and Technologies and the Co-Director of the M.Sc. in Informatics Engineering and Information Systems. He is a Researcher with the Research Centre in Digital Services (CISeD). His research interests include human–computer interaction, interaction design, user experience, sound design, game design, emotions, and support for people with special needs. Recently, he has combined his expertise in design and programming with his will to contribute to better educational experiences in several projects on robotics for children, such as Algolittle and Greencode. He was a member of the Audio Mostly Steering Committee, from 2010 to 2018. He is a member of the Sociedade Portuguesa de Ciencias dos Videojogos. He was awarded the ''Best Presentation'' Award at Audio Mostly, in 2009.

MICKAEL MOTA received the B.S. degree in computer science from the University of Paris-Saclay, Orsay, France, in 2022. He is currently pursuing the M.S. degree in computer science with the Polytechnic Institute of Viseu, Viseu, Portugal. His research interests include interface design, interaction design, and UX design.