HUMAN FACTORS IN TECHNOLOGIES FOR HEALTHCARE ENVIRONMENTS

Davide Bacchin

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Department of General Psychology, University of Padova

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Supervisor

Luciano Gamberini

Co-Supervisor

Alessandro Beghi

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1. Abstract

Health facilities worldwide have struggled with problems like lack of personnel, long and irregular shifts and high workloads, even before the recent pandemic. These problems dramatically increased the risks of stress and burnout among these workers' category. In these cases, technology can often help people mitigate these issues, for example, by using innovative paradigms like the Internet of Things (IoT). However, designers usually approach device creation in a top-down fashion without considering users in the process. This work aims to apply co-design methods in developing helpful technologies for various healthcare environments. Firstly, since its central role in them, this work aimed to improve the usability of the electrical medical bed. Furthermore, this project presents two IoT systems. The first is the smart bed, in which sensors collect information about the patient and the bed's state, providing a comprehensive overview of the ward and sending alarms in risky situations to reduce caregivers' workload and increase patients' safety. The second is the smart home, a domotic ambient assisted living solution for the co-housing of people affected by motor and cognitive impairments. Thanks to the control of lights, curtains, shutters and doors, this highly accessible system aimed to promote independence and reduce social distances.

The work done in this thesis evaluated the stakeholders' perception of such systems in multiple phases of the co-design cycle. The studies in which users participate started with qualitative methods to highlight their desires, followed by prototypes (i.e., user interfaces) evaluation to identify possible problems, and ended with testing the refined system's versions in real environments (i.e., retirement home, domotic apartment) to assess their actual impact. The tests exploited multiple research methods, often contemporary, with qualitative (i.e., focus groups, interviews) and quantitative (i.e., questionnaires, performance, log data, and psychophysiological) natures, resulting in the collection of subjective and objective data. Among the latter, a further methodological aim of this project was testing the feasibility of using an innovative eye-tracking index, namely the Low/High Index of Pupillary Activity (LHIPA), in future Human-Computer Interaction studies.

The results for the first objective highlight multiple desired features and design suggestions for future medical beds, providing useful tools for future tests, such as a usability checklist and User Experience (UX) guidelines. The works on smart systems participative design answer the second objective, presenting a comprehensive evaluation of IoT technologies in healthcare environments, treating themes like UX, Technology Acceptance, usability, patients' safety and comfort, trust and privacy issues with technologies, workload, care quality, sense of home, intention to use, and learning difficulty across multiple tests. These studies indicate that caregivers and patients are ready and enthusiastic to adopt IoT technologies. Finally, the eye-tracking studies performed for the third aim extend our knowledge of LHIPA, taking a step further in its validation for HCI studies.

Concluding, since the great interest that IoT technology in the healthcare field is experiencing, the results of this dissertation could significantly impact these environments, providing solutions, suggestions, limitations and issues derived from final users' opinions. Future designers could create user-friendly systems, thus improving the life quality of caregivers and their patients. Moreover, the eye-tracking studies on the LHIPA index expand our knowledge about the continuously growing field of psychophysiology.

2. Acknowledgements

During the long journey that led me to complete these years of PhD, many people have played fundamental roles, guiding and supporting me. First, I would like to thank my supervisor, prof. Luciano Gamberini, for the opportunity to work with him and to benefit from his exceptional guidance and experience, which permits me to grow as a researcher and person. Almost the same importance has been the help of prof. Patrik Pluchino and dr Valeria Orso, which mentor me through various research activities. Moreover, thanks are due to my co-supervisor, prof. Alessandro Beghi, to the president of the PhD course, prof. Anna Spagnolli, and the technical and administrative staff of the Department of General Psychology. I want to thank prof. Andrew T. Duchowski and the University of Clemson for the opportunity of spending my period abroad in the USA. Many thanks for supporting my work in various ways go to all my colleagues in the HTlab. Finally, many thanks to my friends, family, and partner for helping and supporting me during these three years of study. Thank you very much.

3. Glossary

HCI – Human-Computer Interaction

HCD – Human Centered Design

UX – User Experience

TA – Technology Acceptance

IoT – Internet of Things

ET – Eye-tracking

CL – Cognitive Load

HR – Heart Rate

ICT – Information and Communication Technologies

AAL – Ambient Assisted Living

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Summary

PROJECTS' AIMS

Nowadays, the presence of technology characterizes almost every aspect of modern human life. A significant portion of them exploits their functions autonomously, while many others require the users' interaction. Examples are countless, from computers, tablets, and smartphones to simple objects like electronic toothbrushes or hair dryers. One problem with technologies could be that sometimes they can be extremely complex to use, forcings users to spend high effort in learning how to exploit them. For this reason, almost 25 years ago, the technology design started shifting from a top-down approach to a user-centred vision, *ergo* including users in the process (Preece et al., 2004). This simple concept brings to developing the research field called Human-Computer Interaction (HCI) or, more broadly, Interaction Design. Summarizing the scope of this discipline, developing modern technologies should ensure fast learning of use for inexperienced users and aim to create easy interaction. Nevertheless, the user experience should be enjoyable, pleasant, and satisfying. These two aims belong to the well-known concepts of Usability and User Experience (UX).

The main purpose of the present thesis was to analyze these and other human factors related to innovative technological systems applied to healthcare environments (i.e., hospitals, retirement homes, and home care) that nowadays are experiencing issues they can help manage. Thanks to the new technologies, it will be possible to face problems like staff reduction (*I Numeri Del Personale Sanitario Diminuiscono Mentre l'età Media Aumenta*, 2022). The objective is to increase standards for patients' well-being and quality of stay, as well as care quality administered by caregivers who have to experience long shifts and excessive workloads. A possible way to reach these objectives could be to develop more usable tools, smart hospital objects and infrastructures. Among the former, medical beds have always been one of the cornerstones of healthcare, representing one of the fundamental parameters for comparing hospitals' efficiency, development, and diversity. Therefore, they are the perfect candidate to become active partners and smarter assistants.

Several improvements have been proposed over the years. The vast number of different technologies suitable for medical beds permitted the innovation of their design, materials, ad hoc models for specific populations, ergonomic controls, high mobility, and personalisation of the position (Ghersi et al., 2018). For example, new technologies have permitted features that allow better customisation of patient care and immediate and efficient responses by caregivers. Following this trend, this thesis proposes to extend further the knowledge of medical bed design involving caregivers since the literature does not focus enough on their needs. Furthermore, this work poses particular interests in creating assistive and monitoring solutions with the same design method.

Previous works exploited the same approach, with motion sensors integrated into the bed to detect possible agitations or falls (Banerjee & Rai, 2020), weight sensors to measure the pressure that the patient exerts on the bed (Gunningberg & Carli, 2016), and head inclination sensing (Bachman & Barrow, 2006). These are just a few examples of how beds can provide helpful information to prevent potentially dangerous situations. Examining the market, the multinational leaders in the sector presented some examples of innovative patient monitoring systems capable of alerting healthcare professionals during risk situations. For example, both ©Hillrom and ©Paramount Bed Co. studied and commercialised systems able to detect data, such as respiration and heartbeat, in bedridden patients (Nakajima & Sakaguchi, 2018; Wiggermann et al., 2019). ©Stryker, another major player in the sector, proposed a system capable of connecting multiple existing services (*IBed Wireless | Stryker*, 2022). A vital objective in most of these systems is monitoring physiological parameters, like blood glucose levels and pressure, CO2 concentration, cardiac, brain and muscle activity, oxygen saturation, humidity, and body temperature (Acampora et al., 2013). All these indexes are indicators of the patient's state of health, which control is the main objective of exploiting continuous monitoring. In the proposed system, monitoring aims to create an alarm system for caregivers, comprehending data from the patients and the bed itself. Anyway, a possible strong limitation of such systems is the false positives alarms rate, which heavily modifies, when too frequent, the instrument's acceptance towards those who use it and could trigger episodes of anxiety in the patients (Downey et al., 2018). This theme is particularly important since many false positives can cause alarm fatigue, reducing the quality of the caregivers' interventions and the patient's health (Ruppel et al., 2018). It is essential, indeed, to create reliable systems. However, to provide caregivers with a comprehensive view of their patients, the technologies in monitoring systems need to communicate with each other, exchanging and processing the most significant data in real-time, providing only helpful insights.

This communication is the basic principle of the Internet of Things (IoT) (Shah & Chircu A, 2018), which, applied to medical devices, has been renamed the Internet of Medical Things (IoMT, Joyia et al., 2017). Thanks to IoT for healthcare technologies, this project aims to face another critical environment, home care. In this field, *IoT*-based assistive technologies can promote essential aspects of people's lives, such as communication, self-care, independence, and health. The perfect target users that can gain many advantages from using these technologies can be people with disabilities. Thanks to their flexibility, IoT systems showed the capacity to adapt to many impairments, helping visually, hearing, and mobility-impaired people (H. Lee, 2017). Home automation represents in this field one of the most recent applications. *IoT*-based assistive technologies in the home context led to the creation of the so-called smart homes. These intelligent appliances present sensors that can monitor the environment and people's state, communicating devices to enable automation and remote access, and user interfaces to manage and receive information from the system (Arthanat et al., 2019). People with disabilities could efficiently perform impossible or time-consuming daily activities through ambient assisted living technologies. Also, these solutions can offer greater accessibility to the home, enhancing independence and autonomy (Ulloa et al., 2021).

Summarizing, the first objectives of this project involved three different technologies: the electrical medical bed, the smart-bed, and the smart-home. They all exploited the co-design process in creating easy-to-use and enjoyable instruments. Regarding the electrical medical bed, the research aimed to develop a working tool to help caregivers in their work. The focus was, therefore, on increasing the future beds' usability (H1).

Concerning the smart systems, the studies performed primarily aimed to evaluate the users' perceptions in terms of user experience, usability and technology acceptance to understand if modern working environments are ready for their implementation in the forms developed with the co-design approach (H2). Moreover, studies presented in this thesis explored a plethora of research aims, analyzing the impact of IoT technologies on care quality, sense of home, workload, and many others, with qualitative and quantitative approaches, collecting subjective and objective data.

Finally, the last project's argument regards new methodologies to study user-technologies interaction, focusing on eye-tracking methods for measuring Cognitive Load (CL). The CL is the mental demands imposed on users by accomplishing tasks and their cognitive resources to meet the working requests (Sweller et al., 2011). The literature provides many objective indexes of such a construct, and most of them rely on various psychophysiology signals (Grassman et al., 2016; Solhjoo et al., 2019; Buchwald et al., 2019; Koening et al., 2011). However, in the study presented in paragraph 5.2, some of them failed to highlight differences between short and highly ecological tasks performed on a standard monitor. Given these results, I was interested in researching new and innovative indexes to find reliable alternative measures for HCI studies. Indeed, the last project section aimed to evaluate a new index of eye-tracking based on pupillometry, the Low/High Index of Pupillary Activity (Duchowski et al., 2020), to test its validity with different tasks and experimental settings. The objective, in this case, was to confirm its validity in controlled settings (H3), allowing researchers to further study it in ecological studies.

1. Chapter 1

ELECTRICAL MEDICAL BED

1 Introduction

Healthcare and eldercare facilities are struggling to cope with patients' needs worldwide. Among others, a major problem is the staff shortage which obliges caregivers to face increasingly high workload and stress levels and creates an environment with high risks, precarious working conditions, long and irregular shifts, and emotional pressures (Büssing et al., 2017). A recent extensive study (Hämmig, 2018) described a survey with 1840 hospital caregivers highlighting how the physical, mental, and emotional workload plays a fundamental role in developing burnout and intention to leave the profession. The study showed that work stress accounts for 40-43% of burnout cases and 22-29% of the intention to leave. These data, therefore, pointed out that health systems are greatly affected by the ageing of the population and the contemporary demographic increment. Combined with the lack of personnel, these two set hospitals and nursing homes in difficult conditions. Besides, the COVID-19 pandemic and the health crisis have revealed new weaknesses in the sanitary systems, such as insufficient intensive care units (Ma & Vervoort, 2020), and have exacerbated the lack of personnel. Moreover, the large number of patients who needed regular or long-term hospitalization (Pecoraro et al., 2020) has highlighted the relevance of specific facilities that help caregivers to reduce their workload. All these issues, in different manners, concern both eldercare and healthcare. While they affect the quality of life and working environment of caregivers, they also impact the quality of care delivered to guests and patients. Therefore, helping health workers and nurses will allow all categories to improve care quality, given and received.

One possible solution arises from the intervention of increasingly sophisticated technologies, which can make hospital procedures easier or less tiring. These innovations certainly provide proper support, but, at the same time, they can introduce complex tools into the caregivers' work practice. Therefore, they must be studied and understood, especially when used by patients. It is crucial to ensure that these technologies are designed according to principles that make them effective, efficient, and satisfying. These characteristics fall within the concept of Usability, defined as "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2018). Given the strong influence that usability exerts on the increase of work well-being, the reduction of time pressure and other aspects of the work of doctors and the rest of the hospital staff (Vainiomäki et al., 2017), the point is, therefore, to make more usable the instruments used in these environments.

1.1 Electrical Medical Beds

Ghersi and colleagues review the modern history of hospital beds in two recent reviews (Ghersi et al., 2016, 2018). In their older work, he tackles the evolution of hospital beds from the 1940s to 2000, identifying three macro stages, starting with the era of electric beds, passing through mechatronic beds up to intelligent mechatronic beds. They identified the origin of the electrical beds with the invention of the adjustable side rails between 1815 and 1825 (Who Invented Medical Beds - Medical Beds). Following technological development, beds gradually acquire greater intelligence and automatisms, transforming into what they define as Intelligent Mechatronic Beds.

In modern electric hospital beds, software and hardware work together to allow the bed and its components to move concertedly, thus integrating mechanics with electronics and computer science. The most advanced versions of these tools present an electrical engine capable of moving some of their parts (e.g., backrest, height) to meet users' needs in terms of personalization and comfort. The modern bed is usually divided into four different sections. This configuration, with three articulated parts (back, thighs or upper leg, calves or lower leg) and a central part fixed, prevents the mattress from deforming and guarantees an equal pressure distribution even if the movement of each section reaches its limit. The leg and the torso sections can move thanks to electric or other actuators. Moreover, the double-section configuration of the leg segment, subdivided in thighs (upper leg) and calves (lower leg), allows a slight elevation in the central part at the knees level. This system allows reaching a position similar to an armchair (chair position). A scheme of this structure is shown in Figure 1.1, while a complete scheme of the modern electrical bed is shown in Figure 1.2.

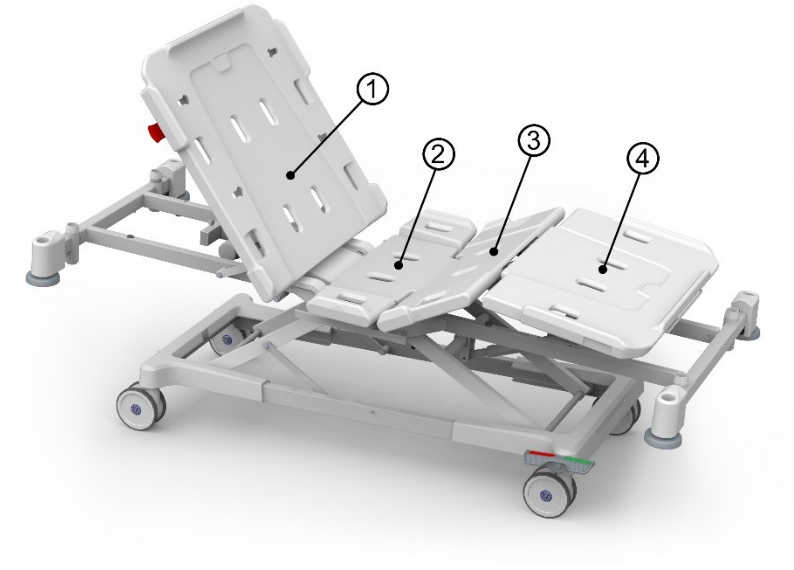


Figure 1.1. Scheme of the structure of the bed. 1 – backrest; 2 – central fixed section; 3 – thighs or upper leg; 4 – calves or lower leg.

The more recent Ghersi review (Ghersi et al., 2018) highlighted how the hospital bed market is increasingly evolving towards smart forms with cutting-edge technologies designed to have high functionality and advanced user interfaces. Anyway, before advancing to a more advanced form, this work addresses the importance of exploiting human-centred and co-design concepts to create a user-friendly version of the medical bed.

1.2 Designing Medical Beds

Despite its central role in caregivers' and patients' hospital life, electrical beds received little attention in human-centred design (HCD) research for innovative features. Indeed, it is rare to find examples of complete design processes in the literature. One could be the extensive work conducted by Wiggerman and colleagues (Wiggermann et al., 2019), where they described the design process starting from an observational study conducted in 29 hospital units in North America. After creating the prototype, they conducted multiple usability tests and concluded their work by listing the selected design features. More common studies describe performance tests of new innovative features and their use. For example, some studies tried to detect unchecked patients' bed exits and falls due to their role in causing injuries (LeLaurin & Shorr, 2019). Hilbe and colleagues (Hilbe et al., 2010) developed a bed-exit alarm system starting its design by reviewing literature and conducting open interviews with 12 nurses. They subsequently built a prototype and confirmed its usefulness in preventing falls through laboratory testing. Another work by Wolf and colleagues (Wolf et al., 2013) tested a similar system.

An important theme is the manoeuvrability of the beds. A work by Zhou and Wiggerman (Zhou & Wiggermann, 2017) evaluated the brake pedal location with nine healthcare workers, establishing its design implications and the preferred height for the push handle. Another study by the same authors analysed the effect of two bed features (i.e., Trendelenburg position and Mattress maximum inflation) on the caregivers' physical stress during typical patient repositioning tasks (Zhou & Wiggermann, 2021).

Less frequently, researchers explored the medical bed with subjective methods. For example, one study investigated the caregivers' satisfaction with the hospital bed, highlighting how often the difficulty in manoeuvring operations, transportation of patients and bed cleaning are the most physically demanding and troublesome tasks (Petzäll et al., 2008). Another study pointed out the importance of technical support and user-friendliness to make the nurses use the functions of the bed (Cai et al., 2016). Another example is a semi-structured interview study that described the bed comfort criteria to create an evaluation checklist (Esengün & Alppay, 2018). Other examples in the literature describe similar features, but they regard laboratory testing without taking into account end-users (Mehta et al., 2011; Soonthornkiti & Jearanaisilawong, 2013) or with novice participants (Alenezi et al., 2018; Jia et al., 2008; Kim et al., 2009).

Since the poor quantity of research on the design of medical beds and their importance in the healthcare environments, this thesis wanted to deepen our knowledge about one important bed's characteristic, namely bed usability.

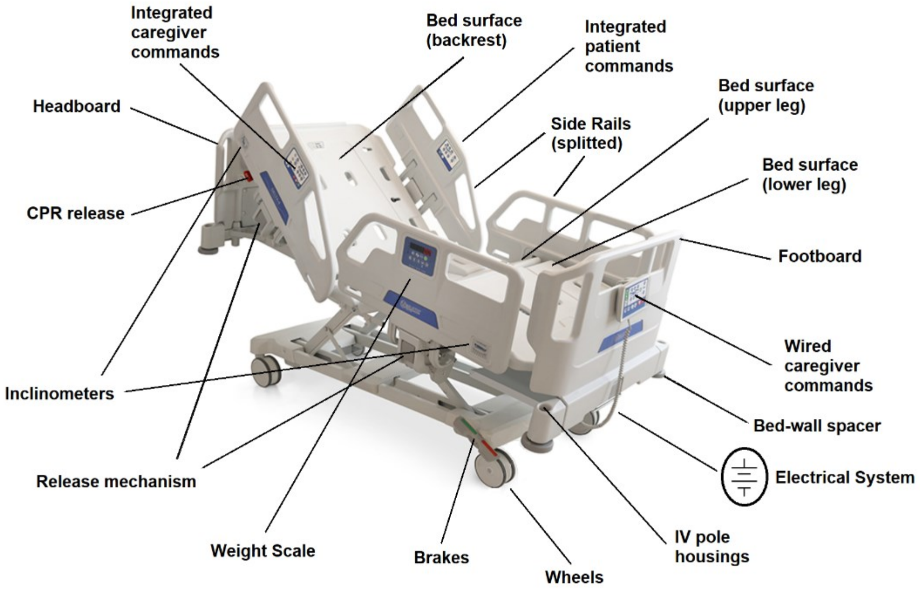


Figure 1.2. Scheme presenting the structure of a modern electrical medical bed.

1.3 Usability of Medical Beds

In the hospital environment, medical device efficiency is fundamental (de Bruin et al., 2010). Regarding medical beds, the control panels represent an example of an improvable instrument, since it is the physical interface that allows patients and professional caregivers to control their movements. Therefore, it would be desirable that the design and development of the beds will consider usability aspects, such as efficacy and efficiency. As described in the previous paragraph, despite the increasingly urgent and well-recognised need to study human factors related to them, the research in this field has mainly focused on technical aspects or sporadic performance evaluations. Studies investigating the subject perception of usability in healthcare environments are less frequent, even though a few exceptions exist. For example, a recent study (Surma-aho et al., 2021) used semi-structured interviews and a usability questionnaire to define the design guidelines for instruments in the operating room. A recent review (Bitkina et al., 2020a) sought to summarize and organize the studies carried out so far in the general field of medical devices, demonstrating the interest of human factors in hospital technologies.

However, pertaining to hospital beds, some investigations concerning their usability are present in the literature. First, the electric hospital bed has been tested to verify its effectiveness as a technological advance compared to previous versions, such as the hydraulic one. A video analysis study (Capodaglio, 2013) has demonstrated its superiority by analyzing tasks carried out by couples of nurses who had to deal with problems relating to bed hygiene and the transfer of a patient from it to a wheelchair. In this study, the outcomes of a survey administered to 63 caregivers highlighted a high level of usability for the electric bed.

The already cited work by Wiggerman (Wiggermann et al., 2019) has shown how bed manufacturers are increasingly interested in the human-centric approach, in which users are involved in the development process. This work presents many usability tests (over 20 studies with more than 130 caregivers) that were carried out to identify the interfaces' potential usability problems. Again, this design approach is concretized, in the final stages, with tests in a real environment, like the one carried out by Cai and colleagues (Cai et al., 2016). In their study, a smart bed, and the associated functions and technologies, were tested for 12 months in a hospital. The nurses involved were then interviewed to define any technical and usability problems.

Going more specifically to particular parts of the bed, one of the issues most encountered by hospital staff concerned the effort required to move a bed, with a patient on it, from one place to another in the hospital. In this sense, the innovations sought by the manufacturers, such as the 5th motorized wheel and alternative brake positions, have been studied to understand which solution could be the least tiring to use (Kim et al., 2009). Thanks to quantitative and qualitative measures, these studies have shown how the 5th wheel drastically reduces perceived fatigue and the need to have the brake pedals particularly accessible to the operators, both for the patient's safety and any operators' back pain.

As for the bed controls, the attention to the usability associated with them is more recent. In a study of 2017 (Fudickar et al., 2017), some interviews showed how gestures were recognized by caregivers as potentially suitable, given the possibility of hands-free control and reduced infection ability due to the reduced use of physical interfaces. Despite the advent of these innovations, the physical interface currently remains the golden standard for beds worldwide. Lin and colleagues (X. Lin & Zhang, 2020) tested the usability of 6 different types of controllers with 20 nurses. Finally, another study (Cai et al., 2016) explored an electronic push-button panel prototype, which the users interviewed defined as very useful.

The first work of this thesis was born from these concepts and from the intention to create an easy and rapid assessment tool to evaluate control panels' usability. For this objective, a usability checklist was devised, and the control panel (Figure 1.33a) present in the Delta4 model (Figure 1.33b) of the beds produced by the Malvestio Spa. was evaluated.

Figure 1.3. a) Patient's control panel; b) Delta4 bed

1.4 Usability Checklist

A usability checklist is a well-established methodology in Human-Computer Interaction that allows evaluating the usability of a user interface rapidly and cost-effectively. Generally speaking, a usability checklist consists of a set of rules or guidelines that the user interface has to meet and that several participants use to evaluate (Nielsen & Molich, 1990). One of the main advantages of usability checklists is that they provide reliable results even with very small samples of evaluators, namely five, thereby being extremely convenient (Nielsen & Molich, 1990). Initially, usability checklists were developed around the ten heuristics proposed by Nielsen (Nielsen, 1994). Such guidelines need to be adapted to the particular case of study.

Over the years, researchers deployed usability checklists to evaluate a variety of different interfaces, including websites (Keevil, 1998), augmented reality applications (de Paiva Guimarães & Martins, 2014), and virtual environments (Munoz et al., 2012), to mention a few. Several studies employed checklists to investigate the usability of mobile apps addressing patient monitoring of specific health issues (Anderson et al., 2016) or to evaluate a software for doctors' appointment management (Inal, 2019). However, the user interfaces with which healthcare professionals directly interact daily have rarely been assessed using such a method.

1.5 IoT Smart Bed

This thesis also proposed a system that turns the hospital bed into a patient data centre, exploiting the possibilities offered by IoT technologies. This tool aimed to collect data from patients' and beds' states, allowing the creation of alarms in dangerous situations. Among the functions of the so-called smart bed, it can obtain the bed position in the structure, directing operators to the source of the alarms. The bed weighting system allows the collection of information regarding the patient's presence and the eventual exit or fall. In addition, an algorithm that works on the weight data can predict the patient's exit, thus speeding up the intervention of the nurses. The bed can also collect the patient's physiological signals as a non-invasive tool detecting heartbeat and respiratory rate signals. Finally, the bed can inform the system about its status, providing data like minimum height, the side rails position, or the reaching of a specific backrest angle (i.e., 30°). All these data are accessible from any browser, where the healthcare staff can consult the status of the bed and the associated patient and set the monitoring rules that trigger the alarms. These alarms are then sent to the web application and can be consulted on smartphones anywhere in the hospital. Finally, the bed has two touch interfaces mounted on the side rails, allowing the management of the single bed and modifying and viewing the alarms. The designers' initial aims were to reduce intervention time and workload for caregivers and increase patients' safety. A graphical explanation of the system is provided in Figure 1.4.

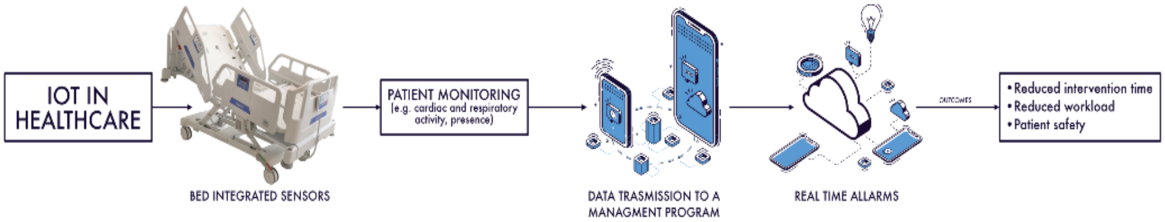


Figure 1.4. Graphical representation of the smart bed IoT system

For sensors-actuator communications, each bed of the system equips a gateway, which will receive information from the bed and patient sensors, providing the information listed above. These will be sent, via protected Wi-Fi technology, to a cloud server qualified as a level 3 data centre, which will, in turn, share them with the web application and mobile devices. The web application can communicate in real-time with the system, which monitors and records the status of the bed and its position in space. The system obtains the latter information by exploiting the beacon technology and allows caregivers to identify the source of the alarms (i.e., the patient that needs assistance). The current system architecture is shown in Figure 1.5.

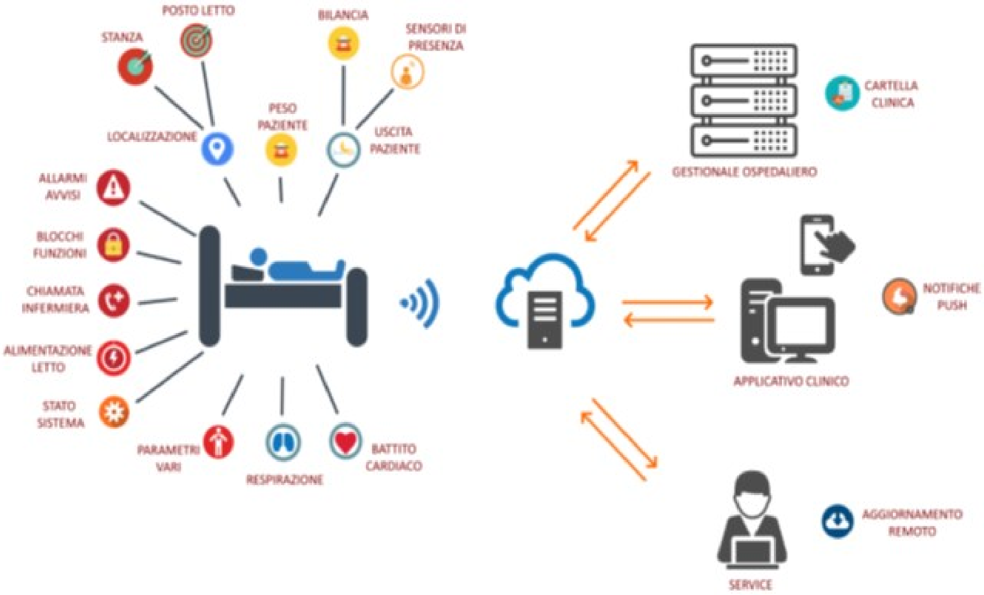


Figure 1.5. Smart Bed System Architecture

1.6 IoT in Hospitals

As previously addressed, the recent advancements of IoT technologies and their almost infinite possibilities permit a step further in bed design. Indeed, researchers started in the past years to imagine a hospital or an elderly caring environment where an IoT system can support operators. For example, Chiuchisan and colleagues (Chiuchisan et al., 2014) proposed system capable of monitoring patients at risk in an Intensive Care Unit (ICU), thanks to the integration of signals from technologies already in use in the hospital. This system used a Microsoft XBOX KinectTM to detect patient movement and a sensing board to monitor environmental parameters such as temperature and humidity. Other works, such as those described by Dhariwal & Mehta (Dhariwal & Mehta, 2017) and Catarinucci and colleagues (Catarinucci et al., 2015), proposed different system architectures to make a hospital smart. Many of these systems operate thanks to a series of sensors positioned inside the room. Instead, other studies aim to centralize all data collection on a single object, easily accessible to operators and in contact with the patient, such as the hospital bed. For example, some studies monitor the patient's pressure on the bed to inform the operator of any dangers regarding ulcers and pressure sores (Brush et al., 2013; Hong, 2018; Yousefi et al., 2011). In other cases, however, monitoring concerns the physiological signals related to the patient, as in the studies by Sivanantham (Sivanantham, 2016) and Hart and colleagues (A. Hart et al., 2010), which develop systems for monitoring cardiac and respiratory signals. Finally, some studies have also focused on the nursing home environment, developing technologies capable of detecting the presence or absence of the patient in bed and their incontinence (Fischer et al., 2019). However, few works have considered all these characteristics in a single IoT system, as the proposed system. An example in the literature is the work of Nakajima and Sakaguchi (Nakajima & Sakaguchi, 2018). There are also some commercial solutions by the hospital-beds leading companies, such as Hillrom with its Centrella Smart + bed (Centrella Smart+ Hospital Bed | Hillrom) and the stryker iBed Wireless (IBed Wireless | Stryker).

Anyway, a topic that still requires in-depth analysis is how operators would react to introducing these systems into their work environment and, in particular, their opinions regarding the social and behavioural implications (Carcary et al., 2018; Economides, 2017).

1.7 Perceived Usefulness in Technology Acceptance

In literature, the intention to adopt new technology is called Technology Acceptance (TA), often described by the Technology Acceptance Model (TAM; Davis, 1989) or, more recently, by the Unified Theory of Acceptance and Use of Technology [UTAUT and UTATU 2; (Ammenwerth, 2019; Venkatesh et al., 2011). Over time, the TAM has become the dominant model for investigating the TA of users regarding numerous technological systems (Legris et al., 2003a) in various fields of application (Granić & Marangunić, 2019; Salloum et al., 2019; Tubaishat, 2018), including healthcare (Holden & Karsh, 2010; Rahimi et al., 2018).

One of the model's critical variables is Perceived usefulness (PU), a dimension for which the users need to obtain useful results, solve a problem, improve their performance and overcome their possible limitations using a particular system (Economides, 2017). Therefore, this TAM dimension is truly important concerning IoT technologies for healthcare and non-healthcare personnel. The study by Tsourela and Neranrzaki (Tsourela & Nerantzaki, 2020), carried out with an online questionnaire on a sample of 812 subjects, showed how PU is one of the factors that most influence users to have a positive attitude and, therefore, a higher behavioural intention, towards IoT products. Focusing on the medical environment, a recent study (Kang et al., 2021) highlighted, through a questionnaire with 348 nursing students, how PU is the most strongly correlated factor to the intention to accept technology within one's work environment. Furthermore, the work by Martinez-Caro and colleagues (Martínez-Caro et al., 2018) has shown how the PU of IoT-based systems is a key factor in creating a positive environment and high perceived patient satisfaction. A further study analyzed 181 subjects via an online questionnaire (ben Arfi et al., 2021). The study showed that for people over 20 years of age, defined by them as IOT immigrants, facilitating conditions play an important role in adopting IoT technologies. Since these facilitating conditions are connected to perceived usefulness (Bhattacherjee & Hikmet, 2008), the assumption is that they play an important role in the TA of the IoT in healthcare.

1.8 Aim of the Studies

The present project comprehends six studies in the field of electrical medical beds. The first two regarded the bed as a working tool for caregivers, with particular attention to its usability and design. The following focused on the smart bed and its evaluation. The following list provides a brief explanation of each study's aim, with indications of the paragraph in which the study will be described in this thesis. Please note that some passages of this thesis has been quoted *verbatim* from the following studies.

Paragraph 4.1 – Development and Testing of a Usability Checklist for the evaluation of Control Interfaces of Electrical Medical Beds (Bacchin, et al., 2021b).

This work aimed to create a usability checklist for evaluating electrical medical beds' push-button panels, starting from the heuristics of Nielsen (Nielsen, 2009). The ultimate scope was creating a tool to facilitate the future evaluation of this tool's main control interface, used by caregivers and patients.

Paragraph 4.2 – Co-Design Electrical Medical Beds with Caregivers (Bacchin et al., 2022a)

This work aimed to provide researchers and companies with a qualitative study that deeply explores the opinions and needs of caregivers regarding the medical bed. The study comprehends a series of focus groups conducted with different types of caregivers belonging to various healthcare environments. The results described the modern electrical bed features' advantages and limitations, creating a valuable tool for analysing bed-related caregivers' problems and providing guidelines for the future design of medical beds.

Paragraph 5.1 – Caregivers' Perceived Usefulness of an IoT-based Smart Bed (Bacchin et al., 2022b)

The first study regarding the smart bed system wanted to approach the problem of assessing this system's perceived usefulness (PU) using a qualitative method, the Focus Group. Six of them were carried out with hospitals, retirement homes and homecare staff. The goal was to analyze PU through these discussion groups to draw conclusions about the fundamental elements for the acceptance of IoT technologies in different environments, from hospitals to home care.

Paragraph 5.2 – Web Interface Evaluation

The first evaluation work analyzes the participants' opinions about the web interface of the smart bed system. The study involves them in five *ad hoc* tasks, collecting both subjective (i.e., questionnaires) and objective (i.e., performance, psychophysiological and behavioural) measures to deeply evaluate the interface in terms of Usability, User Experience, Technology Acceptance, performance, and Mental Workload.

Paragraph 5.3 – Touchscreen Interface Evaluation

The second evaluation work used the same measure of the previous study to analyze the participants' opinions regarding the other user interface installed on the smart bed, the touchscreen. For this test, I elaborated four *ad hoc* tasks.

Paragraph 5.3 – Using Smart Bed in Real Healthcare Environment: Case Study in Retirement Home for Elderly

The last study of this research line aimed to evaluate the interaction of a group of healthcare professionals with the smart bed system designed following the previous phases. The first objective was to evaluate whether the operators' workload was reduced thanks to the use of the system. The second objective was to evaluate the user experience, the acceptance of the technology, as well as the usability of the touchscreen interface evaluated in paragraph 5.3. Finally, factors such as the patient's perception of safety, subjective workload and perception of the quality of care were explored through semi-structured interviews.

2. Chapter 2

SMART HOMES FOR PEOPLE WITH DISABILITIES

2 Introduction

The World Health Organization (WHO) estimates that at least 1 billion people worldwide are affected by some form of disability, corresponding to about 15% of the entire population above 15 years old (World Health Organization, 2020). These numbers are still growing, given the increased population's life expectancy and related health diseases. Insofar as disabilities are a relevant issue in our society, significant efforts must be made to support the health and well-being of individuals that are affected by these conditions. WHO reports the need to help the elderly and people with disabilities, addressing the necessity to overcome healthcare costs, limited access to resources and services, and physical barriers. Moreover, older people and individuals with disabilities are more prone to face risks connected with loneliness and social isolation, which might have catastrophic effects such as increased mortality, susceptibility to dementia, and poor self-rated physical health (Dickens et al., 2011; Emerson et al., 2020). Therefore, in the last years, research focused on innovative technological solutions to mitigate or solve the issues mentioned above to increase the quality of life of these individuals. In this regard, Smart Homes (SH) play a crucial role because they consider comfort, healthcare, safety, security, and energy consumption (Alam et al., 2012). These intelligent tools allow greater accessibility and usability for a broad category of people, overcoming problems like limited access to services and physical barriers. Besides, these technologies belong to networks able to communicate with each other, adopting the Internet of Things (IoT) paradigm (Wan et al., 2017). IoT systems, for instance, allow the possibility of exploiting technological devices to monitor the variables linked to individuals, living spaces, and other technologies functioning to prevent or detect potential issues and supporting those who live in the environment when they need it (Cena et al., 2019; Jiang et al., 2004). The IoT feature also plays a fundamental role in the cost management of people with disabilities and the elderly. These technologies can accelerate eventual medical interventions (e.g., seizures) and reduce the need for home assistance, thanks to reliable and constant monitoring. Moreover, the IoT paradigm could make possible a scaling-up economy to open the market to different players (Zanella et al., 2020a). Nowadays, the market competition has permitted the development of devices such as the Google Nest, Amazon Alexa, and Apple HomeKit, which are increasingly used worldwide.

The present thesis comprehends a real-world trial belonging to the DOMHO project, which evaluated the interaction of professional caregivers with an advanced domotic system. The project's overall objective was to design and develop IoT systems for ambient assisted living (AAL). The domotic technologies aim to support several people with disabilities in a domestic environment while adopting a particular model of sharing living spaces: the co-housing. Indeed, the project technologies permit the supervision of inhabitants by professional caregivers to prevent hospitalization, while the co-housing experience wants to mitigate issues related to loneliness and social isolation. The combination of co-housing and smart tools lays the basis for a supportive environment that could increase social protection, autonomy, and well-being for individuals with special needs and their caregivers.

2.1 Smart Homes

The market of intelligent homes is constantly growing, also thanks to related benefits, such as reduction of energy consumption (Wilson et al., 2017), high degree of innovation of the smart cities (Lund et al., 2017) and expected increment in well-being, quality of life, and sustainability (Schill et al., 2019). A recent market analysis (Berg Insight, 2022) estimates that in 2017 there were 22.5 million smart homes in Europe, which correspond to 9.9% of European households. Another study also quantifies the smart home market growth at ~ 30% annually or 84 million houses by 2022 (Buildup.eu, 2019). A recent review on the topic (Sovacool & Furszyfer Del Rio, 2020) has identified 267 different commercialized technologies on the market, classifying them according to 13 application categories: household appliances, lighting, energy and utilities, entertainment, health and wellness, safety and security, baby and pet monitors, clothes and accessories, vehicles and drones, home robots, gardening, etc. This review also provides one of the most recent classifications of automated and intelligent homes. The authors identify five levels of intelligence (i.e., 1 = lowest, to 5 = highest) defined as follows:

1. *The house presents some smart devices, i.e., a TV or a baby monitor, but users can decide if to activate them, and the technologies do not communicate.*

2. *At this level, the technologies begin to communicate with each other to support some basic or leisure services, such as heat (smart meter connected to a heat pump and advanced thermometer) or entertainment (smart TV connected to a smartphone).*

3. *At the third level, the home represents concrete support for the user, providing a basic level of automation and customization, such as turning on the lights at scheduled times (e.g., just before the user returns home).*

4. *This level introduces some degree of learning based on predicting the user's need and adaptation to events thanks to environmental sensors and user feedback.*

5. *At the highest level, however, the system constantly monitors the home, anticipates, and learns from users thanks to integrating multiple smart devices with the most disparate functions.*

However, as reported in this review, the most recent and known studies on SH aim to assess this technology's technic and economic aspects, showing little consideration for the human factors and potential benefits at the social level. In this regard, Aldrich (Aldrich, 2003) proposed one of the most authoritative classifications that focused on how SH could meet people with disabilities needs, proposing a five-class classification:

1. *Homes in which intelligent objects, such as doors or window shades, can be opened via a remote-control switch. Also, motion-activated lighting could be an example of this level.*
2. *Homes with wired or wireless networks for information exchange, such as a computer-controlled thermostat or lighting.*
3. *Homes that communicate with the external environment are also called connected homes.*
4. *Homes that exploit the possibilities derived from cloud computing to analyze data patterns and adapt their behaviour accordingly.*
5. *Homes that learn and predict human needs anticipate inhabitants' routines and act accordingly to provide adaptive cues. These are called "attentive homes".*

This thesis work focuses more on the user and how automation can support people with disabilities to accomplish daily tasks and routines that usually could represent insurmountable obstacles (Gentry, 2009). Automating the house response reduced human involvement and increased accessibility to the environment (Delnevo et al., 2018). Besides, a smart home improves other aspects such as comfort, protection, security, and management of energy resources (Marikyan et al., 2019).

2.2 Smart homes for individuals with disabilities

The aforementioned impact of disability and older age in our society highlights the potential benefits of IoT technologies for AAL.

According to a recent review of intelligent technologies for AAL, smart homes should be adaptable, interactive, and contextual (Maskeliūnas et al., 2019). Technologies should recognize the context in which they operate through data and sensors to adapt their responses without direct user intervention. The system should also interact with individuals to learn how to act correctly. Maskeliunas and colleagues also underlined that the different sensors, which describe the environmental state, could collect information on time, temperature, noise, pollution, and human data (e.g., human body language, requests, and needs). The intelligent system may exploit these data to assist humans and enhance their health, quality of life, and comfort, thus potentially increasing technology acceptance. For example, older adults have a series of problems that AAL technologies can face, e.g., risk of fall, social divide, reduced well-being and independence (Yusif et al., 2016; Moreno et al., 2015). Moreover, as suggested by Domingo (Domingo, 2012): "We firmly believe that the IoT can offer people with disabilities the assistance and support they need, to achieve a good quality of life [...] Assistive IoT technologies are powerful tools to increase independence and improve participation".

This new vision of the home automation system as a support for social and individual independence has led to different studies exploring the relationship between SH and people with special needs. These last can be both the elderly and people with disabilities because they often share similar issues.

Regarding the elderly, a recent literature review (Marikyan et al., 2019) reported that SH could improve socialization and even help users to overcome the sense of isolation. Another systematic review (Pal et al., 2017) focused on the actual efficiency of SH as a tool to improve the quality of life (QoL). In the context of health monitoring, it results in an enhanced feeling of safety, less fear, and less anxiety. For instance, it serves older people to remember daily tasks (e.g., drugs assumption) and strengthen their independence. Other positive consequences of SH use for the elderly are decreased loneliness, improved satisfaction, and well-being. Furthermore, the contemporary use of Information and Communication Technologies (ICT) and caregivers' help encourages self-independence (Pal et al., 2017). In the work of Carnemolla (Carnemolla, 2018), he highlights the benefits of SH technologies in facilitating self-care and autonomy, supporting older people's safety in the home by automating tasks with a reduction of the related risks.

Regarding people with disabilities, the literature provides several examples of SHs implementation. The first is the ENEA project (Maestosi et al., 2018). Concerning safety, the SH network can monitor specific environmental parameters (smoke detectors, C02, flood sensors) to detect risky situations and prevent injuries and accidents. This housing model is an approach that permits an adaptation of the smart home to the individual's specific needs. In Japan, the Robotic Smart Home (RSH) was designed and developed to increase the comfort, safety, and security of disabled and older people, using three robotic assistive systems (Tanabe et al., 2019). The first was a mobility and transfer assist system, helping people move freely around the house. The second system was an operational assistance system helping the inhabitants manage the house (e.g., opening curtains, turning on the TV, etc.). The third was an information assist system representing the connection with remote systems such as medical institutions or users' physiological monitoring devices. Chen and colleagues (Chen et al., 2017) developed a Morse-based interface for controlling different smart devices. After several months of use by people with severe disabilities, up to total paralysis, the system obtained favourable results considering system feasibility and interaction efficacy. Another project is DAT (Andrich et al., 2006) which proposed an intelligent home environment for users with disabilities. This work evaluated clinical protocols and innovative system control solutions in an apartment of seven rooms. The integrated technologies aimed to promote independence, safety, and health monitoring of people with disabilities and reduce caregivers' burden. Furthermore, the ProACT project (Malavasi et al., 2019) proposed an ICT-based solution for people with special needs, exploiting air quality and physiological sensors (i.e., pulse oximeters and glucometers) and smart cameras. In 2018, Enshaeifar and colleagues (Enshaeifar et al., 2018) described the TIHM (Technology Integrated Health Management) project, which integrates IoT devices into a single platform capable of communicating with caregivers. Thanks to wearable technologies, medical devices, and others, data are collected to inform operators about dementia patients' clinical conditions. The study adopted a co-design approach to evaluate patients, caregivers, clinicians, and industrial partners. The system seems capable of taking care of patients thanks to its predictive systems. The possible detected problems could be urinary infections derived from bathroom use and temperature data or highlighting a dangerous event with the fall detection system.

Regarding the SHs' interfaces, recent research proposed a framework that could allow people with different disabilities, such as blindness or deafness, to interact with the home environment. Mtshali and Khubisa (Mtshali & Khubisa, 2019) detailed a system that utilized commercial voice assistants such as Amazon Alexa, Google Home, or Apple Siri to capture users' voice commands to control the lighting system. Another study (Pradhan et al., 2018) supported the hypothesis of adopting commercial devices such as the Amazon Echo to help people with different disabilities interact with smart objects. For example, a study by Balasuriya and colleagues (Balasuriya et al., 2018) with 18 participants with special needs reported that, in 72% of cases, utilizing voice-based interfaces was preferred over graphical interfaces. These results were confirmed by another study reporting that 16 people with disabilities could effectively operate a voice assistant also if they present a mild cognitive impairment. Still, they can repeat only simple sentences (Masina et al., 2020a).

Besides, the benefits of SH also affect caregivers', particularly minimizing adverse effects on their work-related stress (Machiko et al., 2010) and reducing their burden (Lindeman et al., 2020). For example, imagine a user with a motor disability becoming more autonomous and independent. As a result, the family's quality of life and the caregivers' working conditions might improve. Indeed, recent papers report the positive effect of assistive environments in reducing the perceived burden derived from the constant commitment and effort to care for individuals with disabilities (Dupuy et al., 2017).

Anyway, improving the quality of life for people with disabilities not only comes with technological innovations. Another powerful strategy is creating numerous social interactions. The DOMHO project proposed to create a co-housing experience where people with disabilities could live together, thus forming a community.

2.3 Co-housing to avoid social distancing and loneliness.

The co-housing experiences in Europe and worldwide positively correlate with social inclusion and increasing feelings of well-being, self-efficacy, and esteem (Lubik & Kosatsky, 2019). It is impossible to exclude from this discussion the COVID-19 pandemic, which has inevitably worsened the health risks for people with disabilities. 40% of adults with a disability or a chronic disease reported feeling lonely or socially isolated (Loneliness in Adults with Disabilities: How States Are Taking Action| CHRT). Significant risk factors for those conditions include living alone, motor disabilities, major life transitions, and emerging health problems. Besides, seniors reporting feeling lonely or social isolation have a 45% greater risk of mortality because these problems can negatively affect physical and mental well-being (Banerjee & Rai, 2020). For those reasons, it is necessary to evaluate the co-living experience to face loneliness and isolation and exploit its potential to significantly improve physical and mental health (Burgess & Quinio, 2019).

In co-housing history, a critical phase is the 1970's movements that permit exploring new ways of living, such as sharing spaces. For many years co-housing had been seen as a "utopian dream", too distant from reality. However, in the last decade, people have begun to consider this model of coexistence with renewed interest. Co-housing introduces the relevant concept of autonomy that does not exclude sharing. Vestbro and Horelli (Vestbro and Horelli, 2012) defined this experience of living together as: "housing of common space and shared facilities".

The majority of the studies on co-housing involved older adults. One of the most extensive research in the field (Jakobsen & Larsen, 2019) analyzed 110 co-housing communities in Denmark with two internet-based surveys that explored their daily life and the motivation for choosing such a lifestyle. Results showed that co-housing experience correlates with high life satisfaction. However, the authors stated that a considerable limitation of their study was that the participants were all rich and privileged. Another example is the USA co-housing community, analyzed by Jenkins (Jenkins, 2017) in his research. He evaluates a series of co-housing communities' websites and visits three communities to outline the crucial values of people that choose this sharing experience. The results show that caring (i.e., depth of relationships), community, diversity, and sustainability are considered fundamental in designing supporting technology for co-housing. In the Netherlands, Rusinovic and colleagues (Rusinovic et al., 2019) conducted a qualitative analysis in eight communities for the elderly. Their results showed that co-housing reduced social loneliness and improve the sense of affiliation and social and personal safety. Besides, Brenton (Brenton, 2013) highlighted the advantages of senior co-housing linked to active participation in a group of people. Indeed, it encourages the acquisition of a social role and compensates for the anonymity of the classical single households in which many older people live. Moreover, co-housing could be an additional option for informal care, reducing demand (and costs) for health and social services.

In conclusion, the co-housing experience in a smart home environment could be a new living form to promote and support older people and individuals with disabilities to increase their autonomy and independence, receive social support, and feel safer. Anyway, the literature needs more research on SHs' impact on the human factors of inhabitants.

2.4 Human Factors in Smart Home studies

The studies in this thesis regarding the smart home had multiple aims. Firstly, evaluate the User Interfaces of the DOMHO system involving people with disabilities and their caregivers. Secondly, analyze human factors that ambient assisted living technologies could affect. The following paragraph provides a background for each of the human factors considered:

- *Technology Acceptance.* The intention to adopt new technology is a short definition of the Technology Acceptance (TA; Granić & Marangunić, 2019; Legris et al., 2003b; Miguel Cruz et al., 2020; S. Salloum et al., n.d.; Tubaishat, 2017). This construct presents various describing models, such as the Technology Acceptance Model (TAM; Davis, 1989) or the Unified Theory of Acceptance and Use of Technology (UTAUT and UTATU; (Ammenwerth, 2019; Venkatesh et al., 2011). TA was also utilized in the study of SH for people with disabilities ((Shafi & Mallinson, 2021) or on age-related issues (Pal et al., 2018; van Heek et al., 2018). The work by Yang et al. (H. Yang, Lee, & Lee H, 2018) highlights that the SH design should consider interconnectivity and reliability, along with the right level of automation.

- *User experience*. The user experience (UX) is "a person's perceptions and responses that result from the use or anticipated use of a product, system or service"(*ISO - ISO 9241-210:2010 - Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems*, 2019). UX is an essential concept for healthcare technologies(Adarsha et al., 2019).
- *Usability*. Usability is when a system or product can achieve specific goals with effectiveness, efficiency, and satisfaction in a specific context(*ISO - ISO 9241-210:2010 - Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems*, 2019). Many studies analyzed usability SH's and their user interfaces (Bissoli et al., 2019; Hugo et al., 2021; Sime et al., 2021; Wallace & Morris, 2018).
- *Sense of Home*. It is intended as the meaning of being at home. This is particularly relevant in nursing homes for the elderly (Oswald et al., 2006; Rijnaard et al., 2016; van Hoof et al., 2016). Still, to the best of our knowledge, no studies explored it considering people with disabilities and SH.
- *Caring Behavior*. It is related to how people with disabilities' perception of caring behaviors. This important concept is defined as "actions concerned with the well-being of a patient, such as sensitivity, comforting, attentive listening, honesty and non-judgmental acceptance"(Salimi & Azimpour, 2013). Hospital nurses are usually the main subjects of the research about caring behavior (Labrague et al., 2020). The literature does not present studies that explore the technology's impact on the caring perception of people with disabilities. However, recent studies show the negative influence of new technologies on this construct from the nurse's point of view (Adel, 2014; al Awade et al., 2021).

2.5 The Smart Home Structure

In the two studies presented in this thesis, a smart home (i.e., DOMHO) co-designed with caregivers and people with disabilities has been analyzed.

The 56-square-meter residential apartment in Castelfranco Veneto (PD, Italy) has two bedrooms (each with a hallway), a living area with a kitchen, and a bathroom with an anteroom. The apartment was designed to accommodate a group of three residents and a caregiver. The apartment had been altered and furnished with modern conveniences to reduce architectural barriers and improve accessibility (e.g., external lift, automated beds and rail lifts in the bathroom and the bedrooms, Figure 2.1).

Figure 2.1. Useful elements for the reduction of architectural barriers. Figure 2.1.a shows the controllable electric beds and the lights placed above them; figure 2.1.b shows the motor that allows the automatic opening of doors; Figure 2.1.c shows the window shutter engine; Figure 2.1.d shows the elevator that will take the residents inside the apartment.

2.5.1 System Architecture

Figure 2.2 shows the system architecture.

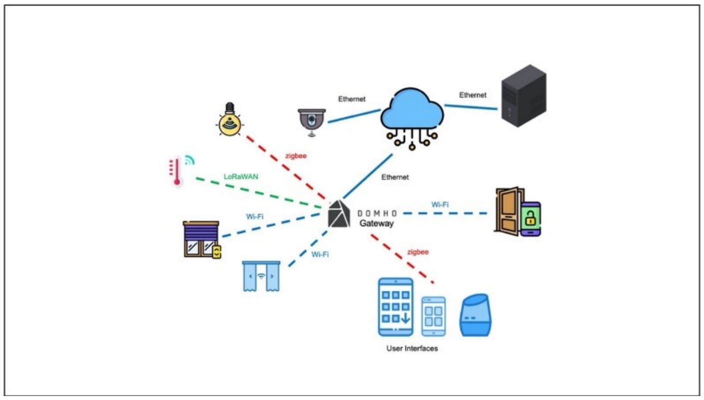


Figure 2.2. System Architecture.

A smart gateway that manages data exchanges (effectively secured and protected) and integrates them with those from the Cloud allows the system technologies to communicate. Different protocol languages (e.g., ZigBee, LoRaWAN) could communicate through this gateway. To accommodate the tastes and demands of the users, the system provides flexibility, modularity, and customization options (i.e., the ability to add or remove devices).

The DOMHO system comprehends three technologies categories (i.e., lighting, environmental sensors, and automation components) which enable controlling, programming (for example, establishing routine scenarios), and monitoring the system devices in more detail.

- Lighting: The applications had complete control over the apartment's lighting and could change their intensity, control and on/off status. The RGB system allows for the temperature and colour of the lights above the beds to be changed (Figure 2.3). These changes increase the degree to which the areas can be customized based, for example, on the activity (relaxed reading).

Figure 2.3. Beds (left) and table (right) lights.

- Environmental Sensors: The various sensors located throughout the apartment work to keep occupants safe and avoid accidents. The house presents Volatile Organic Compound (VOC) sensor in the living room, as well as one controlling the temperature, ambient light, fine particle concentration, and air quality in the space. Further, an ammonia sensor (NH3) to detect urine is located in the bedroom. The ability to transmit alerts and messages to caregivers via all environmental sensors allows prompt intervention.
- Automation: The apartment's doors, curtains, and window shutters were automated. The technology enables the first two pieces to be opened, closed, and stopped from moving at any time.

The DOMHO system offers various user interfaces (e.g., voice-based, tablet, smartphone) to control automation and lights in real-time. Additionally, the operator interface, or smartphone, can configure the operation of all technologies (operation named “scenario”), including environmental sensors, and generate usage scenarios (which activate several IoT devices together). The operator interface, for instance, enables them to create a scenario, rename it, and choose the status (e.g., on/off, open/close) of all the relevant devices. For instance, when operators need to prepare the house for the night by closing all the shutters and curtains and turning off the lights, they can activate the dedicated scenario, which will be activated with only one tap. A scenario can also be manually activated or preprogrammed to start at a specified time (e.g., each day for a month, only one day of the week). The fact that everything mentioned so far can be controlled via a voice-based interface makes DOMHO incredibly accessible to all users. A preliminary experiment demonstrated the viability of such control methods when applied to people with mild cognitive and motor limitations showing that they could command smart equipment with their voices (Masina et al., 2020; Masina et al., 2021).

2.6 Aim of the Studies

This research line comprehends a total of two studies. Both of them regard the evaluation of the system by the users involved. The following list provides a brief explanation of each study's aim, with an indication of the paragraph in which the study will be described in this thesis. Please note that some passages of this thesis has been quoted *verbatim* from the following studies.

Paragraph 6.1 – Smart Co-Housing for People with Disabilities (Bacchin et al., 2021a)

This work described a preliminary trial in the context of the Domho project, involving caregivers in using a mobile application that permits the control of different smart devices of an integrated IoT system installed inside a residential apartment. Participants carried out four tasks designed to examine the performance, user experience, and usability of a control interface designed and developed using a co-design approach during DOMHO project. Besides, the subjective perceptions of caregivers towards Smart Home and IoT systems were assessed using a semi-structured interview.

Paragraph 6.2 - Smart Cohousing: An Evaluation of Human Factors from People with Disabilities and Caregivers' Perspective (Submitted Work to Human Computer Interaction)

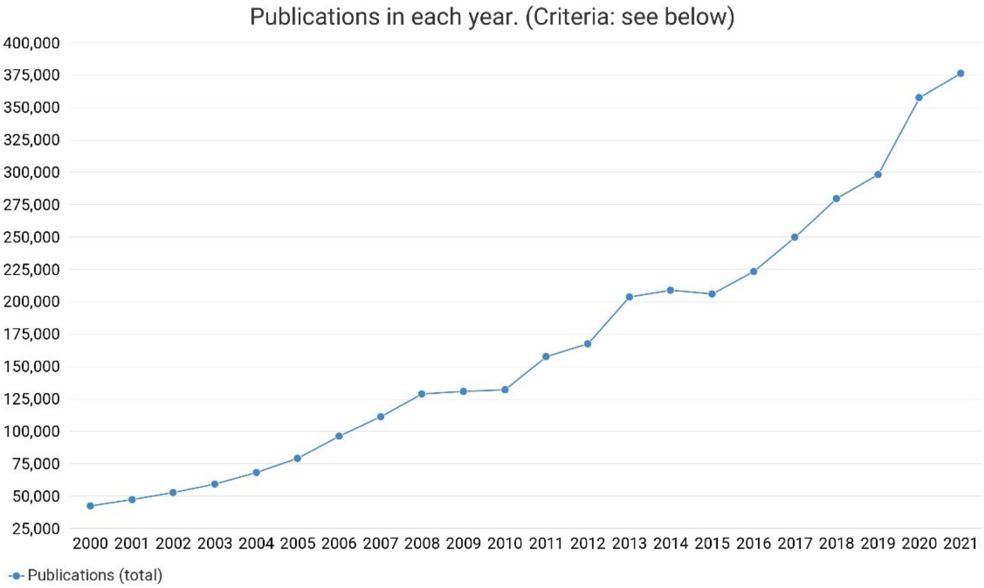
This study explores people with disabilities and caregivers' perceptions of domotic technologies. Firstly, I evaluated a pool of questionnaires (i.e., Technology Acceptance, User Experience, Usability, Sense of Home, Sense of Home related to technologies) and objective measures (i.e., log data, performance) after a single weekend of use. Furthermore, I evaluated the caregivers' potential longitudinal variations in subjective perceptions after three months of domotic technology use. In the last part of the study, people with disabilities lived with and without the DOMHO technologies. The aim was to research potential differences between their subjective perceptions of Caring Behavior and Sense of Home in these two conditions.

3. Chapter 3

EYE TRACKING METHODOLOGY FOR HUMAN-COMPUTER INTERACTION RESEARCH

3 Introduction

Eye tracking is an experimental method in which eye movements are recorded during the execution of a task. Nowadays, this method has a relatively long history, starting from the studies of Bell in 1823 (Bell, 1823) on the effect of visual orientation on eye movements (Wade & Tatler, 2005). The first attempt to track eye behaviour exploited complex, invasive, and difficult-to-use systems, all obstacles to the method's spreading in research. Technology advancements brought the advent of video-based eye trackers, which usually came as remote or head-mounted tools, easy to use and with great data acquisition frequency (Carter & Luke, 2020). The accessibility of this powerful tool allows researchers to exploit it in many fields like reading (Rayner, 2009; Schroeder et al., 2015), economy (Lahey & Oxley, 2016), memory (Hannula et al., 2010), learning (Alemdag & Cagiltay, 2018; Conklin & Pellicer-Sánchez, 2016), decision making (Fiedler et al., 2019; Orquin & Mueller Loose, 2013), diagnosis (Brunyé et al., 2019), various disorders (Armstrong & Olatunji, 2012; Chita-Tegmark, 2016), sport (Discombe & Cotteril, 2015; Kredel et al., 2017), aviation (Ziv, 2017), communication (King et al., 2019), organizational research (Meißner & Oll, 2019), user experience and usability (Bergstrom & Schall, 2014; Goldberg & Wichansky, 2003). Thanks to its flexibility of use, eye-tracking research experienced an enormous growth in the number of publications on the argument, as shown in Figure 1.6.



Source: https://app.dimensions.ai
Exported: November 30, 2022
Criteria: 'eyetracking OR eye-tracking OR eye tracking' in full data.

Figure 3.1. Number of publications about eye-tracking in each year.

In the HCI field, ET has been exploited for a plethora of reasons, such as emotion recognition (Hwang & Lee, 2020; Lim et al., 2020), interfaces evaluation (Sulikowski & Zdziebko, 2020; Wang et al., 2018), performance (Lin et al., 2018) and learning (Rappa et al., 2022). Anyway, this part of the project focuses on using ET in the measurement of Cognitive Load.

3.1 Cognitive Load

The concept of Cognitive Load (CL) and Cognitive Load Theory (CLT) has received considerable attention from the human factors research community since it represents a measure of general demand on working memory and information processing associated with a specific task (Schnotz & Kürschner, 2007). Since its introduction, CL has acquired significant interest in Human-Computer Interaction (HCI) research, which focuses on designing, evaluating and implementing interactive technologies (Hewett et al., 1992). A good design aims to reduce problems linked to complex and time-crucial situations in which users cannot operate efficiently because of cognitive overload. Air traffic operators represent an example of this problem. During their daily work, they face multiple risks and time-critical situations, typically resolved by managing complex interfaces generating high cognitive load, thus reducing their performance (Khawaja et al., 2014). Since their efficiency is related to safety effectiveness, a natural consequence is that this working condition can impair their capacity to resolve unexpected events, potentially leading to accidents (Li et al., 2021). This is just one example of where CL research can help users to improve their attention levels, help them operate at their best, and enhance the ease of use and efficiency of system interaction.

CLT has been applied in educational environments, instruction design, multi-modal interface design, decision-making, hypermedia/information search environment design, distributed CL in groups, game design, analysis methods for cognitive processes, and formal simulation modelling of CL (Hollender et al., 2010). However, CL measurement lacks clarity, with no singular metric that stands out from the various available approaches, including gaze measurement, microsaccades, pupil diameter, and blink rate, among others (see below for details). Moreover, and possibly, more importantly, the tasks used to validate cognitive load measures often rely on fairly straightforward tasks (e.g., arithmetic, number counting, or n-back), which depend on a single feature, not necessarily representative of more realistic task scenarios. In this work, I introduce the Color Visual Short-Term Memory (CVSTM) task based on conjunctive search, dependent on the cognitive processing of dual features. I consider this task a step forward in substantiating CL measures and a lead-in to future studies expanding to conjunctive processing (including visual search) of multiple features.

3.2 Definition of Cognitive Load

Cognitive Load (CL) was first described by Sweller (Sweller, 1988, 1994) in his studies of students' learning processes. Since then, many methods have been developed for its measurement. As summarized by Sweller et al. (Sweller et al., 2011), measurement methods can be subdivided into indirect measures (i.e., reflecting user performance), subjective measures (e.g., questionnaires) through a secondary task, and physiological measures. Regarding subjective measures, one of the most commonly used questionnaires is the NASA Task Load Index (NASA- TLX), a multi-dimensional rating scale (S. G. Hart, 2006; S. Hart & Staveland, 1988) extensively employed in experiments of CL (Biondi et al., 2023; Buchner et al., 2021; Emami & Chau, 2020). As highlighted by Minkley et al. (Minkley et al., 2021), subjective CL measurement has been a primary research approach. However, the technique still lacks validity completeness because of the large variety of questionnaires used and to influencing factors, such as prior user knowledge, interest, and motivation. For these reasons, subjective measures do not necessarily accurately reflect CL. On the contrary, task complexity can be more precisely measured through objective means.

3.3 Psychophysiological Measures

Objective measures of CL offer a series of advantages over subjective measures. Subjective tools can usually be exploited only before task completion, e.g., through questionnaires such as the NASA-TLX, postponing results. Other instruments (i.e., think-aloud methods) can be used during the task, but they carry the disadvantage of lacking ecological validity. Among various objective measures, ones measuring performance and psycho-physiological responses offer reduced intrusiveness in task performance and allow measurement and analysis of interpersonal variability. In this work, I am mainly concerned with these types of CL measures, falling within the realm of other objective measurement approaches, including measures of respiration (Grassmann et al., 2016), cardiology (Jerčić et al., 2020; Solhjoo et al., 2019), electrodermal activity (Buchwald et al., 2019; Mehler et al., 2012), and skin temperature (Koenig et al., 2011). Although these methods are considered non-invasive, they all require sensors in close contact with the user's skin. This characteristic could interfere or influence user behaviour during task performance (Fridman et al., 2018). In contrast, a measure that does not require physical contact is represented by remote eye-tracking methodology.

3.4 Eye Tracking Metrics

Eye movements and behaviour have been extensively studied for CL measurement, with indices such as blink rate (Chen & Epps, 2014), number and duration of fixations (Fitts et al., 1950; Jacob & Karn, 2003; Just et al., 1976), number of regressions (Azuma et al., 2014), microsaccades (Engbert & Kliegl, 2003), and measures related to pupil diameter (Ahern & Beatty, 1979; Beatty, 1982; Beatty & Lucero-Wagoner, 2000). Among these, the latter represents one of the most popular examples since modern eye trackers provide reliable and easy-to-access data that includes pupil diameter (S. Chen & Epps, 2014b; Pfleging et al., 2016; Piquado et al., 2010). The literature presents various examples of CL studies that exploit pupil diameter for its measurement in numerous tasks, such as web maps (Kiefer et al., 2016), arithmetic calculations (S. Chen & Epps, 2014b; Krejtz et al., 2018), decision-making in serious games (Jerčić et al., 2020), n-back (Biondi et al., 2023; Peysakhovich et al., 2017), and simulated driving (Čegovnik et al., 2018; Heeman et al., 2013; Kun et al., 2013; Palinko & Kun, 2012) and flight (Peysakhovich et al., 2015; Zheng et al., 2022). More recently, researchers have begun to explore fluctuations in pupil diameter, with the development of the Index of Cognitive Activity (ICA; Marshall, 2000, 2002), the Index of Pupillary Activity (IPA; Duchowski et al., 2018), and the Low/High Index of Pupillary Activity (LHIPA; Duchowski et al., 2020). In previous work, I focused on microsaccades and LHIPA, which have shown reliability for measuring CL during tasks such as mental counting and n-back (Duchowski et al., 2020). During some of these prior studies, participants were forced to fix their gaze on a specific point on display, with sound prompts used to indicate eye movement straying off-target. Although some earlier work did allow for some limited movement of gaze, most of these tasks relied on visual stimuli composed of single features, e.g., letters or numbers. The next step in furthering the validation of these metrics is to replicate earlier results and extend them with more complex tasks composed of conjunctive visual features.

3.5 Cognitive Load-Inducing Tasks

The CL literature lacks standardized tasks that can be used to validate CL measurement. One common approach is performing a secondary task (Brünken et al., 2004; Hunter, 2021; Park et al., 2014; Schoor et al., 2012). However, this method is mainly used to test the effect of cognitive load on the primary task. Another technique is creating tasks with different difficulty levels, for example asking participants to do some arithmetic operations such as fraction comparisons (Ikehara & Crosby, 2005), addition changing digit numbers (S. Chen et al., 2011), or addition or subtraction of subsequent numbers (Korbach et al., 2018). Recently, Deck et al. (Deck et al., 2021) described common CL-inducing tasks, e.g., the memorization of a visual pattern (commonly a series of dots in a grid) followed by a distracting task, where participants must reconstruct the location of the dots (Gerhardt et al., 2016) or identify a particular position containing one of them (de Neys, 2006).

A second common approach is the n-back procedure, where participants must indicate if the last element displayed is the same as the n^{th} previous one (Appel et al., 2018). To accomplish the n-back task, participants need to encode the incoming stimuli, monitor and update them and compare the currently displayed stimulus with the presented n trials earlier. The n-back task is challenging as it requires simultaneous management of multiple cognitive processes (Jaeggi et al., 2010). The ease of manipulation of the n factor makes it easy to manage task difficulty, making it a fairly reliable instrument in CL research, with numerous examples (Fridman et al., 2018; He et al., 2019; Kesedžić et al., 2020; Khanam et al., 2022). Another variation of the n-back task is the application of time pressure. However, this has been shown to affect mainly social and strategic decisions (Deck et al., 2021; Deck & Jahedi, 2015). Finally, another approach requires the memorization of strings of various lengths. This variation is based on classic work by Miller (Miller, 1956) concerning the retainment of a maximum number of seven pieces of information plus or minus two. Manipulating the string length can modulate different CL levels (Allred et al., 2016; Deck & Jahedi, 2015).

3.6 Color Visual Sort-Term Memory Task

Prior CL-inducing tasks were mainly related to the cognitive capabilities and working memory of participants. In contrast, one of the present works aims to test CL metrics on a task related to visual short-term memory: the Color Visual Short-Term Memory (CVSTM) task. This task, derived from the work of Luck and Vogel (Luck & Vogel, 1997) and Meyerhoff and Gehrer (Meyerhoff & Gehrer, 2017), challenges participants to remember different visual features of a series of objects, such as colour and position. The short-term retention of visual information is conventionally considered separate from prior semantic knowledge, although some very recent studies account for long-term memory involvement in everyday visual environments (Xie & Zaghloul, 2021). In the CVSTM task, the number of objects is controlled in order to vary task difficulty since many studies have shown that increasing the number of items increases memory load, highlighted by an increase in the magnitude of errors of stimulus recall (Lilburn et al., 2019). The scope of this task is thus to test short-term memory in terms of encoding and storing information about the stimulus features, a field that has been studied for memory-related issues thanks to eye-tracking technology (Pavisic et al., 2021).

3.7 Feature Integration Theory

The theory describing visual attention related to multivalent stimulus features is the Feature Integration Theory (FIT, Treisman et al., 1980). Although developed in the context of visual search, FIT still provides interesting insights into how object identification is acquired through identification of component stimulus features. The theory describes conjunctive search, in which the identification of objects requires integration of its features, distinguishing them from distractors (Humphreys, 2015; Singh & Schubert, 2021). FIT has been applied to numerous HCI-related tasks, including, for example, image search (Kobayashi et al., 2013), visual saliency computing (S. Wang et al., 2021), and information visualization (Cai et al., 2015). The CVSTM task, although not strictly a visual search task, is grounded in the CVSTM construct, since it requires the use of visual short-term memory for memorization of multiple features of the target (i.e., position and color). To the best of our knowledge, no previous study has examined eye movements during a CL-inducing task based on multivalent features.

3.8 Aim of the Studies

This research line presents two studies about the use of an innovative eye-tracking index in the measurement of CL. The first one was conducted in collaboration with Professor Andrew T. Duchowski, full professor at Clemson University, South Carolina, USA. The following list provides a brief explanation of the aim of each study, with an indication of the paragraph in which the study will be described in this thesis. Please note that some passages of this thesis has been quoted *verbatim* from the following studies.

Paragraph 7.1 - Using LHIPA to Measure Cognitive Load in a Conjuctive Visual Feature Memory (Submitted to ETRA 2023)

The aim of this work was to evaluate three eye-tracking metrics for measuring CL in a novel task based on conjunctive visual features. Earlier studies mainly focused on testing metrics in tasks involving a single feature, e.g., n-back and arithmetic tasks, where participants had to recognize and remember a particular shape (i.e., letters, numbers). The CVSTM, in contrast, relies on multiple conjunctive features, meaning that participants had to simultaneously store multiple informational elements in their visual short-term memory. Cognitive load metrics validated with such a task are likely to be more reliable and useful for HCI applications, where human interaction requires the manipulation of complex, multivalent information.

Paragraph 7.2 – Evaluating LHIPA with a Head-Mounted Eye Tracker

The main aim of this work was to verify the ability of LHIPA to discriminate the cognitive load connected to an activity when measured with a head-mounted eye tracker. The secondary aim was to compare it with a more robust index in the measurement of cognitive load, the HR. Moreover, since the computation of LHIPA is similar to the temporal analysis of HR variability (i.e., LFHF ratio, Duchowski et al., 2020; Pham et al., 2021), the study aim to correlate LHIPA and LF/HF index to detect eventual relationships.

4. Chapter 4

ELECTRICAL MEDICAL BED

4 ELECTRICAL MEDICAL BED STUDIES

4.1 Development and Testing of a Usability Checklist for the Evaluation of Control Interfaces of Electrical Medical Beds.

4.1.1 Aim of the Study

This study aimed to create a quick, easy-to-use and efficient tool (i.e., Usability Checklist) that allows an in-depth analysis of the usability problems of the pushbutton panels of modern hospital beds. The motivation was to fill the absence in the literature of tools that evaluate hospital beds' control panel design. Due to the possible industrial applications of such an instrument, a further aim was to make it cheap and fast to administer. Since usability checklists provide reliable results even with very small samples of evaluators, namely five (Nielsen & Molich, 1990), I tested it with this number of usability experts. In such a way, companies and researchers that need to evaluate a bed push-button panels fast could involve a minimal amount of people to highlight the major usability problems. Consistently, the Checklist devised highlighted some critical usability issues in a reasonable time (i.e., about 9 minutes).

4.1.2 Materials and Methods

4.1.2.1 Checklist Development

The checklist's creation was divided into three phases: the selection of the usability guidelines, the distribution of the same within the ten Nielsen heuristics, a first pilot to test their effectiveness, and the removal of the unsuitable ones.

Usability Guidelines Selection. During the creation of usability questionnaires or checklists, one of the main limitations is forgetting some critical elements to analyze. To overcome this problem, it was decided to start from the guidelines to ensure the greatest number of controlled features. The Checklist items were elaborated based on the usability guidelines for design technology hospital settings (Weinger et al., 2010). Each guideline consistent with the purpose of the experiment was rephrased to be suitable as a checklist item and translated into Italian.

Items Distribution. The ten Nielsen heuristics (Nielsen, 2009) were used to first define the dimensions and general usability principles of the Checklist. Subsequently, when necessary, they were slightly modified and adapted to the context and the evaluation of a physical interface to permit the insertion of items generated from the guidelines. The dimensions used were:

Visibility of system status. The system should provide clear and rapid feedback to inform the user about its current status.

Match between system and the real world. The system should use a familiar language to the user, following conventions and logical order. Possible user actions should match the real-world effects.

Give the user control with comfort. The user should be free to use the interface without impediments that facilitate errors or make the interaction less pleasant.

Consistency and standard. The user should not worry about finding conflicting elements within the system, which should follow platform conventions.

Error prevention. The system should be designed to prevent errors. In case of errors or dangerous situations, it must provide quick and punctual help for its resolution.

Recognition rather than recall. It is important to minimize the memory load elicited by the system by making the information easily accessible and intuitive.

Flexibility, accessibility, and efficiency of use. Experienced users should be able to use shortcuts to reduce system usage time. This should also be flexible and accessible enough to allow use by all types of users.

Aesthetic and minimalist design. The system should not present information that is irrelevant or infrequently used. The aesthetics should also be nice.

Help users recognize, diagnose, and recover from errors. The error messages should be clear and precise, indicating their resolutions.

Help and documentation. The system should be usable without the instructions. When a system could not achieve this objective, the information should be easy to find and centered on the user's needed actions, with step-by-step guides. The documentation should not be too long.

Pilot Study. After inserting the items based on the guidelines into the most suitable usability principles categories, a first pilot experiment was carried out with some usability experts (N = 4), all researchers working as human factors evaluators in the Human Inspired Technology Research Centre (University of Padova) for at least three years. The purposes were to test the experimental procedure, refine the items statements eventually, remove the unsuitable items, and potentially add missing ones, according to the expert's comments. The final checklist (fundable in the Appendix section) integrated items adapted from specific guidelines and from the usability experts' comments. The total number of items created was 34.

4.1.2.2 Scoring and Measures

Participants' responses to the checklist items could be positive, negative, or not applicable (Yes; No; N.A.). Since the items were formulated to be in accordance with the guidelines, the single item's score was obtained by calculating the percentage of positive responses, and as regards the dimensions, the average was then extracted. The only exception was item 34 ("The documentation material is necessary for the use of the bed control panel"), in which the item was negatively formulated and reversed. In addition, users' notes were collected in the checklist, together with any behaviour or comments that participants made during the experience. Moreover, the time spent to complete the checklist was considered. After the first analysis of the checklist, the participants fill a questionnaire to assess the level of severity of the problem detected. This Severity Questionnaire follows the scoring scale stated by Nielsen (Nielsen, 1995) that assigns to every problem a score from 0 to 4: 0 =I don't agree that this is a usability problem at all; 1 = Cosmetic problem only: need not be fixed unless extra time is available on the project; 2 = Minor usability problem: fixing this should be given low priority; 3 = Major usability problem: important to fix, so should be given high priority; 4 = Usability catastrophe: imperative to fix this before the product can be released. Finally, the frequency in which they were reported on the Checklist or identified by users during the procedure was calculated for each problem.

4.1.2.3 Experimental Procedure

The experiment involved five usability experts (Female=3, Mean age= 31, SD=5.8) and took place in a laboratory setting where a hospital bed featuring a cabled control-panel was placed. The participants evaluating the push-button panel differed from those that participated in the pilot study checklist and worked at the same research centre.

The bed presents two push-button control panels, one for patients and one for operators. The latter can lock the patient's one, to deprive people at risk of bed control. Before the participant's arrival, the experimenter blocked the control-panel to activate the LED associated with this state and permitted its visualization to participants who did not have previous experience with the bed. In fact, they did not receive specific instructions on the control panel to test the intuitiveness of the system. They were asked to perform a series of actions to explore all the bed functions: turning on/off the key panel, reaching the minimum/maximum of the backrest, leg section, and bed height, and finally, setting the chair and safe exit positions. They could freely explore these features in the preferred order as often as necessary and in every preferred position. Due to the starting blocked state, participants initially tried to use the panel, but it was blocked, as the experimenter explained. He unlocked the control panel only after they asked for it. The participants were not allowed to unlock the panel because the related button was placed on a different one, which was not the subject of the study. To not create biases by using different panels, I decided not to allow participants to visualize both panels. After participants decided that they had completed their free exploration of the bed functions, they were administered the Checklist. Finally, the researcher provided the control panel user manual to enable participants to fill in the items of the heuristics Help and Documentation. Following the regulations for the limitations of the COVID-19 spreading, the bed was then sanitized after each use.

4.1.3 Results

This procedure has allowed the collection of different types of data, starting from the results of the items. The average percentage of positive responses showed the strengths of the control panel, while the percentage of negative responses showed the weaknesses. The results of these data analyses follow within the dimensions of the checklist. The results are shown below according to the order of dimensions and are summarized in Figure 4.1.

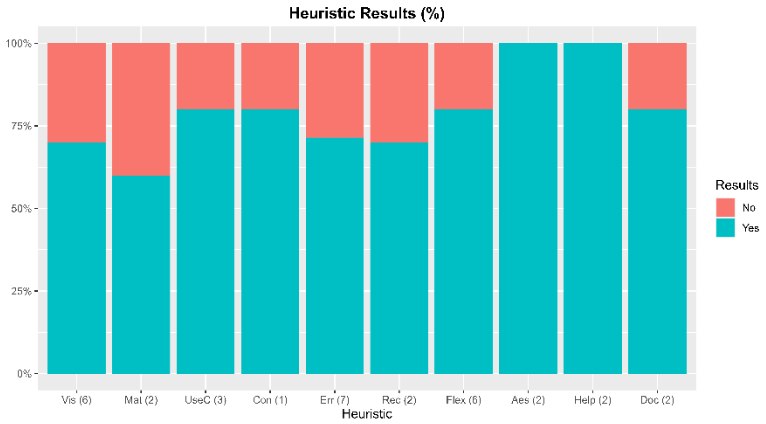


Figure 4.1. The graph shows the mean percentage obtained for each heuristic. Vis=Visibility of system status; Mat=Match between system and the real world; UseC=Give the user control with comfort; Con=Consistency and standards; Err=Error prevention; Rec=Recognition. In brackets the number of items for each Heuristic.

Visibility of System Status. The control panel was found to comply with the usability guidelines in 70% of the cases. In particular, the participants highlighted that there should be more feedback types and a faster bed's response to clarify the activation of the button. The lack of different types of feedback, other than the movements of the bed, was also highlighted by the experts' comments. For example: "Lack of visual feedback that indicates to continue pressing the button."; "Differences in the delay of the response to the key by the movement of the bed"; "At the beginning, it is natural to press shortly the buttons and this does not affect the bed"; "The answer is not always immediate". However, it has been noted that the materials used for the creation of the keys could create an adequate tactile sensation ("holding the button down, it became concave and gave a feeling of feedback"). The notes were also consistent, highlighting the lack of feedback, especially of a visual type ("the number of LEDs should be increased"). The participants highlight an issue regarding the backrest lifting function, which stops in correspondence of 30 ° without giving any indication to the user ("apart for the backrest that stops halfway").

Match Between System and the Real World. 60% of responses complying with guidelines. Most of the participants noticed the same problem about the cardiologic chair button (Fig 4.2), which appears to be the same both for the upper and for the lower position ("the cardiac chair should be clearer").

Figure 4.2. Cardiologic chair buttons highlighted by the oval shape.

Give the user control with comfort. 80% of responses complying with guidelines. The experts highlighted issues regarding the cable that connects the control panel to the bed (e.g., "if the cable were longer it would be more comfortable"), also confirmed by the experimental notes ("too short cable"). Despite this, the checklist highlighted this problem in the comments but met all participants' approval. Moreover, the control buttons panel cannot be used with only one hand most of the times ("It would be difficult to reach all the buttons without moving the hand holding the remote control"; "Especially for the higher keys it was more comfortable to hold it with one hand and press them with the other"). The questions also highlighted that it is not clear which one is a safe position button ("It is not so intuitive what the safety positions are").

Consistency and Standards. Despite the majority of responses comply with the guidelines (80%), question 11 once again highlighted the problems concerning the chair's cardiology button which, unlike the sour buttons, do not have up and down arrows ("Chair buttons do not have up or down").

Error Prevention. The responses were generally positive and in according with the guidelines (71.5%). The buttons for the lowest height (Fig 4.3.a) also lack a textual part to clarify its function and the only one present, the word "low" (Fig 4.3.b), is in English ("English label"). It is not very clear to the participants why the backrest stop at a certain point and one of them also notice that the buttons may be pressed twice or more to reach the end of the movement due to button slippery ("No, and it is not clear that the movement has not reached the end of its travel and can continue with a further pressure of the key (30°); it is possible to lose pressure in a few moments, and the desired movement is interrupted"). The score is also significantly lowered by the absence of visibility in dark conditions.

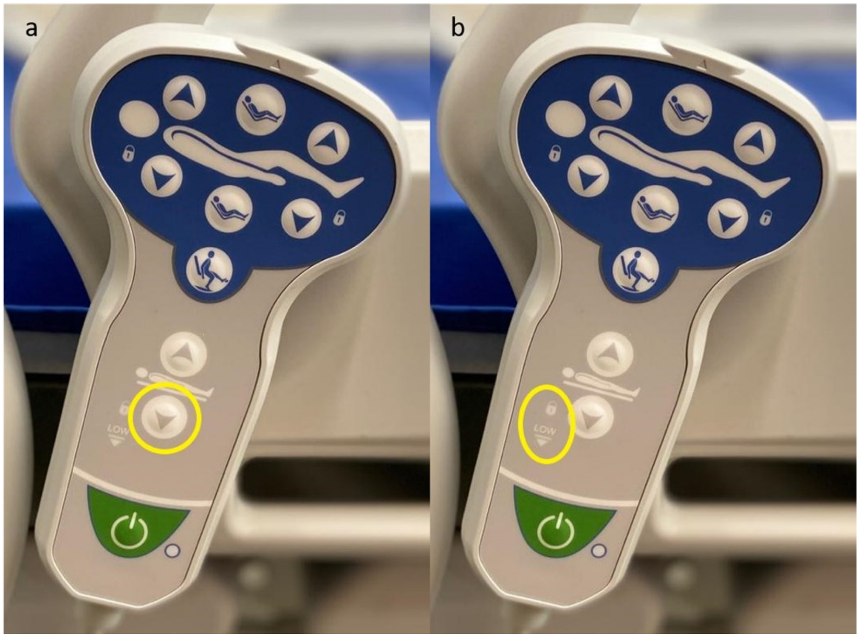


Figure 4.3. (a) the left image shows the button to set the bed at the lowest height; (b) the image on the right shows the "low" label.

Recognition Rather than Recall. 70% of responses complying with guidelines. The cardiologic chair button (Fig 4-4) was mentioned as the major usability problem of the control panel. Three out of five participants have remarked this problem in the comments and during the procedure ("therapeutic chair not understandable"; "not all icons are understandable, the therapeutic chair is not ").

Flexibility, accessibility, and efficiency of use. Despite a good average of responses in accordance with the guidelines (80%), the participants did not highlight major problems regarding visibility and accessibility of the control panel. Although, the score is lowered because of the problem with the English label "low".

Aesthetic and Minimalist Design. No problems founded in this dimension (100%). Materials seem to be very well accepted and liked by all the usability experts.

Help Users Recognize, Diagnose, and Recover from Errors. In general, this dimension achieved excellent compliance with the guidelines (100%).

Help and Documentation. 80% of responses complying with guidelines. Two of the experts highlights that the arrows in the instruction (Fig 4.4) should provide information and point to all the buttons present ("Attention to the arrows of the backrest, lower and upper legs, they should point both directions, up and down"; "they should be indicated for columns"). Also, one of the participants point out that instructions would be necessary to understand the LEDs meaning.

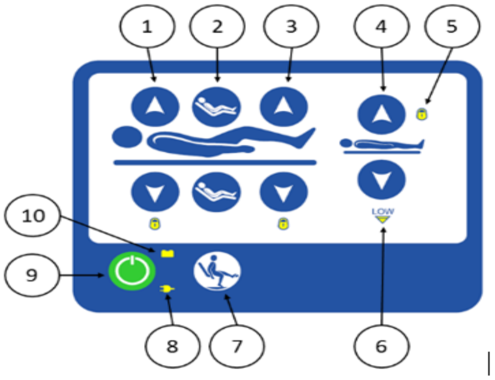


Figure 4.4. Graphic representation of the button panel presents in the instructions.

In conclusion, the checklist's mean completion time was 542 seconds (i.e., ~ 9 minutes). The total mean percentage score of all the Checklist dimensions was 70% of positive answers. The analysis of the checklist results and the following administration of the Severity questionnaire are described in Table 4.1. One of the usability problems (i.e., Delayed response of the movement of the bed's parts) obtained a median of 0 for the severity score, indicating that it should not be considered a usability problem. The frequency number of the usability problems was obtained by counting the number of comments on that particular problem. Since participants sometimes indicated the same problem in different items, this number could exceed the total number of participants (i.e., 5).

Table 4.1. The table shows the median of the participants' score for the severity of the usability problems found on a scale of 0 to 4. 0 =I do not agree that this is a usability problem at all; 1 = Cosmetic problem only: need not be fixed unless extra time is available on project; 2 = Minor usability problem: fixing this should be given low priority; 3 = Major usability problem: important to fix, so should be given high priority; 4 = Usability catastrophe: imperative to fix this before product can be released.

Usability Problems	**Severity Score (Mdn)**	**Frequency (N°)**
Lack of multiple feedbacks in response to a button press	2	6
Lack of backlight	3	6
The icons for the cardiologic chair positionare identical for both raising and lowering of these	3	10
The cable that connects the hand control and the bed appears too short	1	2
Difficulty using the hand control with one hand	2	3
It is not clear why the backrest stops at a certain height (30 °)	3	7
It is not clear what the safety positions are (minimum height and safe exit)	3	3
The push button panel is not very recognizable when hung on the side	1	1
The arrows in the information material do not point to all the drawn buttons	1	2
The label on the LED for the minimum height is in English ("low")	2	2
Sometimes it is necessary to press a button more than once to get to the end of the movement due to the loss of pressure.	2	6

4.1.4 Discussion

The objective of this study was to create a quick, easy-to-use and efficient tool (i.e., Usability Checklist), allowing an in-depth analysis of the usability problems of the pushbutton panels of modern hospital beds. The motivation was to provide researchers and designers with a tool that evaluates hospital beds' control panel design, which is absent in the literature. This instrument was then tested to check its ability to highlight usability problems in a reasonable time.

The analysis results and the subsequent categorization of the problems according to their severity have highlighted some critical issues. Firstly, the Checklist showed a lack of multiple feedback (Mdn=2) provided to the user to assist him/her in understanding how s/he is interacting with the system. The bed itself, with the movement and noises of the actuators, is the primary feedback. Additional feedback, such as haptic and visual, were suggested by the experts as possible solutions. The absence of visual feedback underlined a low level of accessibility of the control panel for people in a dark environment or with visual impairment/blindness (Mdn=3). Combined with the fact that it does not present backlights or LEDs, the checklist results suggest their implementation or the development of a surface, perhaps with elements in relief, which will enable one to recognize the buttons without necessarily using the view. Therefore, this attention is necessary to allow everyone to use the control panel correctly and easily and permit improved accessibility.

Another problem reported by the experts was the "chair position" button (Mdn=3). To reach this position, one would need to press the button located above the man's figure while returning to the horizontal position required to press the lower one. However, since the two icons on the buttons are the same, it was considered not very intuitive. Again, regarding the icons, users have shown how the ones indicating potentially safer positions for the patient (safe exit and minimum height) are not well highlighted (Mdn=3).

Regarding the ease of access and use of the control panel, the checklist highlighted that the push-button panel is difficult to use with only one hand (Mdn=2) and that it is not always sufficient to press the button once to get to the end of the movement (Mdn=2). The latter issue could both due to the loss of grip during the pressure of the button, which is annoying when dealing with the system for a long time, and to the stop of the backrest at 30° by default without comprehensible feedback (Mdn=3). Lastly, the results obtained by the observations of the "low" LED indicate the necessity to use labels in the native language (Mdn=2).

On the other hand, the checklist was also able to highlight the strengths of the control panel. This last obtained 70% of positive responses according to the guidelines, thus achieving a good degree of general usability. Furthermore, excluding the button of the therapeutic chair, the icons used were clear and intuitive. The last four dimensions of the Checklist also showed how the aesthetics, the flexibility of use in terms of ease of grip and recovery from any errors, and, finally, the information materials represent the panels' strengths.

Finally, the checklist was completed in a reasonable amount of time (i.e., around 9 minutes), proving its rapid use.

4.1.5 Conclusions

The usability checklist and the experimental procedure showed the possibility of analyzing the usability aspects of an electric bed button panel in detail, highlighting the strengths and weaknesses of the devised tool. The ease of use and analysis of the collected data, combined with its rapidity, makes it a valid tool for improving these essential control interfaces for hospital beds quickly and at reasonable costs. A possible limitation of the present study is to use the heuristics defined by Nielsen (Nielsen & Molich, 1990), which represent rules for interfaces in general. During the development phase, the items created were then included in the usability heuristic that seemed most suitable to accommodate them. In some cases, not all the items appeared to fit perfectly with the specific heuristics definition. Future work may be necessary to redefine some of these Nielsen's heuristics, as already accessed in other areas (Inostroza et al., 2013; Quiñones & Rusu, 2017), to adapt them to these particular devices to improve the usability checklist. Finally, future studies could consider different versions of the checklist for assessing various types of control interfaces, such as touchscreens that start to be used in the most advanced hospital beds.

Appendix

The complete list of the Checklist items is provided.

Visibility of system status.

Pressing a key corresponds to immediate feedback from the push-button panel.
If present, the feedback provided is easily identifiable.
If present, the feedback provided takes place in multiple ways.
When a key is pressed, it provides tactile feedback.
It is easy to tell if the push of a button affects the bed.
Understanding when the movement has ended is easy.

Match between system and the real world.

The movements that the bed can make are represented understandably by the buttons on the control panel.

Give the user control with comfort.

Pushing the buttons does not require excessive physical effort.
It is always possible to use the push button panel while remaining in a comfortable position.
The push button panel can always be used with one hand.

Consistency and standard.

The icons used are consistent with each other.

Error prevention.

A single push of the button is enough to perform the desired movement until it ends.
The positioning of the push-button panel prevents accidental actions from being performed.
The keys for the safety positions are well identifiable.
The buttons are adequately spaced from each other.
The buttons have a surface that facilitates pressing.
The buttons are clearly visible even in darkness.

In case the wrong key is pressed, it is easy to return to the previous position.

Recognition rather than recall.

The meaning of the icons is intuitive.
The icons have understandable symbols.

Flexibility, accessibility, and efficiency of use.

The push-button panel is easily accessible.
The push-button panel is always visible.
The push-button panel can be easily grasped with both hands.
The travel of the buttons, i.e., the space between pressing the button and its activation, is adequate.
The height of the buttons is adequate.
The icons have both graphic and textual elements where needed.

Aesthetic and minimalist design.

The icons used are aesthetically pleasing.
The icons used are large enough.
The materials used for the buttons are pleasant to the touch.
The materials used for the buttons are aesthetically pleasing.

Help users recognize, diagnose, and recover from errors.

It is easy to understand when the hand control is locked.
It is easy to understand when the hand control is off.

Help and documentation.

The documentation material is easily understandable.
The documentation material is necessary for the use of the bed control panel.

4.2 Co-Design Electrical Medical Beds with Caregivers

4.2.1 Aim of the Study

The bed plays a central role in many healthcare environments, as already addressed previously. It represents the object with which caregivers and patients often interact. In our opinion, it is fundamental that its design encounters end-user's needs to release part of the work-related stress from people who work in such stressful environments. To the best of my knowledge, the literature lacks comprehensive works that can describe the opinions and needs of caregivers regarding the medical bed. Therefore, this work aims to provide researchers and companies with a qualitative study that deeply explores this theme, comprehending issues and solutions associated with every type of electric medical bed. The results will list the modern electrical bed features' advantages and limitations, creating a valuable tool for analysing bed-related caregivers' problems and providing guidelines for the future design of medical beds.

4.2.2 Materials and Methods

4.2.2.1 Focus Group

This study utilized the Focus Group (FG) technique. This consists of forming a selected group of participants, usually homogeneous (e.g., sharing similar professions, backgrounds and experiences), to enhance their comfort during the discussion of a topic. A moderator is present to propose the questions, manage any problems among the participants, control the time of their interventions and maintain the discussion on the desired topics. Finally, an observer is instructed to pay attention to the non-verbal language of the participants to assist in moderating the debate. Health researchers have extensively used Focus Groups because of their capacity to generate ideas and identify issues (Ramirez & Shepperd, 1988).

The six FG conducted in this study were divided into two distinct parts. The first part of the FG start consisted of a rapid phase of acquaintance with a round of participants' names, followed by some easy and immediate questions (i.e., When was the last time you used an electrical medical bed? What are the actions that you often perform with the electrical medical bed?). This initial part was useful in breaking the ice among the participants and introducing them to the subject matter. Next, four questions explored the participants' wishes regarding the hospital bed and its impact on their work. I elaborated four questions starting from the work of Esengün and Alppay (Esengün & Alppay, 2018) and colleagues, where they subdivided the bed-related arguments into five categories. I excluded economic-related questions because this is not a caregiver's responsibility in Italy. The four questions were concerned with the impact of the physical characteristics (e.g., height, weight, etc.), the materials used, the electrical functions (e.g., electric inclination of the backrest, lifting of the bed base, etc.), and any psychological feature able to give serenity to the operator. The birth of new ideas on the beds currently in use was stimulated during the discussion to find new proposals and possible adjustments.

Each focus group lasted on average 2.5 hours, and was audio and video recorded to permit consequential transcription of the contents. The data analysis was carried out with thematic analysis (Maguire & Delahunt, 2017). The interviews were transcribed starting from the audio recordings. Afterwards, three researchers independently read all the transcriptions, defining and then discussing the emerging themes into which participants 'answers could be subdivided. In addition, a series of semi-structured interviews were conducted (6) to deepen the discussion of the topics. The researcher prepared the same list of questions above for FG. The interviews lasted an average of 50 min and were recorded in audio and video. The researchers followed the same analysis procedure as for FG.

4.2.2.2 Procedure

The FGs started by receiving the participants in a welcoming environment, where they could comfortably sit in a circle (Figure 4.5a, b). The objective was to create a place where participants felt equal and could freely express their ideas. They first completed the informed consent and a demographic questionnaire. Then discussion behaviour rules were listed. Food and water were at the participants' disposal for the entire duration of the discussion. Once the preparations were finished, the FGs took place.

(a)

(b)

Figure 4.5. (**a**) Focus Group with nurses employed in a hospital. (**b**) Focus group conducted with a mixed group of nurses, SHO and physiotherapists at a retirement home.

All the participants involved in the study were healthcare professionals from different working situations, namely healthcare institutions and hospitals. Daily, these professionals deal with a wide range of patients with different needs and problems. In my opinion, to encourage discussion, it was important that participants in each FGs belonged to the same structured healthcare facility (e.g., institution for the elderly, home care service). Their common experiences could be crucial in underlining their work limitations and criticalities regarding the electronic bed, providing solutions that can be adopted in a wide range of healthcare settings. Consequently, meeting professionals' different needs could lead to better care for their patients.

To this aim, participants were assigned to six FGs. Specifically, 3FGs collected nurses' experience (FG1-2) and that of healthcare assistants (FG5) who worked in different hospital wards. Two FGs involved professionals employed in institutions caring for fragile patients (i.e., an institution for the elderly in FG3 and an institution for disabled people in FG4). Finally, in the last FG6, I reported the experience of a group of nurses who provided home care assistance. The sample comprised 29 people (Female = 19, Male = 39, SD = 9). Professionals had an average of 13 years of experience in healthcare (SD = 5.17) and generally worked with electronic beds daily. However, only three participants reported that they had been properly trained to use the electronic bed during these years.

A brief socio-demographic description of the different cohorts is represented in Table 4.2.

Table 4.2. Table describing the characteristics of the participants participating in the study.

FG Code	Current Work Organization	Age		Gender		Healthcare Experience (years)		Past Experience in Different Healthcare Facilities		Electrical Bed Experience (years)	
		Mean	**SD**	**F**	**M**	**Mean**	**SD**	**Yes**	**No**	**Mean**	**SD**
FG1	Hospital	38.83	12.34	5	1	15	9.78	6	0	1.5	0.55
FG2	Hospital	41	9.93	2	2	16.8	13.62	3	1	15.25	9.81
FG3	Elderly Retirement Home	41.8	7.33	4	1	20.4	8.59	4	1	9.4	6.84
FG4	Institution for people with disabilities	33.6	70.69	4	1	8.4	5.13	1	4	8.4	5.13
FG5	Hospital	44	8.19	2	1	7	7.81	3	0	7	7.81
FG6	Domiciliary home care	35	4.82	2	4	11	5.06	5	1	9.33	5.65

To further explore the object of the study, I conducted six semi-structured interviews (INT) with bachelor students of nursing science (Female = 3, Mage = 27, SDage = 9.3). They represent the next generations of healthcare professionals, and their opinion could be an opportunity to provide new insight. However, despite already having at least three years of experience with the electronic bed, they were not part of a structured work organization, which was one of the criteria used in designing the FGs. For this reason, their experience was reported separately through semi-structured interviews.

The participants working in the hospital settings (comprehending nursing students) used daily the same model of electrical beds (i.e., Malvestio Delta 4 model, Figure 1.3). The two FGs conducted in retirement home settings used a slightly different model designed for these structures. The main differences are the unified side rails (i.e., four horizontal rods), a single push-button panels (the operator one is missing), and the appearance of the materials (i.e., plastic painted to appear as wood). The home care assistance operators work with a great variety of beds, depending on the availability of the hospital to give them to patients. Their beds are generally less technologically advanced.

4.2.3 Results

During the discussion of the results, I will list every theme that describes a specific element or characteristic of the bed, providing valuable citations. I identify the number of occurrences in which the features appear across the different interviews/focus groups. For each theme presenting comments with more than three occurrences, I provide a graphical representation of the three most common comments and suggestions.

4.2.3.1 Side Rails

Regarding the physical characteristics of the side rails, the analysis highlights the first element of discussion in their composition (i.e., subdivided into two parts or as a single long side rail).

The participants indicated the multiple side rails as a positive element in 10 occurrences; among the advantages, they can facilitate hygiene procedures for the patient (FG1-P04: "The split ones are comfortable for hygiene"), allow the creation of escape routes for tubes and drains, make restraint less evident (FG-P02: "you can only pull up the side rails of the feet, keeping the head part raised and the patient still feels safer") and follow the movement of the backrest. However, a negative found for this type of side rail concerns the creation of spaces in which the patient could get stuck. The single side rail was considered as a positive element in six occurrences. Among the advantages of this type emerged the possibility of being lowered with a single gesture (INT-P06: "Just one move to lower it"), preventing any cables from getting stuck or being cut (FG1-P02: "Then in those no wires or drips got stuck") and removing the risk for the patient of getting stuck between spaces created by multiple side rails (FG1-P03:" With those divided, halfway the space is a danger, they get stuck, it is an escape route"). However, there remains the possibility of the patient getting stuck between the boards that compose the side rail (FG3-P05: "They get stuck in the space between the boards that make up the side wall").

Regarding their shape, according to the caregivers, they should be curved/rounded (FG6-P05: "They don't have to be straight, which gives a sense of containment and suffocation, more dynamic"), and lower to reduce the height of a possible fall (INT-P01: "If they are too tall some patients can climb over them and the higher it is, the higher the fall height"). In addition, they should physically support the patient (three occurrences). The participants showed the need to create support points for the movement of patients (FG5-P02: "Good grip helps us to lift them"; INT-P03: "It would be a support for the patient to hang on or sit down, they shouldn't hang on to the operator").

Regarding possible functions related to the side rails, some comments (four occurrences) that emerged during the FGs show the need to create an electric height adjustment mechanism (FG3-P03: "Often with anti-decubitus mattresses, they are too low") or a manual one in case of need (FG4-P03: "I would need a manual mechanism in case of need"). For their release/movement mechanism, it should allow lowering under the bed surface (eight occurrences; FG-P02: "Closing under the support surface") to avoid accidents (two occurrences; FG1-P04: "When they get off, they cut your feet, giving you a hit"; FG2-P01: "Tall operators bang to maneuver in the center") and the creation of gaps between the bed and other supports (FG-P01: "Even when they are transported by stretcher/bed or bed/bed, there is a big void"). Furthermore, the mechanism should be easy to use and manageable (three occurrences; FG5-P02: “They should be easy to lift down, even for making the bed”), and equipped with an electric self-locking mechanism (three occurrences) and braked (FG-P03: “Often it can pinch you”). Raising and lowering the side rails should require a fast single action (four occurrences; FG3-P02: “That closes with a single action, which does not become difficult to raise and lower them”), operated with one hand (three occurrences; FG2-P02: “The closure should be one-handed”). Finally, they highlight the need for an alarm for lowered sides (INT-P05: “Maybe you pull up the banks, but you also pull down the sides, in which case you would be notified”).

Caregivers have highlighted how the material that composed the side rails should be light (two occurrences) but resistant (five occurrences). The reasons are safety (FG6-P06: “Often we are alone we have to put a lot of pillows between the person and the edge and they often hit knees etc. creating new injuries”) and comfort (INT-P01: “Patients put hands on them and feel a sensation that is not comfortable, icy or too hot or hard. It could also be therapeutic from a certain point of view, evoking good sensations”). Materials should be soft on the inside and padded (seven occurrences). Furthermore, they should be plastic, fireproof and possibly smooth (two occurrences; FG5-P03: “Smooth would be practical to sanitize”). Furthermore, it was indicated not to use wood as a material due to matters of deterioration and hygiene (three occurrences, FG4-P02: “The wooden sides with a single band, sometimes broke, maybe hitting the lifter. Here we talk more about materials, and some are poor“; INT-P02: “I have seen some with wooden sides, but this is much less hygienic compared to plastic”).

Regarding the psychological impact of the side rails, they have been seen as elements that give safety to the patient and the operator (four occurrences; P05-INT: “Sometimes they give a sense of safety, even for operators”). On the contrary, other participants indicated that these were a limitation to the patient’s freedom since they give a sense of being in a cage (seven occurrences; FG3-P02: “Sometimes they represent a limitation of freedom”). For this last problem, the use of sides without holes (two occurrences; P01-INT: “Very beautiful modern sides, perhaps if they could be full and not angular”) or transparent was proposed. Finally, they proposed avoiding the use of straight bars (FG6-P05: “they don’t have to be straight, which give a sense of containment and suffocate”).

To summarize, based on comments' frequency I can say that professionals recruited prefer to work with split side rails, with a soft part inside to avoid patients' injuries. It seems also important that the release mechanism of the side rails should be hidden. The suggestions with more occurrences are described in Figure 4.6.

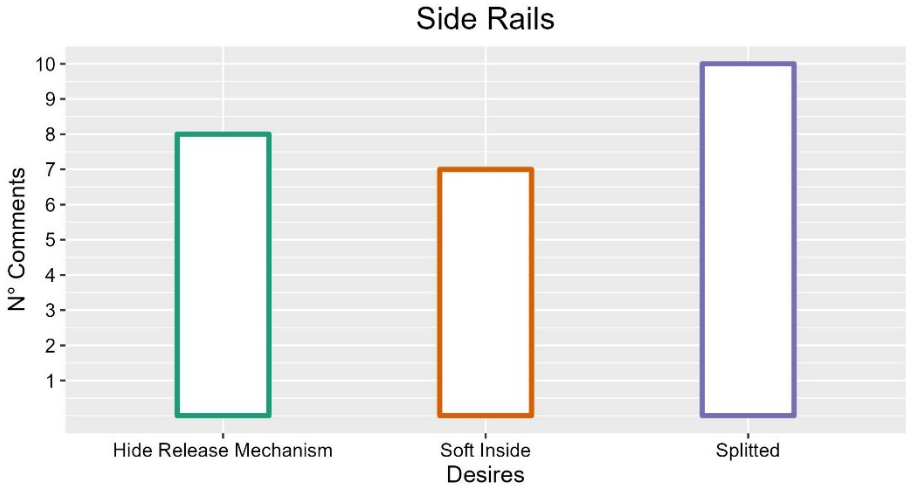


Figure 4.6. Graphical representation of the desires with more occurrences for the Side Rails theme.

4.2.3.2 Headboard/Footboard

Regarding the physical features of these components, they should be a low bulky component of the bed (two occurrences; FG1-P06: "It is still a nice piece, heavy, and then cluttered, you no longer know where to put it"). They should also be able to accommodate accessories and shelves of various types (two occurrences; INT-P02: "Headboard/footboard with elements for hanging devices to be used concurrently").

The footboard and headboard should be removable (four occurrences) for caregivers' comfort and safety (FG1-P03: "It becomes safer for me too, it's a convenience"). One comment further proposed that these bed elements could become interchangeable (FG2-P02).

The material of these elements should be light (three occurrences; FG2-P03: "They should be detachable light pieces") and softer to avoid injury (two occurrences, FG4-P05: "Maybe even a softer material, because they hit their heads").

From a psychological point of view, these elements of the bed should be quick to detach for the operator (three occurrences; FG6-P03: "I should be able to lift it and quickly access the lower and upper limbs") and comfortable for hygiene (two comments; INT-P01: "For various needs, orthopedics and machine encumbrance, cleaning even under the mattress"; FG5-P02: "They are easily washable due to removal, they are practical for hygiene") and for various therapies (FG1 -P03: "We often work from there, it becomes safer for me too, it's a convenience").

Therefore, looking at the frequency of comments regarding the headboard/footboard, the most desired qualities of the bed are removability and quick release, but also lightness of material. The suggestions with more occurrences are described in Figure 4.7.

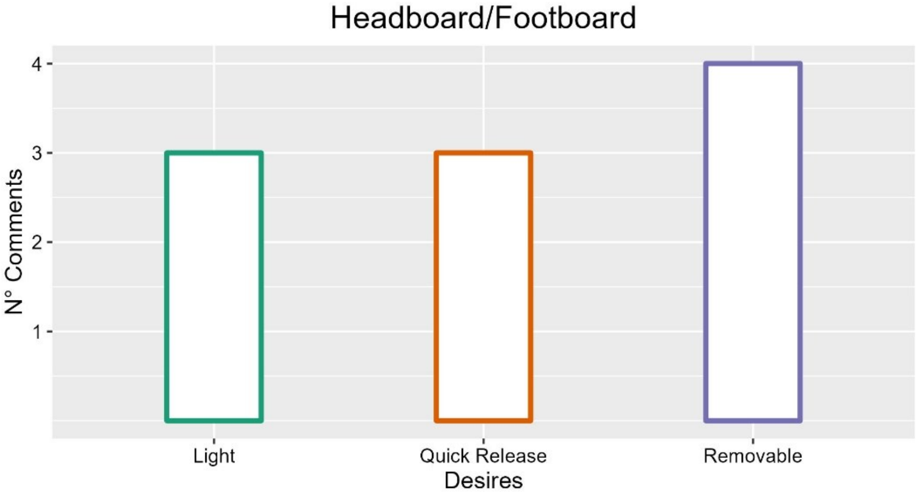


Figure 4.7. Graphical representation of desires with more occurrences for the Headboard/Footboard theme.

4.2.3.3 Bed Base Surface

The bed surface, the plan that supports the mattress, has also been mentioned (three occurrences) because it is an element particularly prone to getting dirty (FG6-P03: "It takes liquids of all kinds"). Therefore, the participants would like solid bed surfaces without holes (two occurrences; INT-P01: "All grooves should be covered to facilitate cleaning"; FG4-P02: "Large holes, like normal bed bases, do not allow to put anti-decubitus mattresses"). This has to be waterproof (FG6-P03).

As for the materials, the composition of the bed surface's cover should be smooth plastic (FG3-P01), resistant (FG6-P02) and fixed (FG6-P05: "Not that it wobbles as soon as you move it").

4.2.3.4 Electrical System

Participants indicated that integrating electric sockets to the bed could be helpful for attaching various instruments (five occurrences) and overcoming issues with cables (five occurrences, FG1-P02: "Often by moving the sides or other, the plugs disconnect"; FG4 -P05: "No more cables can be added").

Regarding the patient, the participants indicated as useful a socket in the internal part of the bed, reachable by the patient, because if placed externally it could be uncomfortable (INT-P04). Moreover, they indicated placing it on the head part of the side rails (two occurrences, FG3-P02:

"Then the socket should always be on the head side; instead, they are all on the foot side"). In addition, participants proposed magnetic loading (FG2-P02). The participants suggest integrating more plugs to connect the anti-decubitus mattress (FG2-P02: "when I did orthopedics, if there was an electric bed, you did not have the anti-decubitus mattress because the bed was connected to the plug and then it happened that in the operating room came the ward bed with a different socket and you had to go in search of the adapter, which cannot be used because it is not standard. Then, you have to contact the mattress manufacturer to change the plug") to attach various electrical tools while moving the bed (three occurrences; INT-P04: "Possibility to use tools even while on the move") and for USB devices of patients (two comments; INT-P04: "Increased comfort for the patient").

Regarding the electric cables, the participants expressed the need (two occurrences) to hide them to reduce wear and improve aesthetics (FG4-P02: "The cables have to be hidden, often they are exposed and wear, could be cut"; FG5-P01: "When you move beds they often go under the wheels "; FG4-P02: "Cables should be hidden for aesthetics and patient safety").

From a functional point of view, the participants highlighted as a practical function the alarm that occurs when the bed electrical plug is disconnected (INT-P03: "Excellent functions, not in all beds but most cases it is the fact that they sound when they are disconnected from the current").

Furthermore, the autonomy of the bed battery received opposite evaluations. On the one hand, it is perfectly adequate (two occurrences; INT-P01: "Exceptional autonomy"; FG5-P03: "Never been a problem"), and on the other hand, it needs improvements (FG2-P03: "We need more autonomy in travel"). In any case, the autonomy of the battery must be adequate to exploit the bed's functions also when it is unplugged from the current (INT-P02: "It must have a certain autonomy even when disconnected from the current as its functions are very useful also for example when entering the elevator"). A possible solution to overcome the problem is an external battery to activate when moving the bed (FG2-P01: "It would be nice to have a small auxiliary battery that allows you to be a support to move").

So, based on the frequency of participants' comments the electrical system should be integrated to the bed and should have multiple plugs. The suggestions with more occurrences are described in Figure 4.8.

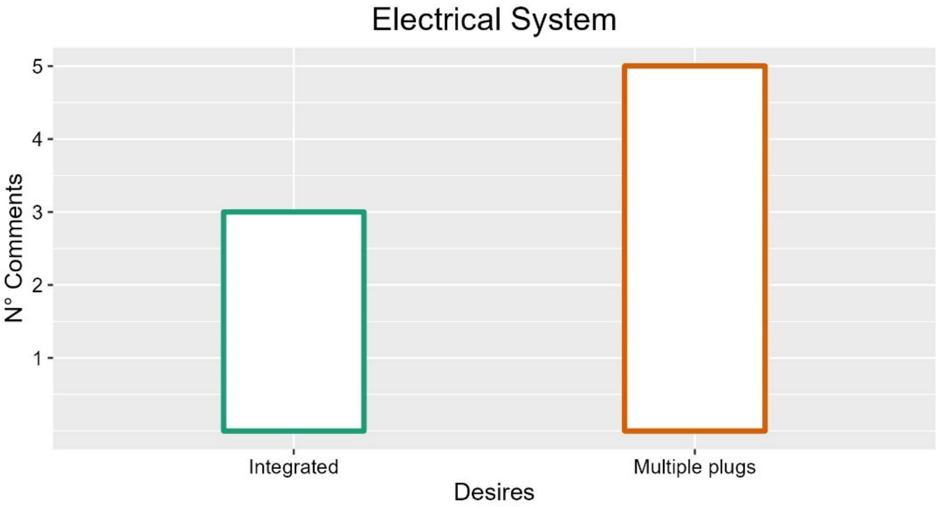


Figure 4.8. Graphical representation of desires with more occurrences for the Electrical System theme

4.2.3.5 Accessories

Although not strictly part of the bed structure, participants often cited accessories as practical elements for their work. In general, the bed should be flexible in supporting the operators and able to accommodate a great variety of accessories to use in various situations (two occurrences; INT-P02: "It must allow the installation of other devices;" INT-P02: "Maybe also that allows you to install applications, devices, such as drip poles, very useful things not so much when the patient is in the ward but during transport, which is a very useful thing"; FG2-P02: "It should be adaptable to many accessories, to reduce the effort of adapting it to different instruments"; FG2-P03: "I also thought that many patients stay in orthopedist ward, and have external instruments. Sometimes using these and making them sit comfortably is difficult. You find yourself in difficulty with back and foot positioning, and sometimes you can't because the mattress doesn't allow it. So, personalizing the final part of the bed is important. Because then you need to re-adapt a series of non-functional conditions. Maybe support for accessories on the footboard is missing").

One of the accessories taken into consideration by the operators is the IV pole, which is considered convenient and useful (four occurrences; INT-P04: "The pole can be a reason for peace of mind because it removes problems with needles and movements with wires attached to the patient"; INT-P05: "Also keeps instruments out of reach of the patient"). For the participants, the bed should integrate the pole, which has to be adaptable (five occurrences, INT-P02: "The IV pole should be foldable, integrated into the bed. Attached to the bed, it would allow it to be used while moving it, and if it were integrated, I would not have to go looking for it"; INT-P04: "Very useful, they must be flexible for different uses or heights ... they are not always standard, they should always be present, even in the nursing home bed"; FG2-P02: "The IV pole should be telescopic"; FG5 -P02: "It should be easier, more flexible the exchange between IV poles and poles for the triangle"), and resistant (two occurrences; FG5-P01: "They are often fragile, maybe you put the nutrition bags and the stakes because those are heavy "; INT-P04: "Put the nutrition bags, the poles break easily").

The participants negatively mentioned the hooks for the diuresis bag several times (six occurrences). Their positions are often too low, causing the bag to touch the ground (six occurrences; FG6-P05: "The holder is too low"; FG5-P02: "The attachment of the diuresis bag is not practical, we need a hook to hold it up. Because when you lower the bed, it goes too low for those bags, and they touch the ground"; INT-P04: "It is difficult to find a position where it does not touch the ground and is low enough to operate"). Precisely for this reason, they expressed the desire for a higher or adjustable attack (FG6-P05: "Even the pole they put on beds is sometimes too low, it is so low that you must always remember to pull it up. It has to be adjustable so that I don't have to pull it up or put the bag on the patient") and to make it standard equipment (INT-P02).

Furthermore, participants suggested the integration of shelves and various types of storage compartments (four occurrences, INT-P03: "The objects should be inside the figure of the bed, perhaps underneath, so as not to collide with external elements during the transport"; FG4-P05: "It would take a space for the compressor of the anti-decubitus mattress, to store it safely and hidden", INT-P04: "There could be a basket for patients, for their comfort"; FG5-P02 "Parrot carrier").

Accessories useful by healthcare personnel are also the anchors for restraint methods (four occurrences; FG1-P02: "It would take a safe and comfortable point to reach. You can't do it on the edge because you risk breaking his arm"; FG5 -P02: "Regarding the hooks for restraint, it would take something more external, more under the bed, something that can be extracted"; FG3-P02: "One thing that is missing is the possibility of putting a restraint belt, at least creating a mechanism to easily hook them. Now the process is very inconvenient").

The participants also mentioned the mattress and its size, which is often not the same as the bed. Therefore, they reported the need to have mattresses of the right size or to create aids to remove spaces and stop the patient slipping (four occurrences; FG5-P01: "The beds are larger than the mattress, it always goes down. It always has a space where the mattress slides down"; FG3-P02: "The beds and the mattress are sold separately, and for the mattress, which is sometimes wider than the bed, you ruin it with the side rails. You pinch it, it deteriorates"; FG6-P05: "The mattress is small compared to the bed and voids are created"; FG6-P05: "The mattress should have hooks to the bed surface because it often slides down together with the patient"; FG1-P01: "We need a mattress already prepared for bed because changing it and ordering the right ones is a waste of energy, time and funds");

The triangle pole (two occurrences) is an accessory that the staff rated as uncomfortable (FG5-P02: "The triangle is a bit uncomfortable at times"), heavy (FG1-P03: "Then there is the pole of the triangle which is very heavy. It indeed has to hold the patient, but it is dangerous") and which needs to physically support the patient's movement (FG5-P02: "Like the triangle, something to support them to cling to because you cannot leave the triangle there because it is dangerous “).

The headrest (two occurrences) has been cited as a support for the patients’ hair washing (FG-1P05: “Hair washing was not provided, it would take a headrest, like hairdressers. An accessory”) or to support comfort (FG3-P03: “A headrest to support the patient”).

The participants also proposed a bed-wall spacer (two occurrences; FG4-P02: “Something we need to distance the bed from the wall to prevent it from banging, perhaps vertical wheels to slide on the wall”).

Some comments emerged regarding the blanket’s lifter (three occurrences). The participants want it integrated into the bed (three occurrences; INT-P06: “The idea that I could put some kind of extractable structure from the bed that can be composed but that it is already integrated into the bed”) and electrically adjustable (two occurrences; FG6-P02: “The height of the blanket lifter, which is adjustable so that I don’t have to pull it up and put it on the patient”; FG4-P02: “The lift blankets, it’s not a quick thing to take off, you usually leave it there even if you don’t need it. Also, when you make the bed, it’s not nice to look at. So it would be convenient”).

The participants also proposed less bulky bumpers wheels (one occurrence; INT_P02: “They must not clutter up because the operators hit us in agitated moments. Then they must not let the patient feel the impact”).

The participants also find it useful to add an armrest for patients (one occurrence; FG6-P02: “When I have to take a venous route or similar, it would be useful to have a support for the patient’s arm”) and an attachment for the anti-decubitus mattress (one occurrence; FG5-P02: “We use MAD a lot, we have the motor to support. We put it where the large remote control of the bed rests, and it just sits there. Maybe a longer space because they don’t fit together, it’s not very practical”).

Moreover, it was highlighted in five comments how the bed-to-bed or bed-to-stretchers spaces cause discomfort among the operators (five occurrences; FG3-P03: “Gaps are created between the bed and prams/stretchers”; INT-P04: “Systems for the interaction between the two are non-existent”). Participants expressed the desire for systems to facilitate this transition of the patient (INT-P04: “It would take a system to be able to move the patient easily”; FG2-P01: “It would take a support base for lateral movement”; FG3-P03: “We need an adjustment in the support surface change”). One of the causes is the space required for the vertical descent of the side rails (FG1-P01: “Even when transported by stretcher/bed or bed/bed, there is a large void”).

Finally, the participants reported that the base of the bed could represent a potential obstacle to the operator’s work (INT-P01: “Often it is an obstacle for patient lifting trolley”).

Therefore, the most desired accessories based on the frequency of participants' comments are the integrated attack of the diuresis, the bed/stretcher transfer system and an integrated IV pole. Suggestions with more occurrences are described in Figure 4.9.

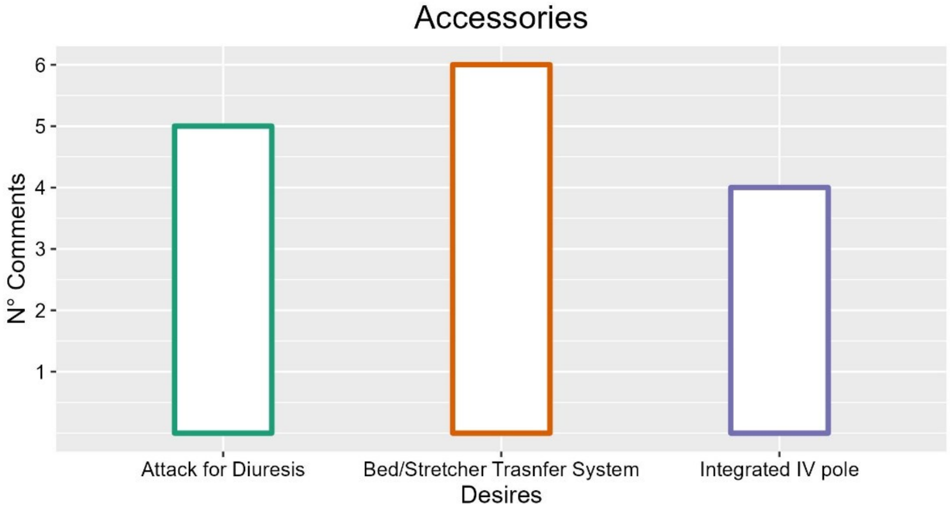


Figure 4.9. Graphical representation of desires with more occurrences for the Accessories theme.

4.2.3.6 Bed Height

The participants reported the height adjustment of the lying surface as a central function for the work and comfort of the operator in nine interviews, underlining several related fundamental aspects. In particular, they highlighted the possibility of setting a minimum height as an element related to patient safety (two occurrences; FG3-P01: "It is essential to reach a minimum (30cm) for the patient's height") and the need to increase the height adjustment range (INT-P04: "It is important perhaps to extend the range in which the bed can actually get up"). Several participants (four occurrences) proposed increasing the speed of the movement in height adjustment (FG6-P02: "A little faster, yes. The whole movement requires a few seconds"). However, some participants suggested that a greater speed could also disorient the patient (two occurrences, FG6-P01: "Many could certainly be disoriented).

In addition, a participant expressed the desire to have a function to automatically adjust height during dressings (FG6-P01: "I would like a function that when you get to the moment you need to reach out to the patient helps you adjust the height").

Finally, regarding the psychological aspects related to the patient, the possibility of independently adjusting the height of the sleeping surface is perceived as an element of participation (INT-P05: "Patients could feel more involved if they can change the bed height").

The suggestion with most occurrences was the adjustability of the bed height, as described in Figure 4.10.

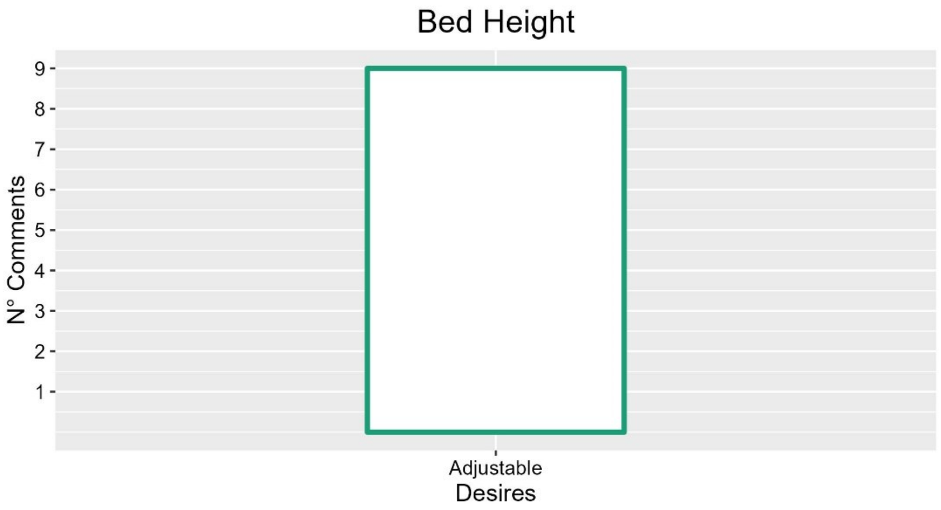


Figure 4.10. Graphical representation of desires with more occurrences for the Bed Height theme

4.2.3.7 Patient Postural Management

Healthcare professionals reported several comments regarding bed functionality to support the patient's posture.

They indicated the inclinometer because of its usefulness (INT-P02: "It would be useful to make sure that the patient is straight because if, for example, the patient is in Trend, he slips, so I would need an indication when I reach 0°") and talk about its position, proposing a location on the foot side rail (FG1-P02: "The problem is where it is placed, on the patient's head it doesn't help, on the feet it would be much more useful"). However, participants highlighted that a protractor showing the bed and backrest inclinations could avoid the patient slipping at the foot of the bed (INT-P02: "Often, due to inattention, a few degrees down or up is left. In practice, the Trend position does not return perfectly horizontal. It is useful to have the indication of the entire bed plus the backrest to avoid whatever problem"). Moreover, the classic inclinometer, which generally works with a sphere that runs on a lane that indicates the degrees, could present many issues (FG-P02: "30° is not always enough, doctors often ask for particular degrees and to do so I have to see the ball, which fits and is not very smooth"). In addition, participants expressed the need for improvements in inclinometer reliability (FG1-P04). For a better view, a small light has been proposed that indicates the degrees of inclination (FG5-P02: "There is also the small light that tells you how many degrees you stopped").

Regarding physical elements supporting the adjustment of the patient's posture, the participants also reported (three occurrences) the need to increase the number of sections (FG3-

P04: “Not adaptable to all heights; FG3- P03: “Creation of multiple postures”; FG3-P02: “Cervical section for patient comfort and hypertension prevention”; FG2: P04: “Increase in section number to help the patient find the right position”).

As for the functionality of the different sections, several comments (three occurrences) highlight the usefulness of handling the various parts of the bed. In general, this possibility could reduce fatigue (INT-P02: “I’m more serene because I don’t break my back”) and promote patient independence (FG3-P05: “It certainly promotes self-sufficiency”). Some comments (six occurrences) show that the sections’ movements appear particularly slow, increasing the time spent on activities other than patient care (FG2-P02: “Having them faster for the operator would optimize time and practicality”). Even in this case, however, the participants indicated that these movements should not be too fast or abrupt in order not to disorient the patients (INT-P02: “The movement should be gentle, not rude”, FG5-P02: “Also the speed, but not for the backrest, the movement must have a certain regularity. But to get the bed up it should be faster”).

Staff also reported other features to support patient posture. In particular, the “Trendelenburg” movement was mentioned in seven interviews, four of which highlighted its usefulness as a function (four occurrences; FG5-P02: “It is convenient ... even for doctors when the patient is sick”; INT-P01 / P04 / P05: “Convenient”/”Important”/” Used”). Participants also highlighted that the Trendelenburg’s primary function is bringing patients to the head of the bed with less effort, solving the problem of the patient sliding to the foot of the bed and reducing the fatigue of the staff (FG3- P05: “Generally used to raise the patient”, FG5-P01: “The trend to avoid slipping”). Some participants also expressed the desire for this function to act autonomously (FG6-P02: “I would like the bed to tilt and use gravity to reposition the patient on its own”) or to work even at minimum height (FG1-P04: “A small inclination would be enough without all that height”);

The participants mentioned “lateral tilt” in five interviews, referring to it as a help in repositioning patients to prevent pressure sores or to facilitate the insertion of medical devices (five occurrences; INT-P01: “Move the side parts to prevent decubitus and insert aids”; FG6-P02: “Also to turn the patient on the side, having the bed tilt to one side would help me”; FG5-P03: “It would help me turn them on my side”). The participants also considered important the “Fohler” position. The inclination of the backrest could be particularly useful for allowing patients to eat comfortably (five occurrences; INT-P04: “Useful for eating”; FG5- P02: “Good because if they have back problems, it is useful”). The participants reported its usefulness to support the patient’s exit from the bed (two occurrences; INT-P03: “Support to the patient to stand straight”) and to reach a sitting position for therapeutic and comfort reasons (FG5-P01: “They breathe better, eat better, sit well, comfortable”).

Participants reported functions not yet implemented, such as the possibility of putting the bed in a “standard position” decided with the manufacturer and reachable with a single press on the push-button panel (FG2-P02: “Reset to a position established with the manufacturer”), the electrical moving of the leg part of the bed (FG3-P05: “It could be useful for unloading”) and the scissor opening of the leg section (FG6-P01: “I see a bed that can open as if they were two legs, to help me dress patients’ legs”). A participant proposed a wave movement of the sections for patient repositioning (FG2-P02: “You know I said that the more articulated the better. Think of it divided into ten pieces, with the ability to move like a wave going upwards and then bring the patient up").

A participant proposed an alarm to remember that a patient needs a change in posture (FG1-P05: "Posture to the right and left I maybe forget, they should be moved after a while, so maybe think of a timer that says you have to move the patient").

From a psychological point of view, participants highlighted that a bed supporting patients' movement could reduce their discomfort (INT-P03: "Patient discomfort when the nurse has difficulty in moving him"). In general, the movements of the bed are a factor important to the serenity of the operators (INT-P06: "Then surely having a multifunctional bed which I can therefore manage according to my needs reassures me a lot. To be able to modify the instrument according to the patient's needs and the patient's needs that are related to the assistance I have to provide").

Therefore, participants' most frequent comments regarding the postural management highlighted the desire of participants for increasing the movement speed while the bed is changing position, but also the necessity of implementing the side tilt and the Fohler position.

Suggestions with more occurrences are described in Figure 4.11.

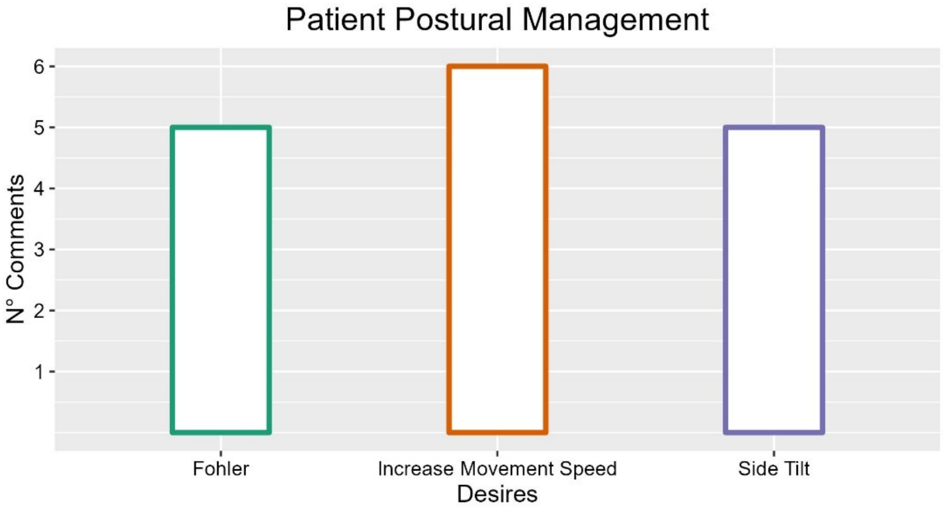


Figure 4.11. Graphical representation of desires with more occurrences for the Patient Postural Management theme

4.2.3.8 *Bed Commands*

A further topic reported in several comments from the health personnel concerns the commands that allow the adjustment of the bed through a remote push-button panel.

From a physical point of view, a characteristic discussed by the participants concerns its position. The participants indicated the integration in the bank on both sides as the best solution (three occurrences; FG5 -P02: "It's comfortable on the side"; FG1-P04: "You can't put it on the other side because the cable doesn't reach it") to solve the wiring problems, which would tend to get stuck in the mechanisms of the side rails (three comments; FG1-P02: "The wire gets stuck in the mechanisms of the side"). They are also concerned about the frequent falls of the push-button panel due most of the time to the breaking of the hooks (five comments; FG5-P02: "Remote control is most often on the ground"; FG3-P04: "It always breaks and you don't know where to put it"). In the case of control panels located on the side rails, they highlighted the importance of a blocking function for the patients (four occurrences, FG3-P01: "On the side panel if you can deactivate it for the patient"; INT-P05: "For some particular participants some functions must be blocked, for example those who have lesions at the base of the skull that cannot raise their head more than 30"). A further solution reported by the healthcare staff concerns using magnetic hooks (INT-P01: "the remote control should be out or maybe having some hooks with a magnet").

The participants also proposed the building of a control panel that integrated other hospital commands (FG1-P02: "I would also unify the remote control of the bed with that of the nurses that usually hangs on the triangle") and that applies to all beds (FG3-P01).

The buttons should be easy to use (five occurrences; FG5-P03: "Sometimes the remote control locks themselves so it might take a simpler way to lock the keyboard"), intuitive (five occurrences; FG1-P02: "Even overly stylized drawings do not understand them, then they call you to do so"; INT-P05: "Have a guide to read to the patient"; FG1-P06: "They don't understand that they must first turn on and activate the push-button panel"), reliable (two occurrences FG5-P01: "At the moment they are not very reliable"), easily readable (INT-P05), large, soft (INT-P03) and not too flat (two occurrences, FG1-P02; FG3-P05). Participants reported the importance of constructing buttons resistant to wear (three occurrences; FG5-P01: "Over time they wear out, they break"; FG6-P05: "They erase, they wear out after even only one year") and to act more quickly (two occurrences).

The healthcare staff then highlighted how the number of the buttons should be less for the patient (three occurrences; FG5-P02: "For example, raising the bed is dangerous for them") and that a backlight could be useful (two occurrences; INT-P01: "Dim lighting, it must not bother the patient"; FG5-P03: "I would like the lights behind the buttons...I think they go haywire if you leave it on all the time, it must turn on request"). Participants reported a problem with losing grip when using the remote control (three occurrences; FG1-P02: "You can easily lose your grip"). In addition, sound feedback has been proposed when pressing the keys (FG1-P02).

Furthermore, the healthcare staff proposed a wireless keypad (two occurrences), the possibility of controlling the bed with the feet (FG5-P02: "We often have our hands full") and voice command for hygiene questions (FG5-P02: "the voice command would be beautiful, it would be very helpful in the hospital. Also, because the remote control is dirty, it would also be more hygienic"). Similarly, they proposed a touch screen control panel (FG2-P02: "To avoid wear on the keys and with the recognition of the user who uses it to distinguish operator and patient") or controlled through applications from a tablet/phone (FG6-P05).

Regarding the materials, the healthcare staff mainly referred to wear resistance, particularly the colours of the icons and the plastics that composed the remote control. They need to be resistant to shocks (three occurrences) and disinfectants (FG6-P05: "Maybe I would add washing instructions"), perhaps thanks to a resistant rubber cover (two occurrences, INT-P06: "The sheath is sometimes severed"). It would also be important that the materials are easily washable.

Regarding the functional properties of the push-button panel, the healthcare staff proposed a distinction between the functions available to the operator and the patient (two occurrences; FG2-P02: "commands should be different between patient and operator"; INT-P01: "Button panel that can be disabled"). The functions should be less for the patient (two comments, FG3-P05: "Patients often find remote controls with many functions that it is difficult to understand", FG3-P01: "Patients often find remote controls with many functions that struggle to understand "). The participants then addressed the need to save favorite commands (FG2-P01: "Personalization with a badge that I insert and find my favorite functions") and to activate multiple functions at the same time (three occurrences; FG3 -P02: "I would like to move several parts at the same time with a single key"; FG5-P01: "At the same time they do not go and we must coordinate"). They also highlighted the importance of replacing the remote control quickly if problems arise (FG6-P05: "The remote-control jams from time to time and to replace it you have to detach and reattach the entire bed").

Psychologically, the remote control helps in the feeling of comfort for the patient (INT-P05: "it helps to feel in control, more involved") and the operator if unified with the hospital systems (INT-P02: "It is a comfort. However, it should be unified with hospital systems"). A comment also highlighted the importance of understandable icons consistent with those used in their context. Moreover, they found it important to highlight the potential of the hospital bed compared to the domestic one (FG2-P03: "It should be easy to use and that it is understood that it is useful. It must be clear that the bed in your house does not give you these possibilities"). According to a comment, the patient's use of the remote control could help to involve him/her and decrease the staff's workload, although some functions would have to be blocked (INT-P05).

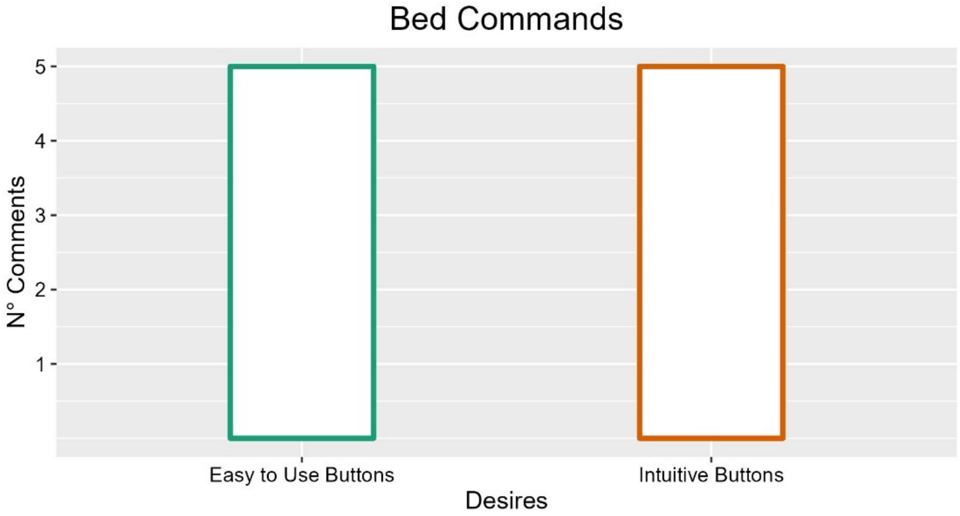


Figure 4.12. Graphical representation of desires with more occurrences for the Bed Commands theme.

In summary, bed commands should be intuitive and easy to use.

Suggestions with more occurrences are described in Figure 4.12.

4.2.3.9 Nurse Call

Users exploited different versions of the nurse call bell. However, they expressed the need to change or modify it (four occurrences). Regarding patients, the addition of a microphone/intercom could allow them to communicate remotely with the ward staff (two occurrences, INT-P04: "With an intercom, to reduce unnecessary interventions or understand where to act first"; FG6-P05: "Intercom type. Maybe the caregiver wakes up as soon as he hears problems"). Furthermore, they indicated the possible addition of a video/monitor (FG1-P05: "Because the doorbells often come off, they are old models"). Regarding its accessibility, the proposals were the implementation of voice command (FG1-P03: "For the elderly, because if they were on the shore, they would not be able") or bed integrated buttons (FG1-P05).

Regarding caregivers, they reported the need to add a specific urgency alarm on the patient's bed (FG1-P03: "An emergency alarm, because I always have the bell to call colleagues but if I have an urgency, I have to shout urgency, it will take a bell, a specific sound that for colleagues"). Furthermore, the doorbell was seen as an element capable of creating tranquility in the nurse's work (INT-P04 "the doorbell takes away a bit of anxiety"). In summary, the participants most frequent comment regarding the nurse call bell highlighted their dissatisfaction with those they have in their workplaces.

4.2.3.10 Patient Parameters

Several comments from operators highlighted the need to monitor patient parameters through sensors integrated into the bed (five occurrences, FG1-P01: "Parameter detector incorporated in the bed"), and display data in an integrated monitor (four comments, INT-P04: "Monitor with data and vital parameters of the person", INT-P05: "If there was a way to integrate also a monitor, ECG, breathing, waking state").

Another tool mentioned by several caregivers was the weighing system, which was indicated as fundamental in two interviews ("FG1-P05: "The weighing system is essential because you don't have to lift patients to weigh them. I had patients weighing 180 kilos"; FG5-P01: "Doctors always ask for weight. Even for therapies, and I don't want to have to use the lifter"). The proposal for a catheter weighing system was also mentioned for its possible usefulness (three occurrences; INT-P03: "I was thinking, for example, that the catheter was maybe attached to something, to a bed sensor so that the read can directly record even more precisely"; FG1-P05: "Then I come from a reality where dialysis is needed ").

Finally, the parameter detection for patients would also allow the implementation of alarms considered useful by the operators. For example, they indicated the bed alarm for patients' exit (four occurrences, FG5-P02: "A bell when they put their feet out, a sensor connected to the bed that says there are particular movements", INT-P05: "Many beds have alarms when they hear the patient get up") and for agitated patients (one occurrence, FG5-P02:" or maybe agitated").

In summary, suggestions with more occurrences were the presence of patient monitoring and an integrated monitor, as described in Figure 4.13.

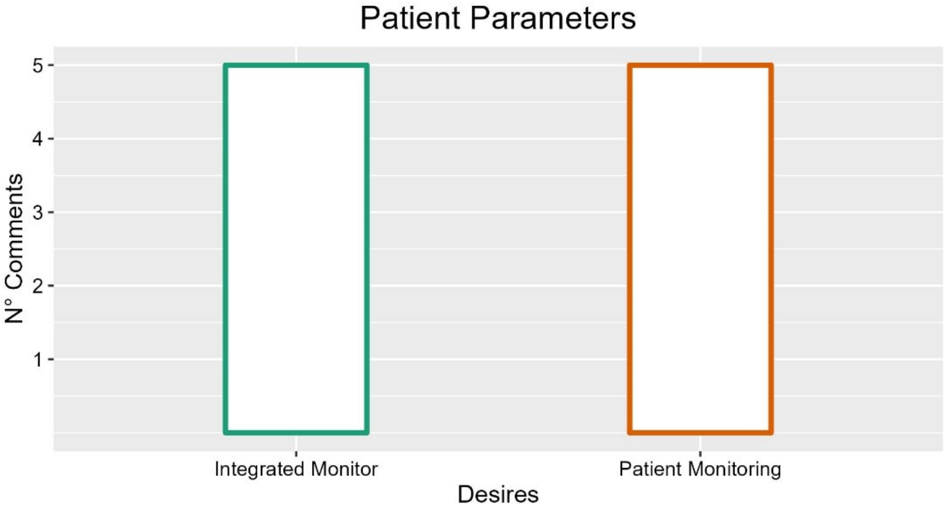


Figure 4.13. Graphical representation of desires with more occurrences for the Patient Parameters theme.

4.2.3.11 Bed Size

Regarding the bed size, the main comments from operators concerned length and width. In particular, the participants expressed the desire to have extendable beds to adapt to patients (eight occurrences; FG3-P03: "The bed must be extendable, also because the average height is higher than in the past"; INT-P05: "Bed extension must be there to have more space for tall patients"; FG1-P02: "There must be, but the mattress slips and is an inconvenience"), and to have wider beds (four occurrences). The main reason was increased patient comfort (four occurrences; FG3-P05: "We often have overweight patients"; FG2-P01: "For people accustomed to two squares which will have to stay a long time"). Furthermore, as regards the bed's width, a participant proposed the possibility of making it adaptable to the patient (FG1-P03: "We would need a bed spreader. If I were in them, I would have claustrophobia"). Some have instead pointed out that the bed should be slightly narrower to facilitate movement across the doors (two occurrences; FG2-P04: "Reduction in width for door passage"; FG5.P02: "Often the rooms are small, and the bed is bulky").

In summary, the most frequent comments regarding bed size and the suggestions with more occurrences are described in Figure 4.14.

Figure 4.14. Graphical representation of desires with more occurrences for the Bed Size theme.

4.2.3.12 Bed Weight

Several participants reported that the bed should be as light as possible (eight occurrences; INT-P05: “It must not be excessive, often the structure is very heavy”; FG2-P03: “Usually two people have to move”; FG5-P03: “It should be light, for maneuverability more than anything else”),

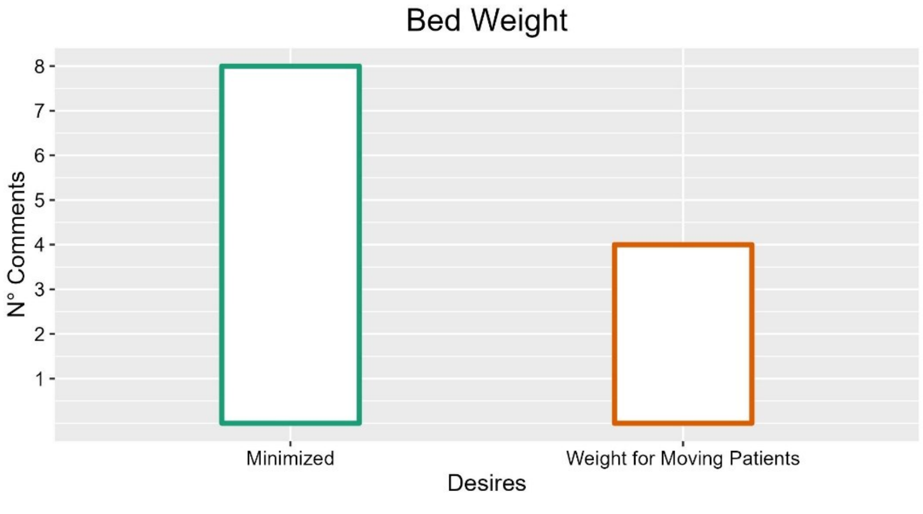


Figure 4.15. Graphical representation of desires with more occurrences for the Bed Weight theme

especially as regards the removable components (one occurrence, FG2-P03: "The single piece that I have to change in the case must be the light one. I have to be able to remove pieces such as back or footboard with ease, must be light ").

On the contrary, some comments underlined the importance of the weight of the bed (four occurrences, FG1-P05: "Electric beds should weigh, for me it is fundamental"), especially as regards the possibility of moving patients (one occurrence; FG1-P05: "Weight is fundamental because if the bed weights it helps moving patients").

Finally, some of the participants did not consider the weight of the bed relevant if the maneuverability is not compromised (two occurrences; FG3-P02: "If there are good wheels, it doesn't matter", INT-P05: "Simple maintenance of the wheels could help").

Suggestions with more occurrences are described in Figure 4.15. The frequency of comments highlighted that the bed weight should be minimized for the participants, even though it has been also suggested that the weight of the bed is an important feature for moving the patients around while on the bed.

4.2.3.13 Manoeuvrability

Participants' comments regarded both the brakes and the wheels of the bed.

The participants highlighted that brakes were adequate (three occurrences; INT-P01: "That's okay"). Furthermore, they needed to lock all the wheels with a single brake (two occurrences; FG4-P02: "single block for all wheels") located in an accessible spot.

Several comments on wheels highlighted the need for high maneuverability (six occurrences; INT-P02: "They must be more maneuverable"; FG2-P02: "The beds are difficult to move"; FG1-P05: "They cannot be maneuvered alone"; FG5-P03: "My ward is narrow, they are difficult to move"). Participants then highlighted problems and some possible improvements. For example, they are subjected to wear (FG2-P01). The main problems, according to the comments, concerned the movement of the bed, similar to a shopping cart (two occurrences, INT-P05: "wheels like shopping carts"), and difficulties in turning (FG2-P02: "go straight when cornering"). Participants then proposed multiple driving modes (FG3-P01: "Four free wheels or with the two fronts locked to face curves or straights") and retractable wheels (two occurrences; FG4-P02:" They would make the minimum height lower"; FG3-P01: "They would promote the appearance of the bed in that of a house"). A further proposal concerns the presence of a fifth motorized wheel (two occurrences; INT-P03: "The weight is often excessive") and the integration of shockproof materials (INT-P02: "the wheels must be fully functional, the material has to absorb the shocks for when I skid so the patient does not have the feeling of having an accident ").

The physical characteristics that seem to have the greatest impact on the maneuverability of the bed relate to its size and weight. Comments about these elements can be founded in the respective paragraphs.

In summary, the most commonly desired features for the electric bed movement concern improving wheels' maneuverability and reducing the bed weight (this feature is according to what has been highlighted in Section 4.12 about bed weight). Suggestions with more occurrences are described in Figure 4.16.

Figure 4.16. Graphical representation of desires with more occurrences for the Maneuverability theme.

4.2.3.14 Materials

Participants cited many general characteristics of the materials that should make up the bed. According to them, these should be smooth (four occurrences), robust (seven occurrences) and easy to clean (10 occurrences).

The material most suggested by healthcare personnel is plastic (four occurrences) rather than metal, as it is antistatic (INT-P05: "in plastic, for an antistatic issue, if an emergency happens and you have to defibrillate, and you made it in iron, you risk the propagation of the impulse for the patient attached to the bar with his hand. Obviously, if it conducts electricity, you may not have noticed it, but you are touching the bar, you also take it too "), a more welcoming element (INT-P05), more comfortable to the touch (INT-P03: "Plastic materials rather than ferrous, iron is cold ") and does not produce an anxious sound (INT-P04: "Iron, creak, paint that goes away fuel anxiety").

Another material that the healthcare staff has advised against is wood (four occurrences), both from a hygienic point of view (INT-P02: "Wood finishes: less hygienic than plastic, it is damaged more and more aggressive products must be used to sanitize") and because of its fragility (four occurrences, INT-P05: "The maintenance that must then be done in the wooden ones is absurd because obviously, the wood ruined fast, the wood breaks"). One comment proposed using plastic-coated metal materials as a solution, creating a robust and antistatic structure (INT-P05: "Maybe you know it is easier for plastic to break than iron, but maybe an iron covered with plastic would be it would be better").

The colours should be resistant to wear both for aesthetic and patient safety issues (five occurrences; INT-P02: "They must resist maintenance and wear"; FG1-P02: "They must also resist gastric materials, sometimes we have nasogastric tubes and acidic material comes out and the stain remains even if you wash with bleach"; FG2-P02: "Plastic with single paste color, resistant to scratches"; FG6-P01: "That the color does not melt in the heat maybe and that they cannot release toxic substances, resistant to disinfectants").

As far as the shape is concerned, the comments of the healthcare staff showed that it is necessary to minimize the edges and cracks for hygiene (four occurrences) and make sure the structure is composed of a reduced number of elements (INT-P04: "Few to clean easily and prevent infections ") which, if covered by a covering (two occurrences) or removable, would facilitate their sanitation (three occurrences). Furthermore, the shape of the bed should be subordinated to its functions (INT-P02: "Not essential but must be subordinated to functions").

The most cited qualities of the electric bed highlighted the participants desire for easy to clean and robust materials with wear-resistant paint, as described in Figure 4.17.

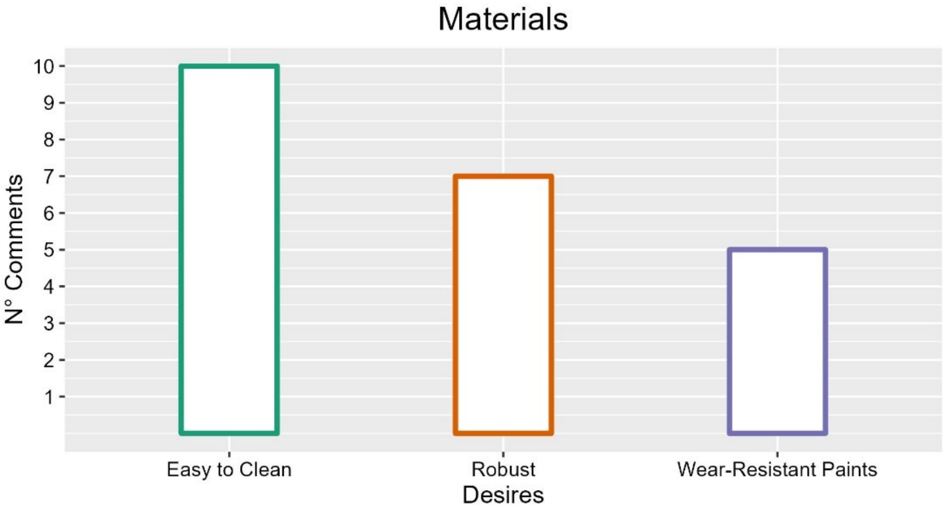


Figure 4.17. Graphical representation of desires with more occurrences for the Materials theme.

4.2.3.15 Maintenance

Regarding bed maintenance and assistance in case of malfunctioning, several comments concerned the need to have manual control of the electrical movements. In case of broken electrical engines or commands, caregivers must not lose control of the bed (nine occurrences; FG1-P05: "Maybe foresee that if something breaks there would be a manual mechanism, an emergency lever", FG4-P03: "Manuals even in case of problems", INT-P01: "Like the CPR lever, to get up quickly without remote control"). Furthermore, the participants suggested the possibility of removing the single defective elements to be repaired or replaced without having to stop the use of the entire bed (three occurrences; FG2-P02: "Interchangeable, which if a piece breaks, you detach it and change it immediately").

Regarding the implementation of functions related to bed maintenance, the participants proposed a sensor that detects failures (one occurrence; FG1-P05: "When the bed breaks, it is not possible to think of something, a sensor, which signals the problem?") and an automatic alarm for assistance in case of failures (one occurrence; FG1-P02: "There could be something that gets the signal to the company and they know they have to do this without making emails, requests, etc."). To summarize, the most frequent comment highlighted that a manual control should be present in case of malfunction of the electrical system.

4.2.3.16 Aesthetics

Several participants mentioned aesthetics as a fundamental element for patient comfort. In particular, a central aspect concerned the possibility of making the appearance of the bed less hospital-like and more similar to a domestic bed (four occurrences; FG2-P03: "You must also make it beautiful to the eye, with something familiar, which leads back to the domestic context, remaining in a hospital context"). In particular, according to the participants, the appearance of the bed should be modern (one occurrence; FG3-P03: "Positive feeling due to being on a technological object for comfort") and with a rounded structure (1 occurrence; INT- P01: "Make the surfaces a bit like to say rounded and smooth a bit everywhere"). Participants also addressed the possibility of hiding some elements, such as mechanical parts (one occurrence; FG3-P02: "Then also cover the mechanism of the bed, it should not be visible") and wheels (one occurrence; FG3-P01: "Even retractable wheels do a lot, you have a bed with four legs"). In addition, four participants proposed colored or oddly shaped beds for children (four occurrences; FG2-P02: "For children full of drawings, possibly even with strange shapes just the bed", FG6-P05: "We can also have children as patients, giving them a colored one would be more cheerful").

Regarding the color of the bed, most of the participants proposed avoiding brilliant colors and choosing instead warm and relaxing ones (eight occurrences; INT-P04: "They create a welcoming environment, they must be simple and relaxing, make you feel like at home"; FG6-P01: "Maybe pastel colours", INT-P03: "If not too strong they can help to give serenity") or shades (one occurrence; INT-P05: "A little more nuance that at least, I'm not saying it makes you feel at home (...) but at least you look at yourself in your bed and have this feeling of welcome for a moment "). Finally, participants underlined the importance of choosing a color that complements the appearance of the room (two occurrences; FG6-P03: "That fits well into the room", FG4-P05: "The top would be the bed in the same color as the wall"). Many participants indicated fake wood as the color that better simulates a domestic environment (six occurrences; INT-P04: "Making them like wood to give a sense of home, clean and tidy"). Some participants also suggested avoiding white because it is more prone to getting dirty/stained (two occurrences, FG6-P02: "I would avoid white because it gets dirty", FG2-P04: "Even the color of the bed may not be white").

In summary, the most frequent comments about the electrical bed aesthetic highlighted that it should be colorful but also have a domestic look. Suggestions with more occurrences are described in Figure 4.18.

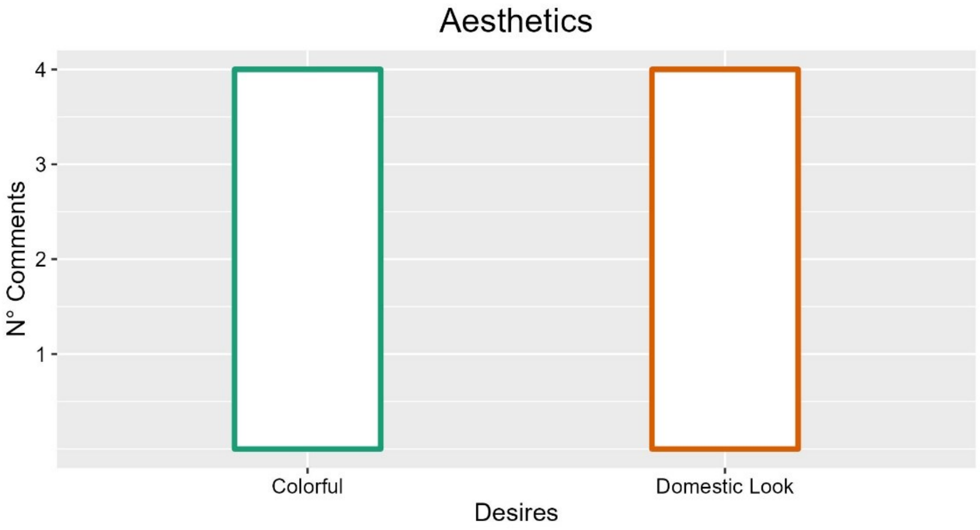


Figure 4.18. Graphical representation of desires with more occurrences in for the Aesthetics theme.

4.2.3.17 Lights

The participants proposed several lighting systems for integration into the bed. The first was a soft night light proposed for patients' well-being and to support caregivers' work (five occurrences). They also proposed a courtesy light to support the work of the operators (two occurrences; INT-P05: "A light would be useful because it often bangs on the bed at night"; FG6-P04: "We often call the caregiver with a mobile phone but having a mobile light would be better, perhaps with a flexible rod. Also, for blood sampling") and a system to illuminate catheters or bags (two occurrences; INT-P01: "Lights aimed at the catheters to identify their position"; FG6-P03: "A light under the bed to see the state of the urine bag").

For patients, participants proposed an external courtesy light for getting out of bed (three occurrences; INT-P01: "Lights directed downwards, to reduce ambient light when they have to go out) or an internal one (five occurrences; INT-P03: "An adjustable reading light"; INT-P05: "An adjustable and customizable light would make them more involved"). The latter could make the environment more domestic and welcoming for the patient (two occurrences; INT-P05: "Little things that make them feel, I don't say at home because obviously, patients will never be able to feel at home, but at least a little more comfortable"). However, several comments underlined the importance of being able to adjust or keep the intensity of the lighting low, to avoid disturbance or discomfort to other patients (four occurrences; INT-P04: "That it is more adjustable because sometimes they make a light and there are patients who want to sleep with light, patients who want to sleep without light").

In summary, the suggestions with more occurrences are for integration of night lights and that lights should be at low intensity, as described in Figure 4.19.

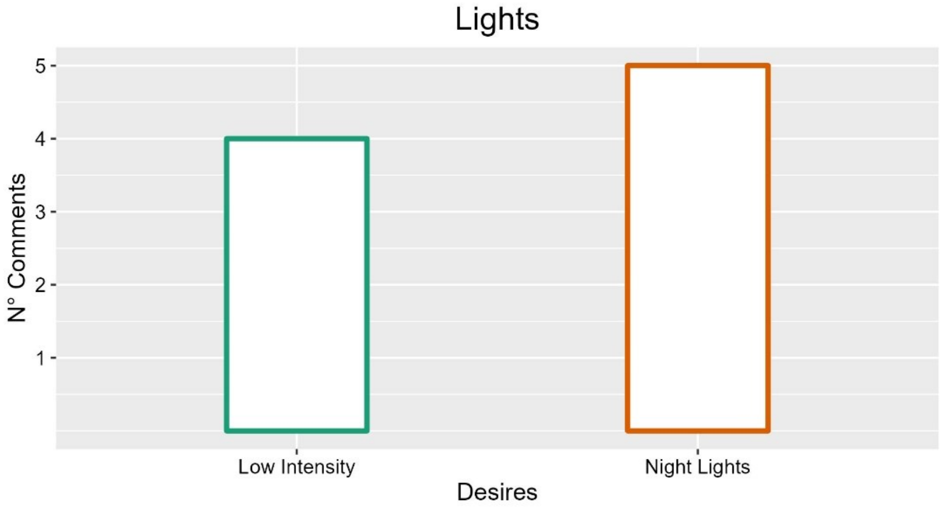


Figure 4.19. Graphical representation of desires with more occurrences for the Lights theme.

4.2.3.18 Patient Relaxation

Finally, the participants proposed accessories/functions to promote the patient's well-being and relaxation. Firstly, they proposed the installation of a screen for video calls (FG5-P02: "A small screen where they can see something or make video calls"). Moreover, they proposed the addition of a surface for putting a television on the bed (FG4-P02: "A TV stand that can be raised/lowered, perhaps at the foot of the bed").

In addition, the participants suggested the implementation of an audio system (four occurrences; FG5-P02: "Having a relaxing music on the bed, already inserted in it could perhaps relax them. Maybe something background, personal for not annoy others in the room", FG6-P04: "Also an integrated radio", FG6-P03: "Bluetooth connection with two speakers"), and an intercom system for children (one occurrence; FG6-P05: "An intercom-type microphone for children so I hear that it happens even if I sleep in another room. Maybe the caregiver wakes up as soon as he hears problems").

The suggestion with most occurrences for an integrated audio system for patient relaxation. as described in Figure 4.20.

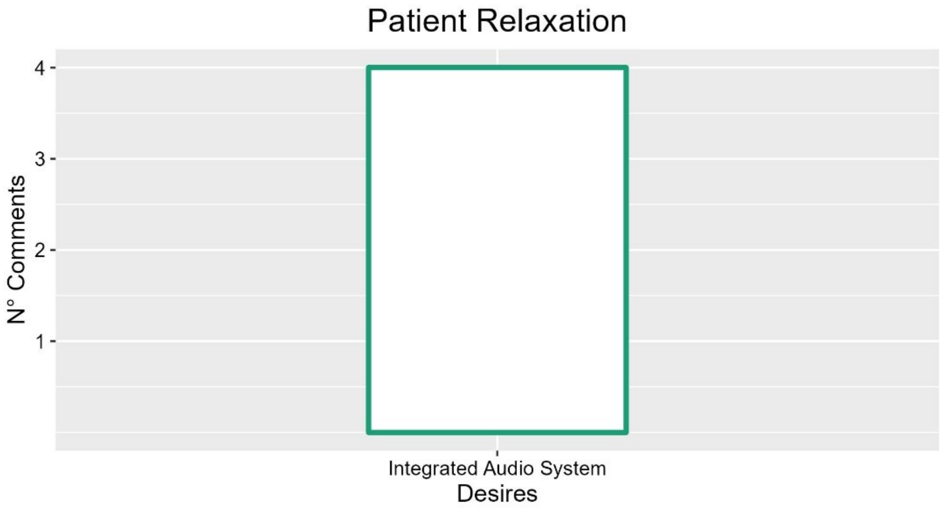


Figure 4.20. Graphical representation of desire with more occurrences for the Patient Relaxation theme.

4.2.4 Discussion

The primary aim of this work was to research end-users' needs regarding hospital medical beds while considering these as a working tool. Indeed, I focused on caregivers' opinions, including nurses, nursing students, social-health operators and physiotherapists, without involving patients since they could face problems unrelated to the bed being seen as a working tool. Moreover, for a comprehensive vision, I involved people from different healthcare realities, such as hospitals, retirement homes for the elderly, retirement homes for people with disabilities and domiciliary assistance. The results present an extensive overview of almost every element of the hospital bed, listing limitations, strengths and caregivers' necessities. A graphical summary of the results is presented in Figure 4.21. The complete list of caregivers' desires and the relative number of comments is provided in Appendix A.

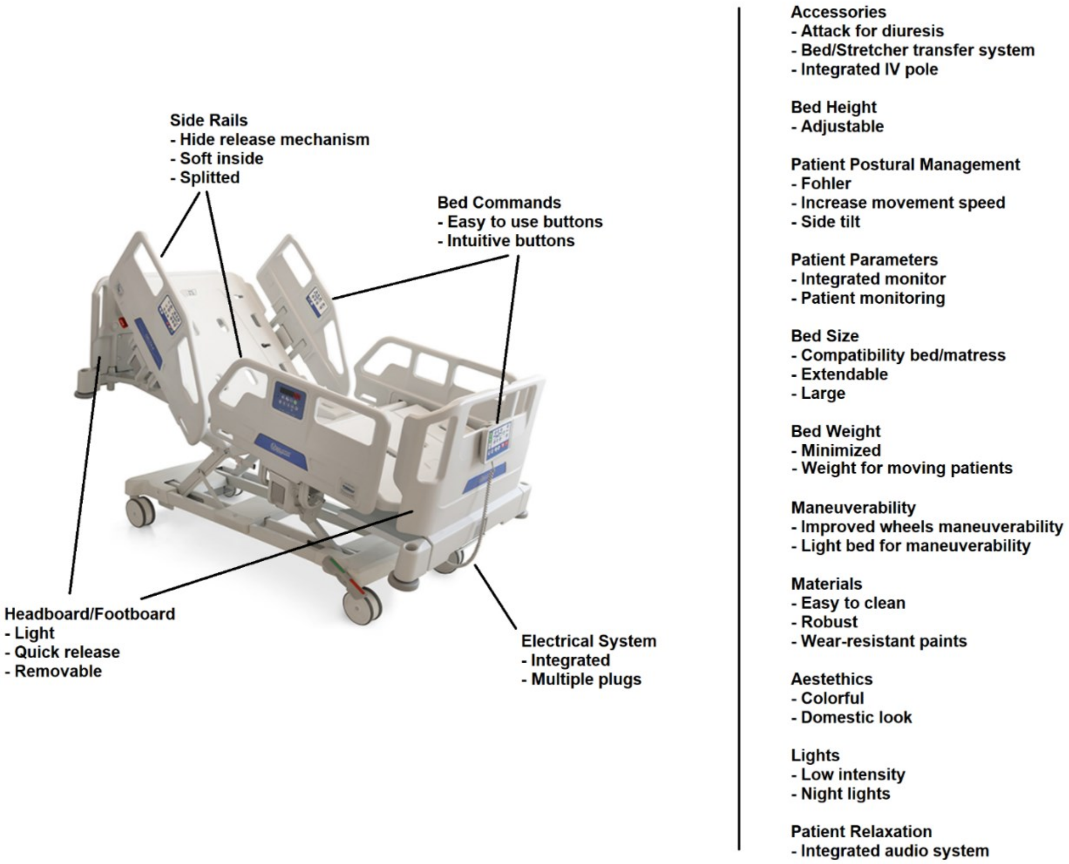


Figure 4.21. Graphical summary of the results of the study.

This work's design suggestions can help future bed designers begin their product development from an advanced starting point, adding necessary adaptations relevant to the application environment. Moreover, new bed designs based on this work will have the advantage of considering users' opinions. To the best of my knowledge, the literature has almost ignored these themes regarding medical beds, since company design is traditionally a top-down or secret process. My work, therefore, identifies some of the main design challenges that can be faced thanks to these results.

4.2.4.1 Design for Physical Workload Reduction

The first challenge is the reduction of workload. Research approached this problem extensively, especially among nurses, addressing it as a cause of low back pain (Shieh et al., 2016), burnout (Diehl et al., 2021), performance reduction (Asamani et al., 2015), quality of life (Sjöberg et al., 2020), and many other factors. A recent study also found that the number of steps and time pressure represent possible operational causes of high workload (Umansky & Rantanen, 2016).

Therefore, our results could help reduce the time spent on procedures, reducing the number of actions needed to perform a procedure or making it faster. For example, our study addresses the importance for designers of researching the best movement speed for adjusting bed height and sections, finding a compromise between safety and time-saving. Moreover, our participants addressed the importance of decreasing the commands' response time.

Many suggestions (i.e., easy-to-use side rails, light headboard, etc.) indicate a great involvement of bed components in increasing physical fatigue, which can be reduced by designing them more lightweight and more usable. Specifically, our participants address the need for lighter and more usable side rails, headboard/footboard, and less complex button panels. This finding is supported by the literature, which addresses the importance of ease-of-use (Reed & Fisher, 2002), design for workload reduction (Nuamah & Mehta, 2020), and reduction in complexity of bed commands (Lin & Zhang, 2020) in healthcare environments. In particular, the headboard/footboard should be easily and quickly removable.

The maneuverability of the bed is another theme that can influence caregivers' physical workload. Many comments addressed the importance of facilitating the beds' movements. For example, lightening the bed, providing multiple driving modalities (i.e., blocking four or only two wheels), and adding a fifth motorized wheel can help caregivers reduce fatigue in moving the bed to and from different places. Among these suggestions, the fifth wheel is the only one explored by the literature (Guo et al., 2018; Horton et al., 2009).

4.2.4.2 Design for Bed Adaptability to Different Situations

Designers should pay particular attention to increasing caregivers' agility during multi-tasking activities frequent in the healthcare environment (Suresh et al., 2021). In this case, technology should help develop more flexible and adaptable instruments. In our study, participants highlighted that accessories and electrical systems (e.g., standard and magnetic plugs, USB ports) should be integrated into the bed structure (headboard/footboard can be a valid support for these accessories), permitting their use in every situation. Our study also provides many suggestions for accessory improvements, such as an attachment for diuresis bags, integrated blanket lifters, a system for the patient transition from bed to stretcher, and a light for catheter bags. Some of these are already the subject of research. For example, systems for transferring patients from the bed to other supports can reduce physical stress (Goh et al., 2014). Our study can provide designers with suggestions about what kind of accessories caregivers want to be directly integrated into the bed.

Many other bed components have been highlighted as too rigid. Participants indicated that side rails design should include systems to adjust the height and the importance of the standard raising/lowering system for bed height. Moreover, another flexibility issue regards the bed battery, whose duration seems too short when the bed is not linked to an electrical plug. Consulting the results for brakes, bed commands, section number, inclinometer and bed base, designers can find suggestions for more flexible bed components. Among these, only bed commands (X. Lin & Zhang, 2020) and brakes (Kim et al., 2009) have been researched in the literature, but not for flexibility reasons.

To the best of my knowledge, the literature is scarce on the importance of technology flexibility and efficiency of use in the healthcare environment.

4.2.4.3 Design for Patient Safety

Another critical theme highlighted by our participants is patient safety. Some of the elements cited in this study represent known problems in the healthcare environment, for example, the safety of the side rails (Babatabar-Darzi et al., 2020; Hignett & Griffiths, 2005; Morse et al., 2015), instrument maintenance (Yasuhara et al., 2012), patient monitoring (Poncette et al., 2020; Taylor et al., 2021), or falls from the bed (Khalifa, 2019). Regarding the side rails, participants addressed the need to design the internal part with a soft, smooth material to give them an appearance that can avoid the patients' feeling of being imprisoned. Other pieces of advice represent features that can be found in modern hospital beds.

My study also presents an overview of caregivers' desire regarding hypothetical smart beds. Many suggestions represent systems explored by literature or industry that are still not usually implemented in standard beds. These are indications about the state of side rails state (Bacchin, Pernice, Sardena, et al., 2022b), posture alarms (Matar et al., 2020), video monitoring (Cournan et al., 2022; Votruba et al., 2016), patient vitals parameter monitoring (Kumar et al., 2019; Rahaman et al., 2019), bed exits (Awais et al., 2019; Y.-L. Lee et al., 2021) and agitated patients (Y.-L. Lee et al., 2021; Muñiz et al., 2020). A few new suggestions from our study are a system that can automatically reposition patients through a wave movement of the section, and automatic detection of bed malfunctions, followed by an alarm to the company assistance department. The users' discussion demonstrates caregivers' great attention to the problem of patient positioning, a significant issue linked to bed sores (Pfeffer, 1991). This study presents a comprehensive vision of what functions caregivers imagine in a smart bed, helping designers select what to implement in their products.

Moreover, the results show caregivers' attention to particular bed positions and movements, such as lateral tilt, Fowler and Trendelenburg. This study shows that designers and companies should provide these with the standard version of their beds.

I believe that these findings can help designers increase patient safety.

4.2.4.4 Design for Easy-to-Clean Bed

Participants addressed some bed elements as especially subjected to dirtiness. Indeed, following the study results, designers should care about ease of cleaning for bed base surfaces and materials used in building the bed and side rails, since environmental hygiene represents a critical issue in healthcare environments (Carling, 2016; Han et al., 2015). The literature has poorly explored this argument, focusing on the general study of hospital materials (Capolongo et al., 2020; Xu et al., 2020) or other technologies (e.g., wearables; Xu et al., 2020). Still, our study shows that caregivers involved in bed cleaning daily have given this problem great attention.

4.2.4.5 Design for Aesthetics and Durability

The results of this study highlight the importance of the materials used in bed development, particularly the importance of balancing durability and appearance. Regarding the former, many comments highlighted the robustness of materials as an imperative characteristic since medical bed components (i.e., control panels, buttons, wheels and materials in general) are usually subject to breakage and wear. Participants indicated mainly plastic materials for the external component of the bed and metallic ones for the base.

In parallel, the visible components of the bed should be aesthetically appealing. The discussion of colors and exposed electrical cables highlights that caregivers desire medical beds with a more home-like appearance. This problem of medical bed design has been explored poorly, with few studies focusing on its appearance and only for elderly retirement facilities (C. Q. Yang, 2012) or homestays (Levinson et al., 2021), representing a new research argument in the field. Some comments pointed out the importance of hiding aesthetically unpleasant parts, such as wheels and electrical cables. As in many other design fields (Sobrino, 2021), reducing elements and increasing appearance simplicity could help design more appealing beds.

4.2.4.6 Design for Patient Comfort

Finally, this study participants show caregivers' worries about patient comfort, suggesting bed improvements for this purpose. Their suggestions were predominantly regarding different types of lights (i.e., for bed exit or reading) and for entertainment (i.e., screen for video calls, TV stand, audio system, intercom). The side rail has also been addressed as a possible source of help for patients, providing support when they need to leave the bed. For the components in contact with the patients, caregivers also address the need to create soft or smooth surfaces, including control panels. Indeed, our study shows that designers need to take care of caregivers' interest in providing a comfortable stay for patients (Gillick, 2013; Lombardo et al., 2013) and the importance of usable push-button panels (Bacchin, Pluchino, Orso, et al., 2021). The latter should be easy to grip and provide appropriate feedback, as the literature suggests for other technological devices (Jaffar et al., 2011; Tao et al., 2018; Yeh & Hsu, 2021).

4.2.4.7 UX Design of Medical Beds

This work highlights the characteristics the medical bed should or should not have in the caregivers' opinions. In this case, the primary concern of users was the creation of good equipment for all the categories listed in the Results section. Indeed, by applying such design guidelines, it will be possible to create tools to help people achieve their goals with minimal effort (Gelsema M A et al., 2006), contemporarily improving their performance (Gurses & Carayon, 2009). Therefore, improving the user experience (UX) and usability of electrical medical beds is fundamental. Despite these two constructs showing differences in concept, meaning and utility, usability has often been indicated as a part of the user experience (Sauer et al., 2020), especially for medical instruments, which are also poorly explored in the literature (Bitkina et al., 2020). According to the work of Bitikina et al., usability and UX are defined by the International Organization of Standardization (DIS, 2009). UX describes the users' response and perception of the use of a product, while usability concerns the capacity of users to achieve goals with efficacy, effectiveness and satisfaction in a specific context. I believe that the present work could significantly contribute to our knowledge of UX applied to the medical bed context. Therefore, I selected from the results some themes participants discussed that could be reconducted into these fundamental concepts.

4.2.4.8 *Emerging Factors for User Experience*

The FGs highlight multiple factors that could contribute to developing electrical medical beds that provide a good User Experience. In Table 2, the UX/Usability constructs that emerged from our FGs and previous studies that have driven our guidelines are reported. From the requirements underlined by the participants, these UX/Usability categories emerged related to electronic beds.

Table 4.3. UX constructs emerging from the study previously explored in the literature.

Safety (Bevan et al., 2015)	Refer to the users' perception to minimize the levels of risk using the system
Comfort (DIS 25010, 2011)	The extent to which the user is satisfied with physical comfort using the system
Ease of Use (Kucukusta et al., 2015)	Refers to the degree to which the user believes s/he can use the system effortlessly
Timesaving (ISO/TS 16071:2003, 2013)	The degree to which a person perceived itself as able to accomplish her/his objectives in a reasonable amount of time using the system
Workload (Feinberg & Murphy, 2000)	The total cognitive load, or amount of mental processing power needed to use a system
Perceived Usefulness (Lah et al., 2020)	The degree to which a person believes that use of a particular system would enhance his or her job performance
Flexibility (DIS 25010, 2011)	Measure of the extent to which the system is usable in all potential contexts of use
Aesthetic (Vermeeren et al., 2008)	Refer to the capacity of a system to pleased one or more of our sensory modalities.
Reliability (Tcha-Tokey et al., 2016)	Refer to the users' perception that the tool assesses the consistency

Follow the UX constructs that emerged from the participants' requirements, which could provide useful guidelines.

Safety

Safety. The caregivers indicated that the bed could provide a safer environment for them and their patients.

Reliability. Lastly, the bed itself should be a reliable tool. Indeed, many participants addressed problems of robustness, deterioration and the necessity for good support from the production company.

Comfort

Another essential feature of the medical bed is comfort. In this case, the meaning of this feature changes across the considered users. For patients, the bed and its accessories are tools to provide a comfortable environment and ameliorate the quality of the stay.

For the operators, instead, it provides a comfortable working tool and represents an instrument that could help them with their everyday work.

Ease of Use

Strictly connected to this theme is the next feature, ease of use. In this case, the operators cited this factor in many bed-connected procedures or elements that emerged during the FGs (e.g., for the transition of patients from bed to other carriers, or the control panel’s buttons).

Ease of Cleaning. One of the most frequent actions during the caregivers’ work is cleaning the bed. For this reason, participants indicate ease of cleaning as a fundamental feature for many parts of the bed (e.g., control panel) and for the composed materials.

Space Saving. The participants showed the importance of having removable parts that create as little encumbrance as possible.

Intuitiveness. Participants mainly cited this characteristic for the bed commands, where they highlighted problems, especially for patients, in understanding control panel icons.

Timesaving and Workload Reduction

Timesaving. Another important theme is the reduction of wasted time. Many bed features permit the saving of caregivers’ time, allowing them to perform procedures faster.

Workload Reduction. At the same time, a well-designed bed could be a helpful ally in reducing the physical workload and for problems such as back pain.

Maneuverability. The bed should be highly maneuverable to reduce time consumption during ward movements and possible collisions.

Perceived Usefulness

Perceived Usefulness. The participants often describe some bed elements as useful, indicating perceived usefulness as an important factor in the overall experience.

Usefulness being a helpful element, the bed could become an instrument that could give serenity to caregivers.

Flexibility

Flexibility. Linked to the last aspect is also the importance of the high flexibility of the bed and its accessories. The participants highlight that the bed should be adaptable to different situations and procedures, giving so the possibility to be a good help for every situation.

Aesthetics

Regarding this last point, the participants addressed this aspect of the bed as an essential element. The bed's aesthetic could lighten the oppressive environment of hospitals or retirement homes for patients.

Home Appearance. Many participants highlighted that the medical bed should be more like a home bed, allowing patients to be distracted from their conditions and experience a cozier hospitalization.

Patients' Serenity. A good-looking bed could have its role in providing serenity to patients.

4.2.5 Conclusions

This work aimed to exploit HCD methods to identify the caregivers' needs regarding the electrical medical bed. Through a thematic analysis of six focus groups and six interviews, I identify 17 themes representing an equal number of characteristics/features that this tool should present for our participants. Furthermore, our work suggests some user experience guidelines that could help to create more usable and enjoyable instruments. The strength of this work is its comprehensive vision of the healthcare environment since it involves multiple types of caregivers and structures. In this case, a possible limitation is missing physicians and clinical engineers among our participants, potential subjects for future studies. Moreover, repeating the procedure focusing on design suggestions specific to every environment would be useful. More interestingly, the same study could be performed with patients, offering their points of view and confirming our results about the caregivers' perception of their needs. Finally, all participants were Italian caregivers, which makes the study not fully generalizable. Future studies should research all the bed models used by participants, ensuring they consider this information before collecting data.

However, following these results, I believe future designers could create beds that significantly impact the caregivers' work. In my vision, the medical bed should represent a proactive and reliable instrument, able to help caregivers and make their work easier and lighter. The results of this study could and should help transform the participants' desires into reality, designing new beds which assist caregivers in their duty and lowering the workload they face during their essential work.

Appendix A

Bed Element	Desires	Description	N°of Occurrences during Interviews
Side Rails			
	Split into two sections	Pro: Easy to clean, escape routes for tubes and drains, less evident restraint, follow backrest movement. Cons: The patient can get stuck in empty spaces.	10
	Unique	Pro: Quickly lowered with a single gesture, avoid that cables and patient stuck between the said rails Cons: Possible patient joint between the side rails boards	6
	Low	Less dangerous falls	5
	Adjustable	Both electrically and manually	4
	Support points	To permit lean of the patient	3
	Curved, rounded	Less sense of restraint and suffocation	6
	Release mechanism that slides under the bed net	Avoid accidents, avoid creating gaps between the bed and other supports	8
	Easy to use and handy	They help in making the bed	3
	Single action to unlock		4
	One-hand release		3
	Quickly closable		1
	Sides lowered alarm		1
	Braked	Avoid pinching	1
	Light		2
	Resistant		5
	Soft inside / padded	Safe and comfortable	7
	Made of plastic		1
	Fireproof		1
	Smooth		2
	Solid/Transparent sides and non-straight bars	They prevent patients' feeling of imprisonment	7
Headboard/Footboard			
	Not bulky		2
	Flexible for accessories		2
	Removable	Facilitate the positioning of bulky equipment, feature that gives comfort and safety	4
	Light		3
	Soft	Avoid injury to the patient	2
	Quick to release	Comfortable for hygiene and therapies	3
Bed Surface			
	Solid surface	Facilitating cleaning as it is a surface that tends to get dirty	2
	Waterproof		1
	Smooth		1
	Resistant		1
	Solid		1

Electrical System	Multi-socket for instrumentation	Solve the cable jam problem	5
	Internal multi-socket bed for the patient		1
	Head side socket		2
	Magnetic socket		1
	Integrated anti-decubitus mattress plugs		1
	Integrated electrical socket		3
	Integrated USB port		2
	Hidden electrical cables	They wear less and improve the aesthetics of the bed	2
	Socket bed disconnection alarm		1
	Battery autonomy	It allows to use the functions of the bed even when you are disconnected from the socket	1
	Auxiliary Battery	Useful in case the bed runs out of current	1
Accessories			
	Bed flexibility to accommodate different types of accessories	IV pole integrated into the bed and adaptable	4
IV pole			
	IV pole	Comfortable and useful	4
	Integrated into the bed and adaptable	It can be used while on the move	5
	Robust	It would solve the problem of poles breaking too easily	2
Attack for diuresis			
	Raised or adjustable connection	It would solve the problem of the pockets that touch the ground	6
Support surfaces			
	Integrated support surface to support the instrumentation		4
storage compartment			
	Integrated		4
Restraint anchors			
	Integrated	Comfortable and remove the risk of harm to the patient	4
Mattress			
	Adequate size to the bed	To cover empty spaces and prevent them from slipping	4
Triangle pole			
	Removable	It would reduce the danger to the patient when this tool is not needed	3
Headrest			
	Integrated	Help for patient hygiene but also an element of comfort	2
Bed-wall spacer			
	Integrated	It would avoid bumps	2
Blankets Lifter			
	Integrated		3
	Electrically adjustable		2
Bumper wheels			
	Space-saving		1

Armrest			
	Integrated		1
Connection for the Anti-decubitus mattress			
	Integrated		1
Bed-stretcher transfer system			
	Systems to facilitate the movement of the patient from the bed and stretcher	They should avoid the empty space between the two	5
Bed Base			
	Flexible	It would help with regards to the use of the patient lift trolley	1
Bed Height			
	Ability to adjust the height	Indispensable for comfort and operator facilitation	9
	Minimum height	Important for patient safety	2
	Quite wide height adjustment range		4
	Increased height adjustment speed	Pro: it helps the staff work Cons: may confuse the patient	2
	Automatic height adjustment		1
	Autonomous height adjustment by the patient	Psychologically it makes the patient feel more involved	1
Patient Postural Management			
	Handling support	Reduce patient discomfort	1
	An element of peace of mind for the operators	Adapt the tool to your needs	1
Inclinometer			
	Useful	0 ° indication	1
	Position	At the foot part of the bed	1
	Inclination of the entire bed	Avoid slipping (Trendelenburg)	1
	Degrees of inclination	Ability to accurately set the inclination, visible degrees (not just 30 °)	1
	Reliability	No ball, light by degrees of inclination	1
Sections			
	Increase number	Adaptable to different stature, multiple postures, patient comfort	3
	Handling	Reduces fatigue, promotes patient independence	3
	Increase movement speed	Usage time reduction	6
	Accompanied movements	Avoid patient disorientation	2
Trendelenburg			
	Useful		4
	Patient movement	Towards the headboard or footboard, solve the sliding problem, reduction of staff fatigue	4
	Automatic	Automatic patient repositioning	1
	Minimum height		1
Side tilt			
	Lateral patient repositioning	Prevent pressure sores, facilitate the insertion of aids	5

Fohler			
	Patient feeding	It favors autonomy and comfort	5
Bed exit support			
	Method for straightening patient		2
	Allow sitting position	Therapy, patient comfort, operator convenience	3
Posture Alarm			
	Posture alarm	Report the need for posturing to staff	1
Proposals for new functions			
	Standard	Preset position reset, via a button	1
	Electric leg movement		1
	Wave movement of the sections	Patient re-positioning	1
Bed Commands			
	Push-button panel integrated into the sides	Avoid wire stuck in the sides, avoid frequent falls (breakage of hooks)	3
	Patient control lock	Maintain posture for therapy	4
	Magnetic coupling		1
	Unified tool	Same remote control for operator and patient, same remote control for all beds	1
	Wireless		2
	Usable with feet	Avoid problem of busy hands	1
	Vocal commands	Hygiene	1
	Touch control panel	Avoid fret wear	1
	Controls on mobile app		1
Buttons			
	Easy to use		5
	Intuitive	Lighter icons, help	5
	Familiars	Referable to a domestic context, highlighting potential bed	1
	Reliable		2
	Readable		1
	Big		1
	Soft		1
	Not too flat		2
	Wear resistant		3
	Command speed	Too slow	2
	Reduce number of keys per patient		3
	Keyboard backlight	It does not have to bother	2
	Improve remote control grip		3
	Sound feedback on pressure		3
Button panel materials			
	Wear resistant	Icon color, shock resistant	3
	Resistant to disinfectants		1
	Rubber cover		2
	Cleanable		1
Button panel functions			
	Distinction between operator and patient commands		2
	Reduced number of commands per patient		2
	Possibility of customization		1

	Ability to use multiple functions at the same time		3
	Replaceable	In case of maintenance	1
Nurse Call			
	Microphone to speak to the guardhouse	Understanding call priorities, avoiding unnecessary interventions	2
	Video/monitor		1
	Vocal command		1
	Integrated		1
	Urgency alarm for operators		1
Patient Parameters			
	Parameter monitoring through integrated tools		5
	Integrated monitor	View vital signs	4
	Integrated scale (weighing)		2
	Catheter bag weight sensor		3
Patient parameter alarms			
	Bed exit		4
	Agitated patient		1
Bed Size			
	Extendable bed (or bed extension)	Adapt to the patient's height	8
	Larger beds	Increase patient comfort, especially for obese patients	4
	Adaptable width (or bed spreader)		1
	Narrower bed	To facilitate movement	2
	Avoid incompatibility between bed and mattress	Avoid gaps and reduce mattress wear	4
Bed Weight			
	Minimized	Encourage travel	8
	Lightweight removable components		1
	Importance of the weight lifted by the bed	Easier to lift heavy patients	4
Maneuverability			
	Bed size proportionate to the environment (doors)		1
	Lighter bed promotes maneuverability		5
	Weight helps for displacements		1
Wheels			
	Improve maneuverability		6
	Improve wear resistance		1
	Double driving mode	Lock front wheel rotation	1
	Retractable wheels	Lower height, less hospital look	2
	Addition of a motorized wheel	Travel support	2
	Shockproof material	Comfort	1
Brakes			
	Possibility of locking all the wheels with a single brake		2
	Brake accessible for operator		1
Materials			

	Smooth		2
	Robust		7
	Easy to clean		10
	Plastics		4
	Light	For removable components	1
	Wear-resistant paints	For patient safety and aesthetic factor	5
	Reduce edges and cracks for hygiene		4
Maintenance			
	Manual controls in case of failure	To be able to use the bed in an emergency	9
	Ability to remove individual components for maintenance	Avoid replacing the entire bed in case of maintenance	3
Maintenance alarms			
	Malfunctioning sensor	Failure reporting	1
	Automatic alarm in case of failure	Automatic call for assistance	1
Aesthetics			
	Domestic look, less hospital	Patient comfort, familiar look	4
	Modern look		1
	Roundish		1
	Hidden mechanical parts		1
	Retractable wheels		1
	Colorful or oddly shaped beds for children		4
Colors			
	Warm and relaxing	Avoid strong colors	8
	Shades of color		1
	Color that integrates with the room		2
	Faux wood		6
	White color (avoid)	Cons: More prone to getting dirty	2
Lights			
	Night light	Patient wellbeing, support for operators	5
	Courtesy light		2
	Catheter bag illumination		2
	Bed exit light		3
	Interior lights	More domestic and welcoming environment	2
	Low intensity lights	Avoid disturbing patients	4
Patient Relaxation			
	Screen for video calls		1
	Integrated TV stand		1
	Integrated audio system		4
	Intercom for children		1

5. Chapter 5

5 SMART BED STUDIES

5.1 Caregivers' Perceived Usefulness of an IoT-based Smart Bed

5.1.1 Aim of the Study

Previous studies on Technology Acceptance examined PU with online questionnaires administered to nursing students or people outside the healthcare environment (see Chapter 1 for more details). The present study wanted to approach the problem differently, using a qualitative method, the Focus Group, carried out with hospital, homecare and retirement homes staff which, in our opinion, are the categories of user who will be most involved with the system in the future. Therefore, the goal was to analyze PU through these discussion groups to draw conclusions about the fundamental elements for the acceptance of IoT technologies in different environments.

5.1.2 Materials and Methods

5.1.2.1 Participants

The experiment involved six groups of subjects, composed of nurses, social health operator (SHO) and physiotherapists belonging to different realities: 2 groups of nurses employed in the hospital, one of which from the University of Padua Hospital (FG1) and one from a mixed group of nurses from various hospitals expert researchers in patient positioning (FG2), 1 group of nurses, SHO and physiotherapists of an elderly retirement home (FG3), 1 group of SHO employed in a facility for people with disabilities (FG4), 1 group of SHO employed in hospital (FG5), 1 group of nurses employed in domiciliary home care (FG6). In total, the study participants were 29 ($F = 19$, $M_{age} = 39$, $SD_{age} = 9$).

The participants were the same involved in the study presented in Paragraph 4.2.

5.1.2.2 Procedure

The first phase of the procedure is described in Paragraph 4.2.2.2. After the initial phase, participants were allowed to pause for about 15 minutes. After that, the moderator explained the IoT concept and described the idea and functioning of the "smart-bed" system (see Paragraph 1.5) before asking the research question about their perception of the usefulness of the systems.

5.1.2.3 Smart Bed System

Paragraph 1.5 describe the smart bed system proposed in this study.

5.1.2.4 Focus Groups

This study exploits the Focus Group technique (Kinalski et al., 2017), which consists of forming a selected group of participants to discuss some problems proposed by the researchers. For further details about Focus Group technique, read paragraph 4.2.2.1. For this study, the three main themes were: Perceived Usefulness (e.g. usefulness to use the system during the night shifts, time saving and improving assistance), Desires (the most desired smart-bed functions, e.g. alerts, physiological signals, fall prevention) and Limitations (critics and limits of the smart-bed system, e.g. fear of the alarm fatigue, reliability of the system, privacy issue). All the participants' answers were then inserted into these categories, and the number of answers' frequencies across the different focus groups was counted.

5.1.3 Results

The results were subdivided into themes according to the participant's answers that emerged during the discussions. The participants' answers were inserted into the three main categories and the number of answers' frequencies, across the different focus groups, was counted.

5.1.3.1 Perceived Usefulness

The results showed that in 100% of the focus groups, in all 6, the participants declared that they found the system useful for their work. Therefore, the system is perceived in all environments as a potential help (P03-FG3: "I believe that all the listed features are useful).

In particular, the importance of the system during the nocturnal phase of health care has also emerged in 100% of cases. For example, the SHO of FG4 declared that they consider an IoT system to be an aid and a reason for serenity in the case of night shifts (P02-FG4: "I don't mind receiving alarms, it would make me safer, especially at night. I would like to know what happens"), for the identification of the many problems they face (P02-FG4:" We have big problems with people getting up, side rails being lowered etc. Then we have many problems that the system could see, people getting up, epileptics…"). These kinds of answers are common to the participants of other groups (hospital nurses, the elderly retirement home group, and the domiciliary nurses).

This result underlined the system's usefulness during the night shift, but its use was also perceived positively during the day. As was highlighted by the hospital nurses (FG1), the system would work greatly also during the day, especially for the management of hectic or particularly busy working moments where the attention of the operators is less present (P04-FG1: "Even during the day that would be fine, maybe you are walking around with the doctor or something else and the ward is uncovered and not immediately noticeable").

As for the hospital environment, both SHO and nurses (2 FG out of 6) stated that the system could greatly simplify their work, lightening the load (P03-FG2: "The listed characteristics can certainly make the workload, that so often exceeds due to a deficient workforce, more manageable”).

Among the reasons that prompted the participants to define the system as useful, the spared time emerged in 2 of the FG conducted. In the case of FG2, this issue has been extensively discussed, leading to the conclusion that the system can be a valuable aid both to optimize times and improve assistance (P02-FG2: "Maybe you have these tools, they do not diagnose but direct attention, they make work more manageable and easier and help to focus on the assistance that must be directed") and to assign priorities to problems, providing help to speed up the response in emergencies (P02-FG5: "At least you know if they are calling you about more dangerous things"). This last issue also emerged among the SHO of the Padua hospital. They highlight that a similar system could save precious time for patients in emergency cases (P03-FG5: "All precious seconds and minutes to save the life").

Another important aspect for the participants (3 FG out of 6) is the advantage of the real-time monitoring of the patients (P01-FG4:" In the case of the measurement of vital parameters it would be great, because even when you are there, and you have to communicate to the nurses ... you can give them an indication by staying in front of the screen").

In 4 of the 6 FG, participants also discussed about how using the data recorded by the smart bed. In summary, some participants expressed their interest in analyzing this data to improve their working environment. In one case, for the participant these data could objectively evidencing the lack of personnel to the management of the structures (P02-FG2: "Tracking data would also allow you to collect information, to understand for example that if there are many falls, then it means that one more person is needed"). In the other cases, however, they want to view the stored data to verify the effectiveness of a procedure (P05-FG3: "I can check if two hours between one posture and the next are adequate"), to view the history (P03- FG5: "Useful ... to have the data as soon as you need it. Even the one previously recorded maybe") or to check the effective progress of the anti-pressure injury therapies (P02-FG6: "A motion sensor would be good to understand our absence as much as the patients moved. Even for informational purposes only").

Safety was among the most cited aspects (3 FG out of 6) for the patient and the operator's work. The SHO find useful receiving alarms from the system (P02-FG4: "I do not mind receiving the alarms would make me safer") and the fact that the system would improve the safety of the environment and the patient (P02-FG5:" For the safety of the environment "; P03-FG5:" For the safety of the patient").

Furthermore, during the focus groups, the participants discussed about what is the working environment in which it is more beneficial to insert the bed system (5 FG out of 6). In the case of nurses in the Hospital of Padua (FG1), belonging to a work environment with frequent use of telemetry, they found only some signals advantageous, those not monitored by hospital's tools (P04-FG1: "Ours is a particular environment. We have the telemetry and there are constant alarms. However, breathing could be interesting for those few who are not monitored"). For the second FG with nurses (FG2), the slower rotation of patients in nursing homes (RSA) would make them perfect for using the system as they are less overburdened by bureaucratic obligations (P01-FG2: "In my opinion, it would be more useful in retirement homes where people stay there for many days"). On the contrary, however, this fast rotation in the hospital would make this environment perfect for this system, as it is more challenging to keep track of the peculiarities of each patient (P02-FG5: "They know them, we have only 20 days, so here it would be much more useful"). The opinion of nurses in retirement homes is according to this last opinion. The participants of FG3 have, in fact, declared that most of the guests are manageable with the instruments available, but that the smart-bed would be very useful for those most at risk (P04-FG3: "in subjects not constantly monitored such as those subject to ALS it would be useful").

In FG6, on the other hand, the home nurses underlined that a similar system would be difficult to implement for them because they don't work in a fixed place, but at their patients' home, (P03-FG6: "I cannot intervene in this way from my home. The functions are excellent, but it changes little for us"). Despite this, they have repeatedly pointed out the system's usefulness both for the hospital and for the care environment (P01-FG3: "In the hospital environment it would be an important innovation. Colleagues can tell me that in this bed there is a patient who tends to have tachycardia, I set the alarm and go"). They hypothesized that it could still be useful in their environment but if managed by the informal caregivers, such as a family member (P01-FG6: "Perhaps remotely, for the sons of the patients it could be very useful to monitor and control"). This particularly significant issue finds a possible solution in one of the FGs. In fact, in FG1, the discussion brought to light the need to design a modular system, therefore adaptable to the specific situations of each environment in which it could be inserted (P01-FG1: "It should be adapted because each department has its needs").

One aspect, which emerged only in one of the FGs, appears particularly interesting. In fact, in FG1, one of the participants pointed out how the system could be useful in the case of isolated patients, where the contact between patient and operator should be reduced for the safety of both (P03-FG1: "For me, it would be very useful especially for those who get up from the bed, to put me on pre-alarm or in those in isolation because we can't go out and in all the time, something would be needed to help us").

The results are summarized numerically in Table 5.1 and graphically in Figure 5.1.

Table 5.1. Appearing frequencies of discussion topic that emerged for the Perceived Usefulness

Discussion Argument	Frequence
Perceived Usefulness	100%
Usefulness During Night Shifts	100%
Simplify Work	33%
Time Saving	33%
Real-Time Monitoring	50%
Data Usage	67%
Safety	50%
Working Environment	83%
Isolated Patients' Monitoring	*17%*

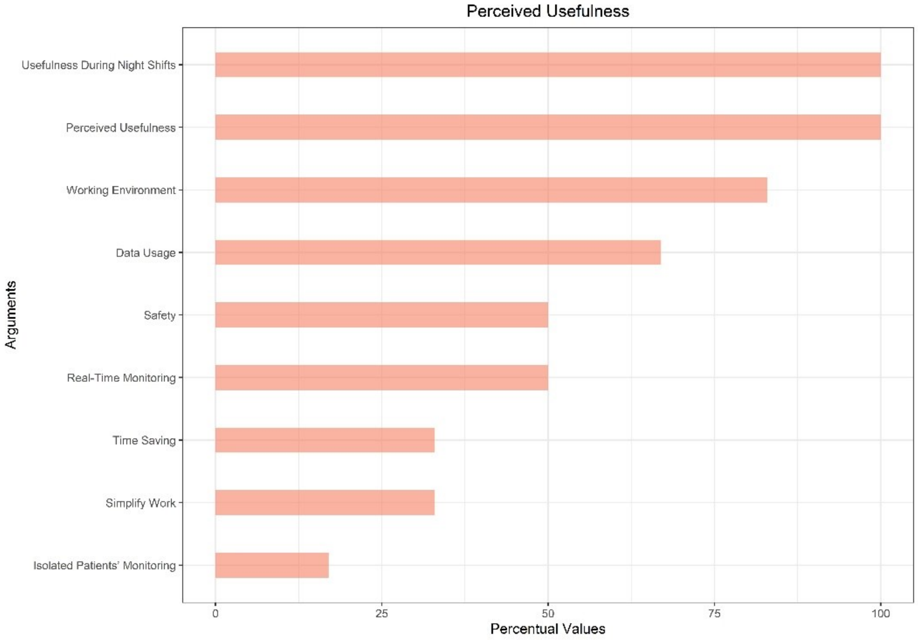


Figure 5.1. Graphical summary of appearing frequencies of discussion topic that emerged for the Perceived Usefulness.

5.1.3.2 Desires

During the FGs, the caregivers highlighted the smart-bed system's more important and interesting functions.

The first was the creation of alerts, which emerged in 2 FG out of 6, those with hospital nurses. In particular, the nurses of FG1 expressed the need to have the alarms displayed on a monitor (P04-FG1: "Maybe it could be connected to a computer, to a monitor") or, for reasons of suitability and visibility, on a mobile device such as a telephone (P03-FG1: "We often go away from the PC, so if the alert comes out there I would have difficulty seeing it, while with the ward telephone I would always have it with me"). They also expressed the need to connect the system to the alerts already present in the hospital, increasing their visibility with a colour code (P05-FG1: "It could also be linked to the alerts already existing in the hospital. It should be something that flashes, a colour that catches your eye"). The same problem of visibility, and therefore of the need for mobile devices, emerged in FG2 (P02-FG2: "It would be interesting if all this information were mobile, not fixed, perhaps a kind of pad, a tablet that allows me to see from any room where there are problems. Otherwise, one has to work in front of the monitor"). The possibility of having the data easily accessible even from the bed has emerged (P01-FG2: "Unless from each bed it could be possible to control the system as if you were always with it") together with the possibility to visualize data from every point of the ward (P02-FG2: "Even two three five monitors, because at night when you are few in number nobody could control a single monitor"). Furthermore, in FG1, the need for an indication of the place where the emergency is taking place emerged (P03-FG2: "It tells you the room where the problem is").

The patient's vital signs control was a high-discussed point (6 FG out of 6). The nurses of FG1, familiar with telemetry, declared that they might need a sensor of a parameter that they do not usually control, for example breathing (P04-FG1: "However, breathing could be interesting for those few who are not telemetry"). Those of FG2 feel the necessity of a sensor for heart and respiratory rate (P01-FG2: "Respiratory heart rate, that yes"), those of FG3, FG5 and FG6 of heart rate (P03-FG5: "If the patient goes under cardiac arrest at least you see it";), while those of FG4 mentioned the control of the temperature and, in general, of various vital parameters (P05-FG4: "The temperature is also useful”).

Another theme is the control of risks for the patient. In 2 out of 6 FG participants discussed about weight/pressure sensors to prevent falls (P01-FG2: "The first cause of adverse events are falling. So, an alert that tells me that the patient has lowered the side rail and I know it, that patient is at risk of falling. Something that catches my attention is certainly fundamental"). In 4 FG out of 6, the discussion regard warnings for uncontrolled patients exit from the bed (P03-FG1: "It would be very useful above all to detect those who get up of the bed"). On the other hand, in 2 FG out of 6, there was the need to be able to weigh the patient (P05-FG4: "Because we have bedridden patients who must be weighed … it would help us a lot, also to establish diuresis"). Finally, in 3 FG out of 6, they discussed about a posture control system (P01-FG3: "It can also be useful if there were pressure points in the mat because knowing them you can adjust how to act on the decubitus. Even only torso or legs").

A further parameter desired by users is wet sensing, which emerged in 2 FG out of 6. It was indicated as useful to prevent injuries (P01-FG2: "Indication of humidity because it is an indicator for operators to say, look, it has been for some hours that the patient lies on the wet. That is essential") or in order not to disturb the patient unnecessarily (P02-FG4: "A humidity sensor could be useful to know whether to change the patient without having to disturb or wake him at all").

In 2 FG out of 6, emerged the need to create a nurse call system integrated into the bed (P04-FG3: "Also a call system that goes beyond the classic bell. Let's see the problem of bedrooms or bedridden patients who cannot move. Maybe touch bells, on the side, or voice command").

Finally, other wishes that emerged individually in only one of the FGs are the integration of the system with the IT medical record (P03-FG2: "It would be useful to have an IT medical record of the patient also for this, which connects to the existing one to make so that I do not have to do the same operation twice"), the creation of checklists for therapies and patient checks (P03-FG2: "It would also be nice to be able to integrate a sort of checklist with the therapies done or missing on that patient"), the creation of different types of users with different degree of access for the flexible setting of the monitoring rules (P04-FG2: "For me, there must also be a manager who decides the settings to be applied for each patient"), and the flexibility of choice for setting times alarms (P02-FG3: "For me, alarms should be able to be set by us, perhaps in time bands").

The results are summarized numerically in Table 5.2 and graphically in Figure 5.2.

Table 5.2. Appearing frequency of discussion topic that emerged for the Desires.

Discussion Argument	Frequence
Alerts	33%
Physiological Signals	100%
Fall Prevention	33%
Patient Outside the Bed	67%
Postural Monitoring	50%
Bed Wet	33%
Integrated Nurse Call	33%
Integration with Hospital Medical Records	17%
Procedures Checklist	17%
Users Differentiation	17%
Flexible Time Settings	17%

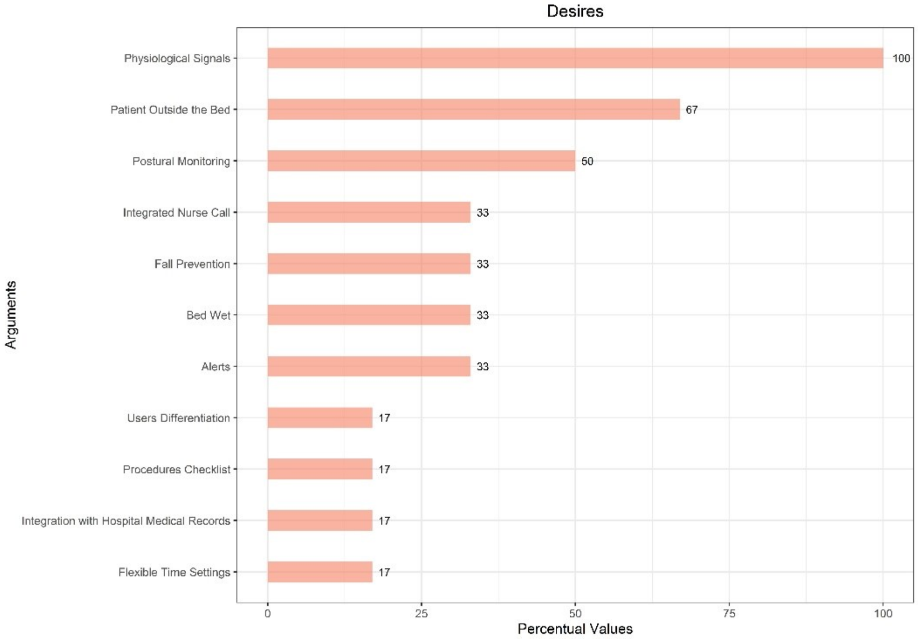


Figure 5.2. Graphical summary of appearing frequencies of discussion topic that emerged for the Desires.

5.1.3.3 Limitations

The methodology used also revealed some criticalities and limitations of the system.

First of all, in 4 out of 6 FG participants were worried by the presence of alarms other than hospital ones, a possible source of alarm fatigue (P06-FG1: "There are positive and negative aspects, you already have many things to do, if you have to keep up with so many alarms you have a hard time").

There is also a risk, which emerged in 2 FG out of 6, on the acceptance of the system due to the trustworthiness of the data (P06-FG1: "Let's say the bed gets jammed, can I definitely rely on it? It can happen ... I don't know if I would totally trust") and on the reliability of the system and therefore on the need for timely technical support (P02-FG1: "I use the PC very little but it always jams. So currently, you hear swearing because the pc is turned off. You need good support").

It is also interesting to highlight a problem detected in one of the FGs, in which the discretion of mobile devices for receiving alarms was discussed because it could impact on the professionalism of the operators (P02-FG1: "However, currently, when doctors use the telephone in hand the patients say they are not working. It would take something smaller, a clock where you have alarm bells. So yes, but with discretion and without letting the patient doubt").

The need to not overload the already overburdened bureaucratic commitments has also emerged as a possible limitation of the system (P01-FG2: "In the hospital where you also have many papers to fill out for an acceptance if you also have to be there to do the bed and patient settings that gets into it becomes challenging").

Another possible obstacle concerns the feeling of the operators of being controlled by the administrators of the structures (P01-FG3: "Yes, but if I do my 8 hours and then someone goes to see what I have done or not, I would feel judged. When they first put the cameras in it was a period of anxiety at the beginning").

Another problem that has emerged is the permissions to view data. One of the FGs points out that the family and the patients should not have access to their data (P03-FG6: "In my opinion the user is not able to manage this data, especially in a domestic context, therefore he should not have access").

Finally, some problems related to incidents and their legal resolution have been highlighted in one of the FG (P03-FG2: "If we then think about the various complaints that many are addressed to us, we could avenge on this instrument by saying that we had it and that maybe we ignored an alarm for any reason, something happened and then with the system we have to give an account").

The results are summarized numerically in Table 5.3 and graphically in Figure 5.3.

Table 5.3. Appearing frequency of discussion topic that emerged for the Limitations.

Discussion Argument	Frequence
Alarm Fatigue	67%
Reliability	33%
Display Devices Discretion	17%
Bureaucracy	17%
Feel of Being Under Control	17%
Data Accessibility for Patients and Families	17%

Legal Issues	17%

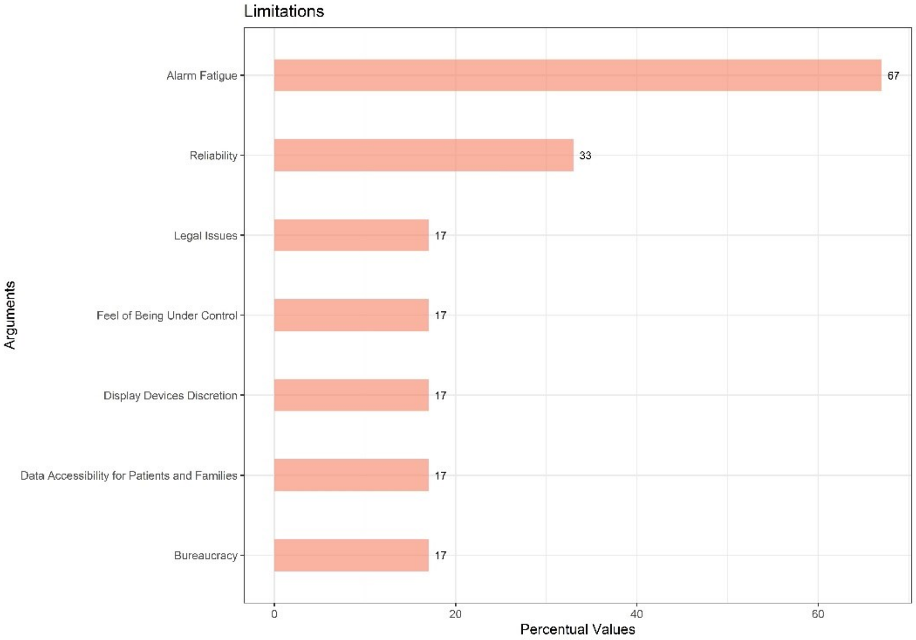


Figure 5.3. Graphical summary of appearing frequencies of discussion topic that emerged for the Limitations.

5.1.4 Discussion

This study aims to explore the perception of the smart-bed IoT systems' usefulness in the medical environment with the end-users, such as nurses, SHO and physiotherapists, working in different healthcare realities.

The first important result is a general positive feeling of usefulness on all the groups involved. This data allows to state that users understand the potential of these technologies and the possible support they could offer them, which is a fundamental indication that caregivers of all categories involved could accept the use of highly technological systems in their work environment. In particular, the perception of usefulness seems to be related mainly to the nocturnal phase of their work. This distinction between night and day and the statements collected about the perceived usefulness suggests that the concept behind the design of the smart bed, an aid capable of lightening the operator's workload, was understood by the participants. Indeed, night shifts are working hours where the healthcare structures see reduced personnel compared to the diurnal phase. Therefore, in the absence of personnel and the consequent workload and responsibility increment, the results shows that technology is seen as an aid to overcome these problems. However, emphasizing the night-time usefulness of the system by the caregivers is not the same as saying that the result is that the system is harmful during the day.

During this last situation, the control system was not opposed but simply less mentioned by participants. The explanation for the minor interest could be founded on one limitation of the system: the number of alarms received. During the day, when the activities are more hectic and numerous, many alarms could cause the phenomenon called alarm fatigue (Deb & Claudio, 2015; Johnson et al., 2017). Therefore, this may have influenced respondents' opinions, who were more likely to consider the system more useful during the night shift, where there is a reduced fatigue alarm occurrence.

Some arguments raised in support of the usefulness of the IoT system were those of saving time and simplifying work. For the latter, the reason is fundable in the workload reduction. Regarding the former, it is interesting to note that alerts and related information management are a way of organizing work, prioritizing some alarms more than others. This would make it possible to deal with severe cases firstly and then move on to minor emergencies, with the consequence of using the little time available by rushing first to the aid of those who need it most. Moreover, the care quality could increment, as the time saved thanks to the use of the system would allow a more focused and direct relationship with patients, consequently increasing their satisfaction with care and clinical outcomes (Ng & Luk, 2019).

The issue of the data collected by the system was then faced from different points of view. Participants indicated the collection and visualization of data in real-time as particularly positive, due to the possibility of viewing and monitoring each patient at the desired times. Smartphones, smartwatches, tablets or monitors directly integrated into the bed, in addition to the computer of the guardhouse, were cited as possible visualization devices. This result, therefore, shows the participants' desire to continuously monitor patients to increase safety for the assisted and the operators themselves. In one of the FGs, the necessity of increasing safety for cases of isolated patients and to reduce contacts while maintaining a high level of attention also emerged. Safety represent an important theme because, as mentioned in the literature, continuous monitoring brings, even outside critical areas, benefits in terms of clinical outcomes, length of stay in hospital and cost efficiency especially overcoming barriers such as false alarms (Downey et al., 2018). Therefore, the result obtained shows that for half of the operators involved, the IoT-based smart bed data is perceived as a positive factor for adopting this technology in their working environments.

The data collected by the smart bed were also cited for the enormous analytical potential they represent. The participants, for example, expressed the desire to collect them to have objective numbers that support them in asking for an increase in the number of personnel from the administrations. Therefore, this result is particularly interesting, as the shortage of operators is a primary concern in hospitals (Metcalf et al., 2018; Tourigny et al., 2019). Finally, the data collected could also represent an aid to verify the correct carrying out of the procedures by non-professional caregivers (domiciliary nurses brought this statement) and to verify their effectiveness.

Moreover, a topic particularly discussed in these FGs was the ideal environment in which to insert an IoT system with these characteristics. The procedure, carried out with different categories of users, has shown that the common opinion is that the hospital is the most appropriate target, especially if the department involved does not have monitoring instruments. The hospital is a more dynamic environment, with a particularly fast patient turnover and a high number of employees who alternate in administering care. These features make a technological monitoring system a valid aid in managing patients, as it allows to keep track of the less known patients. In addition, given the significant differences between the departments of a hospital, it is interesting the suggestion of one of the groups that highlighted the need to create a modular system, therefore adaptable to different needs. Therefore, choosing the most appropriate formula, allowing for customization and cost reduction for the facility, would represent an important element in the intention to adopt the system and so in acceptance. In support of the greater usefulness in hospitals, in the FG for retirement home nurses, the participants highlighted how in most cases, knowing the patients very well, they are manageable with current resources. However, constant monitoring would be welcome for a few patients, the most unpredictable or non-self-sufficient ones. In opposition, the lower frequency of the documents to be filled in for retirement homes would make them a good target since they would not suffer much of the time it takes to insert patients into the bed system, which instead for the hospital has represented a possible limitation. Finally, the domiciliar caregivers find the system not suitable for their work but discuss about providing it, after a simplification of the systems' language, to family members or informal caregivers to monitor their patients in a more sensitive and timely manner. In summary, the system has advantages for its use in all the environments involved (hospital, nursing homes for the elderly, home care), but it seems more suitable for hospitals.

Summarizing the users' desires, the results show the need to create alerts about the patient's vital parameters, especially the heart and respiratory rate, including temperature. Furthermore, the caregivers were particularly interested in avoiding possible risks for the patient, such as falls, getting out of bed unsupervised, immobility, and liquid spills. All these data would allow a complete overview of the patients and, consequently, increase their safety. Furthermore, the caregivers highlight the need to integrate into the bed the facility medical records, a checklist of specific procedures for the patient, and a function for the voice nurse call with easy-to-use interfaces for every type of patients involved.

The system limits highlighted were many, starting from false alarms. For example, the home care caregivers indicate them as a major issue for the acceptance of the IoT bed in their work. Connected to this important problem is the reliability of the data, which could greatly affect the operators' effective use of the system, given the importance of the information's quality in the model of acceptance of technologies also in the medical field (Chismar & Wiley-Patton, 2003). After these two major problems, a series of minor limitations have been highlighted, allowing some reflections. First, the need to not damage operators' professionalism by using mobile devices that patients would consider suitable for recreational use, such as smartphones. Indeed, the patients could perceive a lower care quality or attention, negatively impacting the perceived caregiver's work. In addition, the feeling of control that the caregivers could experience is another important limit. Initially conceived to protect nurses from lawsuits, save and track data is seen as a potential control tool for the administration, like a video camera. A possible suggestion deriving from the FGs could be to guarantee access to the entire database only in legal disputes. This solution seemed to generate greater serenity in the interviewees. Finally, the operators were concerned that the system could be used against them legally when, for various reasons, a caregiver is forced to ignore an alarm to pay attention to something else. If this action were to have any consequences, the recording of the data and the presence of the alarm would make them the target of the legal action.

5.1.5 Conclusion

In summary, this exploratory study on a very varied sample of personal care professionals led to an excellent result in terms of the perceived usefulness of IoT systems, indicating how they can be inserted in the modern hospital working context, considering the importance of PU in the model of acceptance of technologies, also for health (Tubaishat, 2018). Furthermore, the study provides an overview of the key elements to meet users' needs, as well as the possible limits that should be overcome to increase the possibility that similar systems can be adopted in the various settings of patient care. Ultimately, this work offers important insights for the design and planning of IoT systems devoted to patient monitoring and the reduction of operators' workload.

5.2 Web Interface Evaluation

5.2.1 Aim of the Study

This research activity aims to evaluate the interaction of a group of participants with the web interface, the browser-based smart-bed control application that deals with the visualization of patient data reported by hospital beds and their management and logistics. The interface can provide real-time information on each ward's beds and related patients. Therefore, the study wants to consider the strengths and weaknesses of the developed functions. With this aim, the evaluation exploited subjective (i.e., questionnaires) and objective (e.g., eye-tracking, performance) methods, analyzing human factors such as Mental Workload, User Experience, Technology Acceptance, and Usability.

Eye tracking and heart-related measures have been utilized extensively in evaluating cognitive load (Jercic et al., 2020; Cranford et al., 2014) or his Human-Computer Interaction equivalent, the Mental Workload (Charles and Nixon, 2019; Tao et al., 2019). Heart Rate, Pupil Diameter, and Blink Frequency represent robust measures for this objective. However, their use is recently shifting to more applied and ecological studies like the present one. Indeed, a parallel aim of this work was to verify their reliability in less controlled and ecological experiments.

5.2.2 Materials and Methods

5.2.2.1 Participants

I used the software G*Power (G*Power 2022) to calculate the number of participants required. I set the α error probability to 0.10 and the Power to 0.90 for repeated measures ANOVA with five independent conditions, obtaining a minimum total sample size of 22 participants. I recruited 23 participants for the experiment. One participant was eliminated by the analysis for vision correction problems. The final number of participants was 22 (aged between 25 and 46 years; $M_{age} = 30$; SDage=5.49 Female= 12). Participation in the research activity was voluntary, and participants knew they could withdraw whenever they wanted during the experiment.

5.2.2.2 Measures

The study used several methods for research, both subjective and objective.

5.2.2.3 Subjective Methods

Initially, a demographic questionnaire was proposed to the participants to collect some personal data.

The study exploited the NASA-TLX questionnaire to assess the task-related cognitive load (Hart, 2006). The NASA-TLX consists of 6 scales (Mental Question, Physical Question, Temporal Question, Performance, Effort and Frustration) which can be answered using a scale ranging from 0 to 100. The median value of the results of these scales returns the subjective mental load experienced by the participants.

Furthermore, at the end of each task, the corresponding User Experience questionnaire was administered, which analyzed the participants' opinions regarding the specific assignment with a series of questions. The number of items was variable for each task, and the participants could respond indicating their agreement with the proposed statements thanks to a 7-point Likert scale.

Some questionnaires were instead administered at the end of the experiment to evaluate the general interaction with the interface.

The first was a Technology Acceptance questionnaire, taken from an article in the literature (Pai & Huang, 2011) that studied the acceptance model in the field of information systems in medical environments. The questionnaire was then adapted to the study and translated into Italian, resulting in 10 items that participants answered using a 5-point Likert scale. The questionnaire assessed information quality (IQ), system quality (SQ), perceived usefulness (PU), ease of use (EOU), and intention of use (UI) dimensions.

The second was a User Experience (UX) questionnaire, created starting from a work present in the literature (Schrepp & Thomaschewski, 2019), adapted for the study and translated into Italian. The questionnaire presented a series of semantic differentials (i.e., opposing adjectives) that described the sensations felt by the participants while using the interface. Participants could then respond using a 7-point scale, selecting the dot that mainly represented their experience. The dimensions analyzed by the tool were Attractiveness (Att), Efficiency (Eff), Perspicuity (Per), Dependability (Dep), Stimulation (Sti), Novelty (Nov), Trust (Tru), Aesthetics (Aes), Usefulness (Use), Trustworthiness of Content (TrC) and Quality of Content (QuC).

The third was a usability checklist, created ad hoc for the experiment starting from the well-known usability heuristics of Nielsen (Nielsen, 2009). In this questionnaire, participants faced a series of questions which they could answer Yes, No or Not Applicable. They could also add personal comments to all of them. The checklist analyzed dimensions such as System State

Visibility (Vis), Error Prevention (Err), Aesthetics (Aes), Help Provided and Documentation (Help), Recognition rather than Recall (RrR), User Freedom and Control (UsC), Match the Real World (MrW), Consistency and Standards (Con) and Flexibility (Fle).

Participants fulfilled a questionnaire to evaluate the intuitiveness of the icons, consisting of 22 labels corresponding to as many system icons. The labels were presented one by one together with the entire set of icons used in the interface. Participants had to associate the correct icon with the label. The participants, once answered, could no longer change their minds. The order of presentation of the labels was randomized.

5.2.2.4 Objective methods

Various objective data were collected for the evaluation of cognitive load and performance.

Regarding the participants' performance, I considered the time on task for accomplishing the assignments and the errors made while accomplishing individual tasks by counting the user interactions with the Microsoft "Action Recording" tool. In the time-on-task analysis, I also compared the participants' results with the ideal time, measured as the time an expert user performs the task, plus 50%. Furthermore, I considered the weighted mean between these two measures. I weighted the mean giving to time the 60% of the weight and the remaining 40% to the errors since in the caregivers work with the interface time represent, in my opinion, a more important factor. The weighted mean was calculated as the sum of the time values multiplied to 0.6 and the number of errors multiplied to 0.4.

For the Cognitive Load and behavioural indexes measurement, the Eye Tracking methodology was exploited. The indices analyzed were the Frequency and Duration of Fixations, the Frequency and Duration of Blinks (closed eyelid), and Pupil Diameter since they are related to attention and cognitive load (Duchowski et al., 2017, Charles 2019). The instrument used was a pair of wearable glasses from Pupil Core (Fig. 5.4; Pupil Core, 2022) which acquires data at 200Hz.

Figure 5.4. Pupil Core eye tracking glasses used in the experiment.

Moreover, I reviewed the experiment's videos captured by an eye-tracking device to evaluate the interaction of the participants with the interface, thus evaluating if participants completed the tasks successfully and what problems they encountered during use.

An elastic band was used to detect the cardiac signal to derive the average heart rate. The instrument used was a Polar H10 band (Fig. 5.5; Polar H10, 2022), capable of acquiring data at 1024 Hz.

Figure 5.5. Polar H10 band, used for acquiring heart rata data in the experiment.

5.2.2.5 Tasks

Participants faced five different tasks:

> *Login (LO):* in this task, the participants log in to the system and access a specific patient (identified by his name/surname) information panel for a registered person in a room. They had to set for him three monitoring rules at different times (i.e., night, day, 24h);
>
> *Patient Information (IN):* in this task, the participants had to search for a patient with a specific ID, modify a monitoring a rule set for 24h setting it for the night only and then search for a series of information (six in total) which can all be found in the screen patient details;
>
> *Bed Change (CB):* in this task, the participants had to find the patient with an active alarm (i.e., side rails down) and change his/her bed by finding one available in a room with another patient of the same gender;
>
> *Maintenance (MA):* in this case, the participants had to find the patient located in a specific room and place (i.e., 7B), discharge him and send the previously associated bed to maintenance;
>
> *Assignment (AS):* in this task, participants had to find a female patient without a bed and then assign her a bed in an empty room.

5.2.2.6 Procedure

Participants initially participated in a short online training phase held via the Zoom platform. The researcher explained the experiment objectives and showed a demonstration video presenting the interface and its functions. The experimental session was scheduled seven days after this first training phase. The participant fulfilled an informed consent and a demographic questionnaire at the beginning of the testing session (Figure 5.6). At the end of this first phase, the participant was dressed and asked to wear the Polar H10 heart rate monitor and the Pupil Labs Glasses Core eye tracker for eye movement detection. The first phase of the experiment included five minutes of free exploration in which it was possible to practice with the interface without constraints. The experimental setup comprehended a large monitor, mouse and keyboard (Image 5.9). At the end of the practice phase, the participants faced five experimental tasks: Login, Patient Information, Bed Change, Maintenance, and Assignment. Images 5.8 and 5.7 show some participants carrying out the tasks. The relative log files were recorded using Microsoft Action Recording. At the end of each task, participants fulfilled the NASA Task Load Index (NASA-TLX) and a questionnaire to evaluate the relative User Experience (UX), formed by a variable number of items (i.e., from 7 to 14), depending on the task performed. The scale used for this questionnaire was a 7-point Likert scale. The order of the experimental tasks was randomized for each participant to avoid effects of excitement or fatigue on the objective measures (i.e., HR and ET). At the end of the tasks' accomplishment, the participant completed the "Usability checklist" to evaluate the interface's usability, the overall User Experience and the Technology Acceptance questionnaires and, finally, the test to evaluate the intuitiveness of the icons.

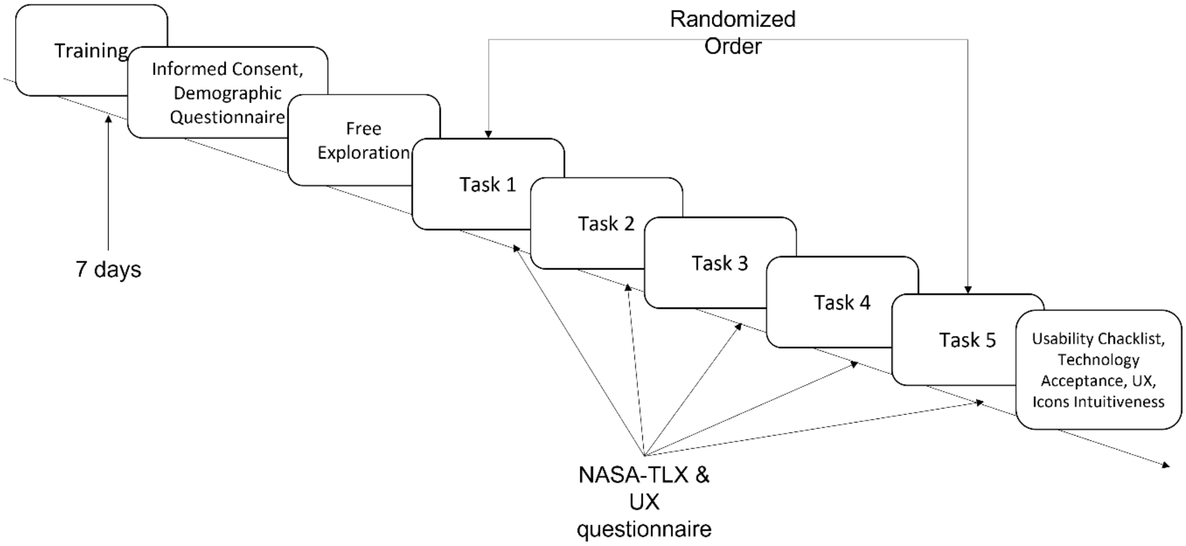


Figure 5.6. Graphical description of the experiment procedure.

Figure 5.9. Experimental Setup.

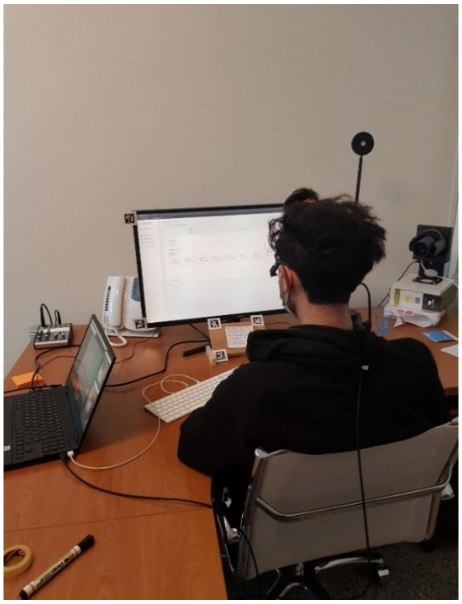


Figure 5.8. Participants during the accomplishment of a task

Figure 5.7. Participants during tasks explanation.

5.2.3 Results

Data analysis was performed using R studio software. For the analysis of the questionnaires, I run a series of Mann-Whitney tests, comparing the median result with the median of the response scale and correcting p-values with the BH method. The only exception was the NASA-TLX, analyzed with the Kruskal-Wallis test. To analyse the objective measures, I verified the normality of the data using their visualization and the Shapiro-Wilk tests. In the case of normality in all conditions, an ANOVA test for Repeated Measures was performed, followed by pairwise T-tests, corrected with the Benjamin-Hopkins (BH) method. In the event of non-normality of the data, a Friedman test was used, followed by pairwise Wilcoxon tests. The results were also corrected with the BH method.

5.2.3.1 NASA-TLX

NASA-TLX data were analyzed using a Kruskal-Wallis test, followed by pairwise Wilcoxon tests. The test results are shown in Figure 5.10. The Kruskal-Wallis test result was significant ($p<0.001$). AS condition (Med=15) results significantly lower than CB (Med=22.5, $p<0.05$) and IN (Med=35, $p<0.01$). CB condition was also significantly higher ($p<0.05$) than LO condition (Med=13.8). IN condition was significantly higher than LO ($p<0.01$) and MA (Med=17.5, $p<0.05$) conditions. A series of Mann-Whitney tests were run to verify if the subjective ratings of the conditions were significantly lower than the median of the scale (i.e., 50). All the p-values, corrected with the BH method, were founded significant ($p<0.001$).

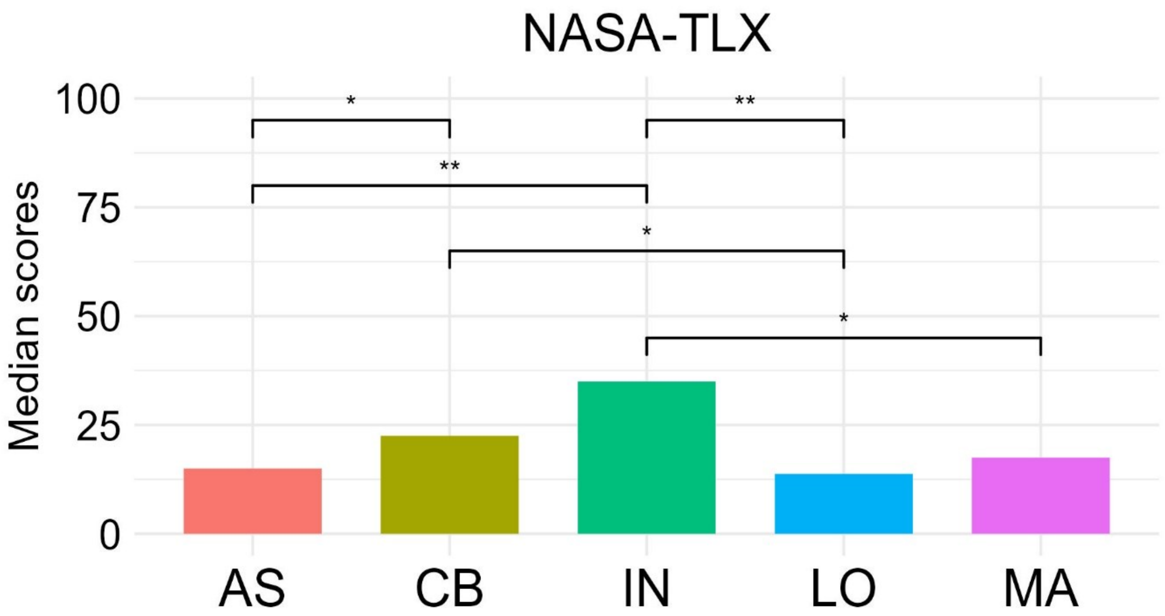


Figure 5.10. Results of the NASA-TLX questionnaire. The x-axis represents the task, the y-axis the average score assigned by the participants.

5.2.3.2 Time-on-task

The time-on-task data were not normally distributed. Therefore, the Friedman-Wilcoxon-BH method was used. The Friedman test results were significant ($p<0.001$). The test results are shown in Figure 5.11. The results of the following pairwise Wilcoxon tests show several significant differences. The IN task (M=242, SD= 75.1) was found to be the longest, differing significantly (V=9, $p<0.01$) from AS (M=87.8, SD=112), CB (M=141, SD= 79.1, $p<0.5$), LO (M=84.7, SD=40.2, $p<0.0001$) and MA (M=84.5, SD=35.1, $p<0.0001$). CB time on task results were significantly higher than AS ($p<0.05$), LO ($p<0.05$) and MA ($p<0.05$) tasks.

The ideal time-on-tasks were: AS=21.85 s, CB=38.1 s, IN=75.33 s, LO=38.04 s, MA= 25.43 s. I compared these times with the ones obtained by participants with a series of Mann-Whitney tests, which p values were corrected with BH method. All participants' results were founded significantly higher ($p<0.001$) than the ideal ones.

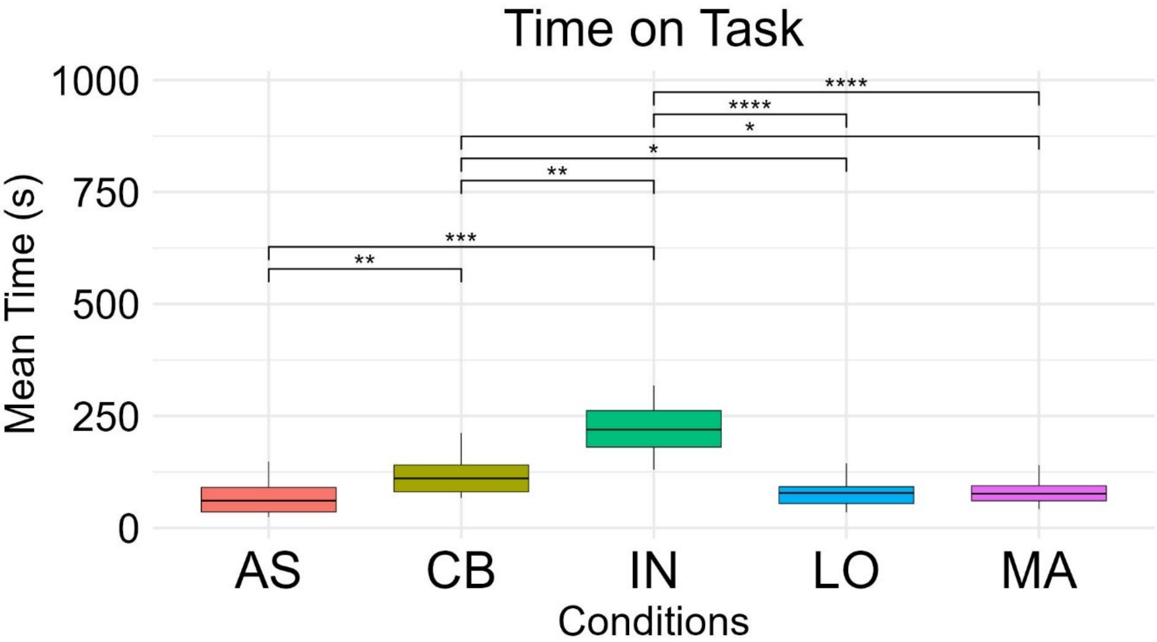


Figure 5.11. Results of completion times by task. The x-axis represents the task, the y-axis the average time spent in seconds.

5.2.3.3 Errors

The performance in terms of errors was then evaluated. The errors were calculated by subtracting the ideal number of interactions to complete the task from the total number of interactions performed by the participants. The data were not normally distributed and ordinal. Therefore, the Friedman-Wilcoxon-BH method was used, showing a significant main effect ($p<0.001$). The test results are shown in Figure 5.12. The condition with the most errors was the IN condition

(M=27.3, SD= 11.8), whose errors were significantly more numerous than the conditions AS (M=9.05, SD=11.7, p<0.001), CB (M=10.8, SD=11.1, p<0.01), LO (M=9.64, SD=9.45, p<0.001), and MA (M=12.8, SD=9.25, p<0.01).

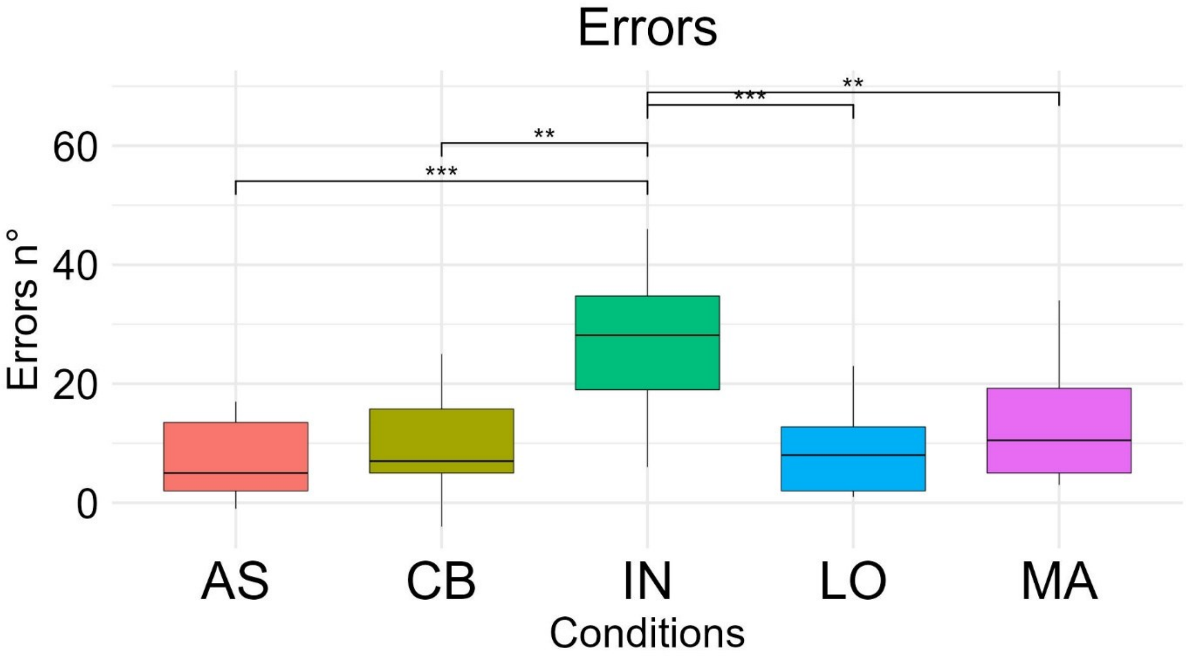


Figure 5.12. Results of the errors made by the participants while carrying out the tasks. The x-axis represents the task, the y-axis the number of average errors made by the participants.

5.2.3.4 Weighted Mean

The weighted mean was analyzed in each performed task. I used the Friedman-Wilcoxon-BH method. The Friedman test results were significant (p<0.001). The test results are shown in Figure 5.13. The results of the following pairwise Wilcoxon tests show several significant differences. The IN task (M=150, SD= 47.9) was found to be the most difficult, differing significantly (p<0.001) from AS (M=54.9, SD=67.1), CB (M=84.7, SD= 48.2, p<0.001), LO (M=54, SD=25.8, p<0.001) and MA (M=54.5, SD=23.1, p<0.001). CB results were significantly higher than AS (p<0.01), LO (p<0.05) and MA (p<0.05) tasks.

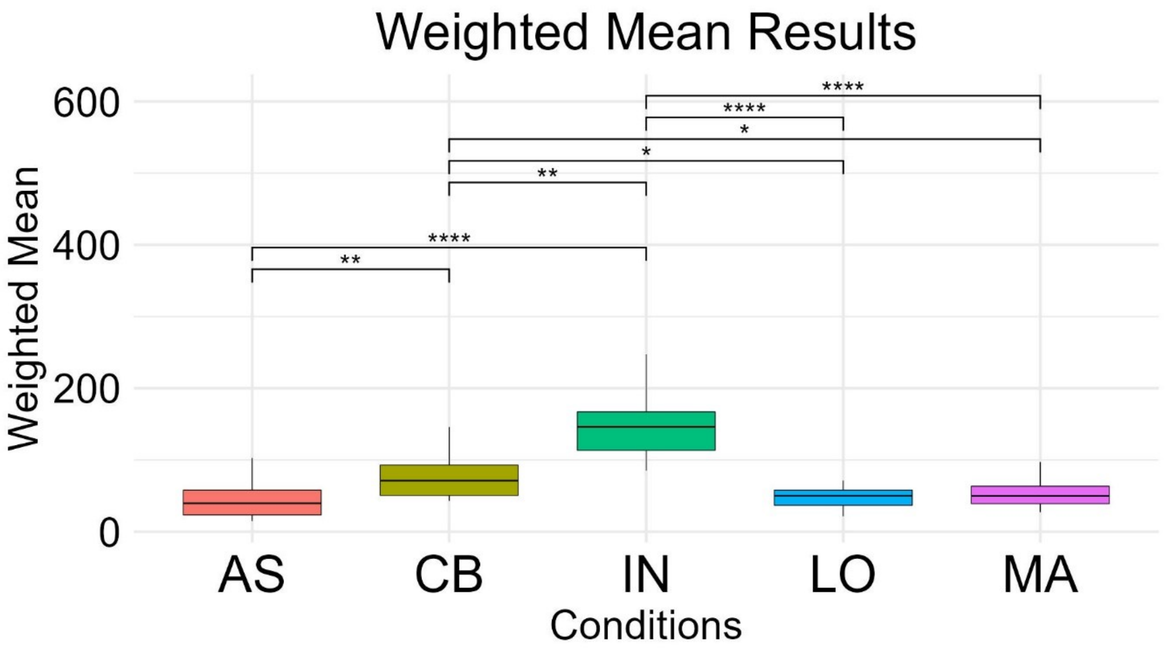


Figure 5.13. Results of the weighted mean which considered errors and times to evaluate the performance. The x-axis represents the task, the y-axis the calculate index values.

5.2.3.5 Eye-Tracking

5.2.3.5.1 Fixations Frequency

The frequency of fixations per minute was analyzed for each proposed task. The data for this analysis were not normally distributed. Therefore, the Friedman-Wilcoxon-BH method was used. There were no significant differences between the tasks. Results are shown in Figure 5.14.A.

5.2.3.5.2 Fixations Duration

The average fixation duration was analyzed for each proposed task. The data relating to this analysis were normally distributed. Therefore, the ANOVA-T.test-BH method was used. There were no significant differences between the tasks. Results are shown in Figure 5.14.B.

5.2.3.5.3 Blink Frequency

The frequency of blinks per minute was analyzed for each proposed task. The data for this analysis were not normally distributed. Therefore, the Friedman-Wilcoxon-BH method was used. There were no significant differences between the tasks. Results are shown in Figure 5.14.C.

5.2.3.5.4 Blink Duration

The average blink duration was analyzed for each proposed task. The data for this analysis were not normally distributed. Therefore, the Friedman-Wilcoxon-BH method was used. There were no significant differences between the tasks. Results are shown in Figure 5.14.D.

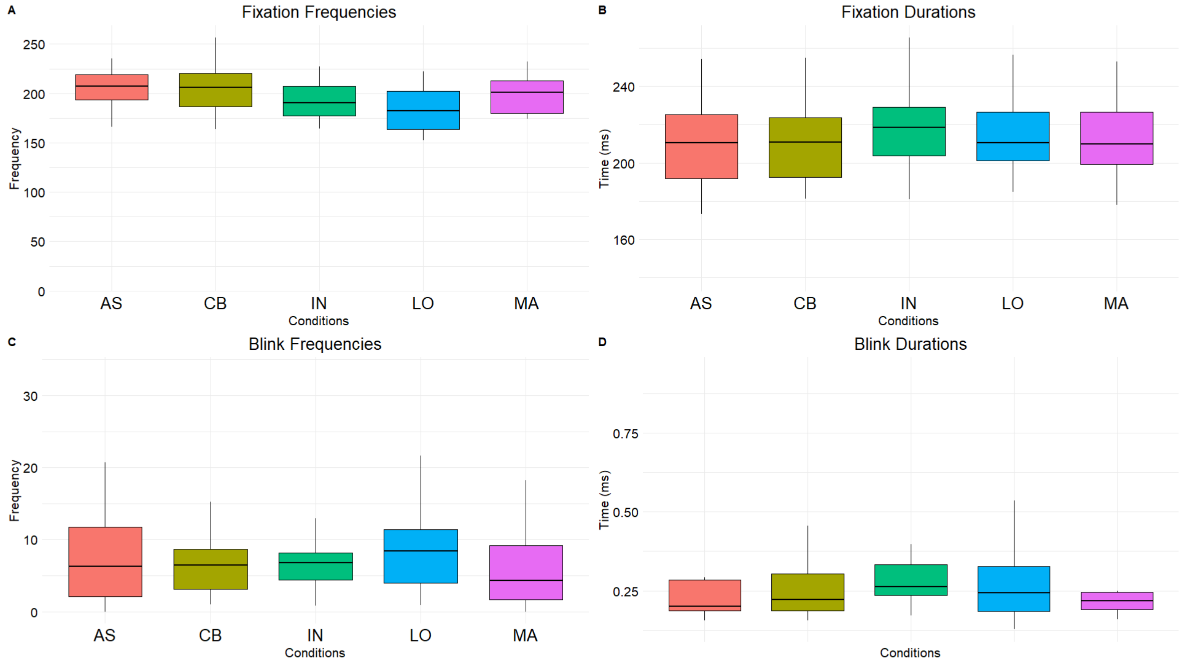


Figure 5.14. Results of the not significant analyses. The graphs presents the trends of Fixation Frequency (A), Fixation Duration (B), Blink Frequency (C), and Blink Duration (D).

5.2.3.5.5. Mean Pupil Diameter

The mean pupil diameter was analyzed for each proposed task. The data relating to this analysis were normally distributed. Therefore, the ANOVA-T.test-BH method was used. There were no significant differences between the tasks. The results are shown in Figure 5.15(a).

5.2.3.6. Heart Rate

The mean heart rate for each proposed task was analyzed. The data relating to this analysis were normally distributed. Therefore, the ANOVA-T.test-BH method was used. There were no significant differences between the tasks. The results are shown in Figure 5.15(b).

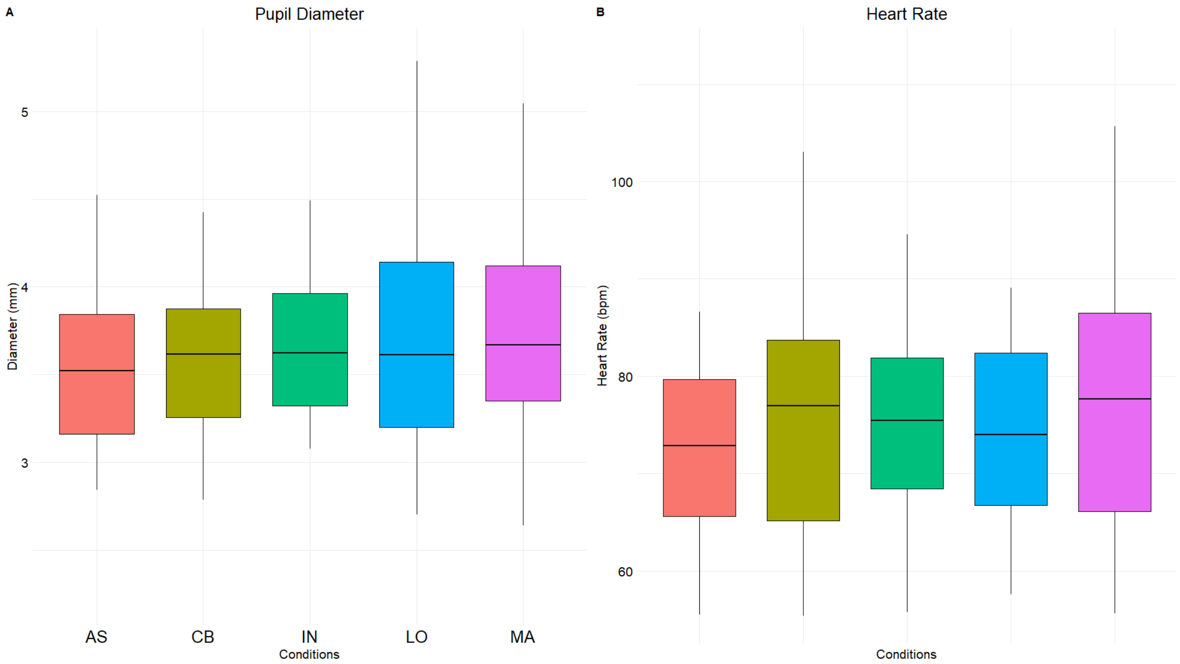


Figure 5.15. Results from the analysis of Pupil Diameter (A) and Heart Rate (b)

5.2.3.7 User Experience Questionnaires

The UX questionnaires created ad hoc for the individual tasks were analysed. Mann-Whitney tests were used, comparing the median result of the items with the median of the response scale (i.e., 4). The results were then corrected by the BH method.

5.2.3.7.1 Task Login (LO)

The items of the questionnaire relating to the LO task were all found to be significantly higher than the median of the scale and are shown in Figure 5.16. Q1 $p<0.001$; Q2 $p<0.001$; Q3 $p<0.001$; Q4 $p<0.001$; Q5 $p<0.001$; Q6 $p<0.001$; Q7 $p<0.001$; Q8 $p<0.001$; Q9 $p<0.001$; Q10 $p<0.001$.

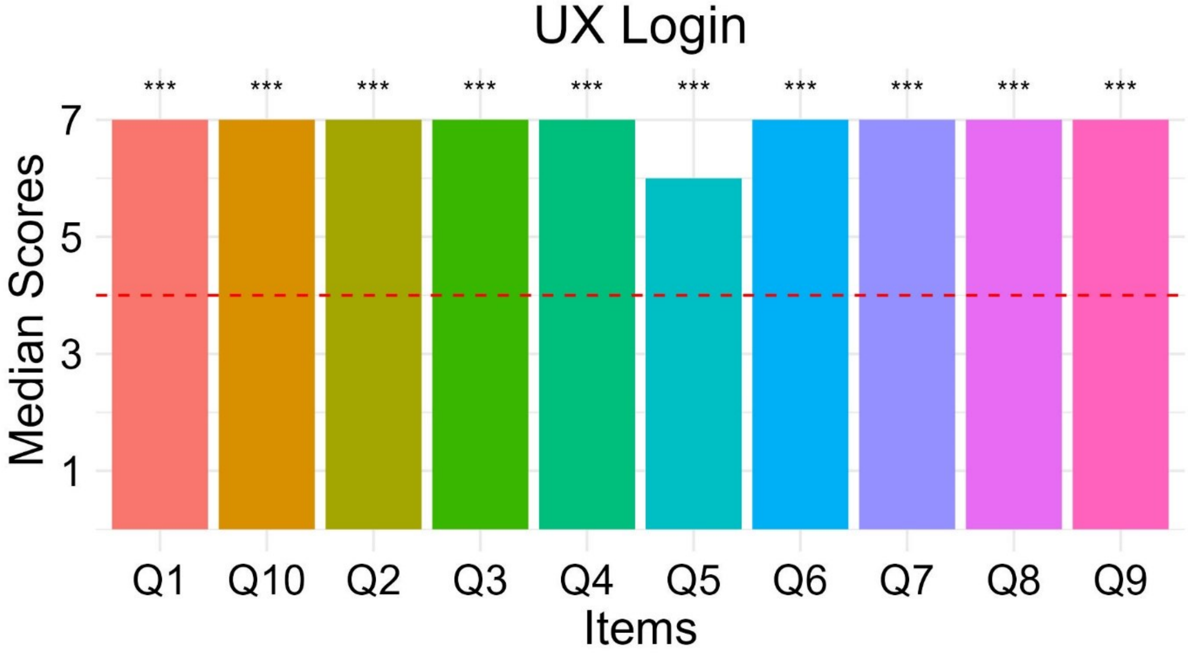


Figure 5.16. Results of the UX questionnaire related to the LO task. The x-axis represents the questionnaire items, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

5.2.3.7.2 Task Patient Information (IN)

The items of the questionnaire relating to the IN task were all significantly higher than the median of the scale and are shown in Figure 5.17. Q1 $p<0.001$; Q2 $p<0.001$; Q3 $p<0.001$; Q4 $p<0.05$; Q5

$p<0.001$; Q6 $p<0.001$; Q7 $p<0.001$; Q8 $p<0.001$; Q9 $p<0.001$; Q10 $p<0.001$; Q11 $p<0.001$; Q12 $p<0.001$; Q13 $p<0.001$; Q14 $p<0.001$.

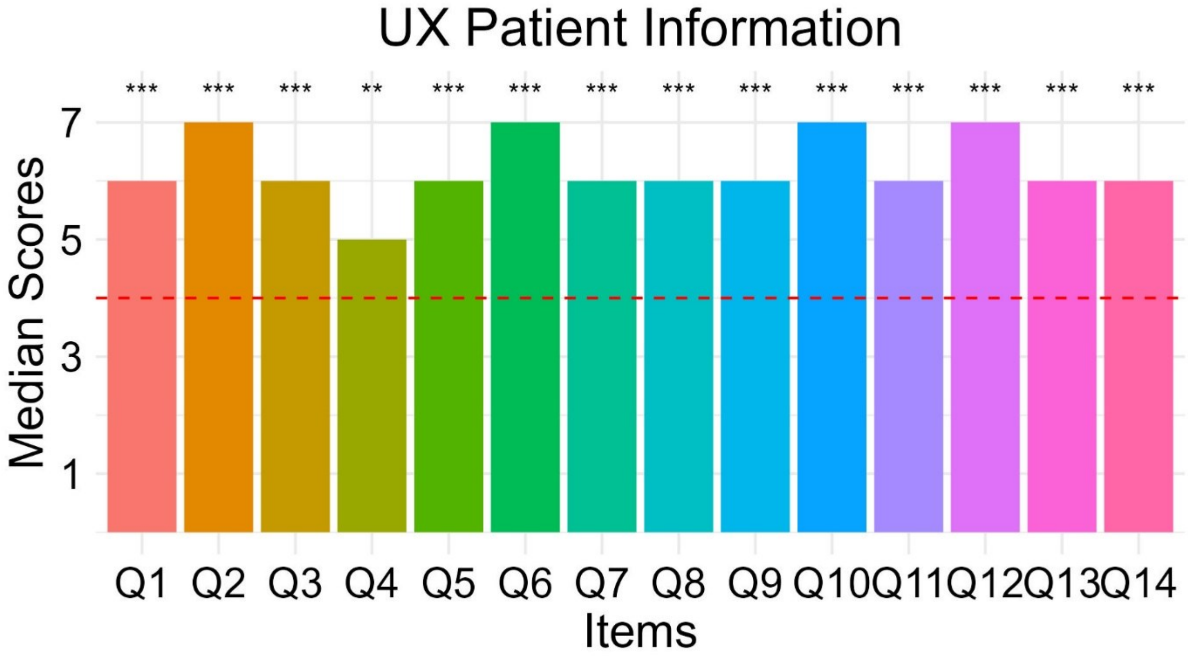


Figure 5.17. Results of the UX questionnaire related to the IN task. The x-axis represents the questionnaire items, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

5.2.3.7.3 Task Bed Change (CB)

The items of the questionnaire relating to the CB task were all found to be significantly higher than the median of the scale and are shown in Figure 5.18. Q1 p<0.001; Q2 p<0.05; Q3 p<0.001; Q4 p<0.001; Q5 p<0.001; Q6 p<0.001; Q7 p<0.001; Q8 p<0.001; Q9 p<0.001.

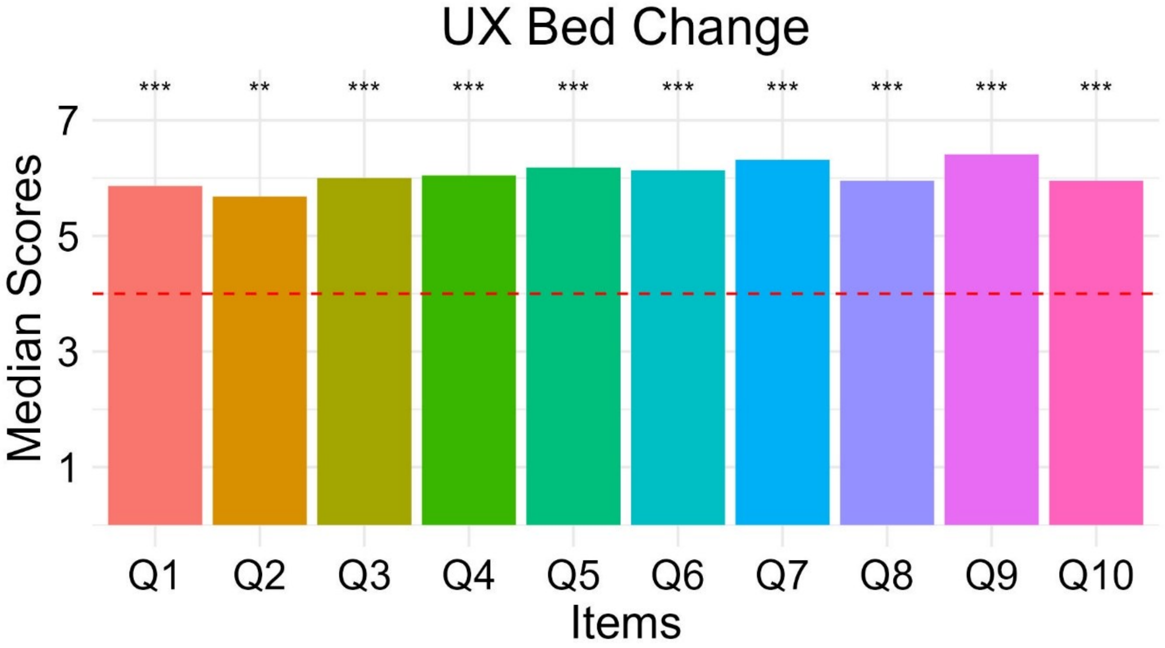


Figure 5.18. Results of the UX questionnaire related to the CL task. The x-axis represents the questionnaire items, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

5.2.3.7.4 Task Maintenance (MA)

The questionnaire items relating to the MA task were all significantly higher than the median of the scale and are shown in Figure 5.19. Q1 p<0.001; Q2 p<0.001; Q3 p<0.001; Q4 p.value<0.001; Q5 p<0.001; Q6 p<0.001; Q7 p<0.001.

5.2.3.7.5 Task Assignment (AS)

The items of the questionnaire relating to the AS task were all significantly higher than the median of the scale and are shown in Figure 5.20. Q1 p<0.001; Q2 p<0.001; Q3 p<0.001; Q4 p<0.001; Q5 p<0.001; Q6 p<0.001; Q7 p<0.001; Q8 p<0.001.

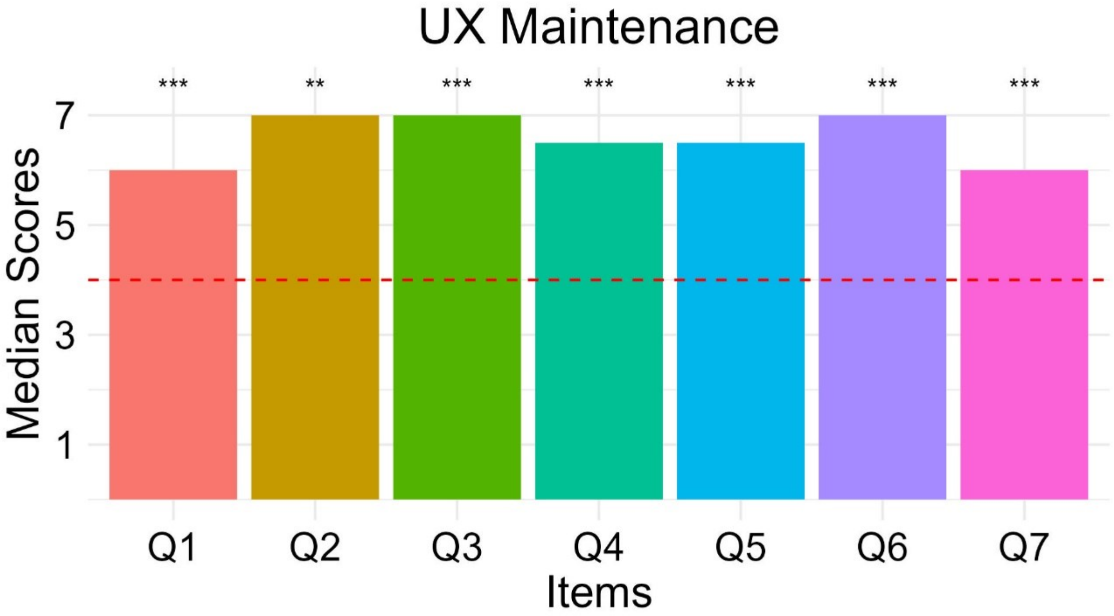


Figure 5.19. Results of the UX questionnaire related to the MA task. The x-axis represents the questionnaire items, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

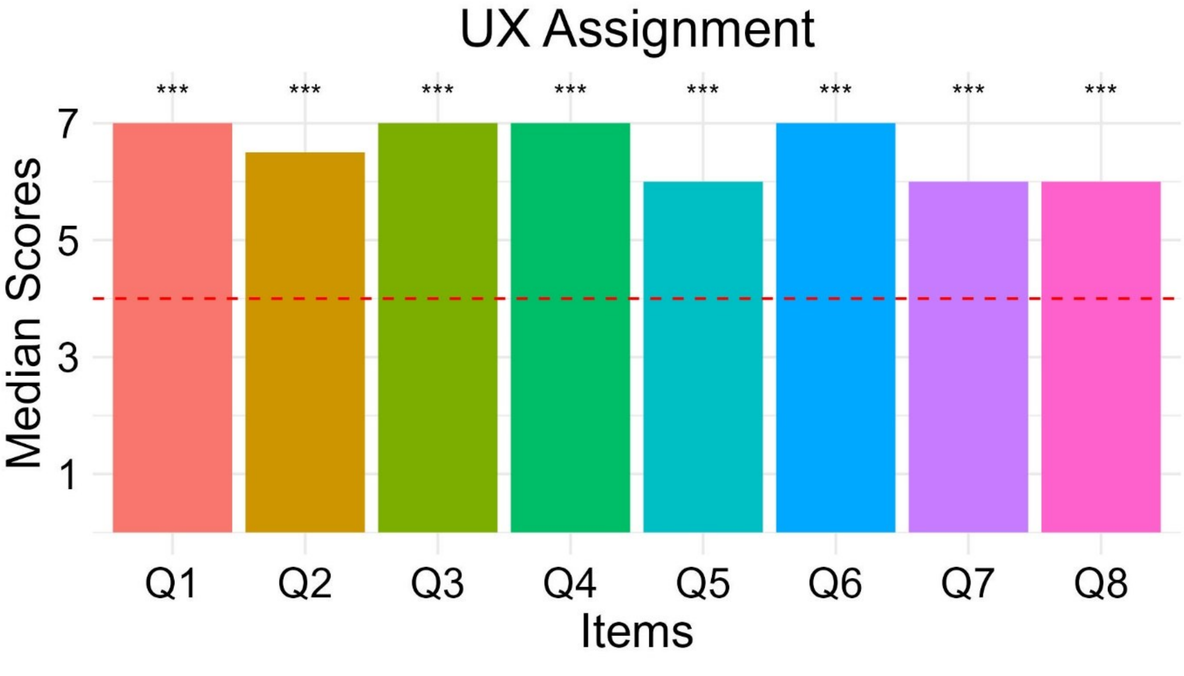


Figure 5.20. Results of the UX questionnaire related to the AS task. The x-axis represents the questionnaire items, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

5.2.3.8 General User Experience

The UX questionnaire created ad hoc for the evaluation of the user experience linked to the interface was analysed. Mann-Whitney tests were used to compare the median size result with the median response scale (i.e., 4). The results were then corrected by the BH method. The results are shown in Figure 5.21. All dimensions analyzed present median results significantly higher than the median of the scale. Aes p<0.001; Att p<0.001; Dep p<0.001; Eff p<0.001; Nov p<0.001; Per p<0.001; QuC p<0.001; Sti p<0.001; TrC p<0.001; Tru p<0.001; Use p<0.001.

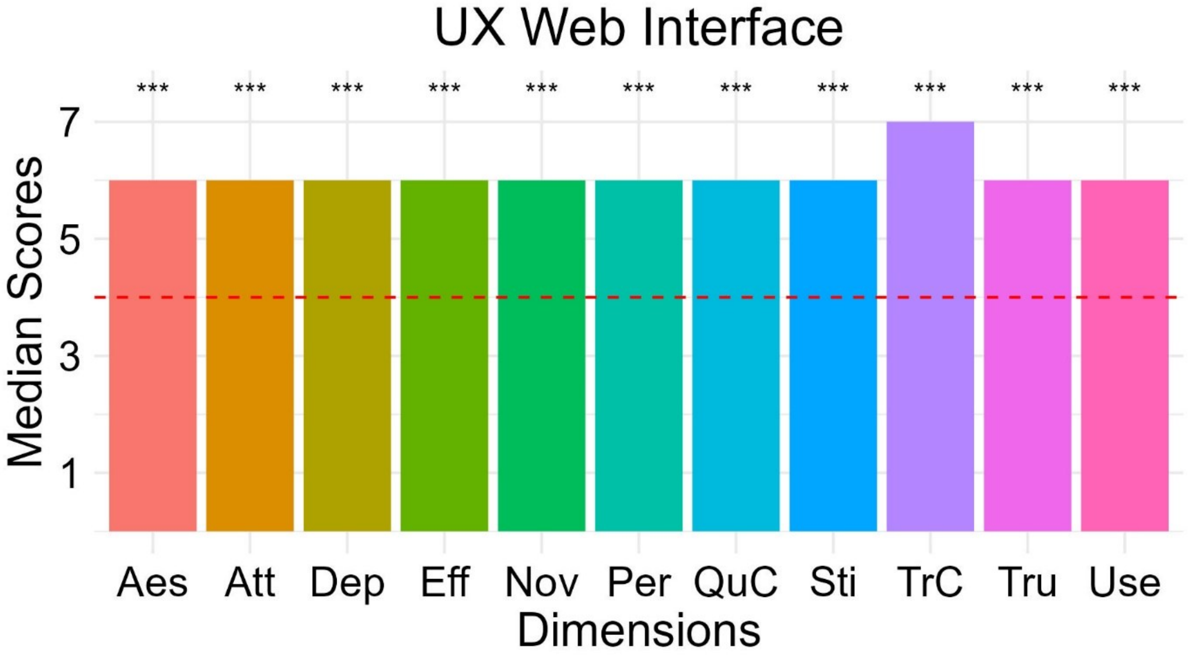


Figure 5.21. Results of the UX questionnaire related to user experience with the interface. The x-axis represents the size of the questionnaire, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

5.2.3.9 Technology Acceptance Questionnaire

The Acceptance questionnaire adapted to the experiment was analyzed for the evaluation of the acceptance of the proposed technology. Mann-Whitney tests were used comparing the median size result with the median response scale (i.e., 3). The results were then corrected by the BH method.

The results are shown in Figure 5.22. The dimensions which results significantly higher than the median of the scale were IQ ($p<0.001$), IU ($p<0.001$), PEOU ($p<0.001$), and PU ($p<0.001$).

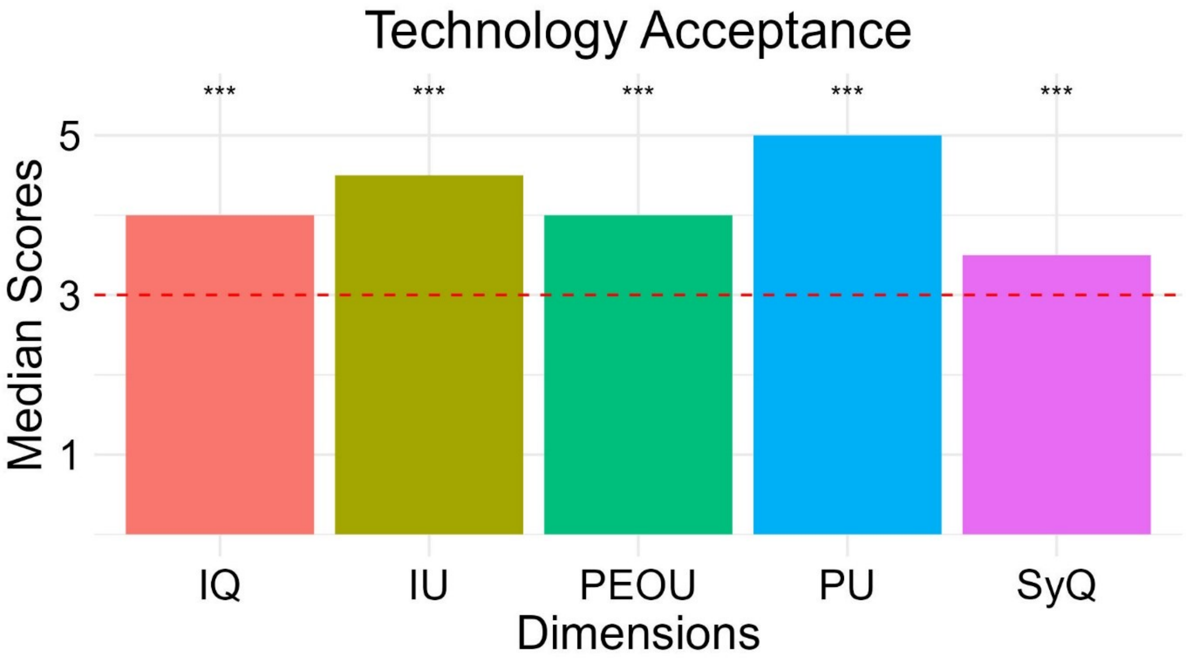


Figure 5.22. Results of the Acceptance questionnaire related to the user experience with the interface. The x-axis represents the size of the questionnaire, the y-axis the median scores assigned by the participants. The red dotted line represents the median of the scale.

5.2.3.10 Usability Checklist

The usability checklist proposed to the participants after using the interface was analysed. The analysis converted the responses by encoding those that respected the usability principle as positive responses. The hit rate for the size of the tool was then calculated. The results are shown in Figure 5.23. All the dimensions analyzed obtained largely positive scores (>85%), except for the Help dimension (0%).

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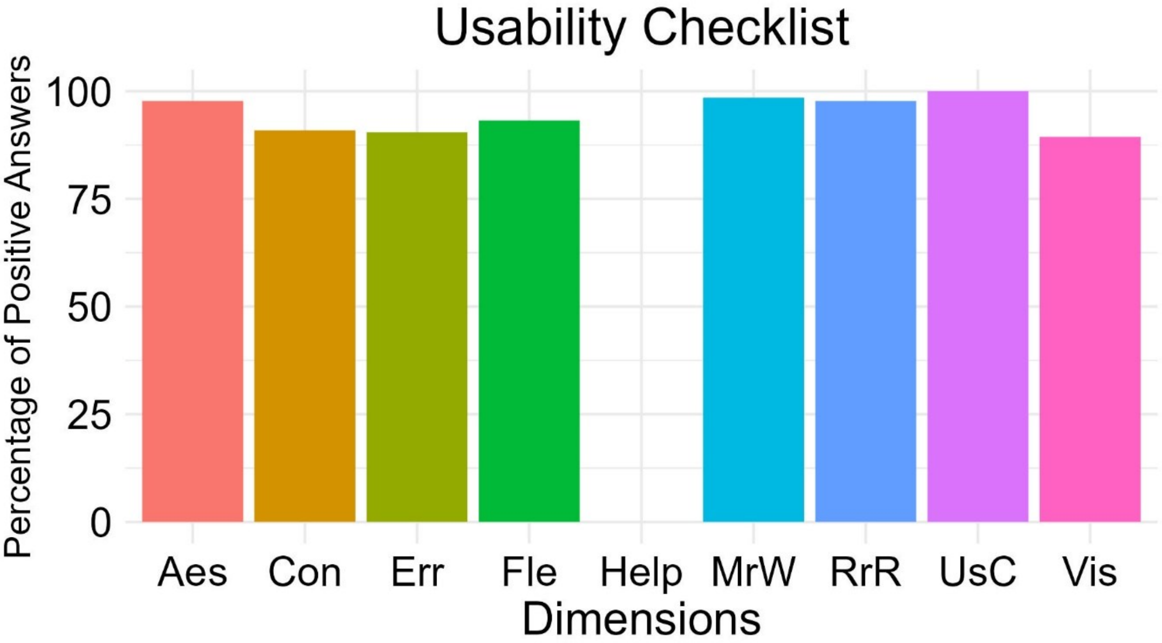


Figure 5.23. Percentage results of positive responses to the dimensions of the usability checklist. The x-axis represents the size of the questionnaire, the y-axis the percentage of positive responses and in line with the heuristics.

The checklist also collected some comments from the participants, which were useful for the usability analysis.
The significant comments are listed:

- Question: Does the application ask for confirmation when you are about to save an action that requires several steps to be completed (e.g. entering a patient in the system)?
Comment P13: "Yes, but not for all functions (E.g. bed maintenance)

- Question: Are messages displayed long enough to be red?
Comment P08: "I have not seen them"

- Question: Are the pages easy to navigate?
Comment P11: "Lots of information but relatively easy to read"
Comment P13: "Navigation path not interactable."
Comment P14: "In some cases a search function could be useful (patient room); maybe I didn't see it"

- Question: Is the information presented clearly?
Comment P16: "Basically yes, but for example patient IDs should be listed in alphabetical order to make searching more efficient. As they are now they are unclear"

- Question: Are the icons commonly used and recognizable?
Comment P14: "In general yes, the icons are not immediately recognizable at the first interaction but the presence of the legend solves the problem"

- Question: Is it clear which interface elements can be interacted with?
Comment P12: "On the home page, for each room there is a blue icon with a pencil with which it is impossible to interact"

- Question: Does the application effectively represent a hospital environment?
Comment P07: "I would arrange the rooms according to how they are arranged in the structure and according to the floors"
Comment P08: "I would create a color code per room category"

- Question: Could the system be applied to different hospital environments? (hospitals, RSA)
Comment P09: "Yes, perhaps more useful in an inpatient ward than in a critical area".

5.2.3.11 *Video-analysis*

Video analysis was carried out to investigate the mistakes made by the participants during the performance of the tasks. I counted the successes or failures of the individual sub-tasks present within the tasks. The results of this analysis are presented in Figure 5.24.

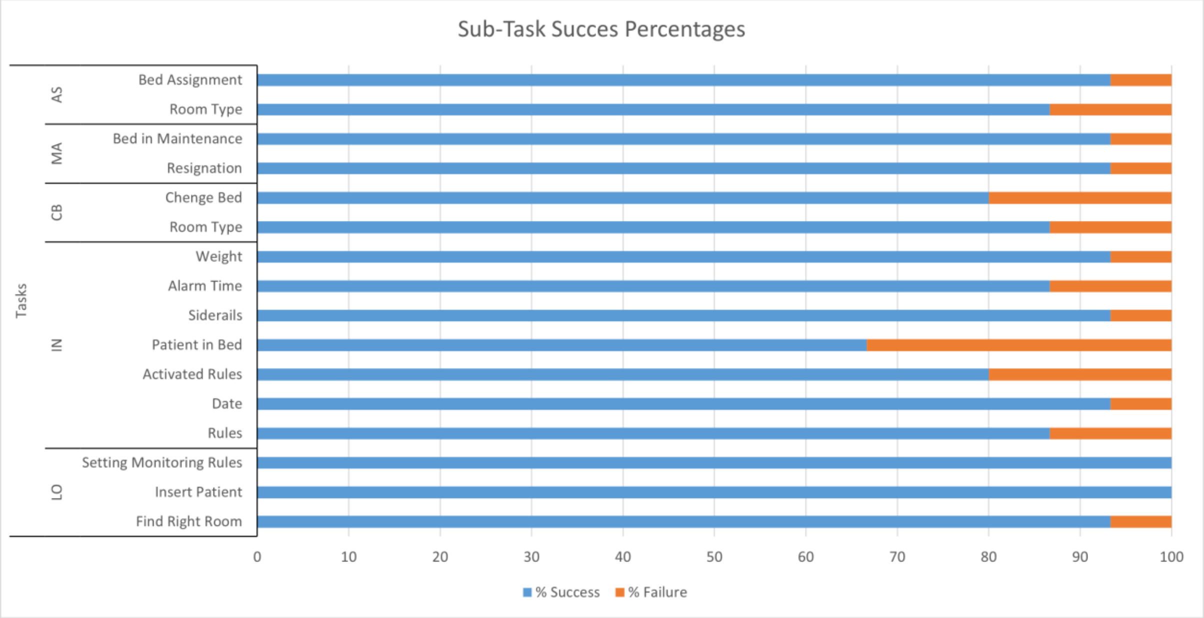


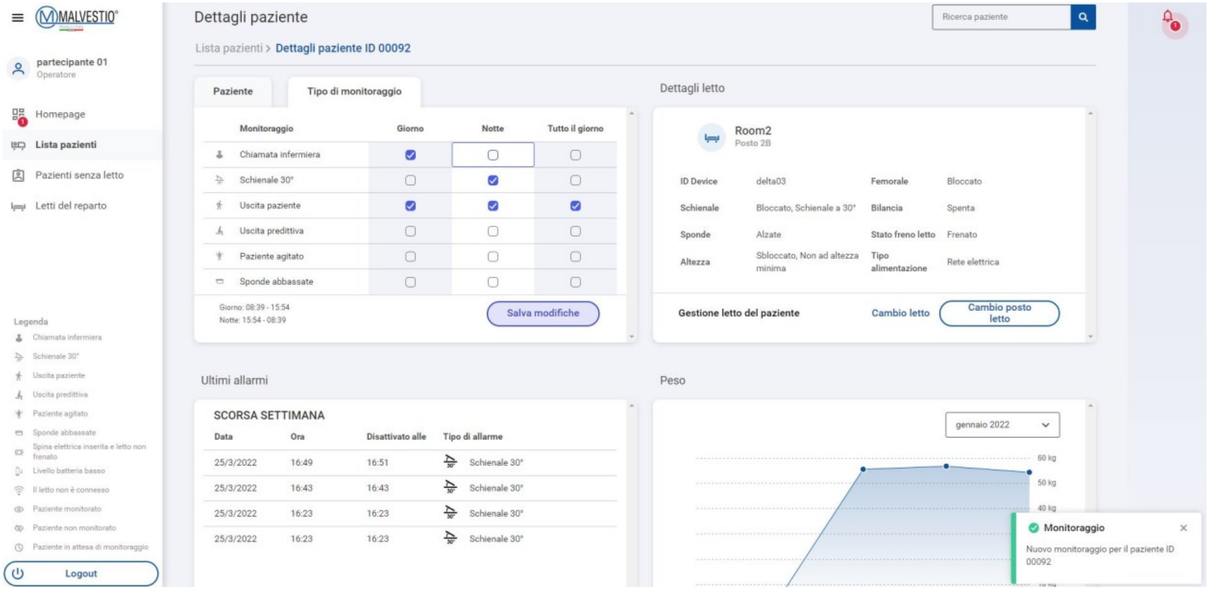
Figure 5.24. Success rates of the sub-tasks of the proposed tasks. The x axis represents the percentage of correct (blue) and incorrect (orange) answers, the y axis shows the division into tasks and sub-tasks of the experiment.

5.2.3.11.1 *Negative Behaviour*

The visualization of the registered sessions permitted the identification of some frequent behaviours of the participants. They were subdivided into negative and positive behaviours. For each of them, I provided the frequency of occurrence.

During the LO task, the participants interacted with the interface more times than necessary to set a rule for monitoring during the 24h (6 occurrences).

During all the tasks, participants had to check that they had carried out the assigned task, not recognizing the feedback (a pop-up, Image 1), which signals the change (8 occurrences).



Dettagli paziente

Lista pazienti > Dettagli paziente ID 00092

Monitoraggio	Giorno	Notte	Tutto il giorno
Chiamata infermiera	☑	☐	☐
Schienale 30°	☐	☑	☐
Uscita paziente	☑	☑	☑
Uscita predittiva	☐	☐	☐
Paziente agitato	☐	☐	☐
Sponde abbassate	☐	☐	☐

Giorno: 08:39 - 15:54
Notte: 15:54 - 08:39

Dettagli letto

Room2
Posto 2B

ID Device	delta03	Femorale	Bloccato
Schienale	Bloccato, Schienale a 30°	Bilancia	Spenta
Sponde	Alzate	Stato freno letto	Frenato
Altezza	Sbloccato, Non ad altezza minima	Tipo alimentazione	Rete elettrica

Gestione letto del paziente

Ultimi allarmi

SCORSA SETTIMANA

Data	Ora	Disattivato alle	Tipo di allarme
25/3/2022	16:49	16:51	Schienale 30°
25/3/2022	16:43	16:43	Schienale 30°
25/3/2022	16:23	16:23	Schienale 30°
25/3/2022	16:23	16:23	Schienale 30°

Peso

Monitoraggio

Nuovo monitoraggio per il paziente ID 00092

Image 1. Pop up feedback for the successful saving of a modification, in the example a time change for the rules.

Some participants avoided using the filters (Image 2) to select the type of room desired, in this case, for the gender (6 occurrences).

Assegnare una stanza

Image 2. Filters for the type of room.

Some participants had difficulty finding the tab for modifying the monitored rules for the patient (Image 3, 6 occurrences).

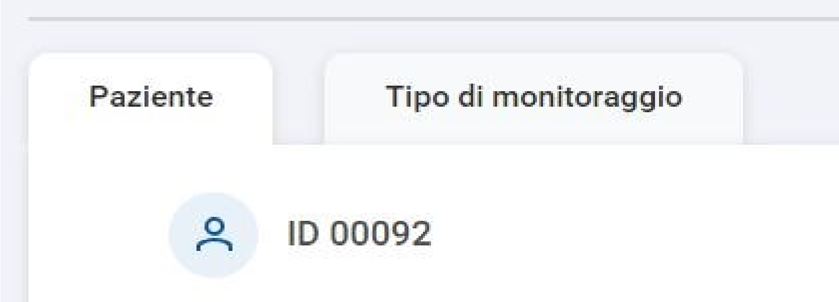
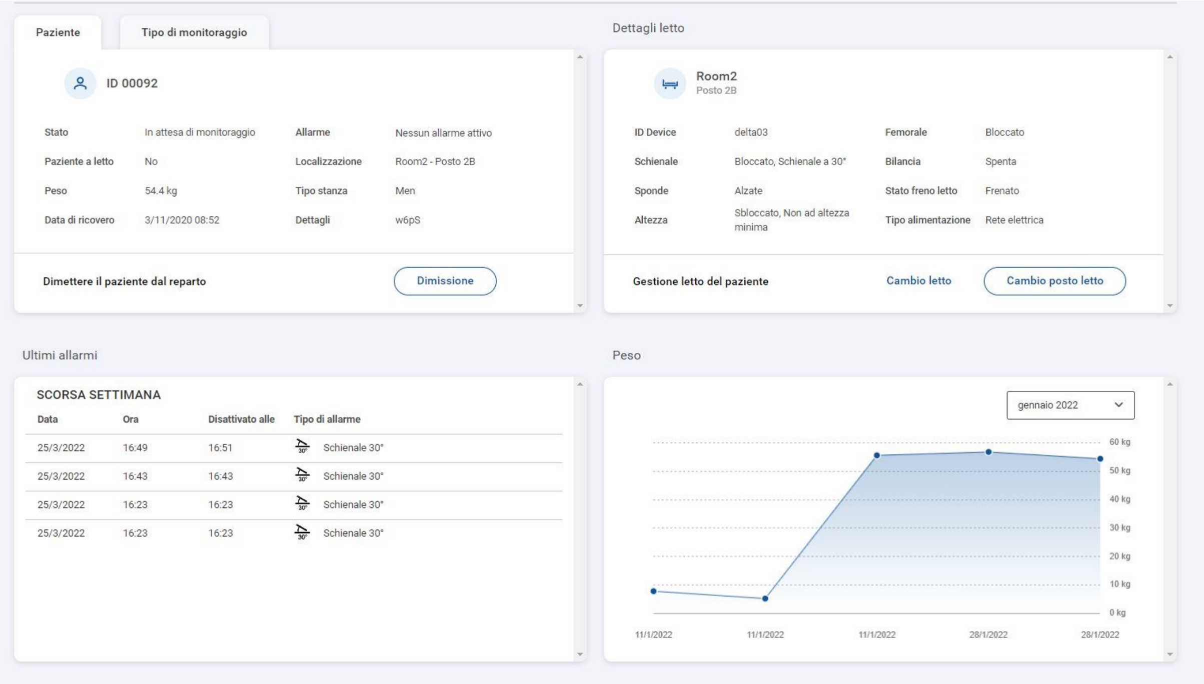


Image 3. Button for entering the monitoring rules ("Monitoring type").

Some participants struggled to find all the patient details required by the IN task, present in the patient details page (Image 4, 4 occurrences).



ID 00092

Stato	In attesa di monitoraggio	Allarme	Nessun allarme attivo
Paziente a letto	No	Localizzazione	Room2 - Posto 2B
Peso	54.4 kg	Tipo stanza	Men
Data di ricovero	3/11/2020 08:52	Dettagli	w6pS

Dimettere il paziente dal reparto

Room2
Posto 2B

ID Device	delta03	Femorale	Bloccato
Schienale	Bloccato, Schienale a 30°	Bilancia	Spenta
Sponde	Alzate	Stato freno letto	Frenato
Altezza	Sbloccato, Non ad altezza minima	Tipo alimentazione	Rete elettrica

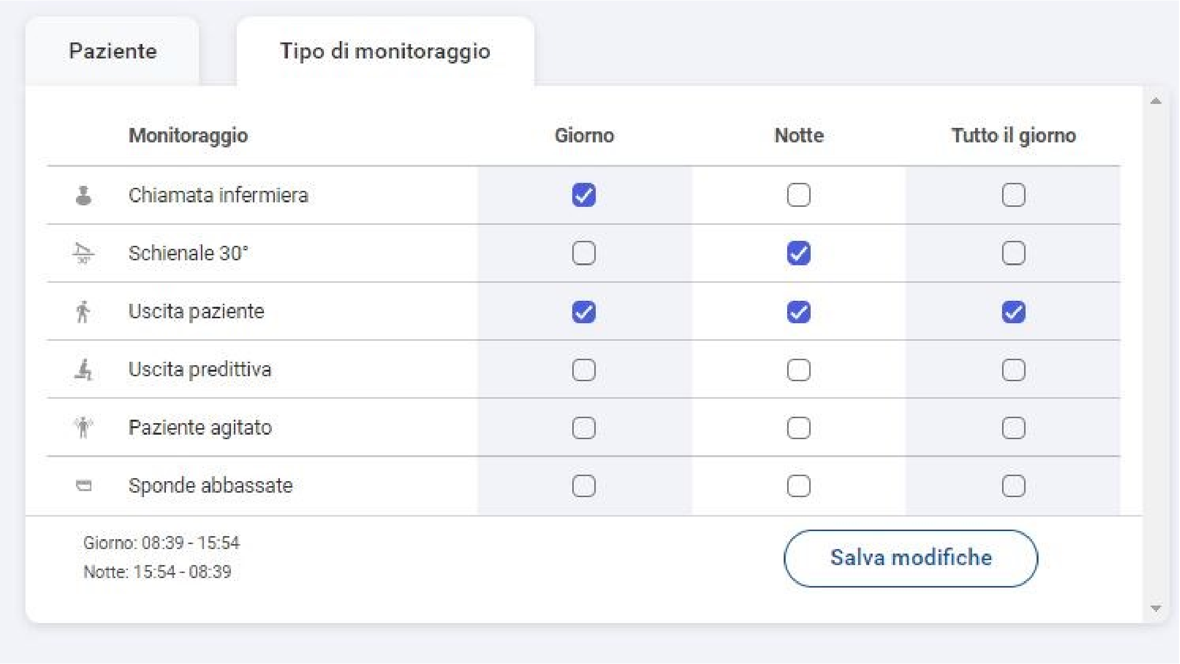
Gestione letto del paziente

SCORSA SETTIMANA

Data	Ora	Disattivato alle	Tipo di allarme
25/3/2022	16:49	16:51	Schienale 30°
25/3/2022	16:43	16:43	Schienale 30°
25/3/2022	16:23	16:23	Schienale 30°
25/3/2022	16:23	16:23	Schienale 30°

Image 4. Page describing patients' details

Some participants (2 occurrences) did not save the rules after having set them, using the appropriate "Save changes" button (Image 5).



Monitoraggio	Giorno	Notte	Tutto il giorno
Chiamata infermiera	☑	☐	☐
Schienale 30°	☐	☑	☐
Uscita paziente	☑	☑	☑
Uscita predittiva	☐	☐	☐
Paziente agitato	☐	☐	☐
Sponde abbassate	☐	☐	☐

Giorno: 08:39 - 15:54
Notte: 15:54 - 08:39

Image 5. Button to save the changes to the monitoring rules set.

Some participants (9 occurrences), while performing an assignment of a patient in a specific gender room, had to go back to recheck the gender.
Some participants (4 occurrences) had difficulty deciding which button to use to change the patient bed (Image 6).

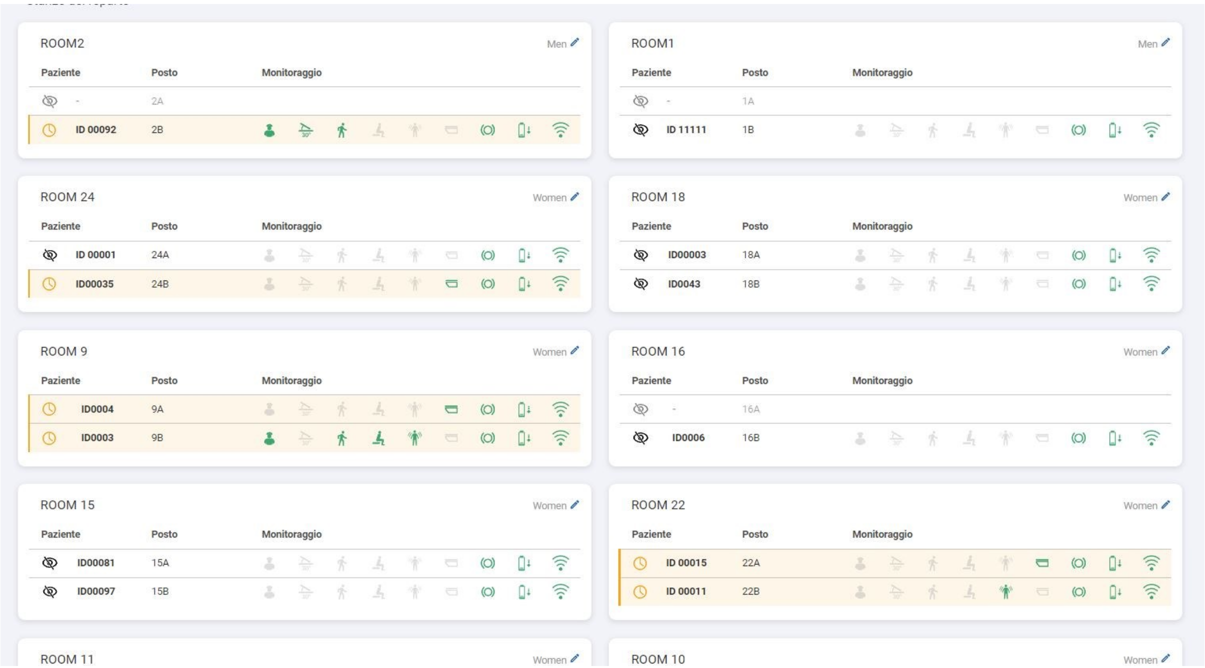
Image 6. Bed Change and Bed Change Labels. The first disassociates the patient from the bed by sending him to the list of patients without a bed, the second instead changes the patient's room and place, transferring the associated bed with him.

A participant tried to use the navigation path to return to a previous page (Image 7).

Lista pazienti > Dettagli paziente ID 00092

Image 7. Work path.

Some participants (5 occurrences) had difficulty searching for a specific room in the home page list (Image 8).



ROOM2 Men

Paziente	Posto	Monitoraggio
-	2A	
ID 00092	2B	

ROOM1 Men

Paziente	Posto	Monitoraggio
-	1A	
ID 11111	1B	

ROOM 24 Women

Paziente	Posto	Monitoraggio
ID 00001	24A	
ID00035	24B	

ROOM 18 Women

Paziente	Posto	Monitoraggio
ID00003	18A	
ID0043	18B	

ROOM 9 Women

Paziente	Posto	Monitoraggio
ID0004	9A	
ID0003	9B	

ROOM 16 Women

Paziente	Posto	Monitoraggio
-	16A	
ID0006	16B	

ROOM 15 Women

Paziente	Posto	Monitoraggio
ID00081	15A	
ID00097	15B	

ROOM 22 Women

Paziente	Posto	Monitoraggio
ID 00015	22A	
ID 00011	22B	

ROOM 11 Women

ROOM 10 Women

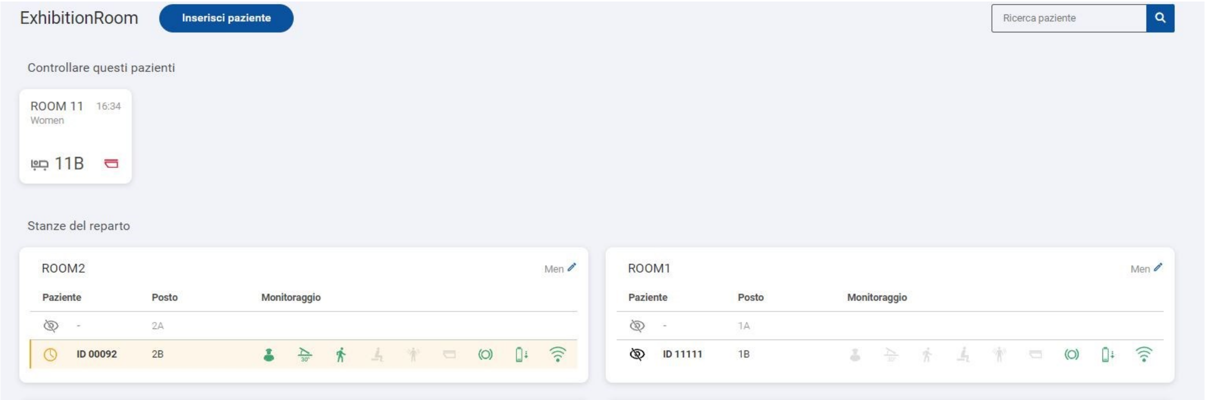
Image 8. Homepage within which the participants had to search for the specific room.

Some participants (4 occurrences) tried to find the bedless patient required by the AS task within the patient list and not within the bedless patient list.

5.2.3.11.2 Positive Behaviour

Some participants noticed the pop-ups that appeared following a user action that changed the system (e.g., Image 1).

Some users (5 occurrences) successfully used the search bar to search for a specific patient ID (Image 9).



Controllare questi pazienti

ROOM 11 16:34
Women
11B

Stanze del reparto

ROOM2 Men

Paziente	Posto	Monitoraggio
-	2A	
ID 00092	2B	

ROOM1 Men

Paziente	Posto	Monitoraggio
-	1A	
ID 11111	1B	

Image 9. Patient ID search bar located at the top right of the interface homepage.

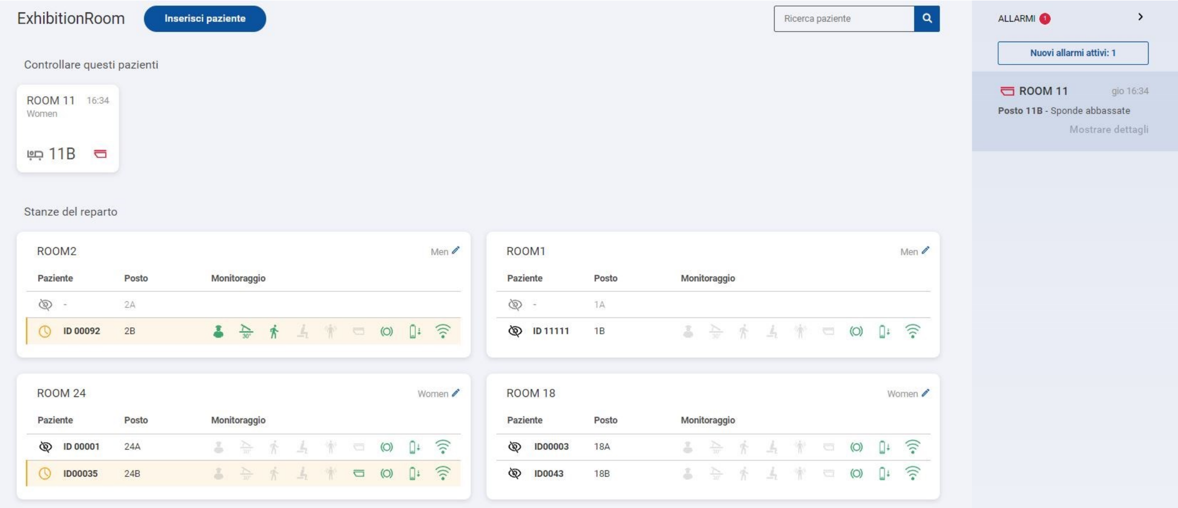
Some participants (4 occurrences) found the active monitoring rules during AL task from the homepage instead of the patient details tab (Image 10).

ROOM1 Men

Paziente	Posto	Monitoraggio
-	1A	
ID 11111	1B	

Image 10. Screenshot of the homepage showing the active rules icons for the patient.

Some participants (5 occurrences) during the CB task used the shortcut represented by the alarm bell placed at the top right of the interface (Image 11).



ROOM 11 gio 16:34
Posto 11B - Sponde abbassate
Mostrare dettagli

Controllare questi pazienti

ROOM 11 16:34
Women
11B

Stanze del reparto

ROOM2 Men

Paziente	Posto	Monitoraggio
-	2A	
ID 00092	2B	

ROOM1 Men

Paziente	Posto	Monitoraggio
-	1A	
ID 11111	1B	

ROOM 24 Women

Paziente	Posto	Monitoraggio
ID 00001	24A	
ID00035	24B	

ROOM 18 Women

Paziente	Posto	Monitoraggio
ID00003	18A	
ID0043	18B	

Image 11. Screen showing the active alarms in the upper right corner.

5.2.3.12 *Icons' Test*

Finally, participants faced the icon recognition test (Image 12). The test then analyzed the percentages of correct answers, which results are shown in Figure 5.25.

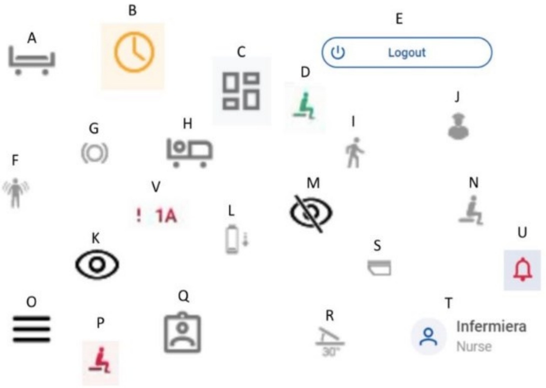


Image 12. Icons and related letters presented to the participants.

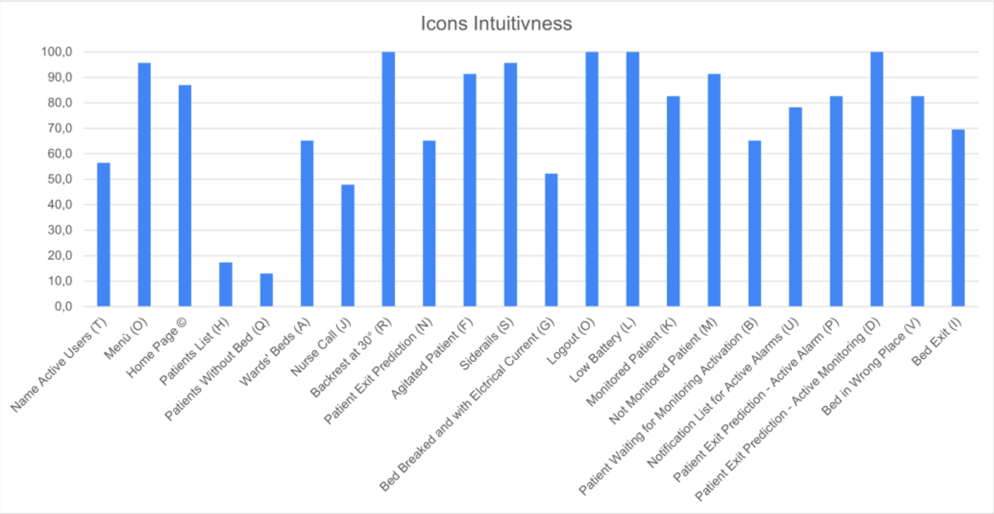


Figure 5.25. Percentage of correct answers to the icon association test with their respective labels. The x-axis represents the labels of the analyzed icons, the y-axis the percentage of correct answers from the participants.

5.2.4 Discussion

The present study analysed users' interaction with the web control interface of the smart bed system. Participants faced five tasks designed to explore the interfaces' possibilities in their entirety. The qualitative and quantitative tools used have therefore investigated the cognitive load connected to each of the proposed tasks and some essential constructs related to the use of the system.

As regards the cognitive load, the first tool utilized was the NASA-TLX, a questionnaire capable of detecting the difficulty in carrying out the task. The results showed that all the proposed tasks were considered simple (median results below 30). This result indicates that the interface was easy to use and that even the most difficult tasks, IN and CB, were considered manageable. The only statistically significant differences showed a greater cognitive load of the IN and CB tasks compared to the LO task, considered by the participants to be the simplest. For IN, this result highlights its greater complexity. This task required searching for a series of patient information and navigating through different schedules and data to identify the right ones. Regarding the CB task, the greater difficulty could be due to a lack of clarity of the labels used for some interface buttons, which are necessary for the correct accomplishment of the task. From the analysis of the video recordings (Par. 5.2.3.11), it emerged that the "Change bed" and "Change bed place" buttons, being very similar, created confusion in some of the participants (See Image 9). Furthermore, the time-on-task analysis highlighted that IN and CB were the most complex tasks since their longer accomplishment times. The error analysis partially supports this last result, confirming that the IN task (higher errors and time-on-task) was the most difficult to carry out. In contrast, the remaining four tasks were statistically indistinguishable. Indeed, these two analyses, taken as a whole in the weighted mean analysis, indicate that IN was objectively the most difficult task, followed by CB.

In addition to the subjective perception of cognitive load and the objective perception of performance, a psychophysiological and behavioural analysis was conducted to verify whether some tasks were objectively more cognitively overloading. The analyses, which included the frequency of fixations and blinks per minute, the mean duration of fixations, the mean pupil diameter and the mean heart rate, showed no differences between the tasks. These missing results contrast with the NASA-TLX scores, which show differences between the perceived cognitive demands of the tasks. HR, pupillometry and the frequency and duration of blinks are all well-known indices of cognitive load (Charles & Nixon, 2019; Galy et al., 2012), while fixations are entabilished indexes of attention (Duchowski, 2017). However, as indicated in the study aim, I aimed to verify the possibility of using such cognitive load objective measures in applied and ecological studies. Since they could not highlight any differences between tasks, I can conclude that such indexes could not be reliably used in this situation. The probable causes of such results could be the very short time of the tasks and the variations of luminosity between the interface's pages. In the first case, the vast majority of studies on cognitive load imply very controlled conditions with fixed time limits, usually from two to five minutes (Duchowski et al., 2020, Mingardi et al., 2020). In this case, four out of five tasks require slightly more than one minute to be accomplished. It is reasonable to say that the measures utilized in this study could not significantly variate in this short amount of time. Moreover, pupillary measures are sensible to luminosity changes. The different pages displayed on the screen during this experiment could have introduced a lot of noise, reducing the reliability of the pupil diameter measure (Duchowski et al., 2018). Another possible explanation could be that none of the tasks requires participants to use additional resources compared to the others. Therefore, the participants experienced the same low levels of cognitive load for all tasks, as evidenced by the overall NASA-TLX median scores below 30 points. The behavioural indexes of fixation duration highlighted the same result. This analysis could indicate that the interface constantly poses low-workload challenges in completing the tasks. Since the NASA-TLX shows low mental workload levels, it could be argued that the interface demanded low cognitive effort in performing every possible task, and that the cognitive load indexes are not sensible enough to show such small differences. In both cases, more research is needed to find innovative ways to objectively measure cognitive load.

As regards the user experience linked to the tasks, all the questionnaires proposed showed particularly high values for all the questions proposed, a symptom that the pre-test interface

Stato	Monitorato	Allarme	Nessun allarme attivo
Paziente a letto	No	Localizzazione	Room2 - Posto 2B
Peso	54.4 kg	Tipo stanza	Men
Data di ricovero	3/11/2020 08:52	Dettagli	w6pS

Image 13. Detail of the patient details page.

design minimized the possible problems. The only value that resulted slightly above the scale median was item Q4 for the IN task, with a median value of 5 (i.e., slightly in agreement). The item asked about the simplicity of searching for the patient's information, a problem detected by the success rates of the relative sub-tasks (Figure 5.24), which obtained only a 67% of success rate. The participants struggle to find information about the patient's presence in the bed, resulting in the worst success rate result. Considering the details screen (Image 13), it could be suggested to make the labels indicating the type of information more evident, perhaps using a slightly larger font and highlighting it in a darker bold.

As regards the general evaluation of the experience, the User Experience questionnaire also shows high median values, especially in the quality of the data provided, indicating that the participants found them reliable, useful and accurate. The lowest score (Median=5) was obtained by the dimension of attractiveness (i.e., pleasant, fun, friendly). This result indicates that the participants rated the experience as friendly but, since its nature of a work-related system, did not rate it as fun or pleasant.

The questionnaire connected to Technology Acceptance also gave encouraging results, with all values well above the median, especially as regards the Intention of Use and Perceived Usefulness. These results indicate the system's readiness to be introduced into the healthcare environment.

The usability checklist shows, once again, excellent results, except for the Help dimension, which asked if the interface had a help function if the user requested it. As there is none, this lack has been detected by the instrument. It would therefore be preferable to insert a guide for

Legenda
- Chiamata infermiera
- Schienale 30°
- Uscita paziente
- Uscita predittiva
- Paziente agitato
- Sponde abbassate
- Spina elettrica inserita e letto non frenato
- Livello batteria basso
- Il letto non è connesso
- Paziente monitorato
- Paziente non monitorato
- Paziente in attesa di monitoraggio

Image 14. Available legend with the description of the icons present in the interface

users to help them understand how to carry out a procedure. However, interpreting the interface can be facilitated by the icons legend located in the lower-left corner of the screen (Image 14). This aspect was mentioned by a user in a comment on the checklist (P14:" In general, yes, the side rails icon is not immediately recognizable on the first interaction, but the presence of the legend solves the problem").
Some comments that emerged from the checklist appear particularly interesting. Users have suggested the presence of confirmation for bed maintenance requests, an interactive navigation path (similar to windows navigation pathway), sorting the patient list in alphabetical order to facilitate searches, to make an unused icon interactable, which calls for modification (Image 15, blue pencil on the right), to arrange the rooms according to the facility, and to create a colour code for the room categories.

Image 15. Symbol of a blue pencil that suggest an interactive button but does not allow it.

The video analysis highlighted a generally good completion rate of the tasks, as almost all sub-tasks obtained a minimum of 80% of success rate. Anyway, it identifies some usability problems. The most common problem was ensuring that the system had accepted the users' commands. The confirmation pop-up (Image 1) did not appear very evident. It is, therefore, advisable to increase its extension to avoid users having to check that they have performed any procedures. A little evident interaction problem regards the room type filter, which in many cases was not used, with the consequence of creating potential mixed-gender rooms. It is therefore recommended to make these buttons more noticeable. The same is true for the patient's rules page, which was difficult for the participants to find (Image 5). Some participants, even if few (2 occurrences), set the rules correctly but avoided saving them, a potentially dangerous mistake in a hospital. It is advisable to warn the user that he is changing the page without saving the modified settings, thus preventing any errors. On the other hand, one of the most common problems was controlling the type of room. The bed change and assignment procedures allow the patient to be repositioned in another room. However, the screen allowing them does not indicate the room from which the patient is about to be moved information. This generated numerous interaction slowdowns because of the rechecks. Adding this information directly within the procedure will allow faster interaction. Among the positive aspects, some functions that could play the role of shortcuts, such as the patient search bar and the notification icon, were correctly utilized by some participants. Furthermore, some participants effectively checked the active rules for the patient of the IN task from the homepage. These results show that the interface presents alternative ways to speed up the interaction for expert users.

Finally, a test on the intuitiveness of the icons was carried out. It highlighted how the most problematic are the patient list icons (H in Image 12) and patients without a bed (A in Image 12). However, thanks to their labels, these icons were not confused during the interface tasks.

Instead, the questionnaire extracted them from the context, making them more challenging to recognize. Given this, the problem could become evident in the case of operators unable to read Italian. Modifying them will make their readability higher. The least intuitive icon after these is that of the bed braked and connected to the current (G in Image 12). It recalls the brake symbol of a car but did not appear intuitive to the participants and should be modified since its importance for safety issues. Other icons do not exceed 50% of correct answers, namely the username, ward beds panel and nurse call. Regarding the first one, some confusion may arise from the name displayed on the test (the word "nurse" in Italian). They would probably recognise it better if a specific name (e.g., Mario/Lucia) was presented. The wards' bed icon represents an empty bed, which should be quite recognisable for its purpose. Anyway, since the interface is devoted to managing a series of beds, an image of it could be applied to various meanings, making this icon (outside its context) not intuitive. Finally, the nurse call icon represents a miniaturized operator. It should be possible that the low level of detail of the icon makes it difficult to interpret. It is advisable to consider changes to the latter listed to improve their intuitiveness.

5.2.5 Conclusions

The study aimed to analyze the use of the user interface of the Smart-bed system. Qualitative and quantitative research techniques and different types of measurements, subjective and objective, were therefore used in the study to allow for an in-depth analysis of the subject of the experiment. The results showed that the interface design was appreciated by the participants, who also found it easy to use and useful for the purpose for which it was designed. The analysis of the data on the cognitive load linked to the created tasks revealed that the participants were able to carry out all the possible procedures with ease. Finally, the qualitative methodologies investigated some small problems detected, albeit marginal, bringing to the attention of the designers the problems that could be solved to finalize the interface and make it ready for introduction on the market.

Finally, the analysis of CL indexes in ecological and low-control conditions reveals the need to research new ways of measuring such construct. A promising tool could be the Low/High Index of Pupillary Activity (Duchowski et al., 2020), based on small pupil size fluctuations, which could be useful in overcoming time and luminosity issues found in this study.

5.3 Touchscreen Interface Evaluation

5.3.1 Aim of the Study

This research activity aimed to evaluate the interaction of a group of participants with the touchscreen interface mounted on the footboard side rails of the bed. It allows the display of a selection of patient data reported from the bed (e.g., weight, body temperature), the use of the weight scale, and alarm management. The study, therefore, explored the strengths and weaknesses of the interface by exploiting multiple measures. I conducted the evaluation using subjective (i.e., questionnaires) and objective (i.e., performance) methods, analyzing human factors such as Mental Workload, User Experience, Technology Acceptance, and Usability.

5.3.2 Materials and Methods

5.3.2.1 Participants

A total of 19 participants ranging from 31 to 58 years old (M_{age} = 44; SDage=8.8 Female= 8) were recruited. Participation in the research activity was voluntary, and participants knew they could withdraw from the study at any time during the experiment.

5.3.2.2 Measures

Initially, a demographic questionnaire was proposed to the participants to collect some personal data, such as age and gender. The study used different methods for research, subjective and objective, quantitative and qualitative.

5.3.2.2.1 Subjective Quantitative Methods

Some of the tools used were used to evaluate the individual tasks proposed to the participants.

Participants fulfilled the NASA-TLX questionnaire in the same way described in paragraph 5.2.2.3.

Some questionnaires were administered at the experiment end, to evaluate the general experience with the interface.

The first was a Technology Acceptance questionnaire. I used the same instrument exploited in paragraph 5.2.2.3.

The second was a User Experience (UX) questionnaire. This was created starting from a work present in the literature in which a series of items to be selected according to the product under examination are presented (Schrepp & Thomaschewski, 2019). The items relating to the study were then selected and translated into Italian. The questionnaire presented a series of semantic differentials, i.e., opposing adjectives that described the sensations felt by the participants while using the interface. Participants could then respond using a 7-point scale indicating the dot that most indicated the experience. The dimensions analyzed by the tool were Attractiveness (Att), Efficiency (Eff), Perspicuity (Per), Dependability (Dep), Stimulation (Sti), Novelty (Nov), Trust (Tru), Aesthetics (Aes), Usefulness (Use), and Trustworthiness of Content (TrC).

The third was a usability checklist, created ad hoc for the experiment starting from the well-known usability heuristics of Nielsen (Nielsen, 2009). In this questionnaire, participants were asked a series of questions which they could answer Yes, No or Not Applicable. They could also add personal comments to all of them. The checklist analyzed the Visibility of the state of the system (Vis), the Aesthetics (Aes), the Consistency and Standards (Con), the Efficiency (Eff), the Prevention of Errors (Err), the Quality of the Image (ImQ), Memory Load (Mem), Physical Fatigue of Use (PhF), Legibility (Read), and User Control and Freedom (UsC).

5.3.2.2.2 Objective Quantitative Methods

Regarding the performance evaluation, I considered the time on task to complete individual tasks. In the time-on-task analysis, I also compared the participants' results with the ideal time, measured as the time an expert user performs the task, plus 50%. For accuracy, the number of unnecessary actions performed while using the interface and the number of sub-tasks not completed by the participants were considered. Furthermore, I considered the weighted mean between these two measures. I weighted the mean giving to time the 60% of the weight and the remaining 40% to the errors since in the caregivers work with the interface time represent, in my opinion, a more important factor. The weighted mean was calculated as the sum of the time values multiplied to 0.6 and the number of errors multiplied to 0.4.

The interaction of the participants with the interface was registered by the camera placed on the top of a pair of Eye-Tracking glasses (Pupil Invisible, Image 1). This tool can record what the user is viewing thanks to a 30Hz 1088 x 1080px camera (Pupil Labs, 2022). The analysis made it possible to visualize the entire experience to determine whether the participants completed the tasks correctly and the major problems encountered during use.

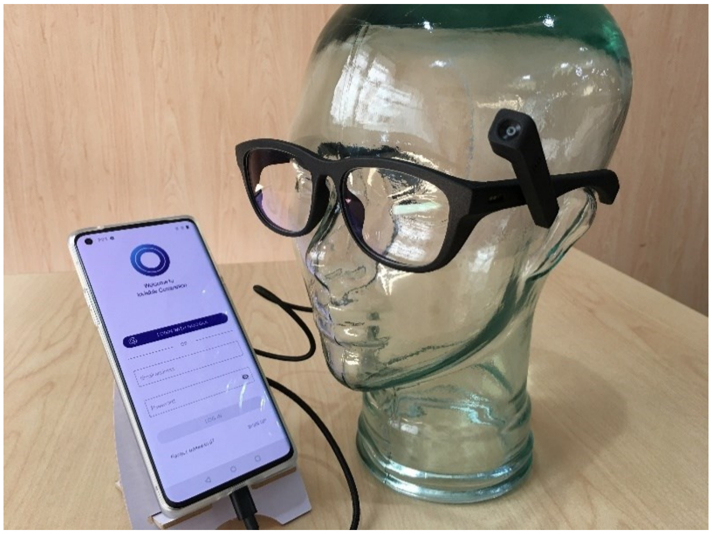


Image 1. Pupil Invisible, Eye-Tracking glasses used in the test.

5.3.2.2.3 Qualitative Methods

The participants faced a short semi-structured interview with two questions, which investigated their interaction with the interface (1) and eventual criticisms or suggestions regarding the experience (2).

5.3.2.3 Tasks

Participants faced four different tasks in a simulated room with two bed spots (Image 2). The four tasks were as follow:

Alarm Resolution (AL): four alarms were triggered (i.e., backrest not at 30°, nurse call, side rails lowered, incorrect bed position in the room). The participant waited in a separate place until all alarms were set. A tablet with the smart bed application installed was provided to participants prior to the test. The participants needed to solve all the problems by acting directly on the bed. The task consisted of 4 different sub-tasks: raise the side rail (1), deactivate the nurse call (2), move the bed (3) and position the backrest at 30° (4).

Weight Management (WE): In this task, the participants had to initially zero the bed weight system (1) and weigh an object provided by the researchers (2) using the bed scale. Subsequently, they had to read the weight of a pre-established day and communicate the reading aloud (3).

Temperature Detection (TD): The participant had to read the patient's previously acquired body temperature recorded on the interface.

Rule Management (RM): At the beginning of this task, composed of 6 subtasks, there were four active rules (30° backrest, patient agitation detection, bed exit detection, and weight detection). The participants were instructed to remove all active rules (subtasks 1 to 4) and instead activate the nurse call (5) and heart rate monitoring between 60 and 80 bpm (6).

5.3.2.4 Procedure

At the beginning of the experimental session, informed consent (on paper) was given to the participant. The participant then completed a short demographic questionnaire. Subsequently, the participants participated in a short training phase with a video in which the interface's various functions were explained. The video lasted about 7 minutes. At the end of this first phase, the participant dressed the eye tracking glasses with the built-in camera (Pupil Labs Invisible). The first phase of the experiment included five minutes of free exploration in which it was possible to use the interface without constraints, putting into practice the features learned during the training phase. After this moment of free exploration, the four experimental tasks to evaluate the touchscreen interface were presented. Figures 5.27, 5.28 and 5.29 show some participants carrying out the tasks. The participants fulfilled the NASA Task Load Index (NASA-TLX) at the end of every task. The order of the experimental tasks was randomized for each participant. In the final phase of the experiment, the participant completed the Usability checklist to evaluate the usability of the interface used, the questionnaire to evaluate the overall User Experience, the questionnaire to evaluate Technology Acceptance, and the short semi-structured interview. Figure 5.26 show the graphical representation of the procedure.

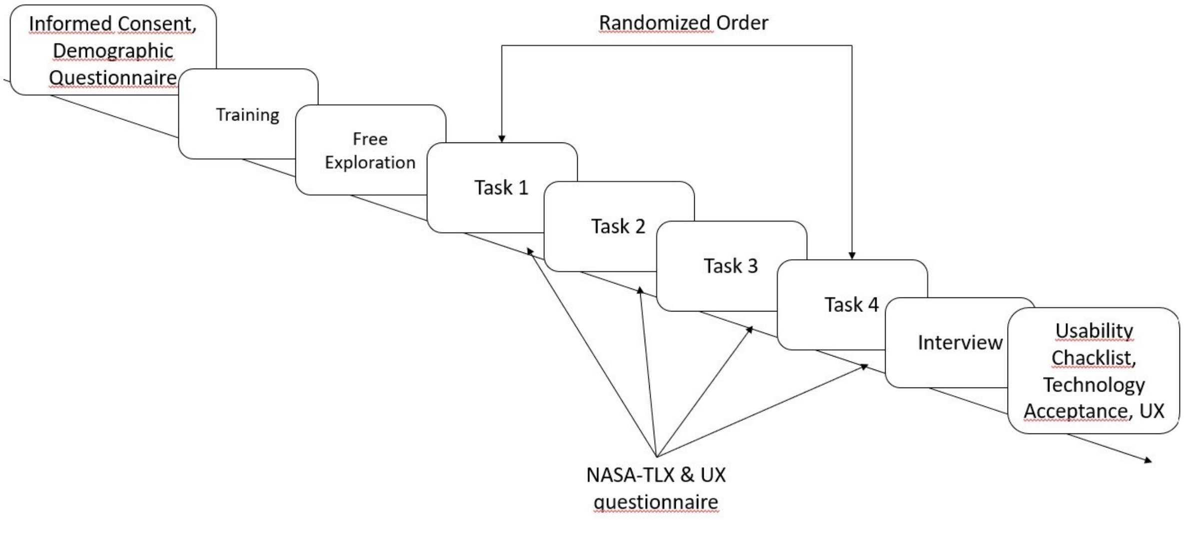


Figure 5.26. Graphical representation of the experimental procedure.


Figure 5.29. Participant performing the task.


Figure 5.27. Participant in carryin the task


Figure 5.28. Participant carrying out a questionnaire.

5.3.3 Results

Data analysis was performed using R studio software. For the analysis of the questionnaires, I run a series of Mann-Whitney tests, comparing the median result with the median of the response scale and correcting p-values with the BH method. The only exception was the NASA-TLX, analyzed with the Kruskal-Wallis test. To analyse the objective measures, I verified the normality of the data using their visualization and the Shapiro-Wilk tests. In the case of normality in all conditions, an ANOVA test for Repeated Measures was performed, followed by pairwise T-tests, corrected with the Benjamin-Hopkins (BH) method. In the event of non-normality of the data, a Friedman test was used, followed by pairwise Wilcoxon tests. The results were also corrected with the BH method.

5.3.3.1.1 NASA-TLX

NASA-TLX data were analysed using a Kruskall-Wallis test followed by pairwise Wilcoxon tests, which p values were corrected using BH method. The Kruskal-Wallis test results significant (χ^2=19.067, p<0.001). The Wilcoxon test results are shown in Figure 5.30. A significant difference was found between the TD (Med=10) task and the AL (Med=40, p<0.001), WE (Med=42.5, p<0.01) and RM (Med=40, p<0.01) tasks results. A series of Mann-Whitney tests were run to verify if the subjective ratings of the conditions were significantly lower than the median of the scale (i.e., 50). All the p-values, corrected with the BH method, were founded significant (TD p<0.001, AL/WE/RM p<0.05).

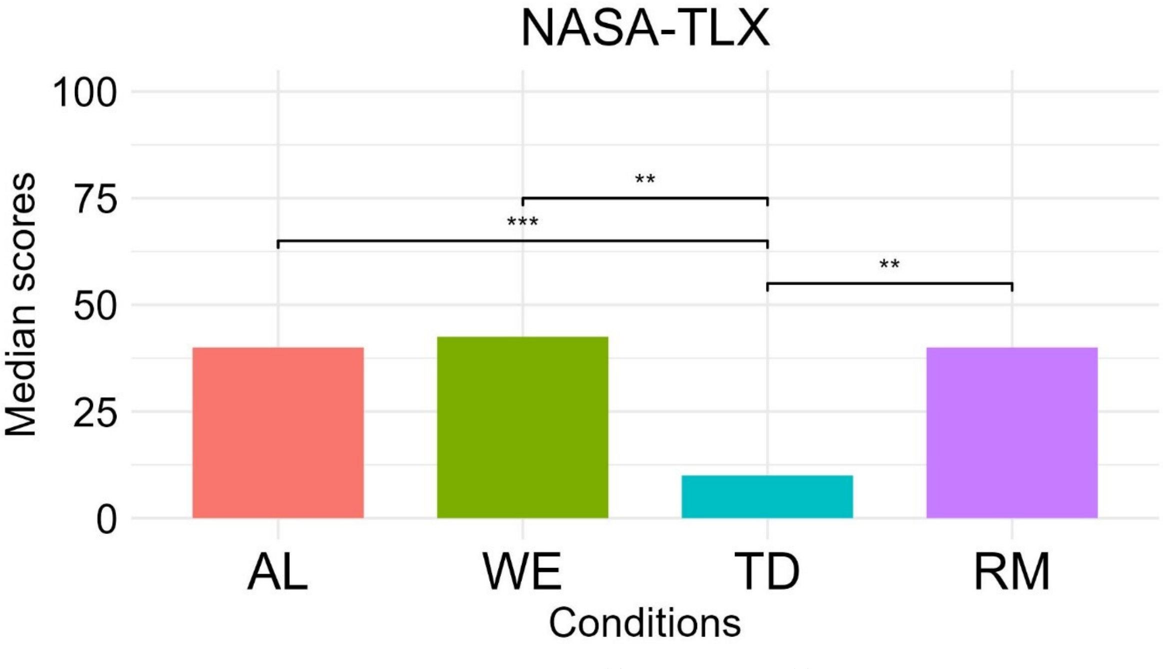


Figure 5.30. Results of the NASA-TLX questionnaire. The x-axis represents the tasks, the y-axis the median results scores.

5.3.3.2 Time on Task

The study considered time on task as a performance measure. The results of the one-way repeated measures ANOVA (data were normally distributed) are shown in Figure 5.31. The ANOVA test showed a significant main effect (F(3:54)=0.496, p<0.001). The results of the pairwise t-tests show a trend similar to that of the NASA-TLX questionnaire, with significant differences between the TD task (M=21.9, SD=32.1) and the AL tasks (M=185, SD=73.6, p<0.001), WE (M=147, SD=66.1, p<0.001) and RM (M=176, SD=86.7, p<0.001).

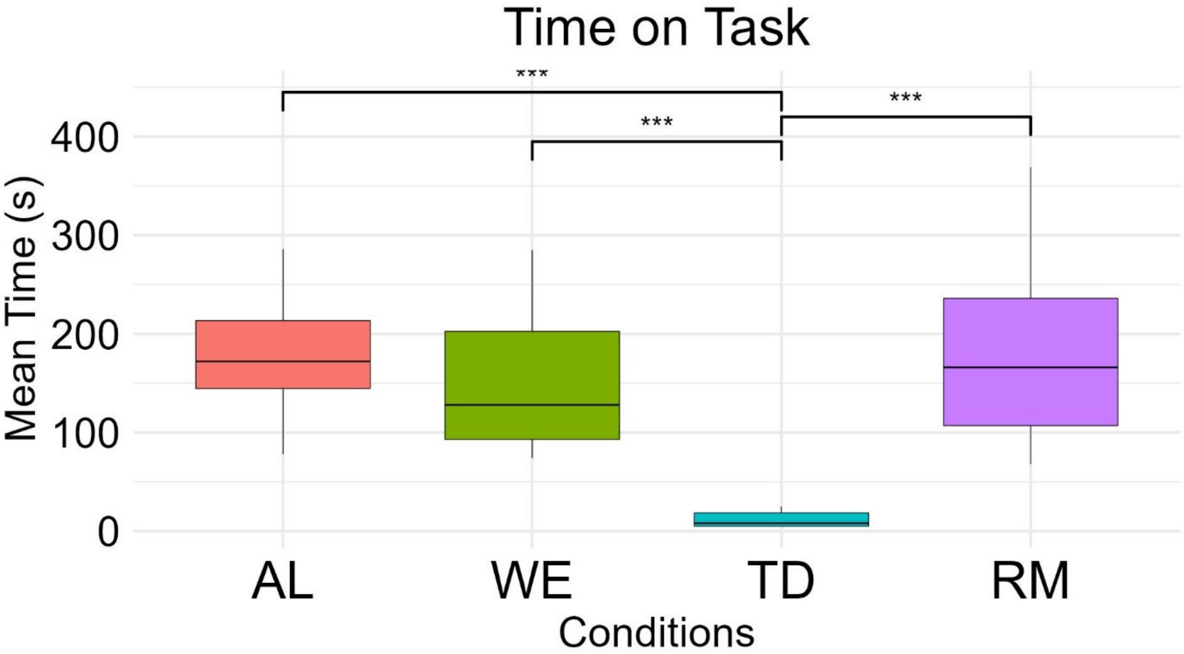


Figure 5.31. Results of completion times by task. The x-axis represents the task, the y-axis the average time spent in seconds.

The ideal time-on-tasks were: AL=103.05 s, WE=94.2 s, TD=7.5 s, RM=71.46 s. I compared these times with the ones obtained by participants with a series of Mann-Whitney tests, which p values were corrected with BH method. The participants' results of tasks AL, WE, and RM were founded significantly higher (AL/RM p<0.001, WE p<0.01) than the ideal ones, while TD did not show a significant difference.

5.3.3.3 Accuracy

Thanks to the video analysis of the tasks performed, the performance in terms of errors was evaluated. Figure 5.32 shows the calculation of the unnecessary actions performed by the participants, calculated by subtracting the number of ideal actions of the task from the total ones performed by the participants. The one-way repeated measure ANOVA test shows a significant main effect (F=0.389, p<0.001). The following pairwise t-tests show significant differences between the TD task (M=0.58, SD= 1.35) and the AL tasks (M=8.21, SD=8.52, p<0.01), WE (M=10.5, SD=10.9, p <0.001), RM (M=22.5, SD=14.7, p<.001), and between the AL and RM tasks (p<0.01).

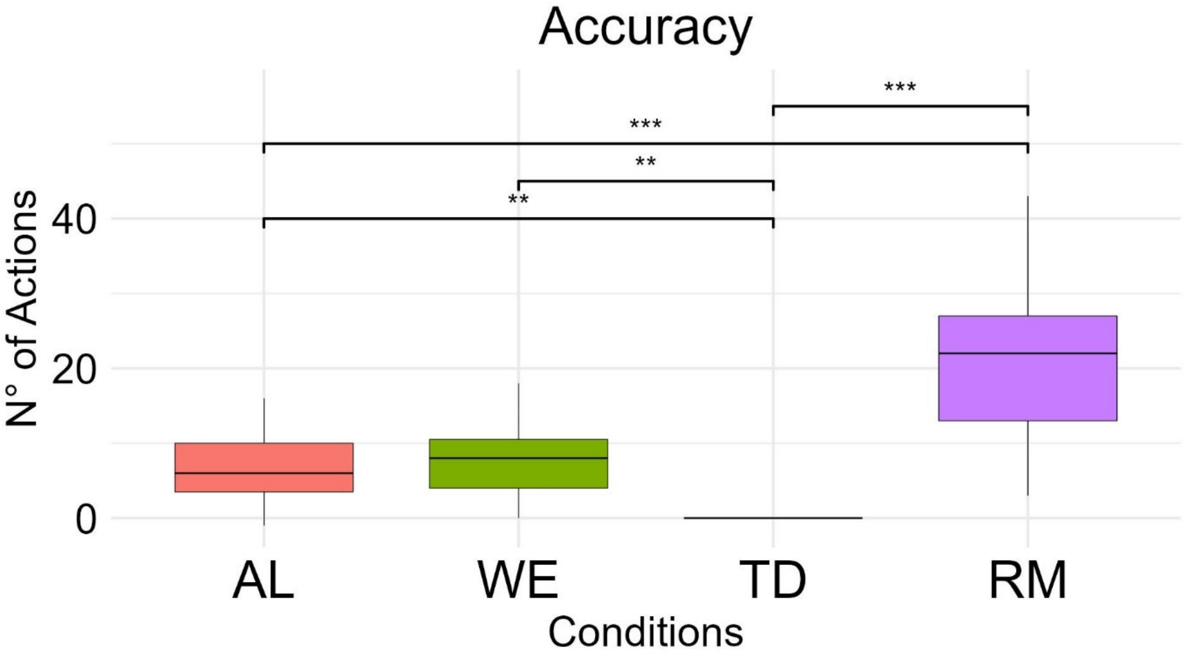


Figure 5.32. Results of unnecessary actions performed by the participants while carrying out the tasks. The x-axis represents the task, the y-axis the average number of actions.

The study considered the errors made during the execution of the tasks, counting the number of unfulfilled or incorrect sub-tasks. The results show no significant differences.

5.3.3.4 Weighted Mean

The weighted mean was analyzed in each performed task using the Friedman-Wilcoxon-BH method. The Friedman test results were significant (p<0.001). The following pairwise Wilcoxon tests reveal that WE values (M=98.2, SD=55.3) were significantly (p<0.01) higher than TD ones (M=50.6, SD=39.8). AL (M=94.7, SD=61.7) and RM (M=75.1, SD=56.1) conditions did not differ from the others. Figure 5.33 shows the results.

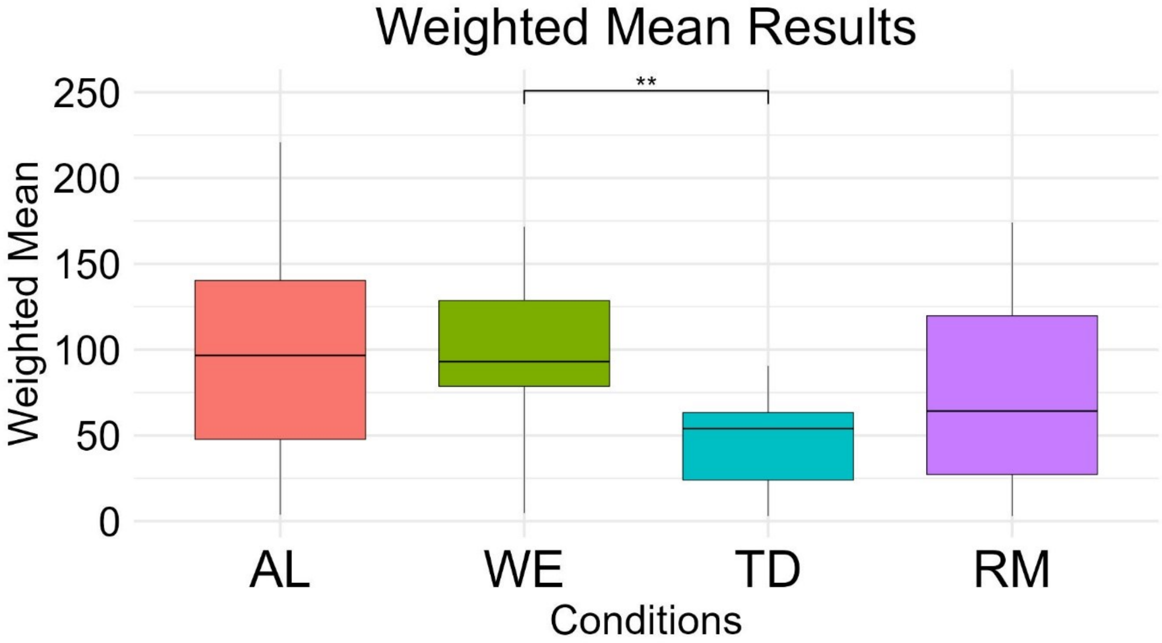


Figure 5.33. Results of the weighted mean which considered errors and times to evaluate the performance. The x-axis represents the task, the y-axis the calculate index values.

5.3.3.5 User Experience (UX) Questionnaire

The UX questionnaire created ad hoc for evaluating the user experience with the interface was analysed. Mann-Whitney tests were used, comparing the median results with the median response scale (i.e., 4). The results were corrected using the BH method. The results are shown in Figure 5.34. All dimensions analyzed exhibit median results significantly higher than the median of the scale. Aes p<0.001; Att p<0.001; Dep p<0.001; Eff p<0.001; Nov p<0.01; Per p<0.001; Sti p<0.001; TrC p<0.001; Tru p<0.001, Use p<0.001.

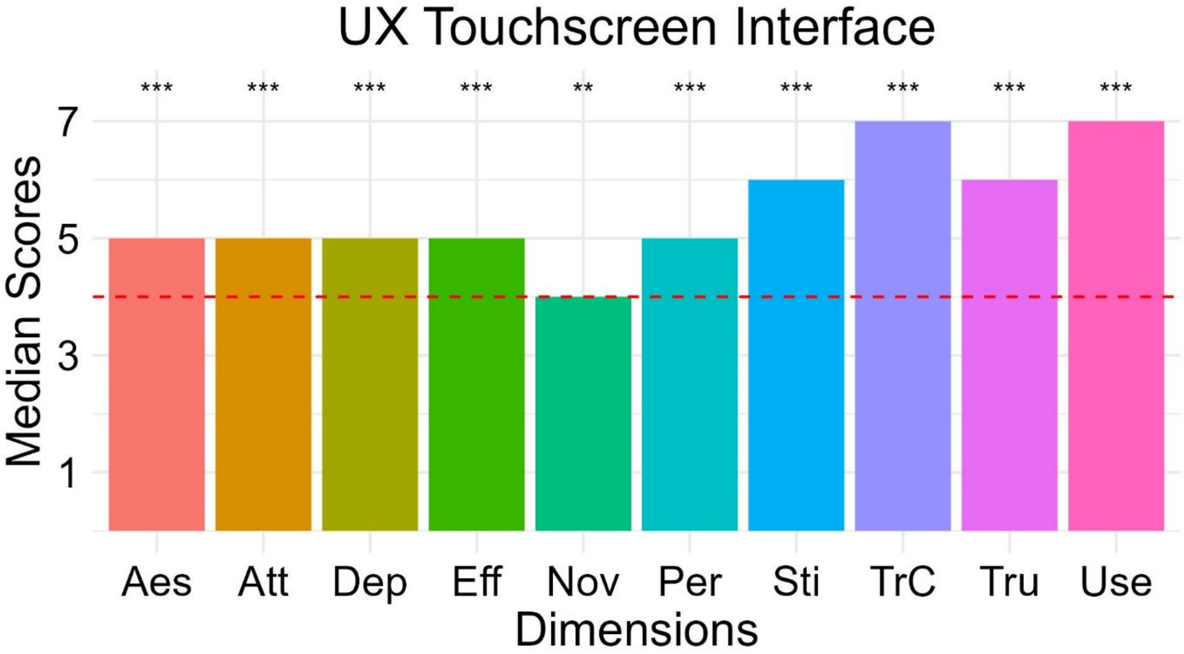


Figure 5.34. Results of the UX questionnaire related to user experience with the interface. The x-axis represents the size of the questionnaire, the y-axis the median scores assigned by the participants.

5.3.3.6 Technology Acceptance Questionnaire

The Acceptance questionnaire evaluated the acceptance of the proposed technology. Mann-Whitney tests were used, comparing the median scores with the median of the response scale. The results were corrected by the BH method. The results are shown in Figure 5.35. All dimensions analyzed exhibit median results significantly higher than the median of the scale. IQ p<0.001; IU p<0.001; PEOU p<0.001; PU p<0 .001; SyQ p<0.001.

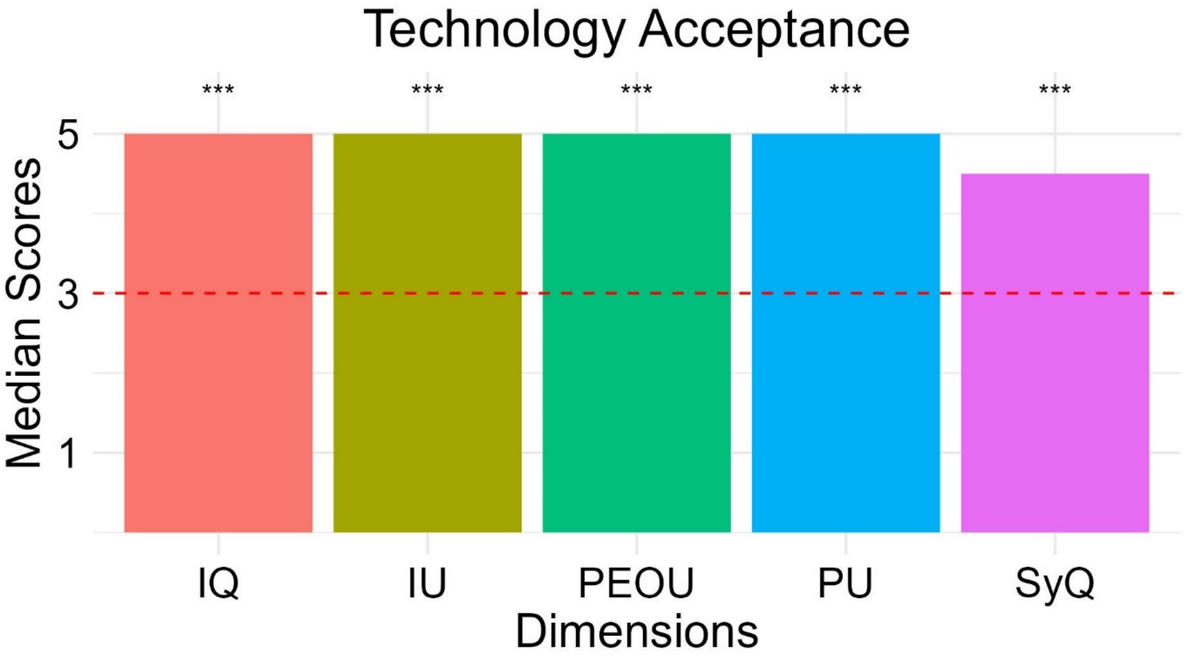


Figure 5.35. Results of the Acceptance questionnaire related to the user experience with the interface. The x-axis represents the size of the questionnaire, the y-axis the median scores assigned by the participants.

5.3.3.7 Usability Checklist

The usability checklist evaluated the usability of the touchscreen interface. The analysis converted the responses by encoding those according to the usability principles as positive responses and calculating the percentage of positive answers. The results are shown in Figure 5.36. All the dimensions analyzed obtained largely positive scores (>=75%).

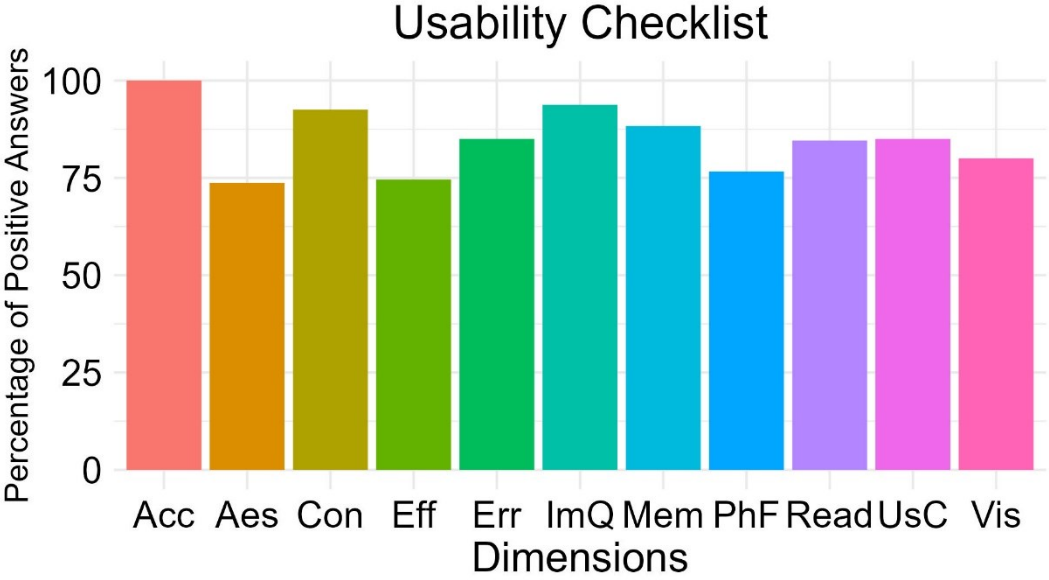


Figure 5.36. Percentage results of positive responses to the dimensions of the usability checklist. The x-axis represents the size of the questionnaire, the y-axis the percentage of positive responses, in line with the heuristics.

The checklist also collected some comments from the participants, useful for the usability analysis, which were collected to indicate the problems detected. Below are two lists, the first for issues encountered by multiple users and one below with individual comments.

Issues shared by multiple users:

Interaction with the touch interface not optimal: 19 participants

Not very intuitive icons, with particular reference to those found within the weight system: 5 participants

Awkward touchscreen position when user standing: 5 participants

Fonts too small on weight trend graph: 3 participants

Difficulty returning to home page: 3 participants

Isolated Issues:

Password requested too many times

Green arrow indicating the position of the weight measurement on the scale graph is not visible

Scale graph to review

The waiting time for displaying the graph of the acquired weights is too long

The back key sometimes leads to the home

Difficult to understand which rules require set intervals and which are not

Unclear brake icon

Delays in feedback after an action

In the scale screen, there are some keys that do not give feedback, and it is not clear whether the pressure has had an effect or not

Unfamiliar icons

Required textual part explaining the error messages

5.3.3.8 Analysis of the Experiment Videos

Some frequent behaviours and problems during interactions with the interface were then identified thanks to the viewing of user recordings during the use of the interface. The most frequent and significant ones are reported. The frequencies of occurrences are between brackets.

Problems using the touchscreen (19) - very often, the interface presented interaction problems, not receiving the command or interpreting the command on a different point.

Errors on subtasks due to alarm cancellation (4) – when some alarms are triggered, if users access the rules panel after silencing them, the interface asks to deactivate all the alarms present. In four cases, this led to failure to manage the alarm due to this cancellation by forgetting to resolve the problems.

Non-clickable elements considered by users as interactable buttons (7) – in many cases, the interface has some non-clickable elements that nevertheless appear as interactive buttons. Users then tried to interact with them to no avail.

Alarm resolution speed on interface (3) – users control on the tablet the resolution of the alarms. Its slow update caused slowdowns in the interaction.

Graph Starting Point (8) – upon accessing the weight graph, users expected to start from the most recent date rather than the earliest recorded, which is currently the default starting point.

Deactivate thresholds (4) – The deactivate thresholds button was not immediately recognizable.

Return to the first page when pressing down on the rules list (2) – in the rules panel, you can scroll up or down to view the entire list. In some cases, once they reached the bottom, the participants tried to select the down-level button to return to the top of the list, an action not allowed by the interface.

5.3.3.9 Semi-Structured Interviews

Finally, at the end of the test, the participants were interviewed. Thanks to a semi-structured interview, they provided their opinions on the functioning of the interface (1) and if they had any suggestions or comments in this regard (2).

5.3.3.10 Interface Interaction

In general, all participants found the interface particularly simple and intuitive. Some of them highlighted an initial difficulty in understanding the icons and functions. They declared that this confusion could be easily overcome with prolonged use (P01: "I liked it, I found it a bit bad because I've never used it. The first impact is that, then after using it two or three times it becomes a very simple and banal thing").

However, many pointed out some difficulties with pressing the keys and with the density of information in the panel relating to the weight system (P10: "Everything was very clear to tell the truth, maybe there are just so many functions on the scale. Practically not it's intuitive at first glance, I didn't remember what the zero setting was").

One participant, on the other hand, encountered numerous problems on the password entry pages, and he/her was confused about how to go back to the homepage (P11: ''Then I didn't understand why he didn't recognize the password, there was no it's an exit key, there's an x but it felt more like one key back, there's no home key").

One of the participants also noticed that deleting all the alarms at the same time from the rules panel presents the risk of forgetting unresolved alarms (P19: "Another thing in my opinion, maybe it was the first approach, but if you deactivate the alarm and go into the parameters, everything is deleted, in my opinion, it's not so convenient. … Perhaps even a distracted person risk that instead of solving it, he deletes everything, you no longer know the parameters, you can't modify them and anyway you haven't solved them").

5.3.3.11 Suggestions

P02 suggested displaying the weight on the trend graph more effectively thanks to a graphic indicator on the trend line and the specific value above the requested date: "to simplify, if there was a dot, go to the date, and it already tells you the value". Still, concerning the weight graph, P18 suggested facilitating the visualization of weight dates: "Then on the weight graph it took me a long time to understand the detection of the date because the first part was the detection of the number, and I thought that that referred to the day. It would be more useful to separate them, so one knows that the day changes rather than the time". Finally, P20 suggested that the weight graph may be more intuitive if the most recently recorded information is displayed first ("The thing I had to look for was the date, I thought the first one was the most recent. I expected that start on today's date. I would prefer it from present to past, it seems more normal like this").

P03 suggested being able to tilt the interface: "Perhaps the position of use, you would need the keypad to be higher or tilted. Both for pressure and grip and in terms of visibility. It is uncomfortable vertically". P14 shared the same suggestion: "the screen is very small and I'm tall, the touchscreen is vertical, tilting it would already be a huge step".

P13 instead suggested the use of a card to unlock the push-button panel, a solution that could solve the password entry problems encountered by some users: "One suggestion is that the bed, which connects to the hospital network if it, could be used instead of with the password perhaps with a badge".

P17 instead suggested discriminating more effectively the buttons used to set rules that provide a range since they lead to different screens from the rules panel: "Pretty good, the only difficulty is that in the settings there are some rules with yes or no and others with range, I would distinguish the type of icon to discriminate them, maybe change colour or enlarge them".

5.3.4 Discussion

The present study analysed users' interaction with the touchscreen control interface of the smart-bed system with four tasks developed to explore its functionalities. The qualitative and quantitative measures explored the interaction to detect problems.

As regards the cognitive load linked to the individual tasks, the NASA-TLX questionnaire detected the perceived difficulty of each task. The results showed a very low difficulty of the proposed tasks, as the median scores fall below 40 points on a scale ranging from 5 to 100, highlighting the system's ease of use. The results showed a greater workload for AL, WE, and RM tasks than the TD task, considered by the participants to be the simplest one, requiring few steps to be completed. Time on task and accuracy analysis confirmed this result. The only difference between the three more complex tasks concerns the number of unnecessary actions to carry out the task, which shows greater errors in the RM task. Based on the video analysis, this greater number of interactions is due to the number of actions performed on non-selectable elements present on the weight management page, which users accessed to deactivate the thresholds. A second reason lies in difficulties finding the threshold deactivation button, leading users to repeatedly enter and exit the alarm page. For both of these problems, it would be possible to use a colour code to make the interaction easier, for example, by making the non-interactable buttons grey and highlighting the "disable" button more with a different border or colour from the rest. Furthermore, the greater number of actions could be due to the density of icons and interactable buttons inside the weight panel, which led to a complex recognition of the button to access the threshold setting. The expectation of users to return to the first page of the rules list by continuing to scroll down represents a further reason. Allowing this feature could increase the flexibility of use. Finally, the main reason was the non-optimal responsiveness of the interface, which generated many unnecessary interactions in an environment full of buttons like the rules panel. In this case, further checks on the accuracy of the command acquisition by the interface itself are necessary. However, in the weighted mean analysis, only WE difficulty results significantly higher than TD. The high complexity of the weight panel, also highlighted by the usability checklist, could have caused an increment in the time spent/errors committed by participants in performing this task. The possible suggestions to improve this functionality will be given later in the discussion.

As regards the general evaluation of the experience, the User Experience questionnaire shows high values, especially in the quality and usefulness of the data provided, indicating that the participants found them reliable, useful and accurate. The novelty of the alarm obtained the lowest score (Med=4), highlighting that participants rated the user experience as generally satisfactory but indicating the presence of similar (albeit not so complete) solutions on the market as a possible limitation.

The questionnaire connected to Technology Acceptance gave encouraging results, with all values well above the median. This confirms the possibility of introducing the system into the healthcare environment.

The usability checklist also shows excellent results in all the analyzed heuristics. Participants indicated with their comments some needs. First, it is necessary to solve the problems related to the responsiveness of the interface, which caused interaction problems for all the users involved. As far as the system is concerned, however, some unintuitive icons have been highlighted, especially those relating to the weight panel, which was full of buttons and functions (Figure

Figure 5.37. Weight system management page.

5.37). These would therefore need more intuitive icons that make interaction easier even for non-expert users. Also, from the same panel, it is possible to access the weight graph, which characters were too small and should therefore be increased to improve the visibility of the information. Regarding ergonomics, however, it has been highlighted how using the touchscreen is uncomfortable if users are standing. It would therefore be necessary to use a system that allows the interface to be tilted if necessary. Finally, some users have commented that it was not always easy to return to the home screen. It might be useful to provide the return button on all interface screens.

The video analysis highlights a generally good task completion rate, as most of the sub-tasks were successfully completed. It identifies some problems, such as the previously mentioned touchscreen problems. Another problem was the errors on the sub-tasks of the AL task. When the four alarms were triggered, the participants could decide to silence them and simultaneously eliminate them from the rules panel. This led to four cases of failure to manage the alarm due to this cancellation as the participants could not remember the previously active warnings. Therefore, it would be preferable not to provide this option or to allow users to view alarms that were not fully resolved during the previous warning. Still, regarding this task, some users exploited the potential of the tablet interface, which reports the alarms present, to control their actions on the bed. In some cases, however, the tablet's response was significantly delayed, leading to multiple unnecessary interactions. It would be preferable to speed up the response, even if hospital staff would hardly verify this information on the tablet after an adequate period of use.

As seen in several points during this evaluation, in many cases the interface had non-selectable elements which have the same shape, size and colour as other interactable buttons. Users tried to interact with them, leading to numerous non-significant interactions. As previously suggested, a colour code could solve the problem, perhaps making them transparent or grey, a common standard for non-clickable buttons.

The last problem concerns the weight graph. For the former, many users expect it to start from the most recent date, whereas the standard is the opposite. To increase ease of reading, this setting could be changed to suit users' suggestions.

Most of the results described up to now have also been highlighted by the interviews, which have finally shown how most users have found the interface intuitive and easy to use, especially after a short period of use which allows to acquire all the knowledge necessary for a rapid and effective use.

5.3.5 Conclusions

The study aimed to analyze the use of the touch interface mounted on the bed rail of the Smart-bed system. Qualitative and quantitative research techniques and different types of measurements, subjective and objective, were therefore used in the study to allow for an in-depth analysis of the subject of the experiment. The results showed that the interface design was universally appreciated by the participants, who also found it easy to use and useful for the purpose for which it was designed. The analysis found that the participants could perform all possible procedures easily. Finally, the qualitative methodologies investigated some small problems detected, albeit marginal, bringing to the attention of the designers the problems that could be solved to finalize the interface and make it ready for introduction on the market.

5.4 Using Smart Bed in Real Healthcare Environment: Case Study in Retirement Home for Elderly

5.4.1 Aim of the Study

This exploratory study aims to evaluate the interaction of a group of healthcare professionals with the hospital bed smart system. The first objective was to indagate a possible reduction in caregivers' workload thanks to the use of the system. The second was evaluating the user experience and the acceptance of the technology of the entire system. Furthermore, given the intense use of the touchscreen interface operators mounted on the footboard side rails of the bed, this work tested its usability in a real environment. Finally, the study examined factors such as the patient's perception of safety, subjective workload and perception of the quality of care through a semi-structured interview.

5.4.2 Materials and methods

5.4.2.1 Participants

A total of 6 participants (age range 41-66 years; M_{age} = 51; SDage=9.5 Males= 4) took part in the study. Participation in the research activity was voluntary, and participants knew they could withdraw at any time during the experiment.

5.4.2.2 Measures

The study used several methods for research, both qualitative and quantitative.

5.4.2.2.1 Quantitative Methods

Initially, participants provided demographic information, such as age and gender.

I assessed the workload using the NASA-TLX questionnaire, which is widely used in nurse workload studies (Tubbs-Cooley et al., 2018; Young et al., 2008). The NASA-TLX consists of 6 scales (Mental Question, Physical Question, Temporal Question, Performance, Effort and Frustration) which can be answered using a scale ranging from 5 to 100. The median value of the results of these scales returns the subjective workload experienced by the participants. In this study, I used the questionnaire version that allows weighting the scales according to their role in participating in the final result on the amount of workload. Differently from the previous studies, NASA-TLX in this study was administered to evaluate potential differences in caregivers workload between a usual working week and a week while they were using the IoT system.

NASA-TLX has been often used for these purposes in previous works (Tubbs-Cooley 2018, Shoha 2020).

The study evaluated the general experience with the system with two questionnaires.

The first was the Technology Acceptance described in the previous evaluations.

The second was the User Experience (UX) questionnaires used in the previous evaluations, adapted to comprehend both interfaces. The dimensions analyzed by the tool were Attractiveness (Att), Efficiency (Eff), Perspicuity (Per), Dependability (Dep), Stimulation (Sti), Novelty (Nov), Trust (Tru), Aesthetics (Aes), Usefulness (Use), Trustworthiness of Content (TrC) and Quality of Content (QuC).

Finally, a usability checklist, evaluated the touchscreen interface. The checklist analyzed Visibility of the state of the system (Vis), the Aesthetics (Aes), the Consistency and Standards (Con), the Efficiency (Eff), the Prevention of Errors (Err), the Quality of the Image (ImQ), Memory Load (Mem), Physical Fatigue of Use (PhF), Legibility (Read), User Control and Freedom (UsC) and Visibility (Vis).

5.4.2.2.2 Qualitative Methods

The semi-structured interview explored the following themes:
- Perception of patient safety following the use of the system
- Perception of the quality of care provided following the use of the system
- Perception of the workload following the use of the system

5.4.2.3 Procedure

This test evaluated the smart beds in a real working environment, namely a retirement home for elderly people suffering from dementia/Alzheimer's. The smart beds have been installed and tested for proper function. After the installation, the NASA-TLX questionnaires evaluated the workload during a usual working week, thus establishing a baseline level. Subsequently, the operators were informed of the functionality and functioning of the system and used it for one month. Subsequently, each participant fulfilled demographic data, the NASA-TLX questionnaire referring to the last week of work (4 weeks after the start of use), the technology acceptance questionnaire, the user experience questionnaire for the system and the usability checklist referring to the touchscreen interface of the bed. After completing the questionnaires, semi-structured interviews were carried out. In these, the investigator asked participants to answer three questions regarding their perception of patient safety, workload, and quality of care following the new system implementation. The interviews were recorded for subsequent thematic analysis.

5.4.3 Results

Data analysis was done using R studio software. I used Mann-Whitney tests for the questionnaires that analyzed the users' opinions with the system, comparing the median result with the median of the response scale and a Wilcox test for NASA-TLX results. For multiple comparisons, I used the BH method to correct p-values. The thematic analysis method was used for the interviews.

5.4.3.1 NASA-TLX

NASA-TLX data were analysed using a Wilcoxon test. No significant difference was found between the pre-and post-introduction levels of the system.

5.4.3.2 User Experience Questionnaire (UX)

The Mann-Whitney test results are shown in Figure 5.38. All the dimensions analyzed have median results significantly higher than the scale's median, except for the reliability referred to the touch control panel. Aes $p<0.001$; Att $p<0.01$; Dep $p>0.05$; Eff $p<0.001$; Nov $p<0.05$; Per $p<0.001$; QuC $p<0.001$; Sti $p<0.05$; TrC $p<0.001$; Tru $p<0.001$; Use $p<0.001$.

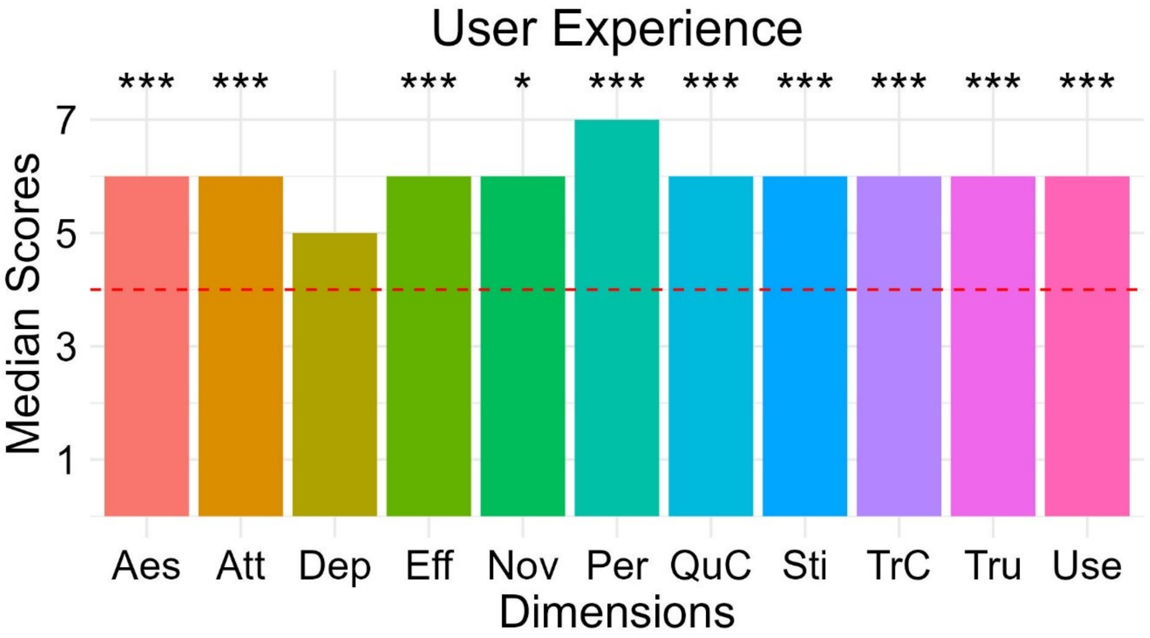


Figure 5.38. Results of the UX questionnaire related to user experience with the interface. The x-axis represents the size of the questionnaire, the y-axis the median scores assigned by the participants.

5.4.3.3 *Technology Acceptance Questionnaire*

The results of the technology acceptance questionnaire are shown in Figure 5.39. Almost all dimensions analyzed have median results significantly higher than the median of the scale, with the exception of system quality. IQ $p<0.05$; IU $p<0.05$; PEOU $p<0.05$; PU $p<0.05$; SyQ $p>0.05$.

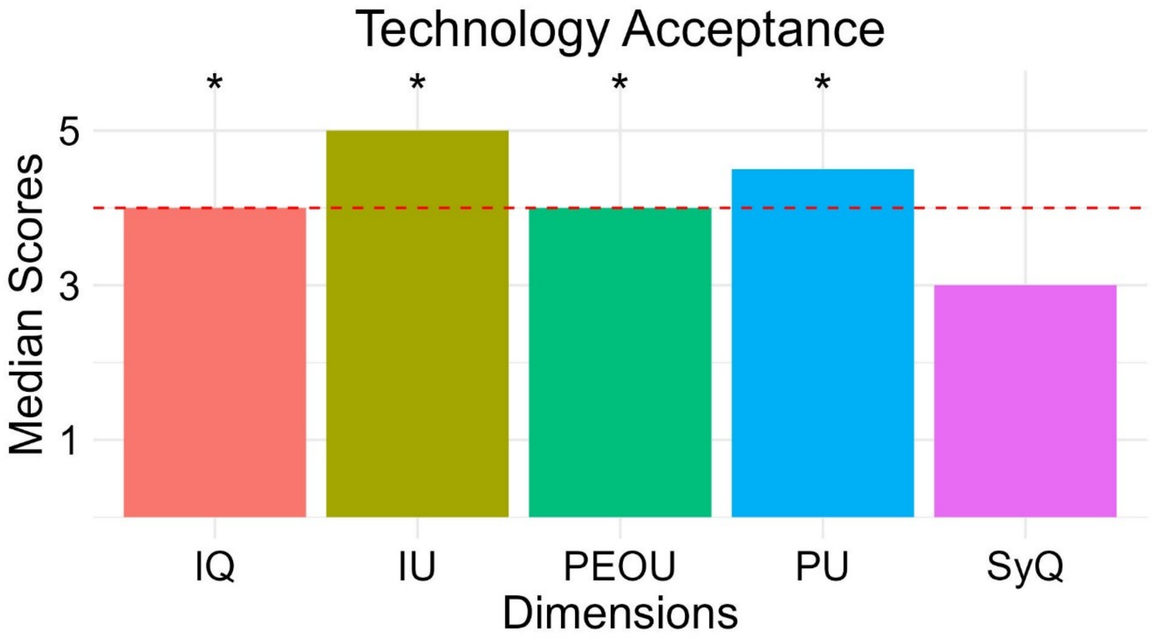


Figure 5.39. Percentage results of positive responses to the dimensions of the usability checklist. The x-axis represents the size of the questionnaire, the y-axis the percentage of positive responses and in line with the heuristics.

5.4.3.4 *Usability Checklist*

The analysis of the usability checklist comprehended the conversion of the responses by encoding those that respected the usability principle as positive responses. The results are shown in Figure 5.40 and the usability problems are showed in Table 5.4. All the dimensions analyzed obtained largely positive scores (> 75%), with the exception of the Aesthetics dimension. One participant commented that the keypad sometimes feels unresponsive, highlighting a known issue with the touchscreen.

5.4.3.5 *Semi-Structured Interviews*

During the interviews, participants answered three questions regarding the patient's perception of safety, quality of care and workload following the use of the system. The results are summarized in Table 5.4, which also provides the total number of times the themes emerged.

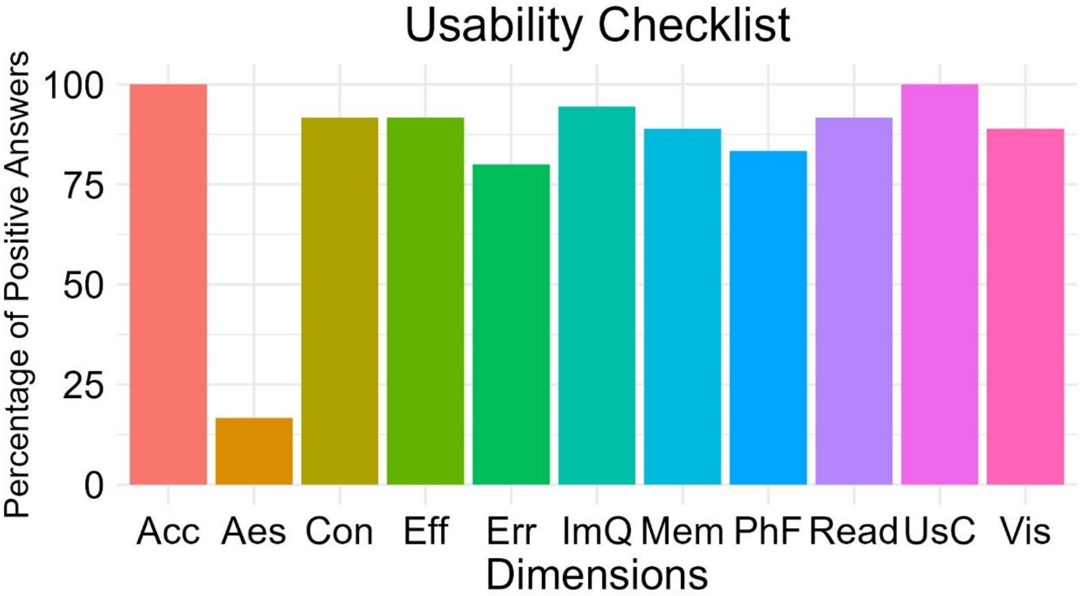


Figure 5.40. Results of the Acceptance questionnaire related to the user experience with the interface. The x-axis represents the size of the questionnaire, the y-axis the median scores assigned by the participants.

5.4.3.5.1 Safety

The general users' opinion is that the system can provide concrete help to increase patient safety (P01: ”The alarms are useful, the system is an aid”; P02: ”The alarms worked very well and put patients in safety "). The reasons were various. For example, P01 indicated that the system could be useful to avoid errors caused by distractions (P01: ”So it is impossible for you to leave the room if you haven't completed closing the side rails or something else”). P04 and P05, on the other hand, indicated that the system could speed up the response of the operators in case of need (P04: ”Maybe it can help to intervene sooner. That's why it helps”; P05: ”Surely an alarm system ensures that those who are far from the room can quickly go to see what the guest is doing, speed up the response). P06 indicated the movement detection system as useful for determining whether or not the patient needs restraint, providing a suggestion for applications of this function (P06: "before putting the restraint on, it could be a step in more to maintain security and avoid restraint in case").

5.4.3.5.2 Quality of care perceived by the patient

The first comment shared by the participants was that in patients with pathologies similar to those present during the study (i.e., dementia/Alzheimer's), the patient cannot fully understand the system's potential. On the other hand, the opinions were discordant regarding the quality of the care provided. Indeed, one operator indicated the system's inability to ameliorate the quality of care (P01: "No, in our case absolutely not, we make the difference"). The other participants indicated that the system's functions could help provide a better image of the operator's work (P05: ”if the image is used correctly, then from that thing it is certainly positive”; P06: "Of course, being more present even when we are absent, a surveillance presence that is not even physical but given by technology. In my opinion, if patients were clear-headed, this system, which our patient does not understand, would appreciate it")

5.4.3.5.3 Workload

Operators' comments regarding workload showed that the system helps reduce it, creating a more relaxed and calm environment (P01: "We are more relaxed and calm, we are more aware of the fact that we are being cared for at technological levels"), lowering fatigue (P02:" I felt I did less effort, the interface, the alarms, everything makes my job easier"; P06:" more efficient and effective"), and lightening work (P03:" Certainly lightened a little, the job is always the same, the guest as well but the bed is better, the experience has certainly been positive, we must probably learn to use them better too") also psychologically speaking (P05: "it is lighter, I feel less weighed down also psychologically"). However, one of the operators indicated that the work had not changed that much. Indeed, the false alarms from the patient's agitation monitoring can strongly impact caregivers’ work (P03: "it has not changed that much, in terms of workload it does not change then a lot. Yes, the alarms in the night shift rings, but if you go to check the patient was still in bed, it was false alarms").

Table 5.4. Table presenting the total number of participants which discussed a particular theme.

Argument	Themes	Frequency
Safety		
	Increase Safety	6/6
	Avoid Errors	1/6
	Reduced Interventions' Time	3/6
	Determine Restrain Need	1/6
Perceived Care Quality		
	No Differences for Patients	2/6
	Increased Perceived Care Quality	4/6
Workload		
	Relaxed Environment	1/6
	Lower Fatigue	3/6
	Psychological Help	1/6
	Increase False Alarm Fatigue	1/6

5.4.4 Discussion

The purpose of this exploratory study was to evaluate the general opinion of the system by operators who used it daily for about a month.

As regards the evaluation of the questionnaires, the first instrument used was the NASA-TLX, used for measuring the cognitive load. The questionnaire results did not show significant differences between the system's pre and post-insertion phases. However, the lack of results at this juncture could be dual. The first was the small number of participants (P=6), while the second was the presence of a limited pool of sensors. The number of participants represents a strong limitation of this study. Unfortunately, the COVID-19 restrictions still applied in retirement homes facilities permit us to evaluate only a small ward in the structure selected for the study, and the high workload imposed on caregivers working on it left only six workers participating in our case study. The second problem of the present study was that the bed could only perceive the patient's pressure and indicate their presence and agitation, together with the side rails status. In future studies, where alarms for heart rate, respiration and weight will also be included, it will be more likely to find a significant difference between the work with and without the system in terms of workload, since these signals provide more valuable insights into the patient's health. Indeed, some studies have proven continuous patient monitoring to reduce the caregivers' workload when frequent false alarms are absent (Boatin et al., 2016; Cordona-Morell et al., 2016). Moreover, in the study presented in paragraphs 4.2 and 5.1, they are among the most desired sensors among Italian nurses.

Despite this result, the interviews showed how the subjective qualitative assessment of the operators was largely positive in this situation. Except for one participant, the majority indicated the system could lighten their work, affecting their psychological and physical stress. This topic has not been extensively explored in the literature, although IoT or wearable technologies are often indicated as potential tools for reducing the workload (Joseph et al., 2019; Mishra et al., 2021; Zamanifar, 2021). The remaining questionnaires provided a positive picture of the system design, highly accepted by the participants, who indicated the interaction of the bed system with the management systems of the structures was a missing feature (Arora et al., 2022). Despite this, the study shows how the system can potentially be accepted by the participants while carrying out their work, as indicated by previous work on the system (Bacchin, Pernice, Sardena, et al., 2022b) and by other studies in the literature on other IoT systems (Al-Rawashdeh et al., 2022; Jara et al., 2011).

The present study also confirmed the results presented in paragraph 5.3, where I tested the usability of the touchscreen interface. The results of this test indeed showed that all the heuristics analyzed achieved high scores, and more than 75% of responses agreed with the guidelines. However, the only unsatisfactory component was the interface's aesthetics, which should be revised.

The last questionnaire concerned the user experience. The results agreed with previous interface UX tests (paragraphs 5.2 and 5.3). The complete system has therefore proved capable of providing a satisfactory user experience. In its entirety, however, it has not proved reliable, as seen from the analysis of the Aff dimension in Figure 5.34. Despite the high score, the numerous false alarms reported in the interviews have probably influenced this dimension, reducing the perception of the system's reliability. Indeed, false alarms constitute a severe problem in healthcare facilities, increasing fatigue (Winters et al., 2018) and burden (Tanner, 2013) on caregivers and decreasing patients' safety (Ruskin and Hueske-Kraus, 2015). Literature extensively treats this argument, proposing different solutions. The first would be to increase the precision of the measurement through the utilization of advanced algorithms (Nguyen et al., 2018, Data et al., 2016). Still, many other strategies have been proposed, as greatly summarized in the works of Tanner (2013) and Winters (2018). Among them, the caregivers could reduce alarm fatigue thanks to using decentralized alarm monitoring rooms, analyzing delay settings to lengthen the time between detecting an event and the alarm trigger, modifying the alarm thresholds according to the unit population, training staff on alarm management, considering alarm-related factors when choosing new equipment, changing the electrodes daily, changing the policy, and customizing alarms based on histograms for pulse oximetry (SpO2). For instance, in our specific setting, the caregivers could have set the threshold parameters, permitting the system not to signal the agitated patient alarm after a slight movement. Nevertheless, also the precision of the acquired data should be improved.

Finally, the interviews highlighted how the use of the system could help to improve the quality of care given to patients, as previously highlighted by the literature (Kotronis et al., 2019), although some responses from the participants indicated that the patients in the analyzed ward were not aware of the changes given the pathologies they presented (Alzheimer/dementia). However, it has been pointed out that improving patient care could be achieved once the operators have fully understood and learned the system's potential. As regards the question concerning patient safety, the participants agreed that the creation of alarms could provide an improvement, in line with the numerous studies present in the literature on other IoT systems (Haddara & Staaby, 2020; A. Park et al., 2018; B. Pradhan et al., 2021; Yesmin et al., 2022). The reasons were speeding up interventions, better awareness of incidents on the ward, and the ability to use the posture tracking system to determine the need for restraint.

5.4.5 Conclusions

Therefore, the proposed system proved usable and accepted by the participants, who also reported a positive experience of use. Although the workload questionnaires did not yield significant results, the interviews highlighted how they could lighten the workload and bring out their potential for improving the quality of care and safety of patients. Therefore, the study was useful in determining how the system can be a valuable aid to the operator.

6. Chapter 6

6 DOMOTIC CO-HOUSING FOR PEOPLE WITH DISABILITIES

6.1 Smart Co-Housing for People with Disabilities: A Preliminary Assessment of Caregivers' Interaction with the DOMHO System

6.1.1 Aim of the Study

The following test involved seven professional caregivers. The motivation that led to the completion of this study was twofold. Firstly, testing how the system was perceived by caregivers, focusing on aspects of perceived security, usability, ease of learning, and privacy protection, delegating job responsibilities to home automation, as essential factors for the acceptance of technologies (Gücin & Berk, 2015; Lah et al., 2020). Secondly, identifying a series of guidelines based on caregivers' opinions and suggestions to inform designers and developers to build cutting-edge systems to improve the quality of operators' work and of the life of people they care for.
The present study's objective is to evaluate in terms of performance, user experience, intention of usage, learnability, and risks perception, the interaction of caregivers with a technologically smart apartment for co-housing.

6.1.2 Materials and Methods

6.1.2.1 Participants

Seven professional caregivers (F = 7, $M_{age} = 31$; $SD_{age} = 13$) took part in the experiment on a voluntary basis. These individuals work in a daycare centre for people with disabilities. The mean work experience in the educational field is 13 years (SD = 12 years). Overall, the sample had experience in smartphone use (M = 9.8 years; SD = 2.5 years), the majority (N = 5) use voice commands at least once a week, and one participant has experience with commercial home automation (e.g., Amazon Echo). We selected the pool of subjects involving the one that followed all the system's co-design phases and would work late in the house with people with disabilities. Indeed, they were highly motivated to learn and effectively use the system and known all its possible strength and limitations.

6.1.2.2 Measures

The present study exploited a mixed approach to assess user experience and usability of the intelligent domotic system and its control interface. The following quantitative and qualitative tools were considered:

- *Computer-supported video analysis (i.e., BORIS software; Friard & Gamba, 2016) to evaluate the performances and the overall interaction of participants with the application.*

- *An ad hoc User Experience (UX) questionnaire to assess participants' user experience and usability. The instrument took into account the following dimensions: Pleasantness, Privacy, Recognition Rather Than Recall, Satisfaction, Security, Trust, Usability, and Visibility of the System Status. It consisted of 23 items on a 5-point Likert scale.*

- *A semi-structured interview with four open-ended questions.*

Several instruments were utilized in the experiment. The application that allows the control of all the smart devices was installed on a Samsung S8 Smartphone (screen 5,8", resolution: 1440×2960 pixel). A GoPro Series 4 camera (GoPro®) and a flexible tripod (GorillaPod; Joby®) were utilized to video-record the experimental sessions and permit the offline computer-supported video analysis. Finally, a Shure MV88 digital iOS condenser microphone was used, paired with an Apple® iPhone® 12 mini, to record (application MOTIV Audio, Shure©) the interviews.

6.1.2.3 Experimental Tasks

Two apartment areas were used for carrying out the experiment: the living room (i.e., an open space that also comprises the kitchen) and two communicating bedrooms. Participants were asked to accomplish four different tasks utilizing the provided smartphone for interacting with the IoT devices of the smart apartment. Two tasks were performed in the living room while the others two in the bedrooms. In the first task (i.e., T1, living room), participants should control single devices in the manual mode through the application (i.e., immediate effect). They had to control the lights (i.e., switching on and intensity) and the automation (i.e., curtains and shutters). The second task (T2, living room) required first to create a manually activated scenario (i.e., turn on all the lights and close all the automation), add it to the preferred scenarios menu, and activate it. The third task (T3, bedrooms) involved the closure of one door and the manual modification of lights through the application (i.e., state: on/off, intensity: 0-100, color: green/white/red, temperature: cold-warm). In the last task (T4, bedrooms), participants had to create an automated scenario (i.e., all lights turned off and all automation opened at 8.00 every day of the week). The order of the rooms' and tasks' presentation was counterbalanced across participants.

6.1.2.4 Procedure

The week preceding the experiment, the participants carried out a short training that presented the entire IoT system and its general functioning that lasted around 45 min. During this training, they were also able to explore and test the system freely.

After a week, the caregivers arrived at the apartment to perform the preliminary trial. Each participant had to fill out an informed consent and a short demographic questionnaire formulated to gather background information (i.e., age, gender, and frequency of smartphone use). A five-minute free exploration of the system allowed the caregiver to familiarize again with the application before the trial. Then, each participant performed all the tasks while the interaction with the smartphone was video recorded using a GoPro Series 4 camera (GoPro®) and a flexible tripod (GorillaPod; Joby®). Then, each participant filled out the ad hoc UX questionnaire. Finally, the four open-ended questions of the semi-structured interview (i.e., audio-recorded) were administered. The questions concerned caregivers' attitudes, intention, and motivation of using smart technologies to support people with disabilities and improve their working-life quality. The whole experimental session, summarized in Figure 6.1, lasted approximately 35 min.

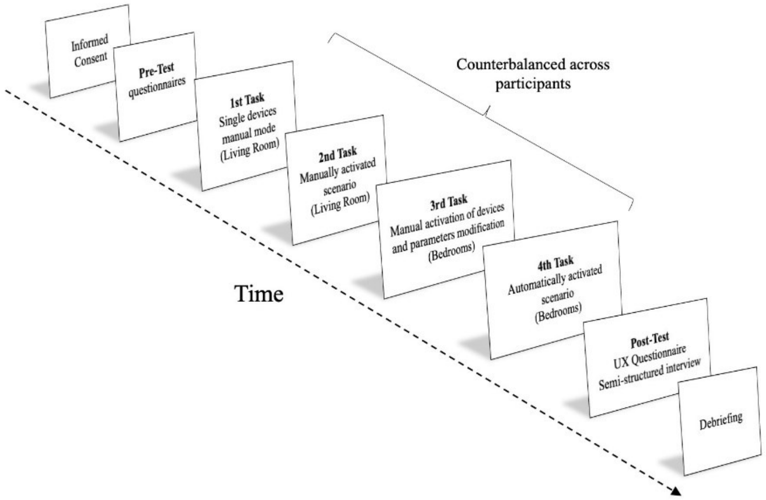


Figure 6.1. Graphical description of the experimental procedure.

6.1.3 Results

Overall, in the case of series of tests the p-values were adjusted with the Benjamini-Hochberg method (BH; (Benjamini & Hochberg, 1995)).

6.1.3.1 Video Analysis

The video recordings of participants' interaction with the control application permitted them to evaluate the various actions accomplished to complete each of the four tasks.

Participants' behaviors were analyzed in terms of number of the taps errors for each task, breakdowns occurrences (i.e., any critical moment in which the interaction slowed down or stopped; (Gamberini et al., 2013), and time on task. Moreover, a descriptive analysis of the average percentage of task success was conducted. The data of the performance in terms of the number of physical interactions (i.e., taps) is shown in Table 6.1.

Table 6.1. Tasks Performance: Required minimum N° Taps, Taps Errors, Percentual Tap Errors)

	Required Taps	Error Taps P01	Error Taps P02	Error Taps P03	Error Taps P04	Error Taps P05	Error Taps P06	Error Taps P07	% Errors/Taps
Task 1	17	4	5	11	3	10	6	21	32
Task 2	37	21	36	1	5	25	4	3	29.5
Task 3	32	21	54	11	5	4	10	2	28
Task 4	52	49	28	12	13	0	9	6	23

The analysis outcomes on time on task (i.e., the time required to accomplish each task) are shown in Table 6.2 and depicted in Figure 6.2. A series of t-test was conducted. The only significant difference was founded between T1 and T3 ($t = -5.04$, $p < 0.01$). T1 and T3 were similar and easier tasks (i.e., controlling single devices); however in T3 the time on task was longer. Besides, a t-test has been conducted to evaluate the impact of age. However, a difference did not emerge ($p>0.05$).

Table 6.2. Task Performance: Time on Task for Each Participant, Mean Time on Task, Standard Deviation, Median Time on Task

	Time P01 (s)	Time P02 (s)	Time P03 (s)	Time P04 (s)	Time P05 (s)	Time P06 (s)	Time P07 (s)	Mean Time (s)	SD	Median Time (s)
Task 1	70	84	125	64	133	136	167	111	39	125
Task 2	169	358	93	192	183	78	104	168	96	169
Task 3	195	355	261	213	235	230	195	241	56	230
Task 4	250	171	110	174	123	258	264	193	65	174

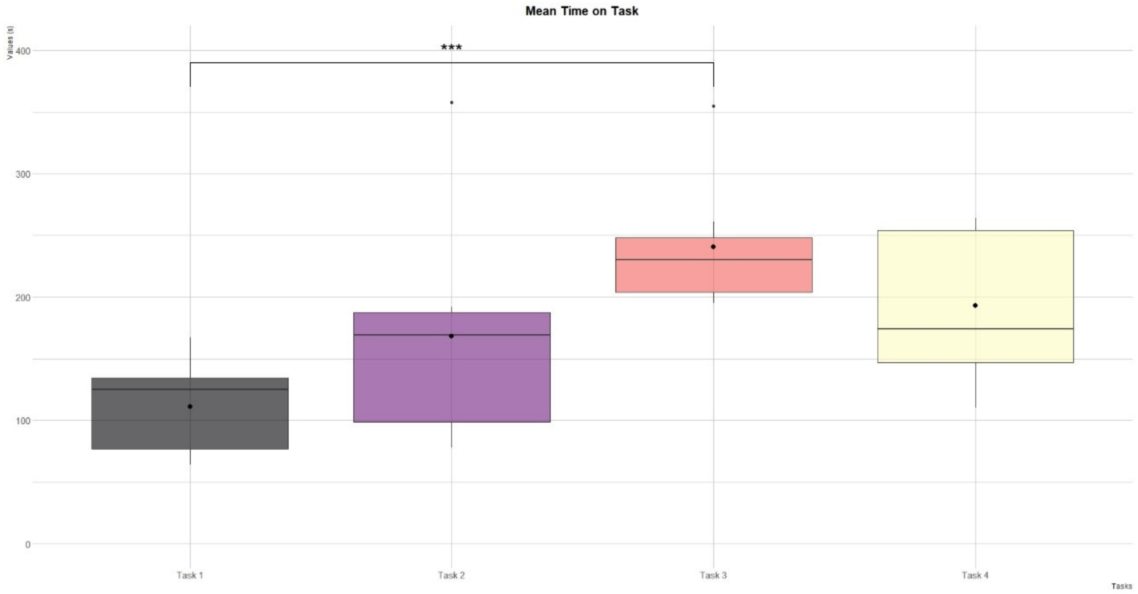


Figure 6.2. Mean Time on Task Obtained in Each Proposed Task

Moreover, Figure 6.3 shows the percentage of success in completing the experimental tasks. T1 and T3 (i.e., success percentage > 98%) were accomplished almost perfectly, while T4 and especially T2 seem to present a lower level of success (respectively 89% and 67%).

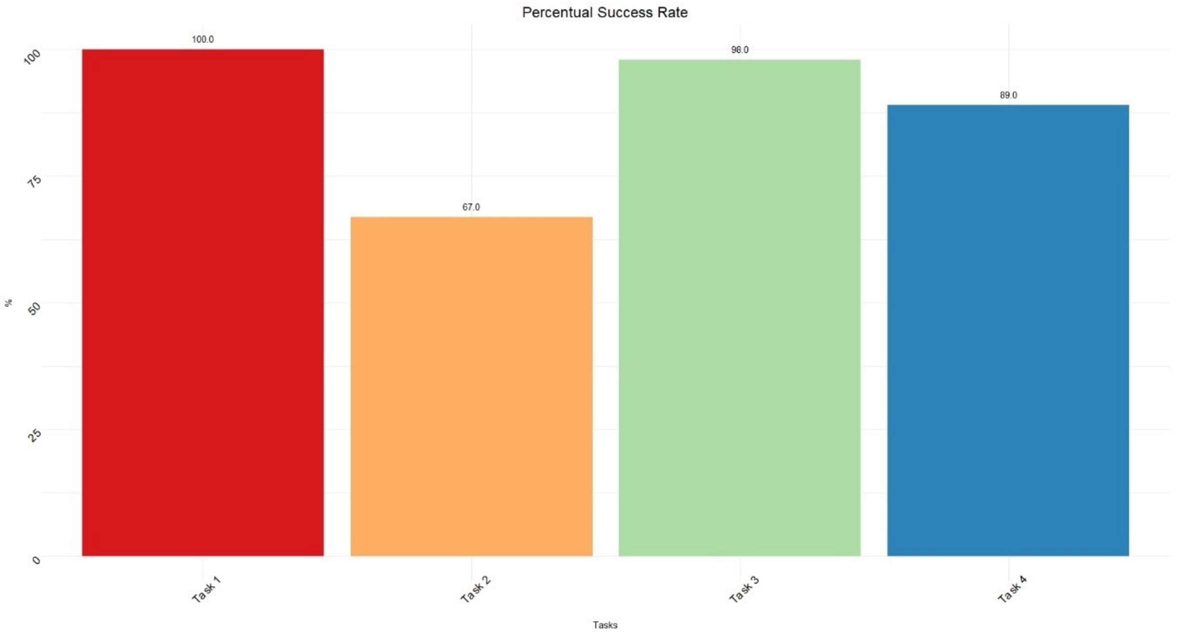


Figure 6.3. Percentual Success Rate for Each Task.

Considering the number of tap errors, no significant differences were founded across tasks (Figure 6.4). Overall, a similar amount of mistakes were made (i.e., < 17). The average errors committed by young (M = 8.4, SD = 6.9) and adult participants (M = 20.3, SD = 18.1) are shown in Figure 6.5. A trend towards significance emerged (t = 2.2, p = 0.05).

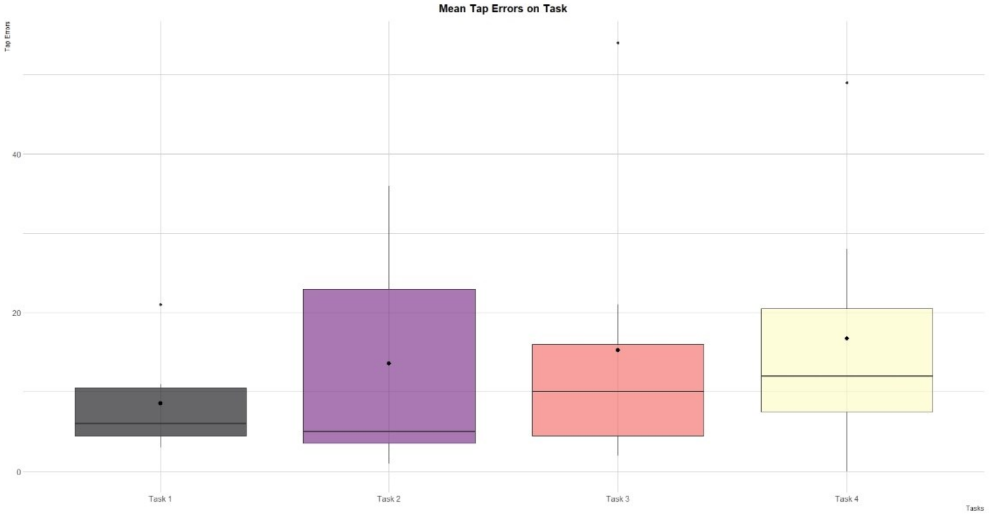


Figure 6.4. Mean Number of Errors for Each Task.

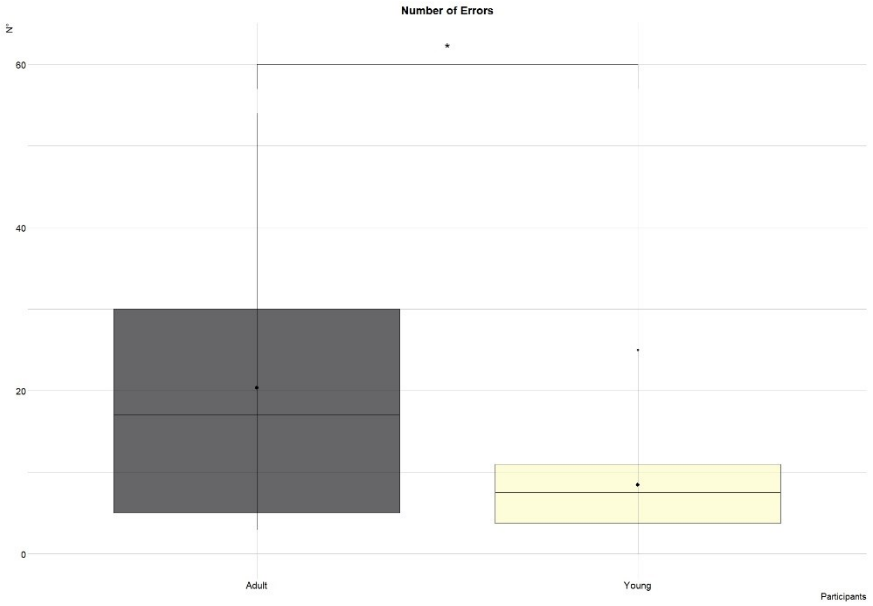


Figure 6.5. Number of Errors as a
Function of Age.

Regarding the breakdowns, two participants showed interaction difficulties in T2 linked to a misunderstanding of the feedback of the light state (on/off). One of these participants experienced a breakdown in T3 due to a doubt relate to labels of the bed lights. A third participant had a breakdown that lasted 90 seconds attempting to create a scenario in T2 by the home page.

6.1.3.2 UX Questionnaire

The participants evaluated the interface by assigning scores very close to the scale maximum for all dimensions (see Figure 6.6). The median of each questionnaire dimension was tested using one-sample Wilcoxon tests against the median value of the scale (Mdn = 3). No differences emerged (all $p > 0.05$). Finally, the analysis performed with a series of Mann-Whitney tests, considering the effect of age on the UX dimensions, did not show differences.

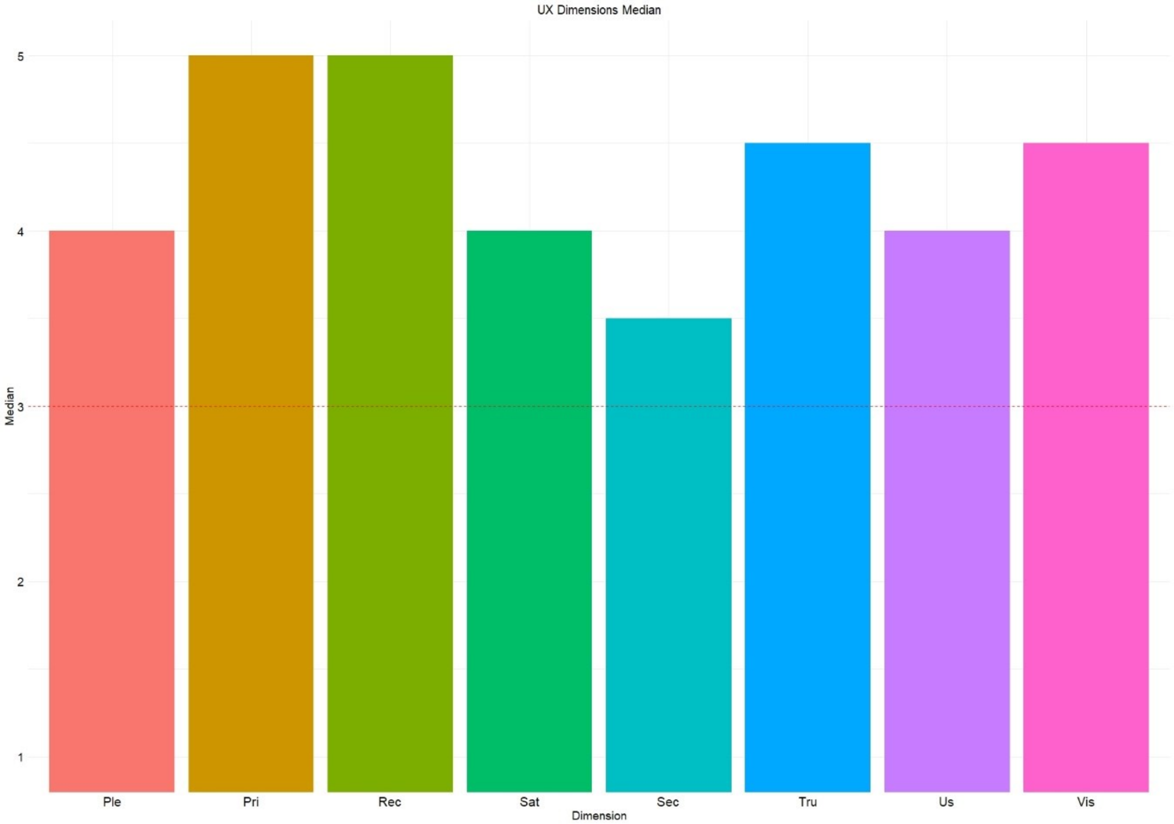


Figure 6.6. UX questionnaire. The labels for the dimensions are: Ple=Pleasantness, Pri=Privacy, Rec=Recognition Rather Than Recall, Sat=Satisfaction, Sec=Security, Tru=Trust, Us=Usability and Vis=Visibility of the System Status.

6.1.3.3 Interview

The semi-structured interview included four questions that investigated the reasons for future use, potential risks, ease of use of smart technologies, and a particular aspect of acceptance, namely the operator's responsibility. The interviews were transcribed and analyzed using the thematic analysis with a deductive approach, dividing the respondents' answers according to the emerged topics and analyzing their frequency and content (Braun & Clarke, 2006). Each question and the relative analysis are detailed in the following sub-sections.

Q1 - After using the application, do you think that you would be intended to use these tools in your work? What are the reasons that would promote you to use them?

An overall agreement was related to the intention of using these technologies in their work. A greater enthusiasm appears in the statements of young operators (P03: "*Oh yes, yes yes yes"*; P06: *of course yes, it would be a significant help, to the users and also for the caregivers*) compared to the older ones (P01: "*So, yes, after trying I would like to use the same things*"; P02: "*on the part of the operators I think so*"), which, however, show feelings of caution but optimism. This can also be found in the words of

P02, which defines the age and her low habits to technologies as fundamental factors for the acceptance of technology (P02: "*the limits for us operators, chronological age and history in the use of these means can make the operator a little more reluctant"*). To what concerns the reasons that would promote the use of IoT systems, it is interesting to note that operators initially answered from the perspective of people with disabilities and not for themselves. Participants stressed the importance of the system for promoting the autonomy of the individuals with disabilities (P01: "*to promote the autonomy of people*"; P02: "*they make the person more independent and more autonomous*"; P04: "*see and enjoy with the people what they can do independently*"; P05: "*because the technologies can give the autonomy that they need"*). Instead, from their point of view, the caregivers would use the system to support the working or daily activities (P01: "*it facilitates my professionalism*"; P06: *"technologies can reduce useless activities"*; P07: *"They make many things easier for you if by simply pressing a button all the lights are turned on, or the shutters lowered"*) and the reduction of workloads and anxiety (P04: "*I have a lower load, it lightens the anxiety and heaviness factor of the work*"). Furthermore, the safety systems have been identified as capable of providing help for greater attention to the people with disabilities and preventing accidents (P03: "*it can help me, as for a fall … to have greater attention and prevent a dangerous situation*").

Q2 - What do you think about the potential risks linked to these technologies?

The operators highlighted how the general concern is linked to the potential incorrect functioning of the smart technologies (P01: "*an uncontrolled activation of scenarios or some aspects*"; P04: "*Non-functioning is a risk*"; P07: "*at the end, it is not a risky situation. Maybe only the non-functioning of the system could be a risk*"). The remaining operators were worried about system failures due to infrastructures, such as the supply of electricity and the internet, on which the system depends and which have their intrinsic reliability. If these systems fail, the participants were worried that this would not allow the system to work (P02: "*if you do not have the current and you cannot open"*; P03: "*I would not want the Wi-Fi to be missing, current, some things may not be correct"*; P06: *"I would be worried in case of a blackout of the entire system"*). In part, this problem has been addressed by one of the participants with a possible solution. She mentioned the presence of manual controls (i.e., walls buttons) that will allow controlling the smart home also if a Wi-Fi connection was not present (P04: "*The not working is a risk, but having the manual part is reassuring*"). These malfunctions, however, are considered more serious when they involve systems for personal safety. Two operators underlined in such circumstances potential severe but unreported risks (P01: "*a sensor may not work, this is also a potential risk"*; P03: *"some emergencies, I don't know for example a fire by magnifying, they are not declared in the app exactly"*). One operator reported the need to be able to call support after trying unsuccessfully to solve a problem by herself (P03: "*first, I try to understand what is not working. I evaluate the situation when the app does not work, and if I find myself in a difficult situation that I cannot solve alone, then clearly yes, I have to call someone, but it concerns events that I hope are important and not in small things*"). The interviews also pointed out the risks from external attacks (P03: *"I think that afterward, it will be up to the technicians to study a security element to avoid external infiltration into applications concerning everything they have to guarantee"*). It should be noted that only one participant reported it, showing a generally low awareness of cybersecurity problems.

Q3 - According to you, is it simple to become quickly proficient in using the application and the home automation system?

Overall, the participants reported that the control interface was easy to use (P02: "p*racticing yes"*; P03: "*In my opinion yes*") and intuitive (P01: "*there are intuitive elements*"; P02: "*the system is* *intuitive, the system is intuitive*"; P04: "*Even scenarios are intuitive*") and that it is possible to learn how to use the application with a short period of practice (P01: "*with a bit of training you can do it*"; P02: "*when you use it, it becomes more automatic*"; P04: "*continuing to use it becomes easier and easier*"; P07: "*with a bit of training it became a natural interaction*"; P06: "*Yes, after you use it a couple of times*"). One participant (P05) was more enthusiastic. She stated that the app and IoT technologies were simple ("*I liked it, it's simple*"), fun ("*It was also fun, I must say*"), quick to learn ("*you learn it quickly*"), and highly usable ("*It's clear. Is explained clearly and it's easy to use*"). The influence of age and technology expertise emerged in the answers (P02: "*those who are younger are already born with the instrument and have a different history and are certainly more skilled*"; P03: "*they are used to the smartphone ... they will be able to use it even better than me*"). Besides, for the first time, the importance of personal technological predisposition was mentioned (P04: "*I believe that there is always the most and the least capable persons*").

Q4 - Do you think that it could be possible to leave some of your working responsibilities to the home automation system?

In general, despite the answers indicated a positive attitude to delegate working responsibilities, caregivers affirmed that they would leave the system with the most practical and low-responsibility tasks (P01: *"In part yes, it can be in control of some situations, of some tasks yes, it is very practice"*; P03: *"More than responsibility I would say for some tasks*"; P05: *"Watching television; open the windows if they need to, get food"*; P06: *"Yes to those more futile things yes. That is in the sense of turning on the light, doors, these things here."*; P07: *" He can safely turn on the lights or check the gas, air, or anything else. I think he could easily handle work duties as well"*). The main reason is that they felt the responsibility of actively supporting and grant the safety of people with disabilities (P03: *"Not for the work that I do, I deal with people, not with objects or materials, I don't want to give all the responsibility to a home automation device I tell you the truth "*; P06: *"Not when is linked to the person safety"*). The concept of not leaving all their work duties to the system can be explicitly found in the majority of the sample (P01: "*However, if I think about security surveillance and other aspects, I still need time to rely on the system fully, I should have something"*; P03: *"Partially yes, absolutely, but the responsibility in the first place must be mine"*; P04: *"the complete 100% no"*). In one comment, this concept can be inferred (P02: "*Then surely the application gives the possibility of being less present as surveillance"*). Her statement does not take surveillance/assistance for granted but indicates how a smart integrated system gives the opportunity of being less present. One caregiver suggests using IoT systems video cameras to surveil residents when they have to leave the apartment temporarily (e.g., going quickly to the grocery store, P01: "*video control could give greater security*"). Other two caregivers stated that they would be more prone to trust a system that allows people with disabilities to call for help in case of need (P01: "*knowing that one of the people can effectively call or activate independently*"; P04: "*at least I'm sure that a child with this device here can give the alarm or thanks to it call me with the tablet or the like for the emergency*"). This question also points out insights about the Q1. Indeed, two of the operators underlined the system usefulness to reduce work-related stress thanks to the active surveillance and possibility for people with disabilities to ask for help through the IoT system (P01: "*I would leave people with disabilities in here [in the apartment], and I can go away, I can go and get something*"; P02: "*Then surely the application gives the possibility to be less present as surveillance*"; P04: "*that time when I have to go out for a moment I go away more calmly*").

6.1.4 Discussion

This work described a preliminary trial in the context of the Domho project, involving a sample of seven caregivers in using a mobile application that permits the control of different smart devices of an integrated IoT system installed inside a residential apartment. Participants carried out four tasks designed to examine the performance, user experience, and usability of a control interface designed and developed in DOMHO. Besides, the subjective perceptions of caregivers towards Smart Home and IoT systems were assessed.

Regarding video analysis, the first result that emerged is the importance of the organization of the living spaces. In T1, 5 out of 7 participants tried to manage lights and automation by selecting the kitchen instead of the living room. This occurrence is linked to the fact that the user interface splits the day area into two parts, i.e., kitchen and living room (Figure 6.7).

This result showed that this configuration causes confusion and slows down the interaction with the smart devices insofar as caregivers considered the wide room as a single open space. Thus, they select the wrong "sub-room" in trying to activate lights or automation. Instead, the control interface organization should be intuitive and clear without requiring users to remember information (Sharp et al., 2019). Using two labels to describe different sub-spaces inside the same room (i.e., open space), even if the system uses known conventions, might negatively influence the interaction. Indeed, participants must remember the exact technologies present in each part of the open space.

Figure 6.7. Subdivision of the SH environment.

Another aspect that emerged from the video analysis of T3 (i.e., bedroom manual control) is the importance of allowing end-users to customize the labels inside a control interface. T3 presented the longer time on task (M = 241s; Table 2) likely because the smart devices labels were selected by the developers and not directly by the operators. T3 breakdowns were caused by difficulties in comprehending the different labels assigned to the smart lights of the beds. Nevertheless, the DOMHO application allows the possibility to customize the names of devices and living spaces (i.e., kitchen, living room) according to the user's preferences. This aspect is even more relevant whether individuals with disabilities are considered. In this case, personalization in terms of simplification is crucial to increase the control interface accessibility and inclusiveness (Estes et al., 2020; Loitsch et al., 2017).

Another aspect of usability that should be present in these types of applications is the flexibility of use. According to the ten Nielsen Heuristics, the interaction should be flexible and efficient, easy to use for the novices, and present alternative ways to accomplish the same action and shortcuts for expert users (Nielsen, 2005). The video analysis shows that during the turning on of the living room lights, one participant (P04) did not click on the white part of the button (like the other participants) but found a shortcut clicking on the lamp icon (placed on the right part of the button) to turn it on instantly (Figure 6.8), reducing the number of taps. However, this result shows that the application is designed to allow the accomplishment of the same task in alternative ways exploiting intuitive icons that might speed up the interaction based on the user expertise (i.e., novices, experts; Sharp et al., 2019).

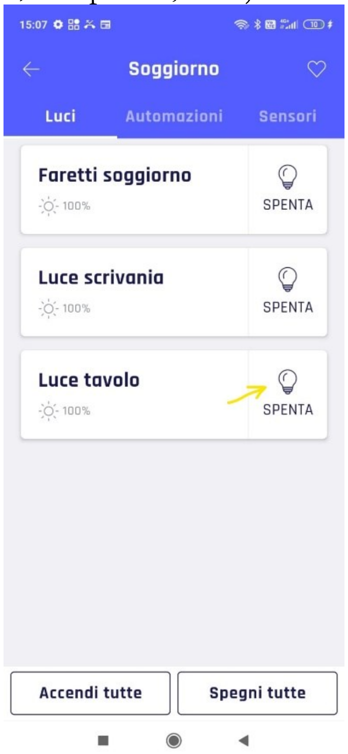


Figure 6.8. Shortcut for switching on lights.

One of the main problems encountered by caregivers was setting up a manual or automated scenario without controlling the settled state with appropriate feedback. For this reason, two breakdowns occurred. In T2, 3 out of 7 participants turn off lights instead of turning them on, failing to accomplish a part of the task. This lack of feedback and interaction-related problems are underlined by the lower percentage success in T2 and T4 (Figure 4, T2 = 67%, T4 = 89%). In particular, the analysis shows the difficulties in understanding the current lights state. However, it was not the same for automation. As can be noticed from the comparison in Figures 6.9, 6.10, and 6.11, the difference was precisely in the type of feedback. For the automation, the screen presents the user with the possible states (Figure 6.11). However, in lighting, the system uses a method more based on logic and text. If the light is set off, the system offers the user a screen with a dark background and a message "turn on" (Figure 6.10). Instead, when it is set as on, it presents a light background and the words "turn off" (Figure 6.9).

Figure 6.11.
Automation
feedbacks.

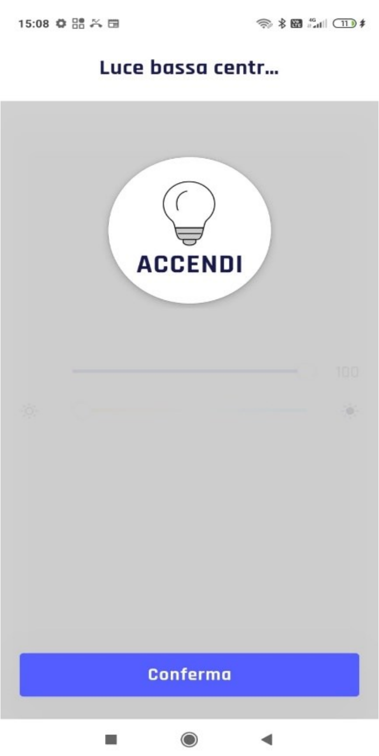


Figure 6.10.
Figure 10. Light
Off feedback.

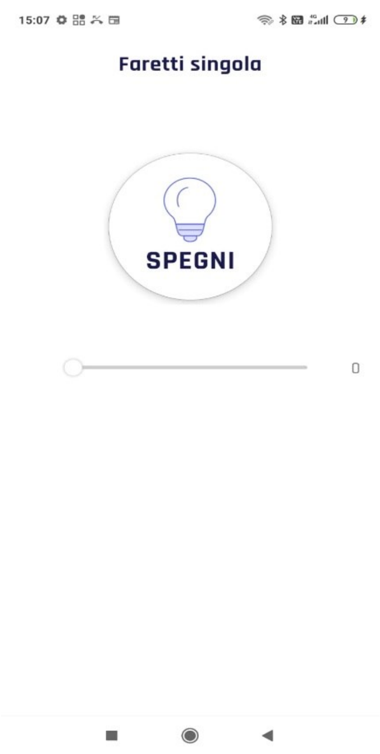


Figure 6.9.
Light On
feedback

Despite being a system that follows a precise logic, the interface is confusing for a novice user, as demonstrated by the analysis. Therefore, it is advisable always to show the user immediate, clear, and understandable feedback, based mainly on the graphic component and not on the logic language rules. Indeed, clear icons accompanied with text are particularly indicated for novice users to reduce the mental load needed to learn the new technology, especially when these people, such as the elderly, have some impairments (Huang et al., 2019). Although the experiment was conducted only with the operators, it is also helpful to extend this consideration to the other type of end-users who will use the system, namely individuals with disabilities. Given the problems of understanding due to potential mild cognitive disabilities, these people could also benefit from using graphical elements (i.e., icons).

An overall positive subjective experience emerged from the analysis of the UX questionnaire. Interestingly, the median scores assigned to privacy, trust, and security dimensions, that represent well-known issues in the IoT field (Atlam & Wills, 2020), were all above the median of the scale (i.e., Pri = 5; Tru = 4.5; Sec = 3.5). A possible explanation could be that because the operators were involved in developing and selecting the devices (i.e., participatory design approach) included in the smart co-housing apartment. Together with the sense of usefulness perceived about the system, their involvement during the design phase could have resulted in an overall positive attitude towards the DOHMO application and IoT system. The interviews data also support this. Also, the multiple clarifications regarding the policies of personal data protection guaranteed by the researchers and companies involved in the project increased the caregivers' confidence in the system ability to protect their data and privacy. Another possible explanation could be that the operators were not fully aware of the IoT system's privacy problems. Summarizing, it seems that involving users actively in the design and selection of technologies has resulted in higher smart home trustworthiness. The interviews show that they were more prone to think about malfunctions and infrastructure problems when the researchers ask about system possible problems and limitations.

Finally, the questionnaire scores show a high level of pleasantness and satisfaction in using the system and highlight the intuitiveness of the system. These aspects could be related to the crucial involvement of participants in the design and development of the DOMHO integrated system. I look forward to assess these attitudes and subjective perceptions considering people with disabilities. Indeed, the scientific literature has underlined the importance of capitalizing on user centered design to co-create intelligent tools and environments with and without disabilities (Augusto et al., 2018; Chin et al., 2019). The analyses described so far regarding the user experience questionnaire and the behavioural data of tasks success percentage show that the participants evaluated the interaction positively, obtained satisfactory results, and evaluated it as usable, reliable, and able to guarantee security and privacy, as hypothesized in H1.

As for the analysis of the interviews, the results can be summarized as follows. In the answers to the first question, caregivers showed positive attitudes towards the system adoption as a supportive tool in their work. The reported advantages are reducing workload and enhancing the autonomy and independence of individuals with disabilities (Carnemolla, 2018). These comments align with the literature on caregivers and decrement in burden due to the exploitation of smart technologies in their working environments (Seelye et al., 2012). The analysis of the interviews' transcriptions highlights how this perceived usefulness seems to be relevant for the envisioned benefits for both caregivers and the individuals that they assist.

Concerning the second question, main concerns emerged about generic system malfunctions and minor errors (e.g., lack of electricity, no internet connection, not working lights, etc.) that become more worrying when they regard the safety systems and, therefore, sensors (e.g., air quality, video cameras, etc.). This problem could be partially mitigated by providing alternatives to control the intelligent technologies, like manual control systems (i.e., wall buttons) and the possibility to control them without an internet connection.

As for ease of use, operators stated that the system and the interface are simple to learn and intuitive, even if they require a short period of practice to be mastered, reflecting a high level of learnability (Grossman et al., 2009). To be more specific, this is known as "initial learnability" which allows users to reach a reasonable level of efficacy and efficiency in utilizing a novel technology in a reduce amount of time (Nielsen, 1994). These findings matched the high scores assigned to the usability in the UX Questionnaire (Figure 7, Us = 4). Among the factors that influence rapid learning highlighted by the interviews are age, expertise with technologies, and personal predisposition. The video analysis results also confirmed this impression of the operators, confirming that the number of errors made is influenced by the participants' age (Figure 6).

Finally, as far as professional responsibility is concerned, the system seems to have been well accepted but cannot completely fulfil the operators' responsibilities. To better define this concept, it emerged that the system is particularly suitable for manual, simple, and repetitive tasks. Nevertheless, it does not generate blind trust in the operator in case of possible risk situations for people's health. Despite this limit, there was a positive attitude towards the intention of adopting this integrated smart system in the future to prevent dangerous situations. Nevertheless, the system is perceived as a "technological collaborator" that has to be supervised in the most important, complex, and delicate tasks. As for the possible solutions to enhance trust in the system during emergency management, the operators suggest that the system should be structured in such a way to ensure high accessibility for people with disabilities to call for help and receive quick assistance. The operators assign great importance to this concept of leaving the apartment in case of need. This behaviour could only be possible if at least one of the people with disabilities could set off an alarm. Therefore, putting the system in the position of empowering one of the occupants with disabilities to call for help could reduce the caregivers' work-related stress and anxiety (Bruno et al., 2018). As for the video surveillance solution, the potential problems probably outweigh the benefits. Indeed, the security and privacy issues and the feeling of being controlled, that may be experienced by people with disabilities, could compromise the whole system's acceptance and decrease the feeling of independence (Krempel & Beyerer, 2014).

Concluding, the interviews showed that the system is perceived as a positive instrument by the operators, who found it reliable, easy to learn and use. Furthermore, the perceived risks were minimal and mostly related to the infrastructures and not to the system itself. These results corroborate the H2 and therefore show the maturity of these systems for introduction into real work environments.

6.1.5 Conclusion

This study firstly highlights some of the characteristics that similar systems should present to elicit a positive user experience and be accepted by caregivers, such as flexibility in the terminology and organization of a control interface elements, the presence of appropriate feedbacks and so on.

The research also highlights that the whole assisted living environment has been well accepted by the caregivers. Moreover, the study hypothesizes that even known problems in the field of IoT technologies, such as trust and privacy, can be mitigated by involving the participants in activities of participatory design. Besides, moderator factors in the acceptance of these advanced technologies are the perceived utility and usefulness in work supporting and in increasing life quality and well-being of the assisted persons. Future trials will involve individuals with disabilities to assess user experience, usability, acceptance of this smart co-housing apartment. Groups of two/three individuals on rotation will live for 2/3 days (i.e., weekends) inside this Smart Home with one caregiver. Specific attention will be devoted to the subjective perceptions of living in a smart environment, quality of life, satisfaction, autonomy and independence, and the co-housing experience itself. Despite the major limitation of this study, namely the participants numerosity, using a set of mixed research methodologies (i.e., quantitative and qualitative) allow a comprehensive analysis of the overall caregivers' experience and performance in interacting with a smart home and its control interface. Designers and developers could benefit from these indications to realize technologies that meet the users' needs, both for people with disabilities and their caregivers.

6.2 Smart Cohousing: An Evaluation of Human Factors from People with Disabilities and Caregivers' Perspective.

6.2.1 Aim of the Study

This study explores people with disabilities and caregivers' perceptions of domotic technologies. Firstly, I evaluated a pool of questionnaires (i.e., Technology Acceptance, User Experience, Usability, Sense of Home, Sense of Home related to technologies) and objective measures (i.e., log data, performance) after a single weekend of use. Furthermore, I evaluated the caregivers' potential longitudinal variations in subjective perceptions after three months of domotic technology use. In the last part of the study, people with disabilities lived with and without the DOMHO technologies (presented in Paragraph 2.5). The aim was to research potential differences between their subjective perceptions of Caring Behavior and Sense of Home in these two conditions.

6.2.2 Materials and methods

6.2.2.1 Participants

Fourteen people with disabilities took part in the study, aged between 23 and 60 (M_{age} = 43.6, SD_{age} = 13). Six participants (M_{age} = 47.7, SD_{age} = 13.1) spent two weekends (respectively with and without smart technologies). As for the caregivers, 10 of them filled out the questionnaires after a weekend stay in the apartment (M_{age} = 34, SD_{age} = 10.95). Besides, 4 of them continued the experimentation and filled in the questionnaires after three months of usage (M_{age} = 26.5, SD_{age} = 8.39). The sample of people with disabilities was characterized by 3 participants affected by traumatic brain injury, 2 participants affected by non-traumatic brain injury (i.e., tumour, encephalitis), and 9 participants affected by congenital or neurodegenerative disorders (i.e., Spastic tetraparesis, Sjogren's syndrome, Fukoyama muscular dystrophy, mental retardation, Arnold-Chiari syndrome, spastic paraparesis with oligophrenia, dysbasia, spastic diplegia).

6.2.2.1 Procedure

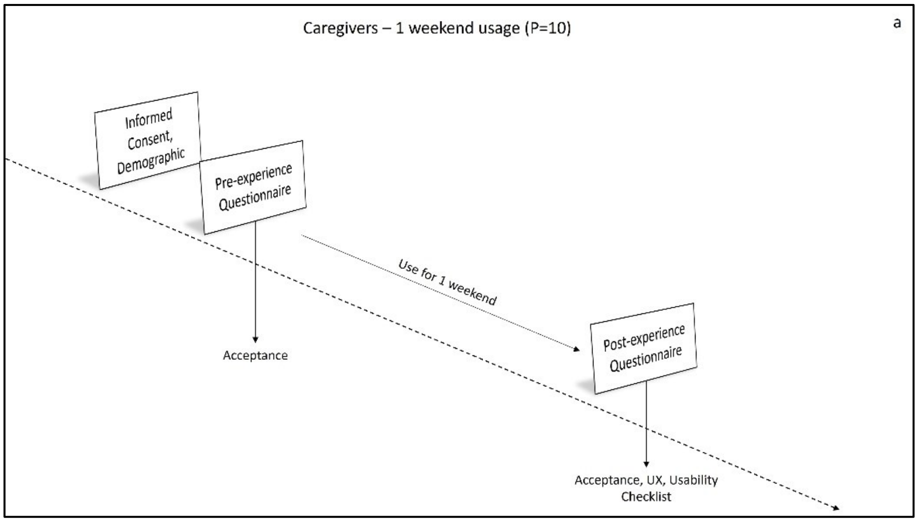
Participants, people with disabilities and caregivers, were recruited from an assistance centre for people with disabilities. Before the study, all participants compile an informed consent. Every weekend, a group of three (different people every weekend) spent three days (from Friday to Monday) in the smart home, assisted by four caregivers organized in shifts.

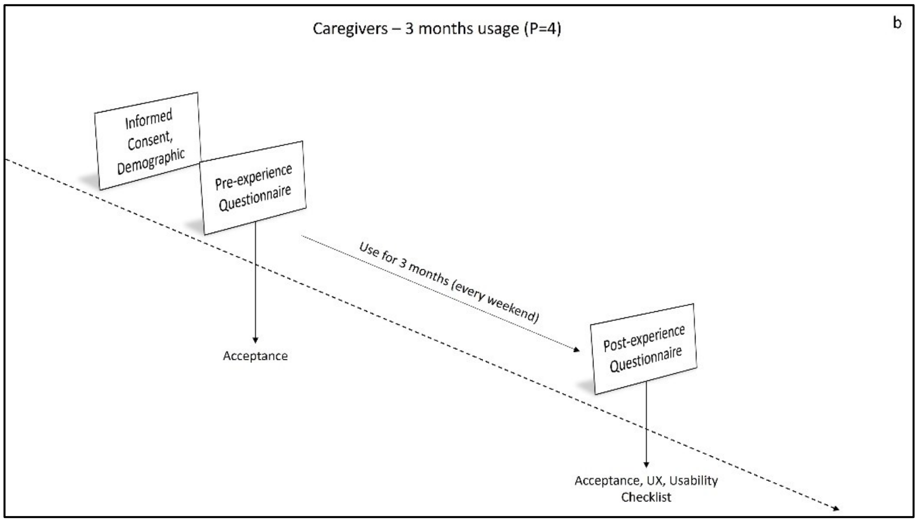
Regarding the caregivers, the study comprehends two different populations. Ten caregivers spent at least one weekend learning how the system works and fulfilled questionnaires before (i.e., Acceptance, Demographic) and after (i.e., Acceptance, UX, Usability Checklist) this single experience with the domotic technologies (Figure 6.12.a). Among them, four caregivers assisted people with disabilities for the entire duration of the experience (3 months). To show possible longitudinal changes, I analyzed the answers of these four caregivers to the same questionnaires before and after the three months of use of domotic technologies. Caregivers compiled the questionnaires on a personal pc on the platform Qualtrics immediately after the conclusion of their shift (Figure 6.12.b).

Regarding people with disabilities, the first experimental design involved 14 participants in evaluating the system after one weekend of use (Figure 6.12.c). Each experimental session started on Friday afternoon. Firstly, a researcher collected the pre-experience questionnaires about technology acceptance and demographic information. The researcher administered the questionnaires reading every item and ensuring participants understood the question's meaning. Frequent pauses were granted in between the questionnaires. Participants could visualize in every moment a printed version of the answering scales. The participants were then trained (familiarization phase) to use the DOMHO system with the control interfaces (i.e., GUI, on a smartphone and a tablet, and the voice-based). Since many users were physically impaired, the study examined the tablet interface instead of the smartphone to facilitate the process. However, participants could also familiarize themselves with the smartphone if they wanted to. The test comprises access to the interface, turning on the table light in the living room, closing the kitchen shutters, and opening the bathroom door. The same tasks were completed with both interfaces (i.e., tablet and voice control). Every task was video registered for further analyses. After the weekend, the researchers collect the post-experience questionnaires (i.e., Acceptance, UX, Usability Checklist, CBI, SOH, SOHT).

A further part of the experiment compared participants' subjective responses in the presence and absence of the domotic technologies (Figure 6.12.d). Six people with disabilities among the 14 participating in the previously described procedure joined this part of the study. They were split into two groups (three members each) to experience the home without the domotic devices. They fulfilled SOH and CBI questionnaires after both experiences (i.e., one with and one without smart technologies).

The complete experimental designs are described in Figure 6.12.





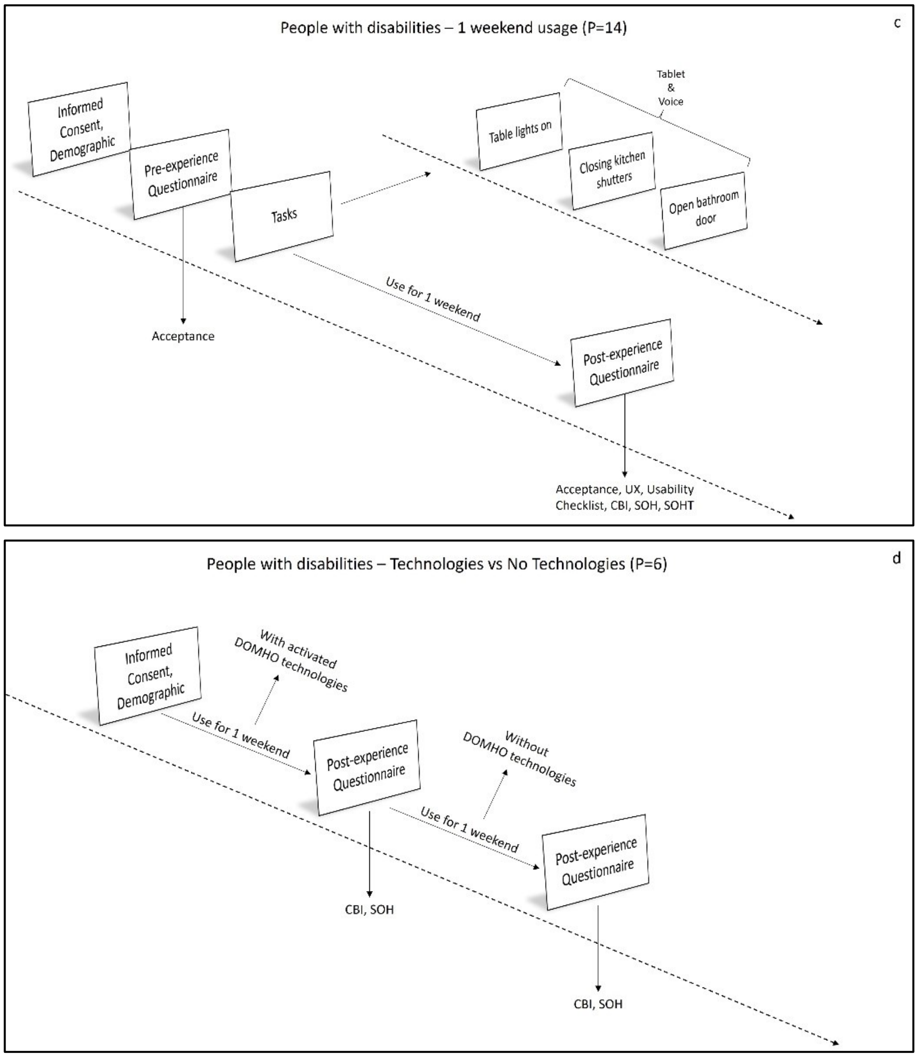


Figure 6.12. Description of the experimental procedures. The figure shows the experiment with caregivers using DOMHO technologies for only one weekend (a), caregivers using technologie for 3 months every weekend (b), people with disabilities for only one weekend (c), and people with disabilities with and without DOMHO technologies for one weekend for each condition (d)

6.2.2.2 Measures

6.2.2.2.1 Technology Acceptance

An *ad hoc* questionnaire assessed the following dimensions: Attitude (AT), Compatibility (COM), Perceived Control (CON), Perceived Cost (COS), Enjoyment (E), Perceived Ease-of-Use (EU-

PEOU), Intention of Use (INT), Perceived Connectivity (PC), Perceived Safety (PS), Perceived Usefulness (PU), Subjective Reliability (SR). The questionnaire includes 38 items, and the answering scale is a 7-point Likert scale (i.e., from 1, totally disagree, to 7, totally agree).

6.2.2.2.2 *User Experience - UX*

An *ad hoc* questionnaire explored the following dimensions: Pleasantness (PL), Satisfaction (SAT), Engagement (ENG), Autonomy (AUT), Benefits (BEN), Privacy (PRI), Security (SEC), and Trust (TRU). The questionnaire includes 26 items, and the answering scale is a 5-point Likert scale (i.e., from 1, totally disagree, to 5, totally agree). At the end of the UX questionnaire, a single item analyzed the interface preferences of the respondents. They could choose from vocal command, tablet, smartphone, and no preferences.

6.2.2.2.3 *Caring Behavior Inventory - CBI*

The CBI questionnaire used in this study was obtained from the short version of the Coulombe instrument (Coulombe 2002), translated into Italian. The scope of the questionnaire was to evaluate the perception of the care quality from the people with disabilities' point of view. The questionnaire includes six items on a six-point scale (i.e., from 1, never, to 6, always).

6.2.2.2.4 *Sense of Home - SOH*

The SOH questionnaire was created ad hoc for the experiment. The tool included 18 items adapted from Wada and colleagues (Wada et al., 2020). The scope of the questionnaire was to evaluate the perception of home regarding the DOMHO apartment from the people with disabilities' point of view. The questionnaire includes four dimensions: Physical environment Feature (PEF); Privacy and Personalization (PP); Autonomy, Choice and Flexibility (ACF); Connectedness and Togetherness (CT). The answering scale is a 7-point Likert scale (i.e., from 1, totally disagree, to 7, totally agree).

6.2.2.2.5 *Sense of Home Technologies - SOHT*

The sense of home related to DOMHO technologies is a 19-item questionnaire that asked participants if the devices listed were able to make them feel like they were in their own home. The items list every smart technology present in the DOMHO apartment. The scope of the questionnaire was to evaluate the perception of home regarding the DOMHO apartment technologies from the people with disabilities' point of view. The answering scale is a 7-point Likert scale scale (i.e., from 1, totally disagree, to 7, totally agree). The questionnaire is subdivided into six dimensions: Kitchen (Ki), Sensors (Se), Entertainment (En), Fixtures (Fi), Lights (Li), and Medicals (Me).

6.2.2.2.6 Usability Checklist

An *ad hoc* usability checklist was prepared to collect subjective perceptions of usability. The questionnaire explores the following dimensions: Navigation (Nav), Accessibility (Acc), Clarity (Cla), Visibility of the System Status (Vss), Recognition Rather than Recall (RrR), Match the Real World (MrW), Voice Commands (Voic). The questionnaire includes 38 items, and the answering scale is a 7-point Likert scale scale (i.e., from 1, totally disagree, to 7, totally agree).

6.2.2.2.7 Video analysis

The practical test was videorecorded. The videos were analyzed to evaluate the performance (time on task and errors) in different tasks. The number of errors was obtained by subtracting the ideal number of interactions (the correct task accomplishment with the minimum actions) from the total number.

6.2.2.2.8 Use Data

The DOMHO system can collect log data about the usage of every technology. I calculated the percentage of use of every control interface (i.e., smartphone, tablet, voice).

6.2.3 Results

For the questionnaire analysis, the median scores of the items grouped in the same dimension were tested against the scale median with a series of Mann-Whitney tests. Wilcoxon tests were carried out to evaluate potential differences between the pre- and post-experience dimensions. In the case of multiple comparisons, p-values were adjusted with the BH correction (BH; Benjamini & Hochberg, 1995). For the Usability Checklist, the percentage of positive answers for each dimension was computed. I compared the answers of caregivers and people with disabilities using a beta-regression test. I used the software R (R studio, 2022) to perform the statistical analysis.

6.2.3.1 Technology Acceptance

6.2.3.1.1 Caregivers (N=10) – 1 weekend usage

Pre-experience. A series of Mann-Whitney tests against the median of the scale (i.e., 4) was performed. The results are shown in Figure 6.13. Dimensions: AT $p<0.001$, COM $p<0.001$, CON $p<0.001$, COS $p<0.001$, E $p<0.001$, EU-PEOU $p<0.001$, INT $p<0.001$, PC $p<0.001$, PS $p<0.001$, PU $p<0.001$, SR $p<0.001$.

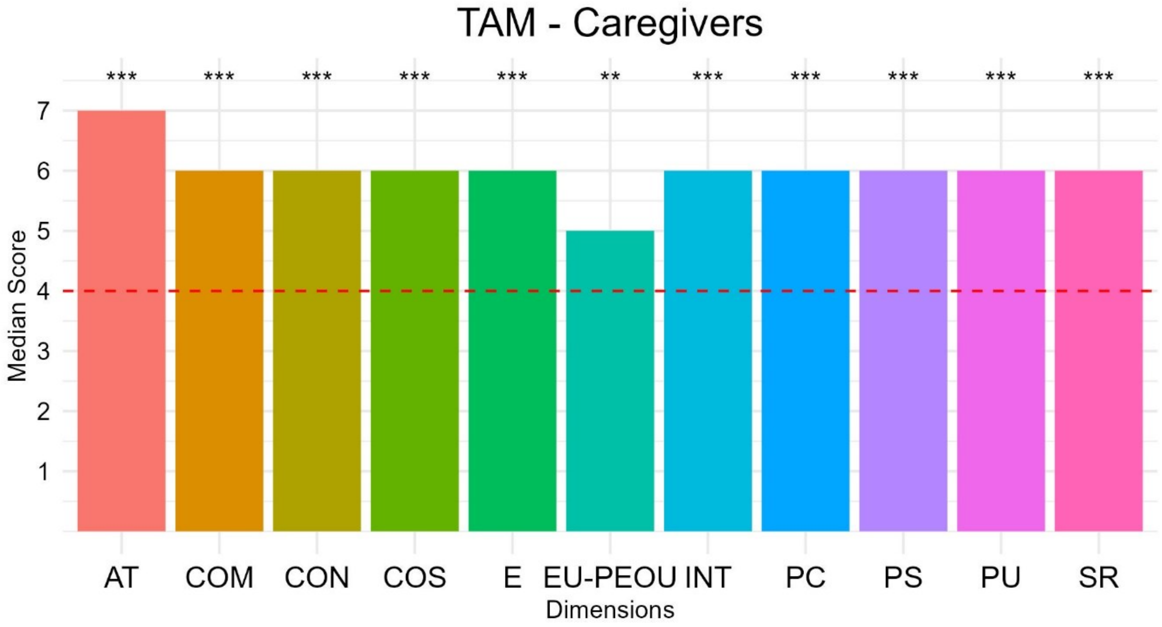


Figure 6.13. Caregivers – 1 weekend usage – Pre-experience.
***=p<0.001; **=p<0.01; *=p<0.05.

Post-experience. A series of Mann-Whitney tests against the median of the scale (i.e., 4) was carried out. The results are shown in Figure 6.14. Dimensions: AT $p<0.001$, COM $p<0.01$, CON $p<0.001$, COS $p<0.05$, E $p<0.001$, EU-PEOU $p<0.01$, INT $p<0.001$, PC $p<0.001$, PS $p<0.001$, PU $p<0.01$, SR $p>0.05$.

Pre vs Post experience. I analyzed the potential differences between the pre- and post-experience using Wilcoxon tests. No differences emerged (all $p_s > 0.05$).

6.2.3.1.2 Caregivers (N=4) – 3 months usage

Pre-experience. A series of Mann-Whitney tests against the median of the scale (i.e., 4) was conducted. The results are shown in Figure 6.15. Dimensions: AT $p<0.01$, COM $p<0.05$, CON $p<0.01$, COS *p*<0.05, E *p*<0.01, EU-PEOU *p*<0.01, INT *p*<0.05, PC *p*<0.01, PS *p*<0.001, PU *p*<0.05, SR *p*>0.05.

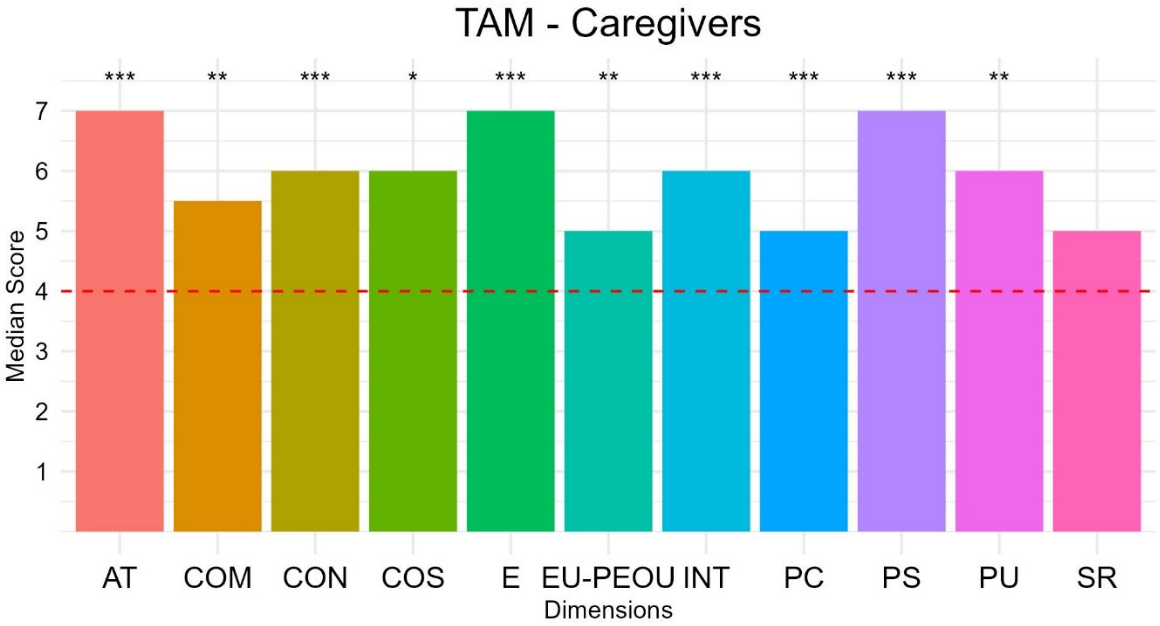


Figure 6.14. Caregivers – 3 months usage – Pre-experience.
***=p<0.001; **=p<0.01; *=p<0.05.

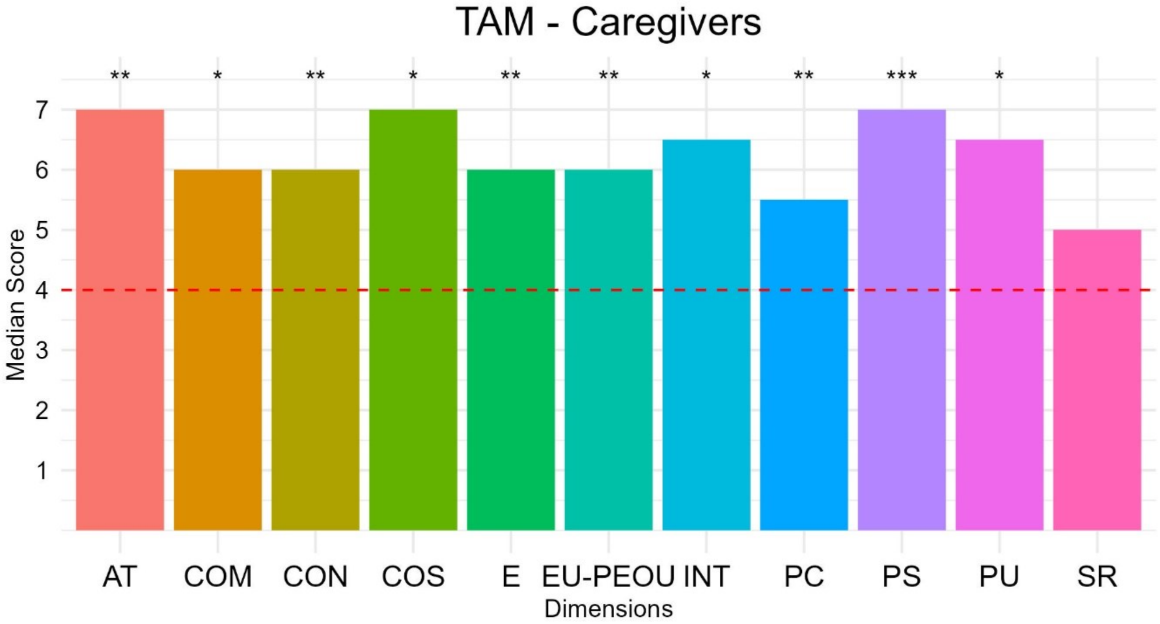


Figure 6.15. Caregivers – 1 weekend usage – Post-experience.
***=p<0.001; **=p<0.01; *=p<0.05.

Post-experience. A series of Mann-Whitney tests against the median of the scale (i.e., 4) was performed. The results are shown in Figure 6.16. Dimensions: AT $p<0.01$, COM $p<0.01$, CON $p<0.05$, COS $p<0.05$, E $p<0.01$, EU-PEOU $p<0.01$, INT $p<0.01$, PC $p<0.01$, PS $p<0.01$, PU $p<0.01$, SR $p<0.05$.

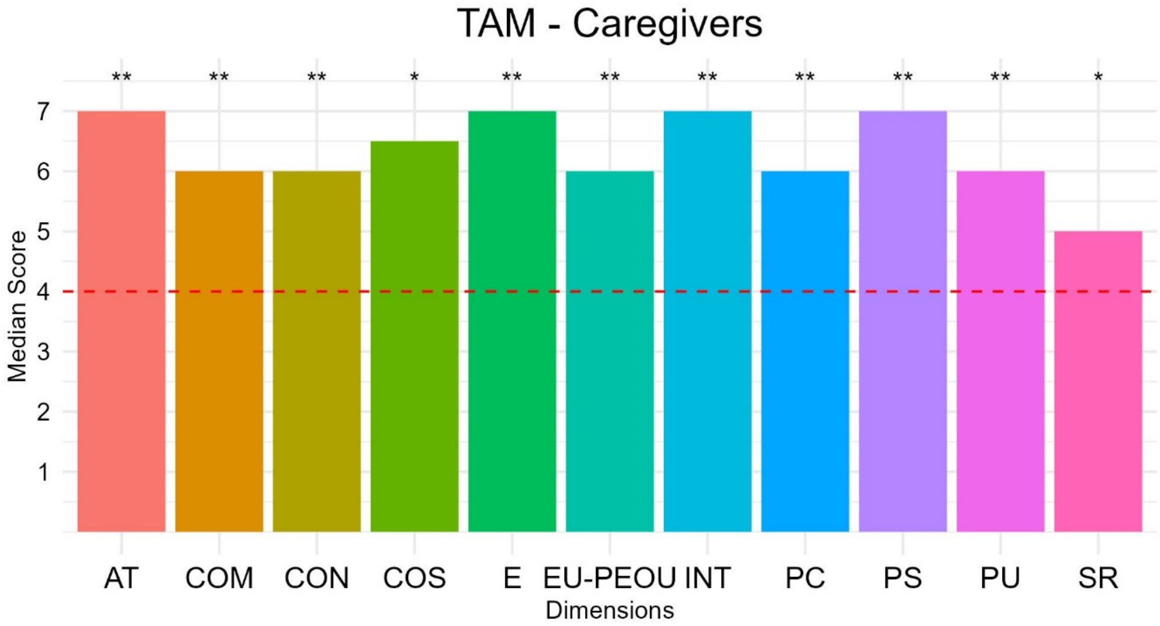


Figure 6.16. Caregivers – 3 months usage – Post-experience.
***=p<0.001; **=p<0.01; *=p<0.05.

Pre vs Post experience. The pre- and post-experience were analyzed using Wilcoxon tests. No differences emerged (all $p_s > .05$).

6.2.3.1.3 Participants with disabilities (N=14) – 1 weekend usage

Pre-experience. A series of Mann-Whitney tests against the median of the scale (i.e., 4) was carried out. The results are shown in Figure 6.17. Dimensions: AT $p<0.001$, COM $p<0.001$, CON $p<0.001$, COS $p<0.001$, E $p<0.001$, EU-PEOU $p<0.001$, INT $p<0.001$, PC $p<0.001$, PS $p<0.001$, PU $p<0.001$, SR $p<0.001$.

Post-experience. A series of Mann-Whitney tests against the median of the scale (i.e., 4) was performed. The results are shown in Fig. 6.18. Dimensions: AT $p<0.001$, COM $p<0.001$, CON $p<0.001$, COS $p<0.01$, E $p<0.001$, EU-PEOU $p<0.001$, INT $p<0.001$, PC $p<0.001$, PS $p<0.001$, PU $p<0.001$, SR $p<0.001$.

Pre vs Post experience. I evaluated the potential differences between the pre- and post-experience using Wilcoxon tests. No differences emerged (all $p_s > .05$).

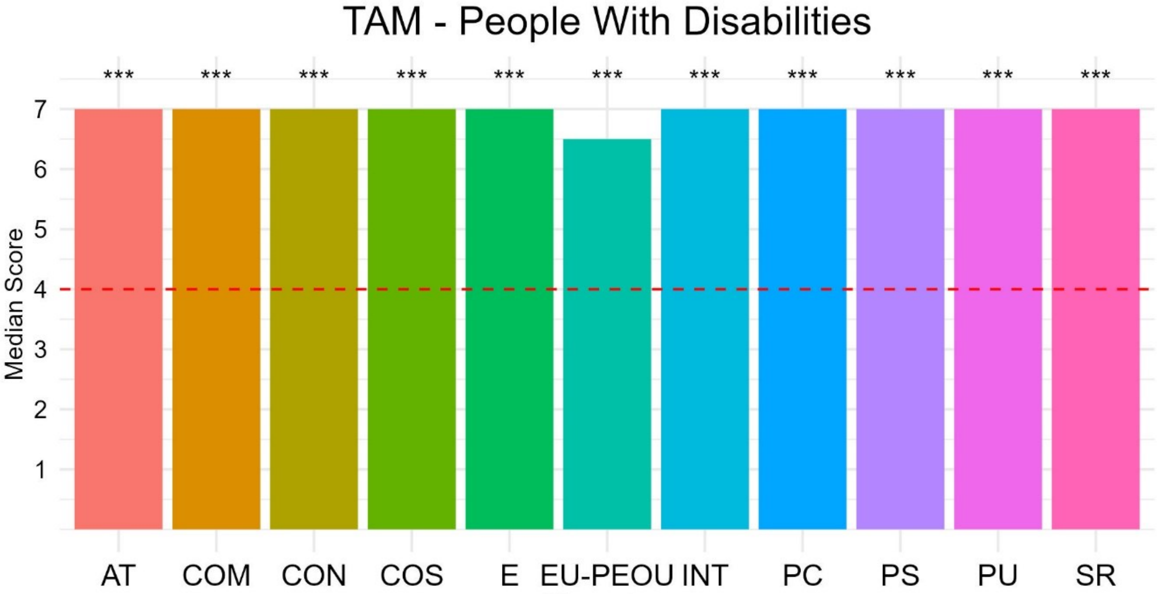


Figure 6.18. Participants with disabilities – 1 weekend usage – Pre-experience. ***=p<0.001; **=p<0.01; *=p<0.05.

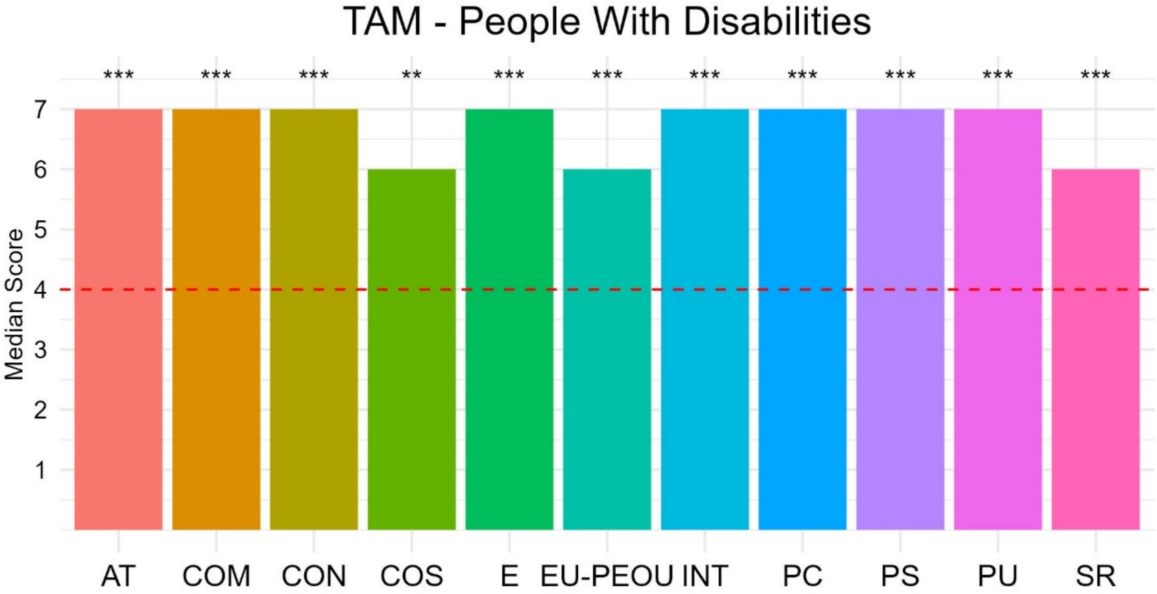


Figure 6.17. Participants with disabilities – 1 weekend usage – P-experience. ***=p<0.001; **=p<0.01; *=p<0.05.

6.2.3.2 Usability Checklist

6.2.3.2.1 Participants with disabilities (N=14) and Caregivers (N=10) - 1 weekend usage.

I analyzed the responses of the two types of users using a beta regression. No difference emerged ($p > .05$; Fig. 6.19).

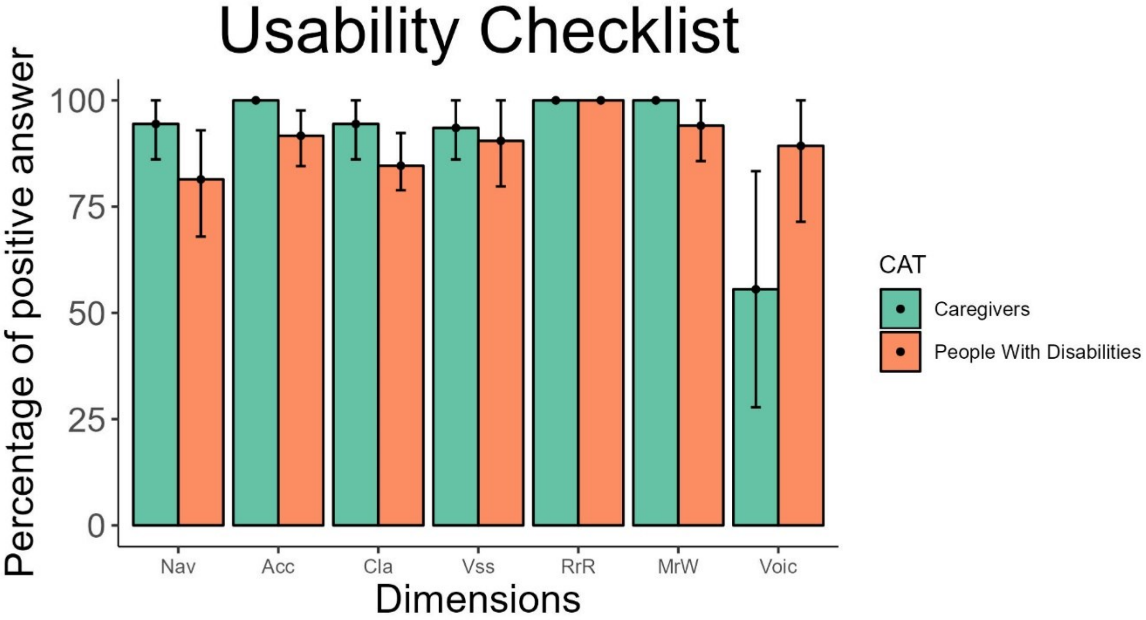


Figure 6.19. Usability checklist results for both caregivers and people with disabilities.

6.2.3.2.2 Caregivers (N=4) – 3 months usage.

I evaluated the differences between the pre- and post-experience of four caregivers. The comparison did not show statistical differences (Fig. 6.20).

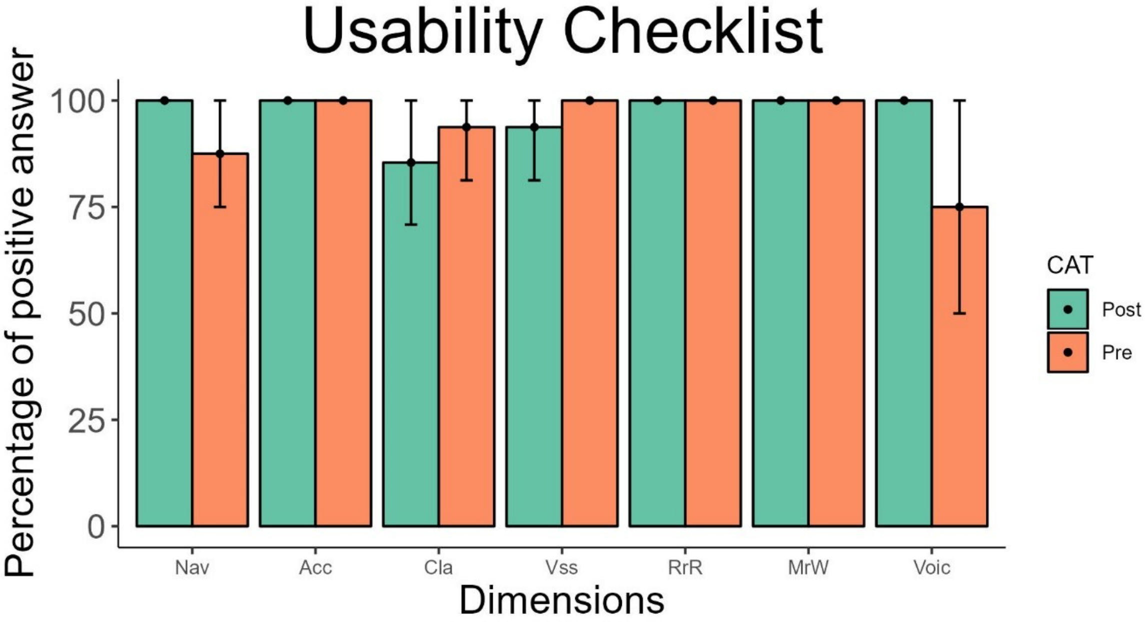


Figure 6.20. Caregivers – 3 months usage pre vs post.

6.2.3.3 User Experience

6.2.3.3.1 Caregivers (N=10)

1 weekend usage. Responses were analyzed using Mann-Whitney tests against the median of the scale (i.e., 3). Dimensions (Fig. 6.21): Aut $p<0.001$, Ben $p<0.01$, Eng $p<0.001$, Pl $p<0.001$, Pri $p<0.001$, Sat $p<0.001$, Sec $p<0.001$, Tru $p<0.001$.

6.2.3.3.2 Caregivers (N=4)

3 months usage – after 1st weekend usage. A series of Mann-Whitney tests against the median of the scale (i.e., 3) was performed. Dimensions (Fig. 6.22): Aut $p<0.05$, Ben $p>0.05$, Eng $p>0.05$, Pl $p<0.05$, Pri $p<0.05$, Sat $p>0.05$, Sec $p<0.05$, Tru $p<0.05$.

3 months usage – after last weekend usage. I analyzed the responses using Mann-Whitney tests against the median of the scale (i.e., 3). Dimensions (Fig. 6.23): Aut $p<0.01$, Ben $p<0.05$, Eng $p<0.01$, Pl $p<0.001$, Pri $p<0.01$, Sat $p>0.05$, Sec $p<0.05$, Tru $p<0.05$.

3 months usage – Pre vs Post 3 months use. I analyzed the pre- and post-experience scores using Wilcoxon tests. The analysis did not show any difference between conditions.
Participants with disabilities (N=14)

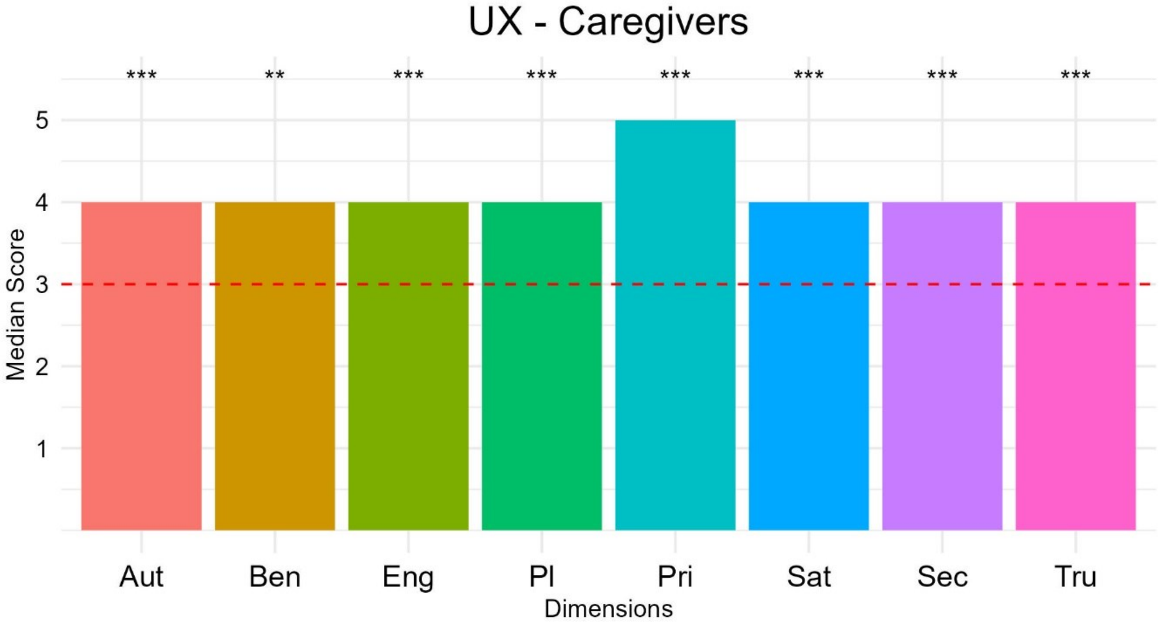


Figure 6.21. Caregivers – 1 weekend usage. ***=p<0.001; **=p<0.01; *=p<0.05.

1 weekend usage. I evaluated the responses of fourteen participants with disabilities using Mann-Whitney tests against the median of the scale (i.e., 3). Dimensions (Fig., 6.24): Aut p<0.001, Ben p<0.001, Eng p<0.001, Pl p<0.001, Pri p<0.01, Sat p<0.001, Sec p<0.001, Tru p<0.001.

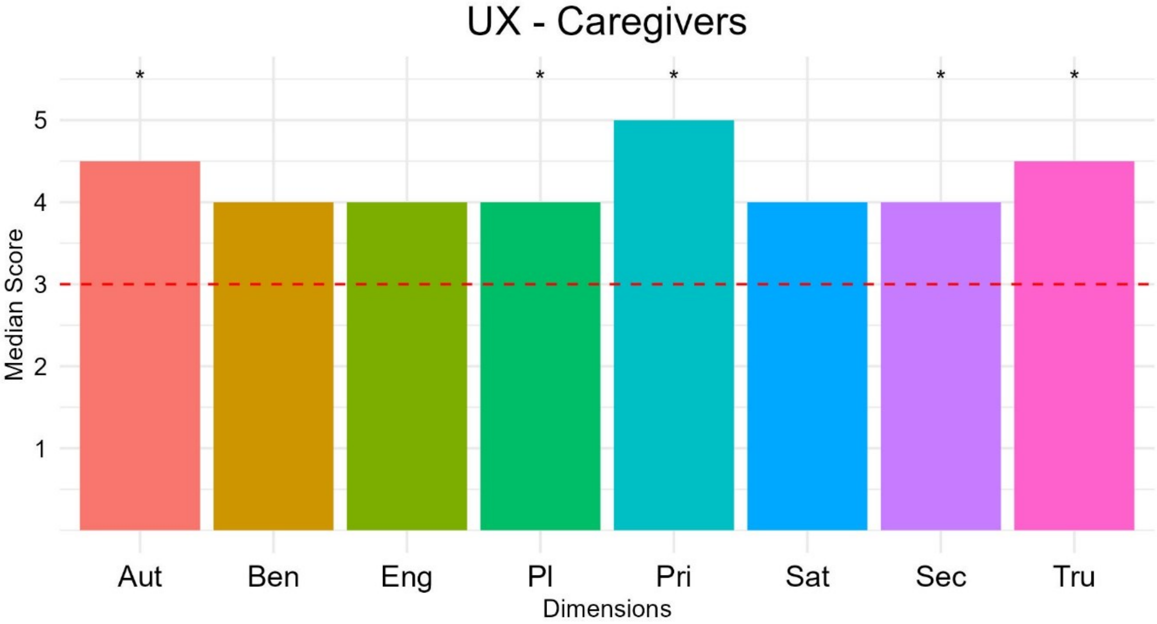


Figure 6.22. Caregivers – 3 months usage – 1st use. ***= p<0.001; **=p<0.01; *=p<0.05.

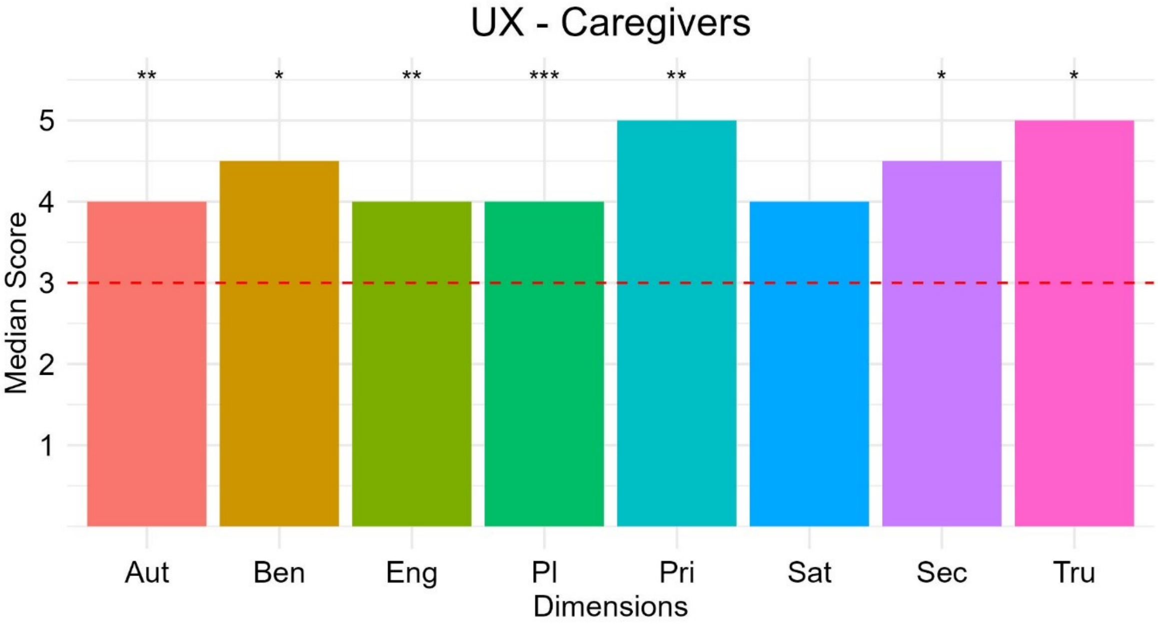


Figure 6.23. Caregivers – 3 months usage – 3 months use. ***= p<0.001; **=p<0.01; *=p<0.05.

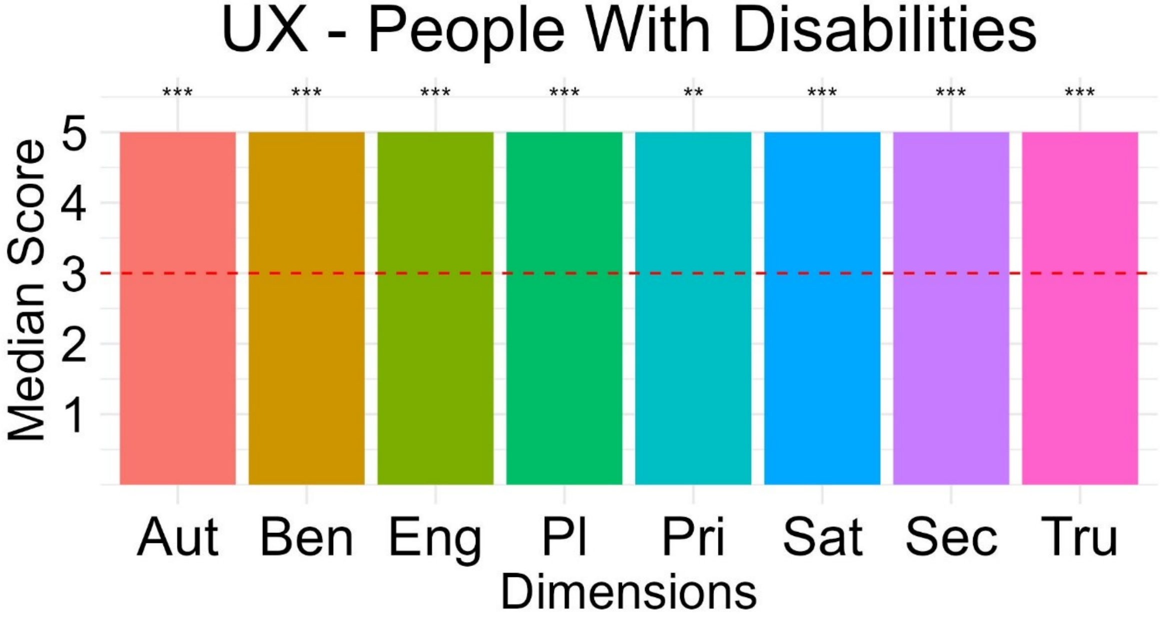


Figure 6.24. Participants with disabilities – 1 weekend usage. ***= p<0.001; **=p<0.01; *=p<0.05.

6.2.3.4 Interface Preferences

People with disabilities and Caregivers – 1-weekend usage. The preference (percentage) for each interface for both the user categories were computed (Figure 6.25).

Caregivers (N=10) 1 weekend use. Voice Command 70%; Tablet 0%; Smartphone 20%; No Preference: 10%.

Caregivers 3 months use (N=4). Voice Command 100%; Tablet 0%; Smartphone 0%; No Preference 0%.

People with disabilities (N=14). Voice Command 57%; Tablet 29%; Smartphone 7%; No preference: 7%.

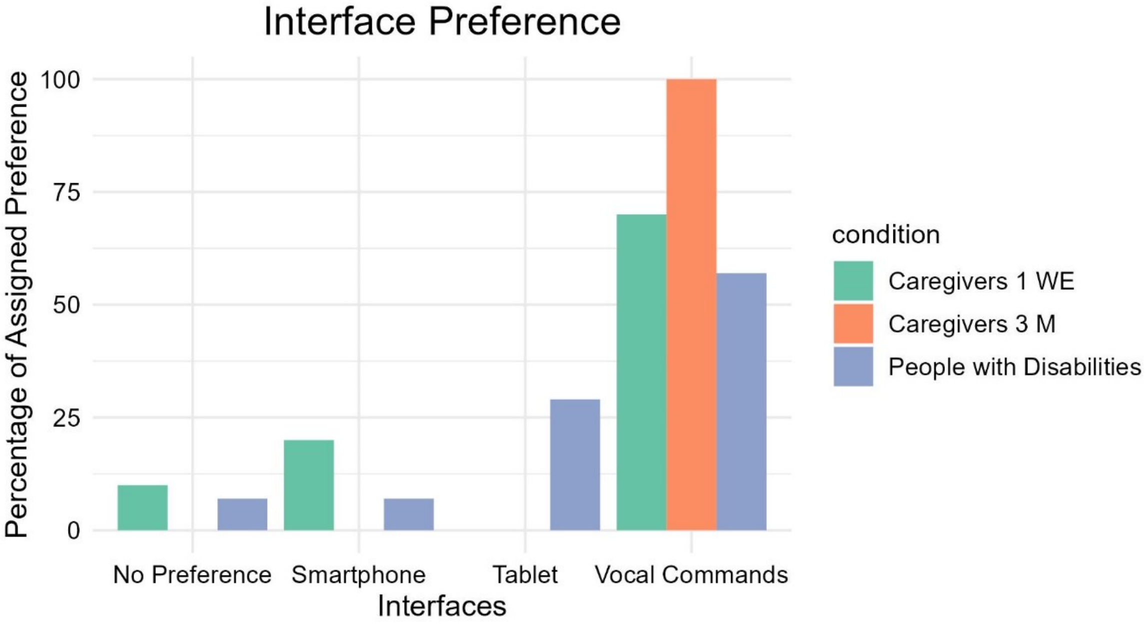


Figure 6.25. Interface Preferences – People with disabilities and Caregivers – 1-weekend usage.

6.2.3.5 *Usage Data*

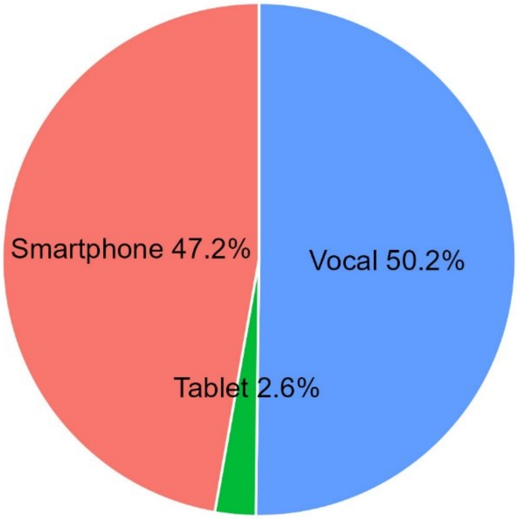


Figure 6.26. Usage Data – People with disabilities and Caregivers – Multiple weekends percentage data usage for every control interface.

I compared the percentage of usage of every control interface (Figure 6.26). The most used interface was the vocal commands (50.2%), followed by the smartphone (47.6%). The tablet was used very few times (2.2%).

6.2.3.6 Performance

6.2.3.6.1 People with disabilities (N=14)

I calculate the mean time on task and the mean number of errors (videorecordings) while participants were using the tablet and vocal interface.

Accuracy. The number of errors was obtained by subtracting the ideal number of interactions from the total number performed. I used a Wilcoxon test to compare the two conditions. A difference between the error made using the tablet (M_{Errors}=10.7) and the ones linked to the voice interaction (M_{Errors}=2.2) emerged (p<001; Figure 6.27).

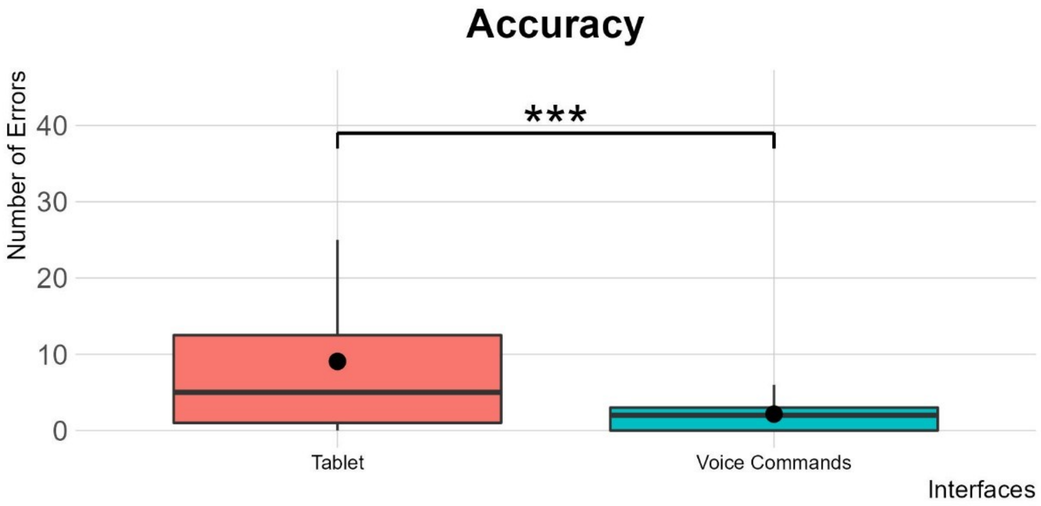


Figure 6.27. Accuracy. ***= p<0.001; **=p<0.01; *=p<0.05.

Time on Task. I used a Wilcoxon test to compare the time on task related to the two types of interaction means. No differences emerged.

6.2.3.7 Sense of Home

Participants with disabilities – 1-weekend usage. I analyzed the responses by performing a series of Mann-Whitney tests. Dimensions: CT *p*<0.01, ACF *p*<0.001, PEF *p*<0.001, PP *p*<0.001 (Figure 6.28).

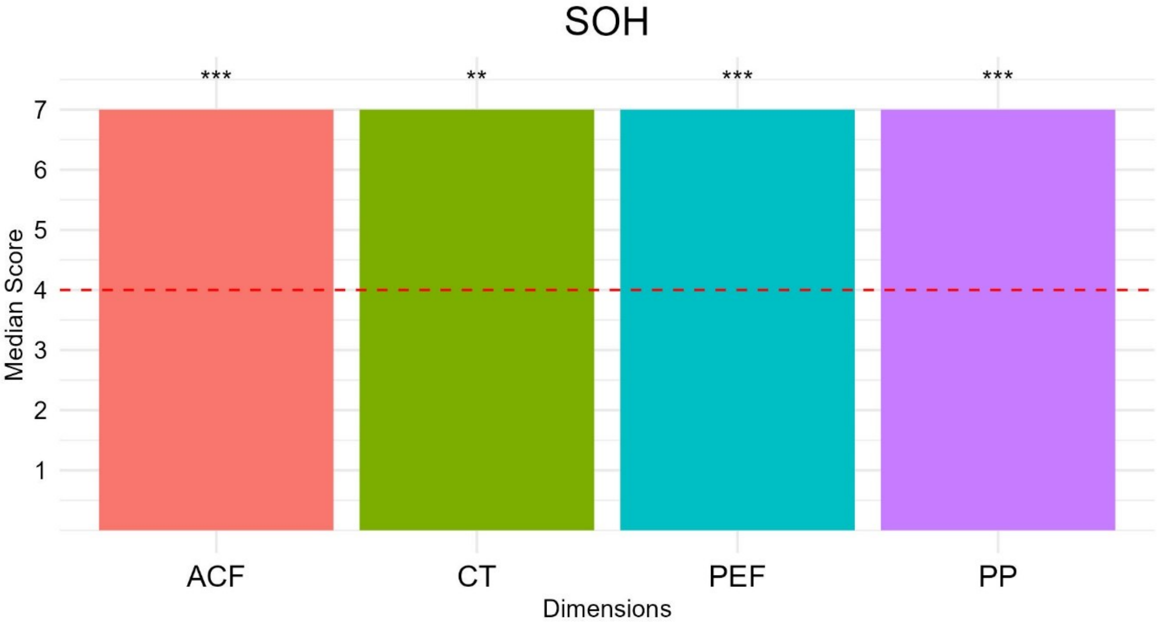


Figure 6.28. Participants with disabilities – 1 weekend usage. ***= p<0.001; **=p<0.01; *=p<0.05.

6.2.3.8 Sense of Home Technologies.

Participants with disabilities – 1-weekend usage. I evaluated the scores by performing Mann-Whitney tests. Dimensions: En *p*<0.001, Fi *p*<0.001, Ki *p*<0.001, Li *p* <0.001, Me *p* <0.001, Se *p*<0.001 (Figure 6.29).

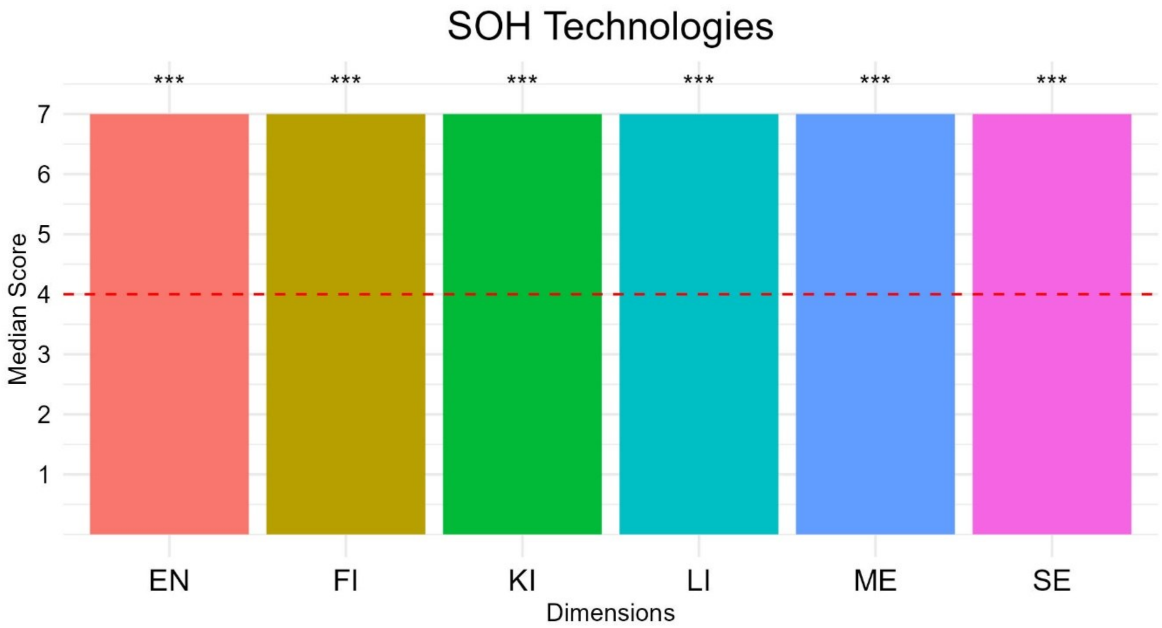


Figure 6.29. Participants with disabilities – 1 weekend usage. ***= p<0.001; **=p<0.01; *=p<0.05.

6.2.3.9 Human Factor in Technologies vs No Technologies conditions

6.2.3.9.1 Sense of Home.

The scores were evaluated using Wilcoxon tests. No differences emerged.

6.2.3.9.2 Caring Behavior Inventory.

The responses were analyzed by carrying out a series of Wilcoxon tests. No differences were shown.

6.2.4 Discussion

This study explores people with disabilities and caregivers' perceptions of domotic technologies. Firstly, I evaluated a pool of questionnaires (i.e., Technology Acceptance, User Experience, Usability, Sense of Home, Sense of Home related to technologies) and objective measures (i.e., log data, performance) after a single weekend of use. Furthermore, after three months of domotic technology use, I evaluated the caregivers' potential longitudinal variations in subjective perceptions. In the last part of the study, people with disabilities lived with and without the

DOMHO technologies. The aim was to research potential differences between their subjective perceptions of Caring Behavior and Sense of Home in these two conditions.

6.2.4.1 System Evaluation

The first objectives of the present study were to study the usability and technology acceptance of the proposed IoT system. I firstly analyzed the answer of the ten operators who utilized the system for one weekend. The comparison of technology acceptance measured pre-and post-experience did not show any statistical difference. However, almost all the questionnaires' dimensions obtained median scores statistically higher than the median of the response scale, with only one exception (i.e., Perceived Reliability). This result indicates that the participants find the system acceptable in their work with a single use. However, the missing statistical significance for Perceived Reliability could be due to some system malfunctions, which could have influenced the score assigned to this dimension (Hensch et al., 2022). The research also tested four operators who could use the system for three months of work to examine the user perception after a longer usage period. The statistical analysis comparing results pre- and post-three months of usage did not show significant differences. However, it is interesting to note that only for the post-three-month condition, the comparison between the median score obtained for the Perceived Reliability dimension and the scale median is statistically significant (Figure 6.16.). This result suggests that prolonged system use can overcome the system's mistrust. This is an encouraging result since reliability is critically important in technology acceptance (H. Yang, Lee, & Lee, 2018). Indeed, the caregiver Technology Acceptance analysis highlights that workers dealing with assistance to people with disabilities can accept help in their work from this system and similar ones.

Users with disabilities show higher enthusiasm for the system, starting from the design phase, because of the dedicated environment and the prospect of independent time (i.e., away from families) with social interactions. Therefore, it is not surprising that the pre-test Acceptance questionnaire (Figure 6.17) answers report median results at the upper scale limit. The post-experience questionnaire (Figure 6.18), while not showing statistical differences from the pre-test phase, shows some decrements in the median scores. The use of the system led the participants to decrease their opinion about its reliability slightly. Indeed, the participants encountered minor difficulties in system usage, highlighted in their responses to the EU-PEOU dimension. This is particularly interesting since the literature individuates the difficulty of operation as a possible barrier to technology adoption (Oliveira et al., 2015). Moreover, a slight decrease is visible in the COST dimension, probably because the participants became more aware of the actual cost of the technologies. Indeed, the prices of devices represent another possible limitation of smart home technologies (Carnemolla, 2018). The answers to the Technology Acceptance questionnaire report encouraging results, highlighting how the co-design methods created enthusiasm for DOMHO technologies. Our study shows that people with disabilities can accept assistive technologies in their daily life, a result in line with the previous research in the field (van Heek et al., 2018).

A second objective was to test system usability. Both users' categories compiled a usability checklist to indicate system and interface problems. The questionnaire heuristics obtained a very high percentage of positive responses, except for the voice for operators (Figure 6.19). The explanation could be that DOMHO's voice interface was not directly accessible. The voice control system was indeed activable by Google Home, thus making the access operation long and sometimes annoying. The caregivers complained about voice commands being cumbersome and not easy to use (e.g., it failed to understand a given order, and it was challenging to remember the specific formulae). However, these results were obtained only in the larger pool of caregivers (N=10). On the other hand, the four caregivers who had more time to familiarize themselves with the system indicated higher usability of vocal commands, as indicated in Figure 6.20. It could be assumed that using the system for a longer time brings the caregivers to remember the commands correctly, thus reducing the errors occurrences and increasing usability perception.

Also, the usability checklist comments highlight tablet limitations in searching for technologies to manage. The interface locates the technologies in different rooms (e.g., kitchen, living room, etc.), but the buttons for switching environments were too small and difficult to understand for people with disabilities. Three participants mentioned this aspect. Another limitation was the inability to enlarge the text in case of need. Since every interface presents limitations and advantages, the DOMHO system proposes multiple user interfaces to manage smart technologies. This solution provides freedom and flexibility to encounter every necessity, thus ensuring high usability and accessibility, as demonstrated by this study. In this specific context, characterized by people with different motor and cognitive disabilities and caregivers with various experiences in technology use, flexibility should be one of the main objectives for a similar system design, as confirmed by the literature (Jamwal et al., 2020).

I administered an ad hoc User Experience questionnaire to both users' categories. The caregivers who spent one weekend inside the domotic environment reported a positive experience. Indeed, their median answers were significantly higher than the scale median for every dimension (Figure 6.21). The long-term analysis of the UX questionnaire scores (i.e., single versus three months of use) did not show any statistical difference between 1 weekend and three months of use. However, in the latter condition, the Perceived Benefits and Engagement dimensions results were significantly different from the scale median (Figure 6.23), probably because of the enhancement in participants' familiarity with the system. Indeed, the literature indicates that users' understanding of UX may depend on the length and frequency of usage (Biduski et al., 2020). The extended use permitted caregivers to discover and master the various DOMHO features, realizing their benefits during the work and enhancing their engagement with the system. I

I did not find the same results for the Satisfaction dimension. The participants' experience could sometimes be frustrating, probably due to the malfunctions of the system, which are established causes of dissatisfaction in user experience with technologies (Meuter et al., 2000). Participants with disabilities' answers to the UX questionnaire (Figure 6.24) confirmed their enthusiasm for the system. The results appear similar to the TAM questionnaire, with every dimension's score at the maximum value, highlighting high motivation for using the DOMHO technologies.

The UX study analyses user preferences regarding control interfaces. Both users' categories indicated their preference for voice command (Figure 6.25) because of its accessibility and the possibility of controlling the system hands-free. The analysis of the log files (Figure 6.26) reports that the use of the control interfaces was equally subdivided between smartphone and vocal commands. This result could have been generated by caregivers' smartphone use for coordination, organizational reasons, and outside the house, which makes it more accessible to give commands to the system. People with disabilities, instead, used voice commands more frequently. The analysis of users with disabilities' performance with the two interfaces (voice and tablet) in terms of time on task did not show differences. On the contrary, the tablet interface was more prone to errors (Figure 6.27). This confirms that participants with disabilities find it easier to use the voice interface. This result confirms the need to provide a voice-controlled interface since fewer errors could prevent users from being frustrated by failures and consequently abandoning the system (Hoque & Sorwar, 2017).

Finally, I was interested in understanding the influence of technology in the sense of home. The median results of the SOH questionnaire dimensions were significantly higher than the median of the scale (Figure 6.28), confirming that the DOMHO environment does not impair the participants' sense of being at home. Furthermore, using the SOHT questionnaire, I analyzed the influence of the various apartment technologies on the sense of home to detect those that could create discomfort. The results did not reveal any negative technology (Figure 6.29).

6.2.4.2 Living With and Without Technologies

I was interested in analyzing the possible differences in user behaviors between weekends with technologies and those without them. Six selected participants experienced the domotic environment with and without DOMHO devices. The first tool that explored eventual differences was SOH. The results did not show statistical differences between the two conditions. Indeed, technologies do not negatively impact comfort and the feeling of being at home in this study. The second tool was the CBI questionnaire, which scope was to check whether the technologies could affect people with disabilities perception of operators' work. The comparison between the two conditions did not show significant differences, confirming that the operators' work was appreciated unregarding the help of assistive technologies.

6.2.5 Conclusions

This study aimed to deepen our knowledge of the users' opinions about a domotic smart home based on IoT technologies, designed using a co-design approach involving people with disabilities. I analyzed their answers and those of their caregivers, finding interesting results. First, I found that users in both categories highly rated the system in terms of user experience, usability, and technology acceptance. This research also identifies minor limitations on which future studies and projects should focus (e.g., system reliability, cost perception, ease of use for voice interfaces). Furthermore, the study confirms the need to use voice interfaces for technologies aimed at helping people with disabilities. Results indeed demonstrate the need to give users high levels of flexibility. Finally, the technologies' usage did not impair the sense of home and the perception of caregivers' work.

However, this work analyzed the answers of 14 participants, which was not enough to generalize the results. Future studies should augment the population numerosity, confirming and generalizing my results.

This work represents an extensive study that considers different types of users, short and long-term usage time, and human factors linked to SH realization. Future studies should concentrate on the social impact of these environments on inhabitants, exploring the effect of technologies and co-housing on the independence and life quality of people with disabilities and the caregivers' workload.

7 EYE-TRACKING STUDIES

7.1 Using LHIPA to Measure Cognitive Load in a Conjunctive Visual Feature Memory Task

7.1.1 Aim of the Study

The aim of this work was to evaluate three eye-tracking metrics for measuring CL in a novel task based on conjunctive visual features. Earlier studies mainly focused on testing metrics in tasks involving a single feature, e.g., n-back and arithmetic tasks, where participants had to recognize and remember a particular shape (i.e., letters, numbers). The CVSTM, in contrast, relies on multiple conjunctive features, meaning that participants had to simultaneously store multiple informational elements in their visual short-term memory. Cognitive load metrics validated with such a task are likely to be more reliable and useful for HCI applications, where human interaction requires manipulation of complex, multivalent information.

7.1.2 Materials and Methods

7.1.2.1 Empirical Validation

Volunteers participated in two tasks, the n-back and the Color Visual Short-Term Memory (CVST) task, to evaluate the effectiveness of gaze metrics for the measurement of CL. The first experiment replicates a previous study using 1-back and 2-back tasks, with removal of the fixed-gaze restriction meant to entice the participant to focus at a single point on the screen. The second experiment exploits the CVSTM task by challenging participants to remember a field of colored dots dispersed over a 10° x 8° visual field (span).

The experimental design was within-subjects, with difficulty level as independent variable, counterbalanced across participants. Volunteers participated in both task types, with order counterbalanced as well. I analyzed the dependent variables including performance accuracy obtained as the percentage of correct responses in each task. I also analyzed three different gaze metrics: LHIPA, microsaccade magnitude, and the ambient/focal K coefficient. For analyzing gaze behavior responses to task difficulty, I first pre-processed the pupil diameter signal removing data 200 ms before the start of, and 200 ms following the end of a blink, as identified by the eye tracker, following Engbert and Kliegl (Engbert & Kliegl, 2003). I then computed the indices from the raw signal. Finally, at the end of each task, I collected the subjective experience of participants using the NASA-TLX questionnaire. This instrument permits the evaluation of subjective perception of cognitive load using the median of six scales: mental demands, physical demands, temporal demands, performance, effort, and frustration.

7.1.2.2 Experimental Setting and Apparatus

Both experiments used the same experimental settings. The eye tracking device used was an Eyelink 1000 with a sampling rate of 1000 Hz. A chin rest was used to stabilize head movement of participants. Eye tracker accuracy is reported by the manufacturer as 0.25–0.5° visual angle on average. Wang et al. (D. Wang et al., 2017) corroborate this accuracy measurement via root-mean-squared analysis, while van der Geest and Frens (van der Geest & Frens, 2002) found the EyeLink's horizontal X vertical precision to be 0.98° x 0.05° visual angle. PsychoPy (Peirce, 2007), a Python package, was used to write the experimental procedure. The experimental setup was composed of a personal computer running the Eyelink 1000 and another for running PsychoPy. The stimuli were presented on a 2560x1440 resolution monitor. Participants could interact with the personal computer through a standard numerical keyboard connected to the personal computer running PsychoPy and placed in front of them. To avoid light fluctuations, the laboratory selected for the study did not possess windows.

The luminance at the computer screen was 96 Lux, while the ambient luminance was 550 Lux.

Figure 7.1 provide an example of the experimental setup.

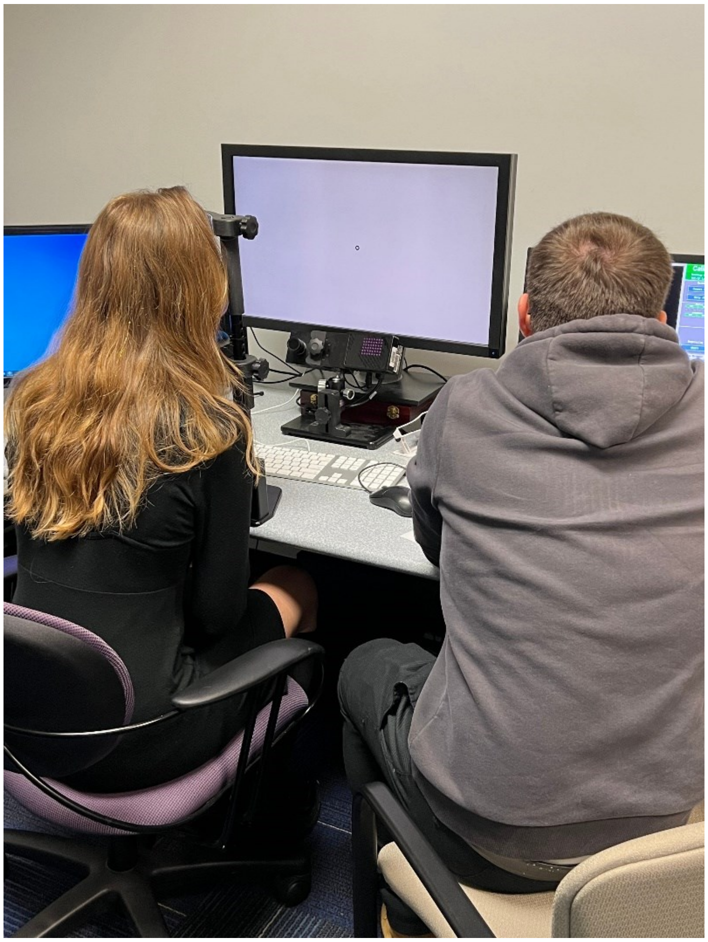


Figure 7.1.
EyeLink eye tracker setup (during calibration)

7.1.2.3 *Participants*

Volunteers (N=24) for the study were recruited verbally and by email (16 M, 8 F with ages in range 19:37 years old, M= 24.00, SD = 4.94). All were right-handed. Five participants wore vision correction aids (e.g., 2 contact lenses, 3 eyeglasses). Two participants reported to be slightly color blind, however, they did not report difficulties in discriminating the CVSTM task-colored targets when tested before the experimental trials.

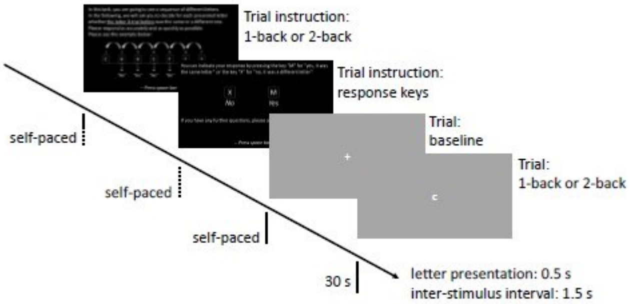
7.1.2.4 *Experiment 1: n-back Task*

To compare the sensitivity of the eye-tracking indices to task difficulty, I first used the same experimental task used by Duchowski et al. (Duchowski et al., 2020), without forcing participants to fixate the same spot during the entire experiment. Specifically, this experiment exploits the well-established n-back task, with n used to evoke different levels of cognitive load.

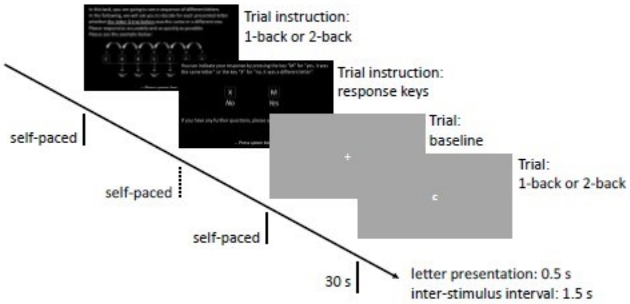
7.1.2.5 Experimental Procedure.

The experimental protocol was based on Ahern and Beatty (Ahern & Beatty, 1979) and Appel et al. (Appel et al., 2018). Two types of experimental trials were presented to participants: easy (1-back) and difficult (2-back). Every participant was presented with a series of letters randomly selected from a set L = [C. F, H, S]. The letters were shown one after another and participants had to state if the current letter was the same as the one before (1-back) or as the one that appeared two trials earlier (2-back). Each trial lasts 0.5 seconds with an inter-stimulus duration of 1.5 seconds, with a total trial duration of 2 seconds (see Figure 7.2).

Before each block, participants underwent a training phase in which they were presented with 15 trials of the same task they were about to conduct. When they reached an accuracy of at least 60% they started the experiment. After the training block, each participant was presented with a 30 s baseline task, in which they fixated a cross at the center of the screen. Each experimental block consisted of 60 trials, with a total duration of 2 minutes. The letters were displayed at the same position, in the centre of the screen. The order of the 1- and 2-back tasks was counterbalanced. At the end of each task, participants responded to the NASA-TLX questionnaire.



(a) Instructions and training.



(b) Stimulus presentation.

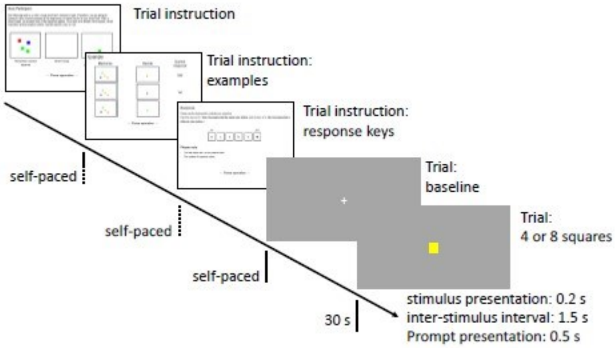
Figure 7.2. Schematic of the n-back task, including (a) instructions and training preceding (b) stimulus presentation.

7.1.2.6 Experiment 2: CVSTM Task

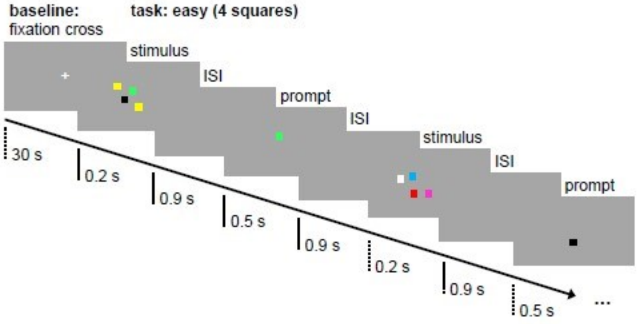
The second experiment conducted was the CVSTM task. The multivalent stimuli used in this task consisted of a series of colored squares, arranged randomly in position and color.

7.1.2.7 Experimental Procedure.

The procedure of the CVSTM task followed previous work by Meyerhoff and Gehrer (Meyerhoff & Gehrer, 2017). The task required recognizing of the location and color of a series of squares. For each trial, participants were presented with a series of colored squares (1° x 1°). In the easy task, 4 squares were displayed, in the difficult task 8. In both tasks, the objects were shown at the centre of the screen, within a field of view of 10° x 8° visual angle. The colors were randomly selected from a set consisting of black, white, turquoise, blue, pink, yellow, green, red. Each task was composed of 40 trials. Stimuli were shown for 200 ms. After a short retention interval (900 ms), a probe appeared, and participants had to indicate if it consisted of the same features (location and color) as one of the squares shown previously. The probe appeared for 500 ms and the inter stimulus interval was 500 ms. The total duration of each block was 84 s. The procedure is schematically shown in Figure 7.3. Prior to testing, participants completed eight training trials in which the starting set was composed of two elements. When they reached an accuracy of at least 60% they could begin the experiment. After the training block, each experiment was preceded by a 30 s baseline, in which participants fixated a cross at the center of the screen. At the end of each task, participants responded to the NASA-TLX questionnaire.



(a) Instructions and training.



(b) Stimulus presentation.

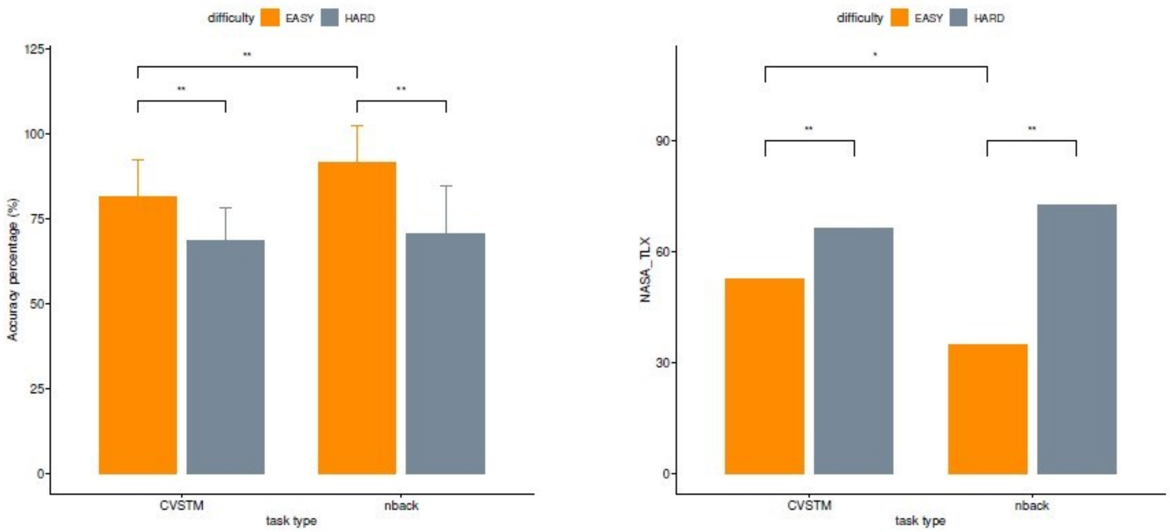
Figure 7.3. Schematic of the CVSTM task, including (a) instructions and training preceding (b) stimulus presentation.

7.1.3 Results

The present experiment tested the response of gaze-based CL indices to two cognitive load-inducing tasks that relied on differing visual stimuli, i.e., single-valent letters or multivalent colored squares. The experiment was of a 2 × 2 within subjects design, with task difficulty (EASY vs. HARD) and task type (CVSTM vs. NBACK) as independent variables. Dependent variables included task accuracy, subjective measures, and gaze-based indices of cognitive processing, e.g., load, including LHIPA and microsaccade magnitude. Gaze-based metrics were contrasted against baseline, serving as two experimental conditions (baseline vs. task).

7.1.3.1 Accuracy and Subjective Measures

Performance and subjective measures (i.e., accuracy and NASA-TLX) show that participants discriminated between task difficulty of each task.



(a) Task type accuracy.

(b) NASA-TLX.

Figure 7.4. Accuracy and subjective measures, including (a) task accuracy, and (b) NASA-TLX.

7.1.3.2 Accuracy

A within-subjects two-way repeated-measures ANOVA was run with the percentage of correct responses as dependent variable and with task difficulty and task type as independent variables. ANOVA revealed that a statistically significant interaction between task difficulty and task type (F (1, 23) = 5.830, $p < 0.05$, $\eta_2 = 0.031$), see Figure 7.4(a). The simple main effect of task type was significant (F (1, 23) =7.377, $p<0.05$, $\eta_2 =0.068$). A post-hoc t-test revealed that the easy task in CVSTM (M = 81.7%, SD = 10.8) yielded a significantly lower percentage of correct answers (t (23) =−3.13, $p<0.01$), than the easy task in n-back (M=91.8%, SD=10.9). No differences were founded between the difficult tasks. The simple main effect of difficulty was significant (F (1, 23) =106.675, $p<0.01$, $\eta_2 =0.363$). Post-hoc t-tests revealed that, in the CVSTM, the easy task (M =

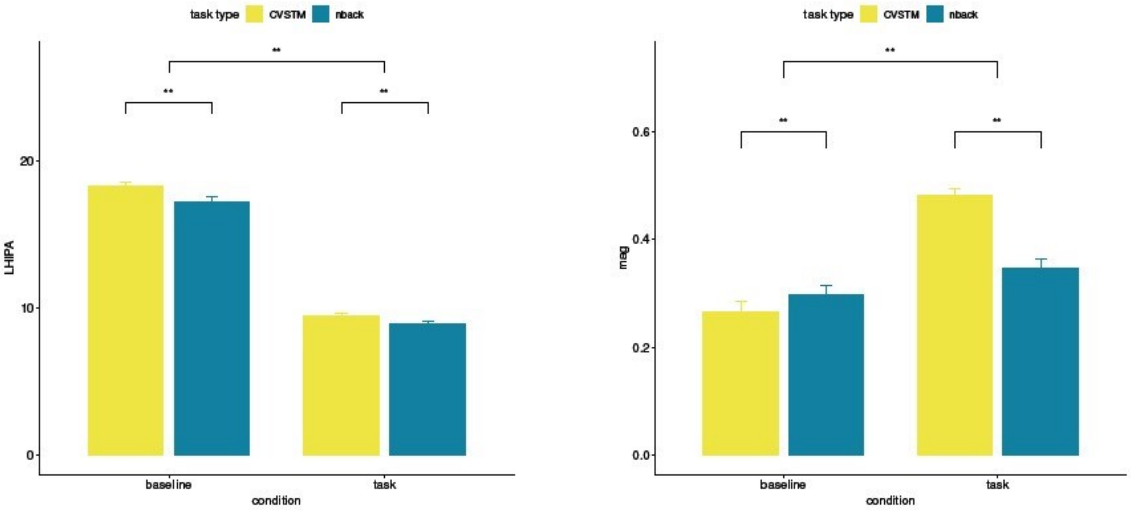
81.7%, SD = 10.8) yielded significantly higher percentage of correct answers (t (23) =7.07, p<0.01), than the difficult task (M=68.5%, SD=10). The t-tests also revealed that, in the n-back, the easy task (M=91.8%, SD=10.9) yielded significantly higher percentage of correct answers (t (23) =7.67, p<0.01), than the difficult task (M=70.6%, SD=14.3).

7.1.3.3 NASA-TLX

NASA-TLX results were analyzed using paired Wilcoxon tests with Benjamini-Hochberg correction (Benjamini & Hochberg, 1995), see Figure 7.4(b). Results showed that the CVSTM easy task (Med =52.5) was considered significantly easier (V =18, p<0.01) than the difficult task (Med =66.2). A similar result was found in the n-back task, where the easy task (Med =35) was considered significantly easier (V =0, p<0.01) than the difficult task (Med =72.5). Results also showed that the CVSTM easy task was considered significantly harder than the easy n-back task (V =217.5, p<0.05).

7.1.3.4 Gaze Measures

Simple main effects of LHIPA and microsaccade magnitude show their ability to discriminate between task and baseline conditions, with LHIPA decreasing and microsaccade magnitude increasing during the task execution.



(a) LHIPA simple main effects.

(b) Microsaccade magnitude simple main effects.

Figure 7.5. Results from the ANOVA simple main effects, including (a) LHIPA, and (b) microsaccades magnitude.

7.1.3.5 LHIPA

I ran a 2 × 2 × 2 repeated measures three-way ANOVA with task type, condition, and task difficulty as within-subjects independent factors. Results are shown in Figure 7.5(a) with LHIPA as the dependent measure. The test did not show a significant three-way interaction. ANOVA revealed a simple two-way interaction between condition and task type ($F (1, 23) = 7.914$, $p<0.01$, $\eta_2 = 0.005$). The simple main effect of condition was significant ($F (1, 23) = 700.246$, $p< 0.01$, $\eta_2 = 0.857$). The simple main effect of task type was significant ($F (1, 23) = 23.521$, $p<0.01$, $\eta_2 = 0.048$). Post-hoc pairwise t-tests, with task type as independent variable, revealed that LHIPA at CVSTM baseline ($M = 18.2$, $SD=1.77$) was significantly greater ($t (23) = 4.45$, $p<0.01$), than at n-back baseline ($M=17, 2$, $SD=2.30$). Results also revealed that LHIPA in the CVSTM task ($M=9.47$, $SD=1.02$) was significantly greater ($t (23) = 4.68$, $p=0.01$), than at the n-back task ($M=8.92$, $SD=1.08$). Pairwise t-tests with condition as independent variable showed that CVSTM baseline LHIPA was significantly greater ($t (23) = 27.6$, $p < 0.01$), than the task LHIPA. A same result was found for the n-back task ($t (23) = 23.9$, $p < 0.01$). The simple main effect was significant for condition and task type. Post-hoc pairwise t-test comparisons confirmed significant differences in LHIPA between CVSTM and n-back ($t (23) = 5.63$, $p < 0.01$), and between baseline and task ($t (23) = 44.5$, $p<0.01$).

7.1.3.6 Microsaccade Magnitude

I ran a 2 × 2 × 2 repeated measures three-way ANOVA with task type, condition, and task difficulty as within-subjects independent factors. Microsaccade magnitude was used as the dependent measure. ANOVA did not show a significant three-way interaction. A simple main effect was significant for condition ($F (1, 23) = 92.014$, $p < 0.01$, $\eta_2 = 0.268$) and task type ($F (1, 23) = 38.561$, $p < 0.01$, $\eta_2 = 0.053$). Post-hoc pairwise comparisons confirmed the differences in microsaccade magnitude between baseline and task ($t (23) = -10.6$, $p<0.01$), and between CVSTM and n-back ($t (23) = 3.21$, $p<0.01$). Results are shown in Figure 7.5(b). ANOVA revealed a simple two-way interaction between condition and task type ($F (1, 23) = 95.7$, $p<0.01$, $\eta_2 = 0.124$). The simple main effect of task type was significant ($F (1, 23) = 38.561$, $p < 0.01$, $\eta_2 = 0.053$). The simple main effect of condition was significant ($F (1, 23) = 92.014$, $p<0.01$, $\eta_2 = 0.268$). Post-hoc pairwise t-tests, with condition as independent variable, revealed that microsaccade magnitude during CVSTM baseline ($M=0.266$, $SD=0.124$) was significantly lower ($t (23) = -12.8$, $p<0.01$) than during CVSTM task ($M=0.481$, $SD=0.092$). Similar results were found for n-back baseline ($M=0.297$, $SD=0.118$), and ($t (23) = -3.20$, $p<0.01$) n-back task ($M=0.347$, $SD=0.108$). Pairwise t-tests, with task type as independent variable showed that, in the baseline condition, microsaccade magnitude of CVSTM was significantly lower ($t (23) = -2.88$, $p<0.01$) than n-back. In the task condition, microsaccade magnitude of CVSTM was significantly greater ($t (23) = 10.4$, $p<0.01$) than n-back. ANOVA revealed a simple two-way interaction between condition and task difficulty ($F (1, 23) = 7.038$, $p<0.05$, $\eta_2 = 0.006$). The simple main effect of task difficulty was not significant. The simple main effect of condition was significant ($F (1, 23) = 92.014$, $p<0.01$, $\eta_2 = 0.297$). Post-hoc pairwise t-tests, with condition as independent variable, revealed that, in the easy task, microsaccade magnitude during baseline ($M = 0.287$, $SD = 0.122$) was significantly lower ($t (23)$

$= -6.82$, $p < 0.01$) than during the tasks (M = 0.402, SD = 0.086). Similar results ($t(23) = -11.2$, $p < 0.01$) were obtained between hard task baseline (M=0.277, SD=0.107) and task (M=0.427, SD=0.098).

7.1.3.7 Microsaccade Rate

I ran a 2 × 2 × 2 repeated measures three-way ANOVA with task type, condition, and task difficulty as within-subjects independent factors. Microsaccade rate was used as the dependent measure. ANOVA did not show any significant interaction.

7.1.4 Discussion

The aim of this work was to evaluate three eye-tracking metrics for measuring CL in a novel task based on conjunctive visual features. Earlier studies mainly focused on testing metrics in tasks involving a single feature, e.g., n-back and arithmetic tasks, where participants had to recognize and remember a particular shape (i.e., letters, numbers). The CVSTM, in contrast, relies on multiple conjunctive features, meaning that participants had to simultaneously store multiple informational elements in their visual short-term memory. Cognitive load metrics validated with such a task are likely to be more reliable and useful for HCI applications, where human interaction requires manipulation of complex, multivalent information.

I started the two-task analysis with the most common methods: subjective and performance measures (Figure 4). Both measures show that participants performed and considered differently the difficult and easy conditions (i.e., easy condition yielded higher accuracy and lower NASA-TLX scores) in both tasks, as expected. Accuracy analysis also shows that the CVSTM and n-back easy tasks were significantly different (i.e., CVSTM was harder than n-back), while no differences were found between the difficult tasks. The difficult task of the CVSTM scored lower than n-back on the NASA-TLX questionnaire, but not significantly so. The easy CVSTM task was perceived as requiring more CL than the easy n-back task, which agrees with accuracy scores. Interestingly, accuracy measures would suggest that the multivalent features of the easy CVSTM task indicate it as significantly harder than the monovalent visual nature of the easy n-back, agreeing with subjective impressions of significantly increased difficulty of the former versus the latter. I analyzed the differences between the two tasks with two eye-tracking indices, LHIPA and microsaccade magnitude. LHIPA, which is based on the oscillatory behavior of the pupillary response to CL, has been demonstrated to be a reliable indicator of classic CL-inducing task like the n-back or arithmetic operations (Duchowski et al., 2020). Previously, LHIPA only discriminated between baseline and task phases, and under strict and not necessarily ecological conditions. The data collected shows that LHIPA can discriminate between baseline and task conditions (see Figure 5(a)), confirming previous results (Duchowski et al., 2020). As before, LHIPA did not indicate differences between task difficulties within each task. However, LHIPA appears to discriminate between the CVSTM and n-back, indicating greater CL for the n-back task, which is incongruent with both performance and subjective measures.

In line with previous work, microsaccade magnitude was able to discriminate baseline and task conditions, in line with literature (Siegenthaler et al., 2014) (see Figure 5(b)). Contrary to

LHIPA, however, microsaccade magnitude suggests that the CVSTM task elicited greater CL than n-back, in congruence with subjective and performance measures. Perhaps in anticipation, the situation is reversed for baseline, where microsaccade magnitude suggests greater CL needed for n-back.

Results highlight a fundamental difference between the two main indices, with LHIPA indicating n-back as the harder task, and the reverse for microsaccade magnitude. One possible explanation is that LHIPA is more sensitive to tasks involving short-term memory while microsaccades are more sensitive to visual- hort term memory. Another possible explanation for microsaccade magnitude response can be derived by taking into account the nature of the two tasks. The n-back task requires participants to fixate a single spot on the screen. Moreover, once the letter appears, participants no longer need to fixate it, allowing vision to fade while concentrating on recalling the previous stimuli, thus reducing the need for microsaccades to maintain focus. Moreover, despite microsaccades being largely involuntary, it has been demonstrated that they can be reduced by voluntary and stable fixation on target (Martinez-Conde et al., 2013), possibly explaining gaze behaviour in the n-back task. In the n-back task, visual control is not linked to image preservation, one of the reasons for occurrence of microsaccades [Martinez-Conde et al. 2006]. In the CVSTM task, participants need to maintain visual contact with the stimulus to retrieve all the features of stimulus for the entirety of its duration. In this case, microsaccade magnitude could increase to prevent image fading. As reported by Martinez-Conde et al. (Martinez-Conde et al., 2006), during transition from fading to visibility, microsaccade magnitude increases, suggesting a relationship between their production and visibility during fixations. Furthermore, in the CVSTM task the target area is wider, forcing participants to perform larger eye movements. This result is also supported by the analysis of microsaccade rate which did not differ significantly between task type (i.e., exploring a wider area with same microsaccadic rate requires greater microsaccadic magnitude). This phenomenon can be seen in the average greater microsaccade magnitude in the CVSTM task compared to the n-back task. This can be an advantage for the use of microsaccade magnitude in the CVSTM task, as it shows greater sensitivity than LHIPA in a task that requires continuous visual attention to the task.

Taken in whole, the CVSTM appears to suggest greater difficulty in task execution than n-back, which is reflected by microsaccade magnitude, performance, and subjective measures. Subject to future replication, these findings would suggest that the CVSTM task could be a good starting point for future research of cognitive load with multivalent, conjunctive visual features.

7.1.5 Limitations

The main result of this work is that CVSTM task has been demonstrated to be more difficult than n-back.

The study also shows the LHIPA, mag, accuracy, and performance measures ability to discriminate between CVSTM and n-back task. This result was not significantly shared by mag, even if the descriptive statistics suggest it.

However, LHIPA and mag still not discerning between different CL level. This limitation could impact their feasibility in being used for technology evaluation, where the test often involved measuring users CL during multivalue information tasks. In this context, indeed, would be very important to exploit a measure that can compare different features, to provide indication of where to focus the designers' work.

Other limitations could be represented by the experimental ecology and the eye-tracker used. In this work the participants heads were stabilized with a chin rest and the data were collected using a remote eye tracker. In the HCI field, it is usually not recommended to block users' movement, because this makes the use of technology less realistic. One of the future study could focus on validating LHIPA with a different experimental setup, without using a chin rest.

Moreover, regarding LHIPA, it has been compared with only other eye-tracking indexes yet, and it would be interesting to validate its performances against more robust measures. One example could be the Heart Rate Variability, that represent a common used measure in CL (Larmuseau et al., 2020; Urrestilla & St-Onge, 2020) and it is also conceptually similar to LHIPA, since it rely on low and high frequency wave of the heart signal related to Peripheral Nervous system activation (Pham et al., 2021).

Finally, it would be interesting to test mag with two tasks involving similar short-term memories of CVSTM and n-back but with equal target number and visual areas of stimulus appearance. The results will help understanding the influence of visual attention on microsaccadic magnitude.

7.1.6 Conclusion

This work explored the response of gaze-based metrics to induced CL during introduction of a novel task featuring multivalent visual stimuli, the Color Visual Short-Term Memory (CVSTM) task. This study supports and extend previous work in CL measurement by replicating previous results obtained using the n-back task and shows that the gaze-based metrics respond similarly to the new CVSTM task. This suggests that the involvement of conjunctive features is a suitable new tool in validation of cognitive load indices, especially ones derived from eye movements.

Validation of these metrics over increasingly complex stimuli carries potential application to future experiments dealing with, for example, evaluation of human-computer interfaces, where the visual component plays a fundamental role and information is usually comprised of multiple features.

7.2 Evaluating LHIPA with a Head-Mounted Eye Tracker

7.2.1 Aim of the Study

The previous study validated LHIPA as a robust mea- sure in multiple cognitive workload inducing tasks. The limitations of this index were the restricted head movement permitted to participants, the gaze fixed on the screen and the use of a remote eye tracker. In order to expand the reliability of this index, the main aim of this work was to verify the ability of LHIPA to discriminate the cognitive workload connected to an activity when measured with a head-mounted eye tracker in free head-movement conditions

(H1). The secondary aim was to compare it with a more robust index in the measurement of MWL, the mean HR, to check if they measure MWL levels accordingly (H2). Moreover, since the computation of LHIPA is similar to the temporal analysis of HR variability (i.e., LF/HF ratio, Duchowski et al. 2020; Pham et al. 2021), the study aimed to research possible correlations between LHIPA and Heart Rate based LF/HF index (H3). Finally, I evaluated the influence of gaze position on the screen on LHIPA (H4), subdividing participants looking at different portions of the screen during the tasks (i.e., centre vs up) and the percentage of on-screen fixations.

7.2.2 Materials and Methods

7.2.2.1 Participants

I recruited 23 participants for the experiment. Four of them were eliminated from the analysis for missing eye-tracking data. The final number of participants was 18, aged between 25 and 46 years old (M_{age} = 30, SD_{age} = 5.36, Female = 10).

7.2.2.2 Tasks

Participants faced two different types of tasks, based on a previous experiment presented in the work on LHIPA that exploit a remote eye-tracker (Duchowski et al., 2020). In this work the participants initially faced a baseline phase of five minutes, followed by the two experimental tasks. In the first one (i.e., EASY condition), they had to count forward adding 2 to a given number, selected randomly from a predetermined set (i.e., 363, 385, 143, 657, 935, 141). In the HARD condition, instead, they had to start counting backward -17, starting from a randomly selected number, selected randomly from another set (i.e., 1375, 8489, 5901, 5321, 4819, 1817). The counting was performed loudly, permitting to researchers to register the participants' answers. The two conditions were counterbalanced across participants.

7.2.2.3 Measures

Various data were collected for the evaluation of MWL. The first measure used was the NASA-TLX questionnaire, a subjective tool which uses six subscales (i.e., mental, physical, temporal demands, performance, frustration, and effort) to evaluate cognitive load (Hart, 2006). Regarding the objective measures, I considered the performance (i.e., the average accuracy of the mathematical operation performed during the task). I exploited three psychophysiological indexes derived from eye-tracking methodology and cardiac metrics: LHIPA, mean Heart Rate, and LF/HF ratio of Heart Rate derived. To evaluate the influence of gaze position on LHIPA, I further analyse its data by subdividing participants considering where they were looking on the screen (i.e., Gaze on screen position, GOS) and the percentage of gaze inside the surface (i.e., Fixation on screen percentage, FOS). I used Aruco markers to delimitate the screen area. Pupil Player software was used to extract relative data. For computing GOS, I calculated the median y position values and analysed data from EASY and HARD conditions (baseline was ignored since participants were instructed to look at the centre of the screen and did not present counting strategies that could modify this behaviour). I subdivided participants into three sets: Down (median y position < 0.35), Centre (0.35 < median y position < 0.65), and Up (median y position > 0.65). Regarding FOS, I calculated the percentage of fixations on screen, subdividing our data into two subsets: High Percentage (< 70%) and Low Percentage (>70%) on screen.

7.2.2.4 Apparatus

I exploited a 32 inches monitor placed 90 cm away from participants, with four Aruco markers placed at the angles (Figure 1). The instrument used for acquiring eye behavioural data was a pair of wearable glasses from Pupil Core (Fig. 7.6; Pupil Core 2022), which acquires data at 200Hz. An elastic band was used to detect the cardiac signal to derive the average heart rate and the IBIs. The instrument used was a Polar H10 band (Fig. 7.7; Polar 2022), capable of acquiring data at 1024 Hz. The considered indexes were the average Heart Rate signal (HR) and the LF/HF ratio. The two signals were then synchronized thanks to the exploitation of a smartphone application (i.e., TimeSync). I eliminated the first and last minute data to avoid effects due to fatigue and adaptation. The environmental light was maintained fixed across participants and fixed during the tasks, thanks to the exploitation of the same lights for every participant and black curtains to the windows

Figure 7.6. Pupil Core eye tracking glasses used in the experiment.

Figure 7.7. Polar H10 band,
used for acquiring heart rata data

7.2.2.5 Procedure

The experiment started with an initial phase in which I collected the informed consent and the demographic information about participants. Immediately after that, I proceeded to attach the sensors to them. The sensor comprises a chest band for collecting heart rate signals (Polar H10, Figure 2) and the head-mounted eye tracker (Pupil Core, Figure 1). After this initial phase, I performed the eye-tracker calibration. The experimental phase started with the collection of the baseline data, which last a total of five minutes, in which participants had to fixate a grey screen at an approximal distance of 60 cm. After the baselines, participants faced the experimental tasks, comprising two task difficulties (i.e., EASY and HARD conditions), which order was counterbalanced. During each task, the screen was maintained with the same grey color of the baseline, to avoid light disturbances during the experimental phases. The participants were instructed to look at the screen during all the tasks. Each tasks lasted five minutes. After each experimental task, I administered the NASA-TLX questionnaire. The counting was performed loudly, and the session was registered to permit the analysis of performance. Between the two conditions, participants take a pause of two minutes permitting to rest and return to the baseline levels. An example of an experimental session is provided in Figure 7.9 and the graphical representation of the procedure is shown in Figure 7.8.

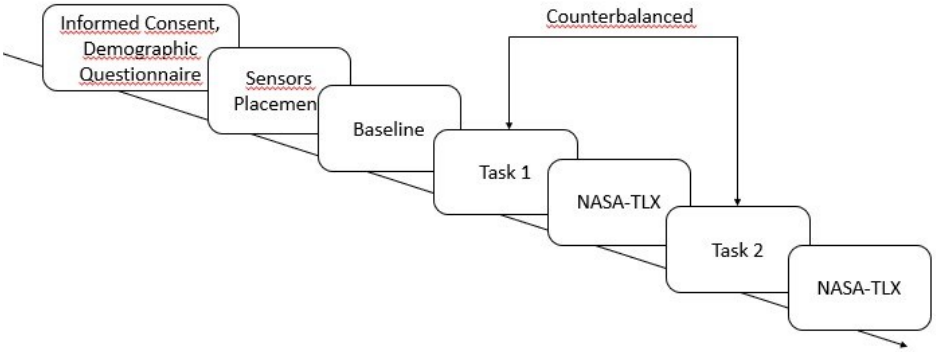


Figure 7.9. Graphical representation of the procedure.

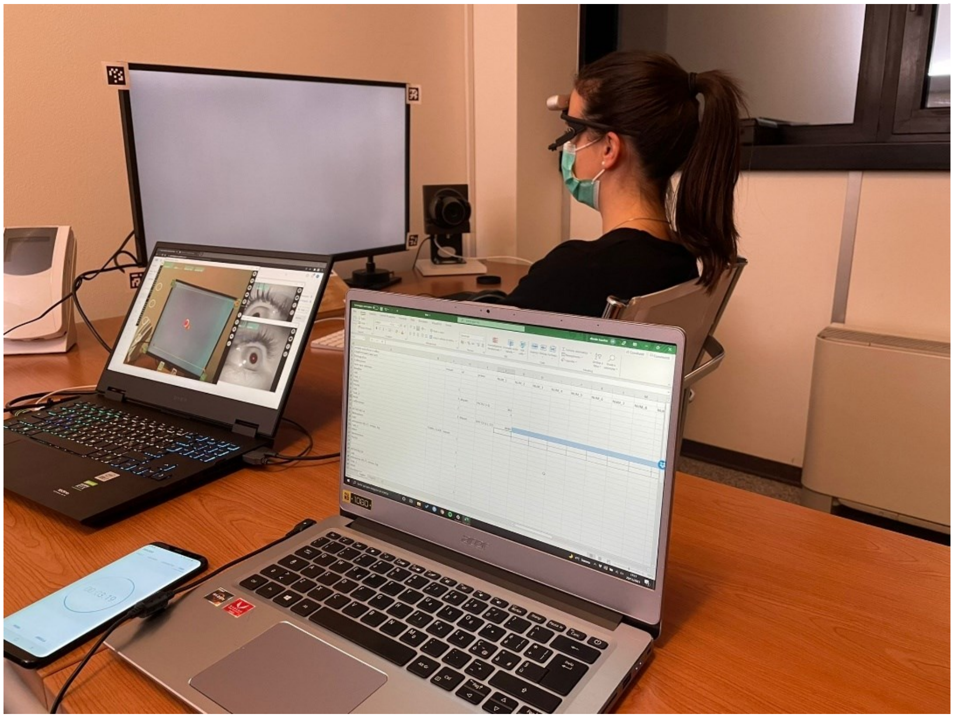


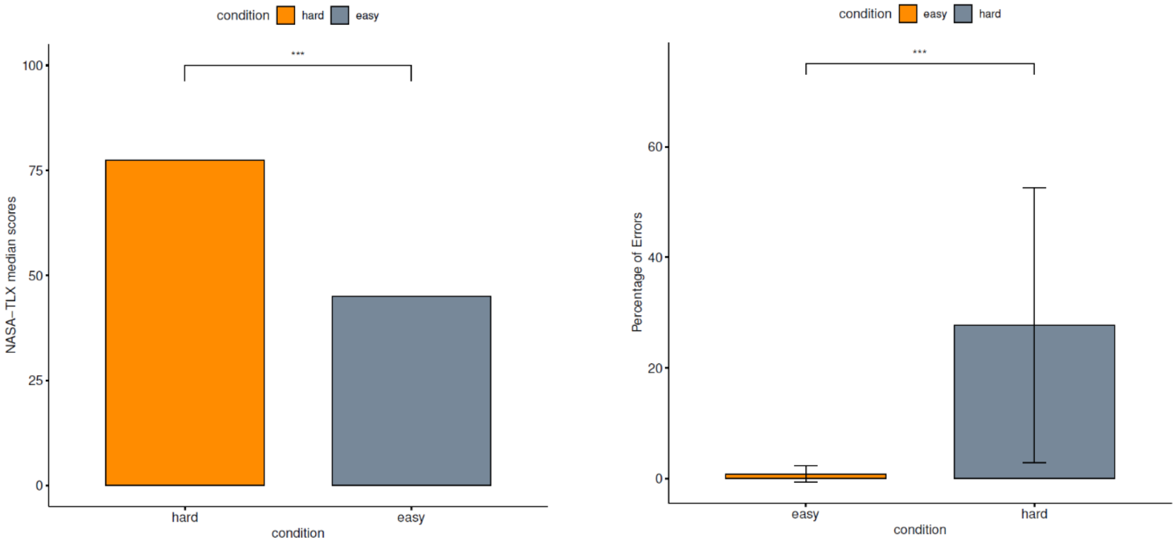
Figure 7.8. Participants during the baseline phase of the experiment. The setup comprises a monitor with a grey screen.

7.2.3 Results

The present experiment tested the response of LHIPA and Heart Rate indexes to two cognitive load-inducing tasks that relied on mathematical skills. The experiment was of a 2 × 2 within subjects design, with task difficulty (EASY vs. HARD) and condition (baseline vs. task) as independent variables. Dependent variables included task accuracy, subjective measures, gaze-based indices of cognitive processing load (i.e., LHIPA), and heart rate measures (i.e., average HR and LFHF). Gaze-based and cardiac metrics were contrasted against baseline, serving as two experimental conditions (baseline vs. task).

7.2.3.1 Accuracy and Subjective Measures

The analysis of the data regarding performance and subjective measures shows that the difficult task proved its ability to induce higher cognitive load levels.



(a) Task Difficulty NASA-TLX

(b) Task Difficulty Accuracy

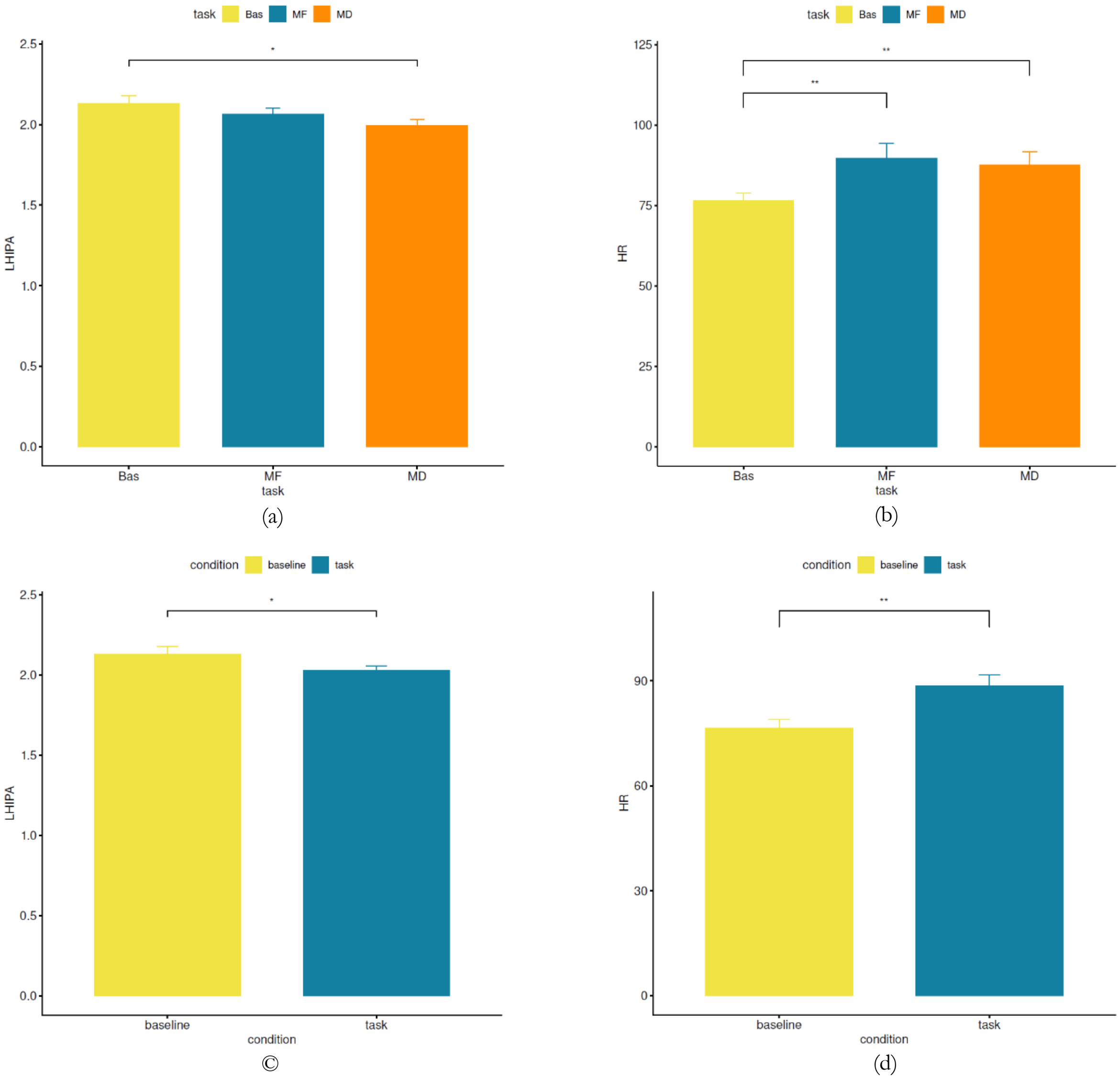
Figure 7.10. Accuracy and subjective measures, including NASA-TLX median scores (a) and task difficulty accuracy, calculated as the percentage of errors (b)

7.2.3.1.1 NASA-TLX

The results of the NASA-TLX questionnaire were analyzed using paired Wilcoxon test (see Figure 7.10a). Results showed that the HARD condition (MED=77.5) scored significantly higher cognitive load values (V=2, p<.001) than the EASY condition (MED=45).

7.2.3.1.2 Accuracy

I calculated the percentage of errors during the two task difficulties using paired Wilcoxon test (see Figure 7.10b) after checking data normality with the Shapiro-Wilk test. Results showed that the HARD task (M=27.73, SD=24.87) yelded significantly higher errors (V=1, p<0.001) than the EASY task (M=0.85, SD=1.5).



(a)

(b)

©

(d)

Figure 7.11. Results from the ANOVA paired t-test, including LHIPA task difficulty and baseline (a), LHIPA condition (c), HR task difficulty and baseline (b), and HR condition (d).

7.2.3.2 Psychophysiological measures

7.2.3.2.1 LHIPA

One within-subjects one-way repeated-measures ANOVA was run for each independent factor (i.e., task difficulty and condition). Results are shown in Figure 7.10a and 7.10c. Regarding task difficulty, ANOVA reveled a significant main effect (F(2:36)=0.08, p<0.5). The following pairwise t-tests showed that the baseline condition (M=2.13, SD=0.22) obtained significantly higher values (t(18)=3.23, p<0.05) than the HARD condition (M=1.99, SD=0.17). No differences have been founded between baseline and EASY condition or between HARD and EASY conditions. Using condition as the independent variable, ANOVA revealed a significant main effect (F(1:18)=0.08, p<0.05). The following pairwise t-tests revealed that baseline LHIPA values (M=2.13, SD=0.22) were significantly lower (t(18)=2.69, p<0.05) than the task ones (M=2.03, SD=0.13).

7.2.3.2.2 Heart Rate

One within-subjects one-way repeated-measures ANOVA was run for each independent factor (i.e., task difficulty and condition). Results are shown in Figure 7.10b and 7.10d. The ANOVA test run with task difficulty as independent factor reveal a significant main effect (F(2:36)=0.105, p=0.001). The following pairwise t-tests showed that the mean HR in the baseline condition (M=76.5, SD=10.6), were significantly lower (t(18)=-3.21, p<0.01) than the ones obtained by the HARD condition (M=87.5, SD=10.6), and significantly lower (t(18)=3.24, p<0.01) than EASY condition (M=89.6, SD=21.0). No differences have been founded between EASY and HARD condition. Regarding the condition as the independent variable, the ANOVA test revealed a significant main effect (F(1:18)=0.142, p<0.01). The following pairwise t-tests showed that baseline values (M=76.5, SD=10.6) were significantly lower (t(18)=-3.46, p<0.01) than the values obtained by the tasks (M=88.6, SD=18.6).

7.2.3.2.3 LF/HF

I run a within-subjects one-way repeated measures ANOVA for each independent factor for LFHF index. The results did not show any significant main effect.

7.2.3.2.4 Correlation

I run Kendall correlations tests between task values of LHIPA, LFHF and HR indexes. The results did not show any significant correlation.

7.2.3.3 Correlation Analysis

We run Kendall correlations tests between task values of LHIPA, LF/HF and HR indexes. The results did not show any significant correlation.

7.2.3.4 Gaze On Screen

We subdivided our measured data into Down, Centre, and Up conditions, depending on the median y position on the screen. We run a series of unpaired Wilcoxon tests, corrected with the BH method for comparing LHIPA results on the two task difficulties with GOS as independent variables. We considered only Up and Centre conditions since Down Bacchin et al. 2023: Preprint submitted to Elsevier Page 6 of 9 LHIPA Evaluation in Ecology Settings presented limited data numbers (i.e., five). We also run a Wilcoxon test without considering task difficulty as a factor. Both analyses did not show any significant difference.

7.2.3.5 Fixations On Screen

We subdivided our data into two subsets, calculating the percentage of fixations on the screen. All the conditions scor- ing higher than 70% of fixation on screen were considered high percentage, while data scoring lower than 70% were considered low percentage. We ran a series of Wilcoxon tests corrected with the BH method considering LHIPA as the dependent factor and task difficulty and FOS as independent factors. The results did not show any significant difference.

7.2.4 Discussion

The main aim of this work was to verify the ability of LHIPA to discriminate the MWL during a task when measured with a head-mounted eye tracker. The secondary aim was to compare it with a more robust index in the measurement of cognitive load, HR. Moreover, since the computation of LHIPA is similar to the temporal analysis of HR variability, the study aimed to correlate it with the HR- derived LF/HF index to detect eventual correlations. Finally, we were interested in researching possible influences of gaze position on LHIPA values.

Regarding the first hypothesis, this work partially respects previous results, where LHIPA tested with the same tasks significantly discriminated MWL levels between baseline and task conditions (Duchowski et al., 2020). This study confirms this result only between baseline and difficult tasks (see Figure 7.11a), with the latter showing higher MWL levels. This result indicates a lower precision in LHIPA calculation in the present work. This can be due to instrumental and experimental differences. First of all, the main aim of this research was to allow a more ecological collection of data. The first main difference is indeed the removed head restrictions with the chin rest, absent in the present work. The gaze freedom of this experiment represents another possible factor since participants were not forced to watch a specific portion of the screen. In the previous work, they were instead forced to look at the very centre of the screen and prompted when the gaze went too far from it. Finally, the last important difference could be the data acquisition frequency. The in strument utilized for the reference experiment was an Eye- Link eye tracker with a 1000 Hz acquisition frequency, while the Pupil Core acquired data at 200 Hz. Anyway, this last difference is unlikely to strongly impact the index since its based on previous pupil fluctuations studies, 200 Hz exceed the minimum requirement (Hachol et al., 2006; Nowak, Hachol an Kasprzak, 2008; Reimer et al., 2016). Moreover, since this index is based on the pupillary response, and pupils' sensitivity to illumination and eye movements are well-known problems for its measurement (Duchowski et al., 2018a), it is reasonable to affirm that gaze freedom could have an impact on LHIPA calculation. However, our results from GOS and FOS analyses did not support this hypotesis, showing no impact of gaze position on LHIPA. Indeed, our hypotesis is that the eye rotation could have induced pupil foreshortening errors (Petersch and Dierkes, 2022), generated by the combination of three optical effects (i.e., Perspective foreshortening, Foreshortening with gaze angle and Corneal refraction). These errors could have reduced the precision of LHIPA measurement, thus causing the missing results between baseline and EASY task. Despite LHIPA didn't show the sensibility to discriminate between difficulty levels, these results are encouraging and pose the base to take a step further in its application in future MWL evaluation studies. Indeed, the discrimination between rest and cognitive overloading working phases allows LHIPA utilization in, for instance, future studies in Human-Computer Interaction experiments, where it could be used to detect stressful situations with a cheap and comfortable eye-tracker. Moreover, our analysis regarding H4, namely the influence of gaze position on the screen, indicates that the number of fixations on and off the screen and their relative positions on it (i.e., in the upper or centre part of the screen) did not influence the index performance. This result confirm the possibility the exploitation of the index allowing participants a higher degree of gaze freedom. However, further studies should better explore the influence of head movements on the index.

The second hypothesis was to compare LHIPA and HR performances. This study's results highlighted that HR showed higher sensitivity to lower CL levels, discriminating the baseline from both EASY and HARD tasks. However, also HR did not show significant differences between the two difficulty levels. This result is both, in contrast (Mingardi et al., 2020; Splawn and Miller, 2013), and according (De Rivecourt et al, 2008; Ding et al., 2020) to previous studies. The loud declaration of numbers during the tasks could be responsible for the missed significative difference between the difficulty levels. Indeed, in accomplishing the EASY task, participants performed more calculations in the same amount of time, resulting in a higher frequency of spoken numbers. This could correspond to a higher respiratory rate, which can modulate HR activity (Cacioppo et al., 2016), bringing the mean value of the EASY task slightly above the HARD one. The two indexes' results highlight commonalities and differences between them. In this medium-controlled experimental setup, they could discriminate a high cognitive task, while HR showed greater sensibility to lower cognitive duties. The main take-home message lies in the possible situations where they can be used. Indeed, HR could be strongly affected by movement artefacts (Kumar, Komaragiri and Kumar, 2022; Berwal et al., 2019), making it less suitable for in-motion experiments, frequent in HCI research. LHIPA could be a better choice in these cases, though further studies should test it in such situations. However, in an experimental setup similar to this study, both indexes should be used to increase the robustness of the collected data.

The third hypothesis of this work was the possible correlation between LHIPA and Heart Rate derived LFHF ratio. The correlation analysis did not show any significant relationship between the two indexes. However, this hypothesis should be further explored with more accurate instruments (e.g., classical electrocar diogram electrodes and high- frequency acquisition rate eye trackers) to confirm that these two signals are unrelated. Increasing the accuracy of the acquired data could shed more light on this important theme.

7.2.5 Conlusions

This study shows the feasibility of LHIPA to be used in discriminating difficult tasks and rest levels with a high degree of movement freedom for participants and with head-mounted eye trackers. Moreover, our results permit to show LHIPA's feasibility for being utilized in HCI experiments involving highly MWL inducing tasks requiring a high level of experimental ecology, an element of primary importance in this field. Furthermore, LHIPA shows remarkable results when compared to the most reliable index of average heart rate, though this showed its higher sensitivity to lower levels of MWL. Future studies in this field should better explore the influence of screen luminosity and head movements on LHIPA when used in real usability/user experience tests, to finally verify its feasibility in measuring MWl in applied studies.

8 CONCLUSIONS

The present work represents a valid example of a co-design cycle. Indeed, the project started from the very early phases of design, with qualitative methods (i.e., focus groups and interviews) exploited to collect opinions and suggestions regarding various technologies related to the healthcare environment. More specifically, I involved final users in the design cycle of the electrical medical bed and its smart system, analyzing their opinion in the studies presented in paragraphs 4.2 and 5.1. Moreover, the studies presented in Chapter 6 regarding the domotic co-housing evaluated the user interfaces developed during the DOHMO project, an extensive work in which early phases comprehended multiple co-design work (Bacchin et al., 2021; Masina et al., 2020b, 2021; Zanella et al., 2020b). The following phase in the design cycle is the evaluation of the prototypes created. In the present work, I performed multiple tests involving final users to evaluate multiple human factors (e.g., Cognitive Load, User Experience, Technology Acceptance, and Usability, among others) related to the use of the two smart bed interfaces (i.e., web interface at paragraph 5.2 and touchscreen at paragraph 5.3), and the smart co-housing ones (paragraph 6.1). These works lead to the re-definition of their design, i.e., to small adjustments based on the studies' suggestions. The last and probably the most important phases of my work were the real-environment tests. Indeed, paragraphs 5.4 and 6.2 represent the previous studies' finalization, with the tests outside laboratory environments thanks to the implementation of technologies in places where they can truly exploit their functions. The very aim of the entire project was to evaluate their usefulness when challenged with real users and real working situations. The two studies inserted the IoT technologies in a co-housing reality created for people with disabilities and their caregivers (domotic technologies) and in an elderly retirement home (smart bed).

The described works permit me to answer the first two objectives of this thesis. The first was to improve the usability of the electrical medical bed, while the second was to shed light on the readiness of working healthcare environments to adopt such advanced technologies while understanding their impact on them.

In the last part of the thesis, I instead switch the subject of the research to evaluation methods, analyzing innovative psychophysiological indexes for CL research and testing their validity for future HCI studies.

8.1 Improving the Electrical Medical Bed

The first two studies this thesis presents regard the design of electrical medical beds. The project's innovation lies in designing this object's future characteristics to overcome its general impression of being only a passive support for patients. In this new proposed vision, it instead becomes one of the main supports to caregivers' work. Since its central role in hospitals, retirement homes, and homecare life, these studies deeply analyze it, providing readers with missing features, amelioration and new ideas. Literature vastly ignored these arguments since most studies regarding medical beds to date concern tests of a single innovative element and are often very technical (Gunningberg & Carli, 2014; Schmid et al., 2017). Therefore, there was a need to revise this tool deeply to update its design to modern standards.

The results of the study present in paragraph 4.2 exhaustively answer this problem. Thanks to qualitative methods such as focus groups and semi-structured interviews, I provided a comprehensive vision of caregivers about the electrical medical bed. In order to give a starting point to future companies or researchers that will face a new bed design, I involved participants belonging to all the possible stakeholders. Indeed, the study involved nurses, nursing students, physiotherapists, and social health operators belonging to multiple realities, namely hospitals, home care, and retirement homes for the elderly and people with disabilities. The comprehensive vision that resulted will have a strong impact on the future design, providing suggestions and caregivers' opinions on almost every component and feature of this tool. Citing some examples, the results could help design side rails that account for patients' safety and comfort, accessories which permit high flexibility of use, elements to improve manoeuvrability, lights for nocturnal workers, more usable control interfaces, and systems for on-time maintenance. Moreover, the analysis of the collected data permitted the identification of some major themes that designers should keep in mind in creating new bed versions. These, provided in paragraph 4.2.4, showed caregivers' attention to the issues they expect a useful medical bed should solve. Many are known concerns in healthcare settings, such as workload, time-saving, patient safety and comfort of the stay. Many other, instead, represents themes again ignored by literature. Indeed, caregivers showed great attention to beds' flexibility of use and their materials, which should be resistant but easy to clean and aesthetically pleasant.

A further step forward in bed design in this work was the creation of helpful evaluation tools. The first is a usability checklist for the main user interfaces of the bed, the push-button panel, developed and deeply discussed in paragraph 4.1. The second was the identification of many user experience guidelines in the discussion section of paragraph 4.2. Following these works, future designers can develop new user-friendly instruments with the possibility to truly change the working life of caregivers and patients all around the world. Figures 8.1 and 8.2 show the first example of my work application. Following the study on push-button panels, the company I collaborated with during my PhD (Malvestio spa.) completely redesigned the push-button panels to make them more usable. Hopefully, the UX guidelines of the focus groups/interviews work could represent the same stimulus to improve bed design for the same and other companies.

Concluding, the impact of this works on healthcare workers could be huge. The practical implication of improving UX and usability will lead to the creation of more effective and efficient beds, permitting the reduction of workload, time-consumption procedures and physical fatigue while helping with the psychological components of work, providing a comfortable and enjoyable experience of use.

Figure 8.2. Push button panels new version project.

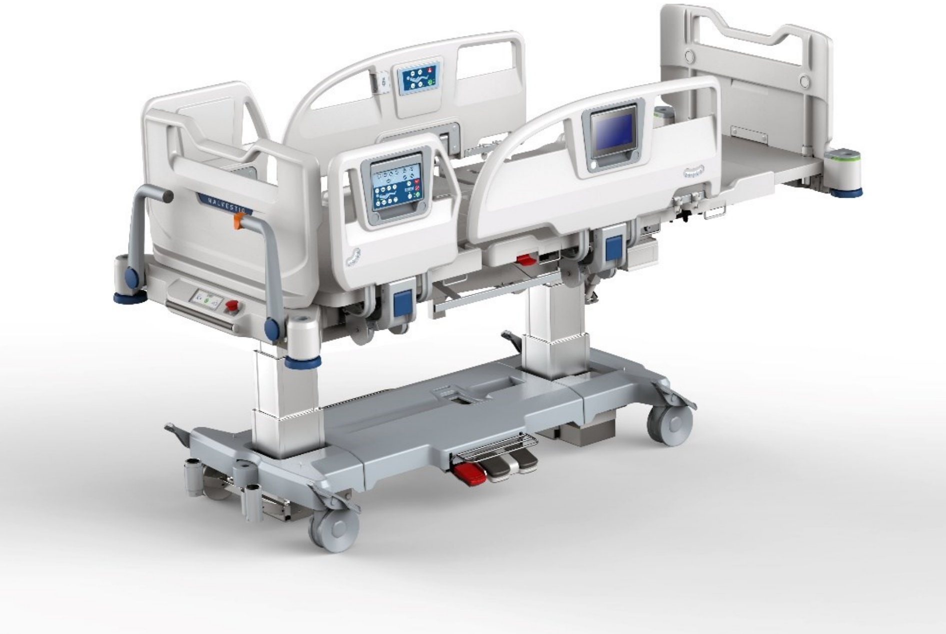


Figure 8.1. New version of the push-button panel inserted in the electrical medical bed.

8.2 Impact of IoT technologies on Healthcare Environments

The present thesis analyses two IoT systems: the smart bed and the smart home.

Regarding the medical bed, this project represents a cutting-edge monitoring system in Italy, where the Smart bed and Hospitals 4.0 concepts are still at the beginning of their development. On a global level, however, the study of smart beds' characteristics is becoming increasingly popular, often in small innovations or isolated technologies, as discussed in the introduction. Furthermore, the DOMHO smart home represents a unique and world-leading example of advanced systems for ambient assisted living and is another example of a recent and poorly explored technology. Despite the growing interest in these technologies, it is rare to find comprehensive studies on such systems' impact on the final users in real situations. Therefore, this project part aimed at determining, at first, the features and characteristics that smart IoT systems should have according to their future utilizers. This aim precedes the most important objective to deepen our knowledge about human factors related to IoT technology's use outside the laboratory setting.

Regarding the former aim, this thesis started the analysis with another qualitative study on the smart bed (paragraph 5.1). This work deeply explored a fundamental component of the technology acceptance model, the perceived usefulness, with results indicating caregivers' great interest in utilising advanced technologies. The qualitative study conducted for the DOMHO system (paragraph 6.1.4) shares the same results, strengthening the conclusion that caregivers are ready for this technological innovation and believe in its usefulness in increasing their working conditions. Moreover, the results of these two studies could potentially significantly impact future studies and projects, providing essential elements to meet users' needs. An example is their attention to workload reduction, shared between these two studies and the simple medical bed ones. The future system should indeed pay particular attention and ensure reaching this objective because of its importance shown in these studies. Another critical finding regards the possible limits to overcome to increase the willingness to adopt IoT technologies in various healthcare settings. The two systems of this thesis presented monitoring devices designed to ensure patients/people with disabilities' safety through the dispatch of notification to caregivers. Among all the studies, the reliability of these acquired data and alarms seemed of primary importance (see Introduction for details about alarm fatigue). Furthermore, the comparison of the two studies highlights some environmental peculiarity, showing, for example, how caregivers of people with disabilities primarily focus concern people's independence and social behaviours. In contrast, hospital caregivers mainly concentrated on patients' safety and on-time interventions, requesting reliable monitoring systems.

Furthermore, the evaluation studies presented in paragraphs 5.2, 5.3, and 6.1 provides a shared enthusiastic view of the proposed systems. In these studies, I tested the users' interfaces using a combination of instruments (i.e., objective and subjective). In all the studies, I evaluated human factors such as User Experience, Usability, Technology Acceptance, and cognitive load levels during *ad hoc* tasks exploring interfaces' functions. The results for any interface analysed showed extremely positive scores for all the questionnaires, with few to no major problems (e.g., data reliability). At the same time, the method was able to highlight minor usability problems (i.e., the need for colour codes, confusional pages, not intuitive icons, etc.), helping in the interfaces' redesign and refinement. In my opinion, these results show the strong impact of the interaction design cycle on the final users' appreciation of technologies.

UX, Technology Acceptance, and Usability were the main subjects of the following studies in real environments (paragraphs 5.4 and 6.2), representing the core result of this thesis and the answer to its second objective. These two studies comprehend the caregivers' evaluation of the smart bed in an elderly retirement home and the extensive tests conducted in the DOMHO apartment with caregivers and people with disabilities. Once again, all the results highlighted and confirmed the extremely positive behaviour of final users towards the implemented technologies regarding UX, usability, and TA. Moreover, these works showed that the DOMHO system did not impact the sense of being at home or the caring perceived quality. The study on the smart bed shares these former results, adding interesting insights about the ability of the smart bed to reduce workload and increase patients' safety, even if the NASA-TLX questionnaire did not confirm this last result. The extensive analysis of these studies provides extremely useful suggestions for future IoT system development in healthcare environments. For example, for people with disabilities, the flexibility and accessibility of the system (e.g., providing multiple user interface modalities like voice controls) represent a fundamental characteristic. Moreover, the two studies again highlighted the importance of data reliability. For example, during the experience with the smart bed, caregivers experienced false alarms during the trial, resulting in lower trust in the system. This extensive study confirms the literature advice to paying particular attention to this important theme (Downey et al., 2018; Ruppel et al., 2018).

Concluding, all these section studies provide a comprehensive vision of IoT technologies in healthcare environments, treating themes like UX, TA, usability, patients' safety and comfort, trust and privacy issues with technologies, workload, care quality, sense of home, intention to use, and learning difficulty. All the data gives the same answer, indicating that caregivers and patients are ready to adopt IoT technologies, confirming previous literature results (Al-Rawashdeh et al., 2022).

8.3 Ethical Considerations on IoT Systems for Healthcare

In this dissertation, I presented two IoT systems designed to impact involved people in many different ways, with the final objective of increasing users' health. In the case of the Smart Bed, the system can acquire patients' health-related data, showing this information to caregivers, while DOMHO ambient assisted living system helps people by allowing high accessibility to home spaces. Both technologies pose important ethical issues for all the users involved, for instance, the trustworthiness of information, protection of privacy data, and cybersecurity, which are common problems in every IoT system (Zheng et al., 2014).

Starting from the latter, the security of data is of vital importance. In the Smart bed, very sensible data (potentially medical data such as heart and respiration rates and body temperature) are stored in the system. DOMHO smart apartment presents technologies that could expose inhabitants to intrusions into their homes. In both cases, the system should be protected against malicious or unauthenticated users, respecting the requirement of Confidentiality (Maple, 2017). Adopting strategies such as strong encryption algorithms, updated antivirus, security by design approach, and educating users on password management are essentials to provide the maximum level of information security (Suo et al., 2012). In these cases, users could become fully confident about their system security, which will become integrated into their usual activities (Iqubal, 2016).

Another strong ethical issue is the protection of privacy (Atlam, Walter, and Willis, 2018), a major point, especially in the Smart Bed system where physical privacy is at high risk. Regarding DOMHO, the system does not collect personal data about users, but possible issues could arise from territory information leaks (Padilla-Lopez, Chaaraoui, and Florez-Revuelta, 2015). The IoT systems, in this case, should provide protected users' identifiers, localization, inventory attacks, and profiling (Ziegeldorf, Morchon, and Wehrle, 2014). All these problems could lead to users being tracked by external entities, with the further problem of being unaware of that since the data collection is often passive, pervasive and unintrusive, reducing people's awareness. The strategies to overcome these issues could be creating the technology with a Privacy by Design approach, making the user aware of the risks, minimising data collection, and encrypting and anonymizing data (Atlam and Willis, 2020). In my opinion, patients should be allowed to agree or not to be monitored after being fully informed about the risks and the type of data collected. Since the intrinsic personal nature of health data, this issue is particularly relevant in the Smart bed system. Moreover, the situation is mitigated in Italy, where public health allows everyone to be cured. However, in the case of the insertion of this or a similar system in other countries where the health system is private (e.g., USA), the problem is possibly more essential since the insurance company could use this data to raise the price of the insurance policy.

Finally, safety is another crucial issue in IoT systems since they should never produce physical or other types of damage. Since the proposed system cannot move the bed, this issue is more prominent in the DOMHO apartment, where ambient assisted living technologies could move in response to a command given after a hacker attack. In such cases, the attacker could indeed manipulate the devices, causing damage to the structure or the inhabitants (Hussein et al., 2017).

Another type of issue derives from ethical considerations. A clear example is the issues highlighted in paragraph 5.1.4. In that study, caregivers addressed some interesting problems. The first was feeling under control of the structure management when the IoT system used video cameras. The concern was so strong that they felt the need to address it if the smart bed did not use such devices. They also cited problems regarding a possible legal issue. Since the system can record the alarm activated during the day, they were concerned about ignoring some for working duties. In that case, they were worried about the possibility of being charged for ignoring them and if the reasons were legitimate. Finally, some caregivers were worried about losing patients' trust since they would have to pay attention to personal devices in working areas. In this case, unaware patients who do not know that these devices are used for their monitoring could think that the care quality and caregivers' attention to them is poor.

To these concerns, the IoT field poses some known ethical ones, such as data owner identification, boundaries between public and private data for their accessibility, and people's life attacks (Atlam and Willis, 2020).

Surely, IoT systems pose difficult challenges. Anyway, the strong advantages that they can provide to people make them worthy of constantly researching new solutions to overcome these problems.

8.4 Eye Tracking Methodology for Human-Computer Interaction Research

The vast majority of the studies of this thesis exploited multiple research methods. The initial phases utilized purely qualitative procedures (i.e., focus groups and interviews), followed by the mixed qualitative/quantitative technique during the interface's evaluation studies. Nevertheless, most studies presented both subjective (e.g., questionnaires) and objective (e.g., eye-tracking, performance) data. I firmly believe that their contemporary exploitation should be a standard research practice.

As described in paragraph 3.3, subjective measures often present strong limitations, such as the possibility of using them only at the end of the experiment, an aspect particularly limiting validity during experiments involving the accomplishment of a task (e.g., interfaces' evaluation). In my personal experience gained during the collection of the studies data, on many occasions I had to encourage participants to criticize the designers' work if they found something not working perfectly. Moreover, I notice many factors which can participate in acquiring poor data: bad mood by participants during data collection, hurry for other appointments, tiredness, people's character (talkative and not, prone to critics or not, etc.), unfamiliarity with questionnaires, shame, excessive enthusiasm, and sometimes gratitude towards designers or researchers. All these reasons, and probably many others, could participate in collecting unreliable data. Instead, objective measures have the advantage of being collected during the accomplishment of the task and are very difficult to fathom. For the sake of fairness, they also present many confounding factors, such as tiredness, substance abuse, fatigue, and others (Cacioppo et al., 2016). Still, I believe they are generally more reliable, although presenting greater analysis difficulty. Unregarding my opinion, since both types have advantages and disadvantages, combining them and comparing results to deeply analyze a study's results could be the key to collecting better data.

The objective measures used in this thesis belong to behavioural (i.e., performance and some ET indexes) and psychophysiological (i.e., HR and ET) indexes. The latter are controversial since their analysis needs extensive data cleaning for artefacts and because they are intrinsically related to the advantage/disadvantage of taking interpersonal variability into account. For these and other reasons, literature teems of studies about new psychophysiological indexes and their validity for multiple types of tasks (for further details, see paragraphs 3.3 and 3.4). Among them, I decided to explore an innovative index related to the ET methodology: the Low/High Index of Pupillary Activity (LHIPA). The aim was to study its possible application in HCI studies, like the interface evaluations presented in this work. To achieve such an objective, I tested its reliability in two highly controlled laboratory environments to validate its performance in controlled settings.

The first study (paragraph 7.1) had the twofold aim to confirm LHIPA reliability in a highly controlled setup while moving further towards the definition of a new paradigm for psychophysiological index testing. Moreover, it compares its results with another innovative index, namely the microsaccades magnitude. The study presents the definition of a new task based on the Feature Integration Theory, nearer to the HCI testing with respect to the classical task in the field (e.g., n-back). This study supports and extends the previous work in CL measurement with LHIPA, replicating the results of an n-back task reported in previous studies and thus contributing to this index validation. Furthermore, both indexes respond similarly to the CVSTM task, indicating higher CL levels during working conditions. This result suggests that the involvement of conjunctive features is a suitable new tool for validating cognitive load indices, especially ones derived from eye movements. Validation of these metrics over increasingly complex stimuli carries potential application to future experiments evaluating human-computer interfaces, where the visual component plays a fundamental role and information normally presents multiple features.

The main limitation of the previous study was the experimental setup, which greatly restricted participants, fixing their head position and limiting the gaze target area on the screen. Both these aspects strongly impair the index use during HCI research, where the ecology of the experiment represents a fundamental point. Furthermore, the eye tracker utilized was a professional instrument, particularly expensive. Thus, the second experiment proposed a more unrestricted environment, using a cheaper eye tracker to permit the exploitation of this method to a broader audience. The study utilized a free-gaze location task (i.e., mathematical counting in front of a grey monitor) and a head-mounted eye tracker with lower data acquisition frequency (i.e., Pupil Core). The results show the feasibility of LHIPA in discriminating the difficult task and baseline CL levels, partially confirming its validity. Although the results showed a lower sensibility of LHIPA in these conditions, they permit it to move further towards its utilization in HCI experiments, since the test presented a greater ecology, closer to realistic evaluation. Furthermore, LHIPA shows remarkable results compared to the most reliable index of average heart rate, though this showed its higher sensitivity to the lower level of CL.

The missing difference between lower and baseline CL levels suggests the necessity to explore better confounding factors, such as the influence of screen luminosity and eye movements. With a deeper understanding of LHIPA functioning, it could be easily exploited in real usability/user experience tests to verify its feasibility in measuring CL in applied studies.

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