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Prevention of Delirium in Geriatric Patients using Virtual Reality

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Prevention of Delirium in Geriatric Patients using Virtual Reality

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Dissertation

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Resumo

O delirium pós-operatório é uma complicação neuropsiquiátrica clinicamente relevante e frequente entre pacientes cirúrgicos geriátricos, no contexto dos cuidados perioperatórios em oncologia. A sua incidência está constantemente associada a um declínio funcional, aumento de morbidade, hospitalização prolongada e desfechos clínicos piores. Conhecem-se vários fatores que contribuem para o desenvolvimento do delirium, tais como a ausência de familiaridade com o ambiente e a desorientação espacial, o que reforça a importância de estratégias de prevenção não farmacológicas focadas na orientação e adaptação do paciente. Embora o número de aplicações de realidade virtual nos cuidados de saúde tenha crescido com o desenvolvimento tecnológico, relativamente à prevenção do delirium, o foco encontra-se principalmente na relaxação, no estímulo cognitivo e distração, com praticamente nenhum foco em preparar e familiarizar os pacientes com o seu ambiente clínico de recobro. O propósito desta dissertação é desenvolver e realizar uma avaliação preliminar de um ambiente de realidade virtual imersivo concebido para familiarizar pacientes oncológicos geriátricos submetidos a cirurgia com o seu ambiente de recobro pós-operativo. O objetivo principal é investigar a viabilidade do uso desta representação virtual como ferramenta para contribuir para a orientação ambiental do paciente e como um potencial complemento às estratégias de prevenção do delirium não farmacológicas.

Durante o desenvolvimento deste projeto, foi seguida uma abordagem metodológica interdisciplinar que reúne princípios dos cuidados de saúde, de tecnologias imersivas e de design centrado no utilizador. O protótipo foi desenvolvido através da análise e reconstrução de uma unidade de cuidados intermédios real, incluindo equipamento médico, propriedades ambientais, organização espacial e características auditivas. O processo de desenvolvimento e implementação baseou-se em software acessível, Unity e Blender, e de hardware comercial, nomeadamente o capacete de realidade virtual Meta Quest 3. Doze profissionais de saúde, todos enfermeiros com experiência direta em gestão de delirium pós-operatório, participaram numa avaliação preliminar, na qual exploraram o ambiente virtual e preencheram um questionário estruturado com itens numa escala de Likert e questões de resposta aberta sobre realismo, fidelidade clínica, usabilidade do sistema, intuitividade e experiência de realidade virtual.

Os resultados mostram que o ambiente virtual desenvolvido fornece uma representação clinicamente relevante e realista da unidade de cuidados intermédios. Os resultados numéricos demonstraram perceções positivas sobre realismo espacial, fidelidade do ambiente, representação do equipamento médico e usabilidade do sistema. O feedback qualitativo identificou áreas de possível melhoria e destacou o valor potencial da intervenção como ferramenta de familiarização do paciente. Através do feedback recebido, o ambiente virtual foi melhorado iterativamente, o que resultou num protótipo atualizado com maior realismo e melhor qualidade geral. Estas observações apoiam a viabilidade e potencial da abordagem proposta para familiarização ambiental pré-operatória. Este projeto serve como uma base para investigações subsequentes que avaliam se a exposição pré-operatória a ambientes clínicos futuros através de realidade virtual pode influenciar a incidência do delirium pós-operatório.

Palavras-chave: Delirium pós-operatório; Realidade virtual; Familiarização ambiental.

Abstract

Postoperative delirium is a frequent and clinically relevant neuropsychiatric complication among geriatric surgical patients, particularly within the context of oncological perioperative care. Its incidence is consistently associated with functional decline, increased morbidity, prolonged hospitalisation and poorer clinical outcomes. There are several known contributors to delirium development, such as environmental unfamiliarity and spatial disorientation, which highlight the importance of non-pharmacological prevention strategies focused on patient orientation and adaptation. Although virtual reality's list of applications within healthcare has grown alongside the development of this technology, in the context of delirium prevention, the focus has been primarily on relaxation, cognitive stimulation and distraction, with virtually no focus on preparing and familiarizing patients with their specific postoperative recovery environment. The aim of this dissertation is to develop and preliminarily evaluate an immersive virtual reality environment designed to familiarize geriatric oncological patients undergoing surgery with their postoperative recovery environment. The main objective is to explore the feasibility of using this virtual representation as a tool to support environmental orientation and as a potential addition to non-pharmacological delirium prevention strategies.

An interdisciplinary methodological approach combining healthcare, immersive technologies and user-centred design principles was followed. The prototype was developed based on the analysis and digital reconstruction of a real intermediate care unit where patients will wake up after surgery, including medical equipment, environmental features, spatial organisation and auditory characteristics. The development and implementation process relied on accessible software, Unity and Blender, and commercial hardware, namely the Meta Quest 3 virtual reality headset. Twelve healthcare professionals, all nurses with direct experience in postoperative delirium management within the represented clinical environment, took part in a preliminary evaluation, in which they explored the virtual environment and completed a structured questionnaire with Likert-scale items and open-ended questions assessing perceived realism, clinical fidelity, system usability, intuitiveness and overall virtual reality experience.

The results show that the developed virtual environment provided a realistic and clinically relevant representation of the intermediate care unit. The quantitative results demonstrated positive perceptions regarding spatial realism, environmental fidelity, representation of medical equipment and system usability. The qualitative feedback identified areas for improvement and highlighted the potential value of the intervention as a patient familiarisation tool. Based on the feedback received, the virtual environment was iteratively improved, resulting in an upgraded prototype with improved realism and overall quality. These findings support the feasibility and potential of the proposed approach for preoperative environmental familiarization. This study serves as a basis for future research studies assessing whether preoperative exposure using virtual reality to a future clinical environment can influence postoperative delirium incidence.

Keywords: Postoperative delirium; Virtual reality; Environmental familiarization.

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"A journey of a thousand miles begins with a single step."

Lao Tsu

Honour Declaration

I hereby declare that this dissertation is my own work and has not been previously submitted or evaluated at this or any other institution. References to other authors (statements, ideas, and thoughts), as well as the use of published works, strictly comply with the rules of attribution and are duly indicated in the text and in the bibliographic references, in accordance with the applicable referencing standards. I am aware that the practice of plagiarism or self-plagiarism constitutes academic misconduct as established in the Code of Ethics of the University of Porto.

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Declaration of Artificial Intelligence Use

I declare that I used Artificial Intelligence to assist with grammar, argument structure, and proofreading. I remain solely responsible for all content generated, the preparation of the data used, as well as the revision of the entire manuscript.

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1. Introduction

1.1 Delirium

Despite already having been described in the ancient Roman Empire by nobleman and encyclopaedist Aulus Cornelius Celsus in his seminal work, *De Medicina* [1], delirium is relatively poorly understood and often unrecognised [2]. Delirium is a common clinical syndrome in older adults characterized by several factors, such as acute disturbance of attention, awareness and cognitive function, resulting in impaired focus and reduced ability to appropriately shift attention [3]. Symptoms typically emerge over a short period of time and fluctuate throughout the day, affecting multiple cognitive functions including memory (both long-term and short-term), motor abilities, thought process, sleep-wake cycle, among others [4].

From a diagnostic perspective, delirium is defined in the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5) as an acute disturbance in attention and awareness accompanied by an additional cognitive change that develops over a short period of time, fluctuates in severity, and cannot be better explained by a pre-existing or evolving neurocognitive disorder [5]. Although DSM-5 criteria serves as the diagnostic gold-standard criteria, delirium remains difficult to identify in clinical practice due to its fluctuating presence and frequent overlap with other neuropsychiatric conditions. Therefore, various other bedside screening instruments are frequently deployed in fast-paced clinical environments.

Delirium prevalence and incidence at a global level vary according to healthcare setting, diagnostic practices, socioeconomic conditions and patient population's characteristics [6], but delirium consistently remains one of the most common neuropsychiatric complications in hospitalized individuals. Delirium in geriatric patients in the emergency department is reported to be around 15.2% worldwide [7], although this may be an underestimation as delirium might go unrecognized or might not yet fully manifest in early stages. Meanwhile, the prevalence and odds of developing the condition whilst in the hospital depend on the severity and complexity of the patient's condition, as shown in Table 1. Critically ill patients are more vulnerable due to greater physiological instability and exposure to invasive interventions and medications [8].

Hospital Ward	Prevalence of delirium	Odds of developing delirium
Intensive Care Unit (ICU)	83.3%	12.34
Intermediate Care	39.8%	1.42
Medical Services	34.2%	1.19
Surgical Services	28.7%	0.72

Table 1: Prevalence and odds of developing of delirium in different Hospital Wards [9].

Beyond its prevalence, delirium is also heavily associated with a broad spectrum of adverse clinical consequences across both short-term and long-term phases of illness, which have an immediate negative effect on patient outcomes, especially in elder adults and postoperative populations. In the short term, evidence from prospective clinical studies demonstrates that delirium is strongly linked to

an increase in in-hospital mortality, prolonged periods of acute medical instability, delayed cognitive and functional recovery trajectories and a higher rate of adverse inpatient events during hospital admission [10]. These effects are not limited to the hospitalisation period, as patients who experience delirium frequently demonstrate poorer post-discharge recovery and increased healthcare dependency [10].

In the long term, delirium has been increasingly recognised as both a potential contributor to sustained cognitive deterioration and a possible accelerator of pre-existing cognitive decline. Neuropathologic evidence further suggests that delirium may interact with underlying pathological processes of dementia and related neurodegenerative conditions, thus representing an independent pathway to chronic cognitive impairment and dementia [11]. Delirium is not merely an acute and reversible syndrome, as it may also be a marker of increased vulnerability to later-life cognitive impairment. Delirium is also associated with a greater likelihood of discharge to a long-term care institution rather than to independent living, which is related to a loss of functional autonomy [12].

In addition to the clinical consequences, delirium also constitutes a major global health burden, due to its association with adverse medical, socioeconomic and functional outcomes that extend beyond the confusional episode itself. Delirium's impact manifests in increases in healthcare utilisation, prolonged hospitalisation periods and higher healthcare expenditure. A systematic review across multiple high-income healthcare systems in multiple countries reports that delirium is consistently associated with substantially high nationwide healthcare costs, reaching tens of thousands of millions of euros each year depending on the country and the healthcare setting, rendering it one of the most expensive neuropsychiatric conditions in hospitalised patients [13]. At the individual patient level, excess healthcare costs attributable to delirium were estimated to range from €942 to €28,636 per patient, illustrating the substantial cumulative financial burden [13].

Beyond the financial impact, delirium is significantly associated with a reduced quality of life, with patients frequently experiencing cognitive impairment, functional decline and persistent impairment in daily functioning even after being discharged from the hospital, demonstrating that its burden extends beyond the period of hospitalisation through increased dependency, which also places additional strain on families and caregivers [14]. These long-term effects often manifest as difficulties in returning to the levels of independence shown before hospital admission. In Portugal, this broader burden is also recognized in the clinical literature, which highlights the need to educate and train health professionals through the development of delirium protocols that support prevention, early recognition and the timely implementation of appropriate intervention strategies. The national literature emphasizes the importance of prevention as the most effective therapeutic approach, particularly given the frequency with which the condition remains underrecognized in clinical practice, a factor that contributes to diagnostic delay and increased risk of adverse clinical and functional outcomes [15].

Multiple risk factors have been identified for delirium, categorized as predisposing, referring to characteristics of the patient, and precipitating, referring to factors related to the person's illness or the hospital environment. Predisposing factors include: advanced age (generally considered from 65 years onwards in healthcare contexts), pre-existing dementia or cognitive impairment, functional, visual or hearing impairment, depression, and frailty, among others [16] [17]. Precipitating factors include medication (antihistamines, antipsychotics, opioids, etc.) [18], infection, trauma, surgical procedures, electrolyte imbalances, sleep disruption, uncontrolled pain and prolonged hospital stay, among others [19]. Notably, older adults diagnosed with neoplastic disease present an elevated risk profile and

generally experience poorer outcomes, likely attributable to the combined adverse effects of disease burden, treatment-related physiological stress and increased exposure to precipitating factors during hospital care. Rather than an isolated event, delirium typically results from acute stressors acting on patients with pre-existing risk factors, such that the smallest of physiological disturbances may be enough to precipitate the condition in older, medically complex individuals [19].

Many precipitating factors are potentially modifiable or preventable, and their effects may be mitigated. Therefore, prevention and early risk identification strategies remain central to reducing delirium incidence and thus improving patient outcomes. Furthermore, the wide range of contributing factors spanning across biological, psychological and environmental domains suggests that delirium is likely driven by multiple, overlapping and heterogeneous neurobiological processes, although its complete pathophysiology remains incompletely understood [19].

Delirium's clinical manifestations range from a near-comatose state to a state of extreme agitation [20]. Based on the patient's motor manifestations, delirium may be classified into three subtypes: hyperactive, hypoactive and mixed. Hyperactive delirium is characterized by increased motor activity, agitation and in some cases hallucinations, delusions and uncooperative behaviour. In contrast, hypoactive delirium is characterized by decreased motor activity, increased lethargy and reduced responsiveness from the patient, all of which are associated with an increased risk of morbidity and mortality. Lastly, the mixed subtype is characterized by fluctuations between hyperactive and hypoactive states throughout the course of the delirium episode [21].

The various types of delirium are also reported at differing rates. Due to its considerably agitated and disruptive presentation, hyperactive delirium is more readily noticed by medical staff, whereas hypoactive delirium is frequently underdiagnosed due to its less disruptive clinical presentation and diminished behavioural disturbance, and is more prevalent in hospitalized and critically ill patients [22]. This discrepancy in detection is clinically significant, as delayed or missed recognition of hypoactive delirium may result in poorer outcomes for the patient.

1.1.1 Postoperative Delirium

Postoperative delirium represents one of the most frequent complications affecting older surgical patients and is particularly common following major vascular, abdominal, orthopaedic and cardiothoracic procedures. Although delirium prevalence among hospitalized older patients is already considerably high, as previously noted, incidence rates in postoperative settings are even higher, with one study reporting an incidence of 41% among older surgical patients [23]. Postoperative delirium incidence can vary depending on several factors, such as the characteristics of the surgical population (patient frailty, comorbidity burden, etc.), the type of procedure and the diagnostic method employed [24].

This exceptionally high incidence value is attributable to an intense combination of factors, including emergency admission, polypharmacy, and perioperative physiological stress, among others [23]. In addition to those general risk factors, the acute physiological trauma of surgical intervention triggers a systemic inflammatory response characterized by the release of peripheral cytokines. This inflammatory cascade increases blood-brain barrier permeability and facilitates neuroinflammatory

processes, which in turn may contribute to disruptions in neurotransmission and overall cerebral function, thereby leading to acute cognitive dysfunction and postoperative delirium in vulnerable individuals [25].

In addition to inflammatory mechanisms, several intraoperative and postoperative factors may also further exacerbate this vulnerability. These include excessive anaesthetic depth, intraoperative blood loss and cerebral hypoperfusion, postoperative pain and high exposure to opioid medications. Collectively, these factors may impair neurocognitive resilience and contribute to adverse outcomes in older patients [26]. Furthermore, the environmental disorientation resulting from the patient transfer between hospital units following surgery significantly affects spatial familiarity, circadian stability and sleep continuity, all of which are key determinants of cognitive functioning in older patients [27].

Postoperative delirium is also associated with substantial clinical and economic consequences, including prolonged hospitalisation, increased healthcare resource utilisation, higher overall costs of care and subsequent for rehabilitation services following discharge. These consequences underscore the importance of preoperative prevention strategies and early recognition protocols, particularly in older adults undergoing major surgical procedures [28].

1.1.2 Current Delirium Prevention Strategies

Given delirium's previously discussed high prevalence, associated morbidity, significant socioeconomic burden and tendency to go unrecognized in clinical practice (especially in patients presenting with hypoactive symptoms), prevention strategies have become a major focus of contemporary geriatric and perioperative care. These strategies are particularly important given delirium's multifactorial nature and its rapid development in response to modifiable precipitating factors during hospitalisation. Several non-pharmacological interventions are employed by health professionals, with some of them demonstrating greater effectiveness than others.

Among these strategies are physical therapy and early mobilization. Delirium and physical function are closely interconnected, as physical dysfunction may serve both as a predisposing risk factor for delirium and as a consequence of the condition itself. Delirium is also associated with several functional consequences, both short and long term [29]. Studies have shown that a greater intensity of physical and occupational therapy is associated with a shorter duration of delirium in older emergency department patients requiring hospitalisation, suggesting that mobility focused interventions may contribute to reducing delirium's persistence and improving recovery outcomes. Early mobilisation may also support a more rapid cognitive recovery by enhancing physiological stability, improving sleep regulation and reducing the adverse effects of prolonged bed rest during acute illness [30].

A further important preventive strategy is comprehensive geriatric risk assessment, an example of which is shown in Figure 1. Older hospitalized patients frequently present with the multiple predisposing risk factors previously discussed. Comprehensive multidimensional geriatric assessment enables healthcare professionals to better identify modifiable risk factors before delirium develops and possibly preventing it, as demonstrated by multiple studies [31]. This structured approach facilitates a more holistic evaluation of functional, cognitive, medical and psychological domains, which is

particularly relevant for older adults that are undergoing surgical interventions. Additionally, optimization strategies informed by a comprehensive geriatric risk assessment have been associated with reductions in postoperative complications and an improved functional independence at hospital discharge in older surgical patients [32].

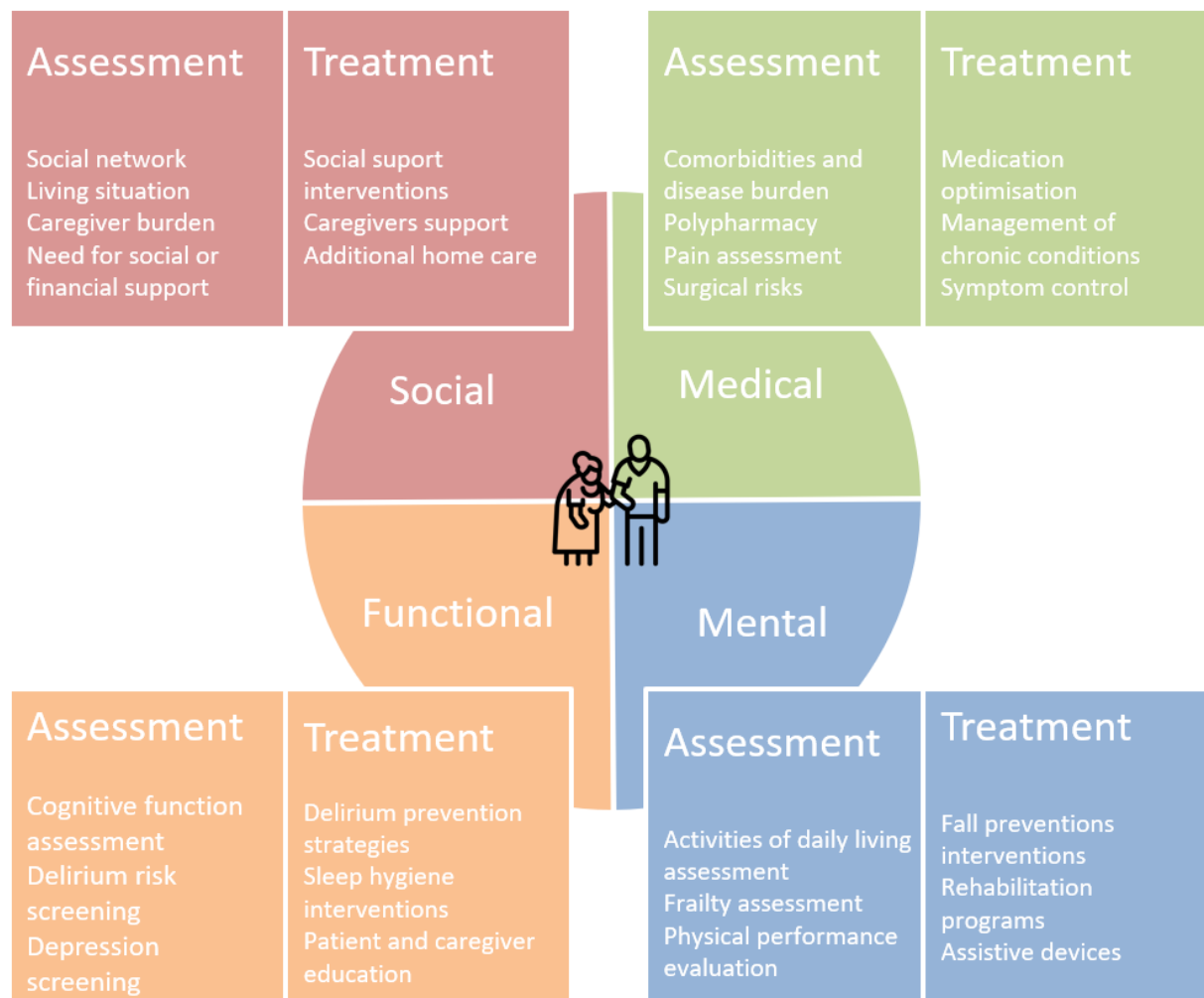


Figure 1: Comprehensive Geriatric Risk Assessment [33].

Reorientation protocols are another widely used non-pharmacological strategy for delirium prevention, particularly in older hospitalized patients who tend to be more vulnerable to environmental disorientation and cognitive fluctuations. The goal of these interventions is to maintain the patient's awareness of time, place and person through repeated cognitive stimulation and environmental support measures, including clocks, calendars, verbal reminders and regular interaction with both family members and health professionals. These strategies have been shown to reduce delirium incidence and duration in critically ill patients, through the continuous reinforcement of cognitive anchors that help stabilise attention and reduce perceptual confusion during periods of acute illness [34]. The participation of family members in these interventions has also been shown to be beneficial, with family reorientation messages leading to improvements in patient orientation and reductions in delirium incidence among critically ill patients [35]. Promising results were also obtained from repeated recorded orientation messages [36]. These results suggest that structure and repeated

cognitive cues, whether delivered actively or passively, may contribute to maintaining cognitive continuity in vulnerable patients.

Music therapy and other auditory-based interventions have also emerged as a potential non-pharmacological methods for delirium prevention, mainly due to their effects on anxiety reduction, environmental comfort and emotional regulation in hospitalized older adults. These interventions aim to reduce sensory stress and promote patient relaxation and lead to a reduction in delirium incidence, given how excessive environmental stimulation and psychological distress may contribute to cognitive disorientation during hospitalisation [37] [38]. Music-based interventions may additionally help reduce patient agitation, improve emotional well-being and provide cognitive stimulation during hospitalisation. Music can function not only as a calming stimulus, but also as an environmental reorientation tool that supports cognitive stability [37] [38].

Other non-pharmacological strategies for delirium prevention include hydration management and bright light therapy. Dehydration is considered a clinically significant modifiable precipitating factor for delirium in older adults, particularly within a patient population in which reduced oral intake, acute illness and functional dependence are common. Inadequate hydration may further exacerbate metabolic imbalance and reduce cerebral resilience to acute stressors [39].

Bright light therapy has also shown potential for reducing the incidence of delirium in critically ill hospitalized patients over 50 years of age, by reducing insomnia and minimizing the effect of disturbances associated with hospitalisation and intensive care [40]. Through the regulation of sleep-wake cycles and the reinforcement of circadian signalling, light-based interventions may also support cognitive stability in vulnerable patients.

Irrespective of the impact of each strategy individually, the multicomponent non-pharmacological interventions that combine several of these single-component strategies have been shown to be the most effective approaches for delirium prevention in older adults. These bundled approaches integrate multidomain interventions into coordinated care framework that targets multiple pathophysiological and environmental risk pathways rather than addressing each factor as an isolated component. These interventions are not only are they effective in reducing delirium but also shorten the length of hospital stay and improve cognitive function [41].

Pharmacological strategies for delirium prevention have also been researched, particularly for patients considered to be at high risk for delirium development. These medications include antipsychotics, sedatives and melatonin-related agents aimed at regulating sleep-wake cycles, reducing agitation and minimizing neurochemical disturbances associated with delirium. However, current evidence regarding their effectiveness remains inconsistent, with studies showing variable results and limited support for the routine use of these medications for delirium prevention alone. Some findings suggest that any potential benefit may be limited to specific subgroups or administration timing rather than broad prophylactic use. Given the potential adverse effects associated with pharmacological therapies in older adults, non-pharmacological multicomponent interventions continue to be regarded as the first-line strategy for delirium prevention and management [42].

1.2 Virtual Reality

The concept of VR can be traced back to the 1960s, when Ivan Sutherland described VR as a window through which a user perceives the virtual world as though it looked, felt and sounded real and in which the user could act realistically [43]. Since then, driven by the substantial investments made by industry pioneers, such as Google, Samsung and Sony [44], and by the thousands of articles published by the researchers across the interdisciplinary community [45], VR has rapidly evolved from a conceptual novelty into a highly sophisticated technological ecosystem. This evolution has been accompanied by parallel advances in computing power, graphics rendering, and sensor technologies, which have significantly enhanced system realism and accessibility. As this technology has developed, progressing from bulky laboratory prototypes into lightweight, commercially accessible headsets, its utility quickly expanded beyond consumer entertainment and into other fields, such as medicine [46]. This shift has allowed VR to be explored as an applied clinical tool rather than merely a technological or experimental platform.

To fully understand VR's practical application, the technology may be classified into three categories, based on degree of immersion. Non-immersive VR includes computer monitors or television screens that display images or videos of the virtual world. Immersive systems provide a complete simulated experience through several sensory outputs devices such as head mounted displays, which enhance the user's stereoscopic view of the environment in response to their movement, as well as audio and haptic devices. Lastly, semi-immersive systems provide a stereo image of a three-dimensional scene viewed on a monitor using a perspective projection coupled to the head position of the user [47]. Systems with higher technological immersion have been shown to provide a closer approximation to reality, affording the user with the feeling of being present in the virtual environment and allowing interactions and actions performed within in the virtual environment are perceived as real [48].

Ultimately, a critical aspect of virtual reality is the extent to which the user disengages from their real physical surroundings and becomes fully engaged within the virtual environment, a phenomenon enhanced by higher levels of technological immersion. While immersion constitutes a more objective characteristic of the user experience and virtual environment design, presence refers to the user's subjective response to the simulated space [49]. Studies have shown that greater quality and quantity of allocated resources as well as increased accuracy in objects and characters contribute to improved levels of immersion, as expected. Other features that may enhance user engagement and interactivity include performance feedback and character customization [50].

This technological evolution has allowed virtual reality to find a valuable role within healthcare, initially serving as an advanced method for medical education and training exercises for future health professionals. Through simulated environments, the technology provides a safe, interactive platform for students to practice procedures and develop key clinical competencies without compromising patient safety [51]. However, the utility of VR in the field of medicine has expanded beyond only professional training alone to focus directly on enhancing patient care. Immersive technologies are increasingly being developed and implemented as innovative tools to directly improve patient care and well-being [52]. In clinical use, VR can function as a powerful non-pharmacological approach that acts as an active psychological distraction. By completely absorbing the patient's attention within a calming

virtual space, these systems have demonstrated several potential benefits, including the reduction of perceived stress, sensory overload and improved emotional regulation [53].

In oncology wards, this technology has served as an effective tool for symptom control, demonstrating a significant clinical capacity to decrease acute pain and improve overall comfort for a longer period for hospitalized patients [54]. Similarly, in postsurgical patients, VR has been explored as an investigative, non-invasive method therapeutic approach to reduce postoperative pain, stress and anxiety, offering a method to alleviate distress during early recovery and distract the patient from the pain and anxiety related stimuli [55]. Beyond pain alleviation, VR was also applied in hospitalized patients with COVID-19 and led to improvements in vital signs, such as heart rate, respiratory rate, blood pressure and peripheral capillary oxygen saturation. Significant improvements were also observed in reduced anxiety, tiredness, and shortness of breath, as well as an increase in general well-being [56]. In geriatric care, early feasibility studies have successfully used interactive, headset-based VR paired with cycle ergometers to facilitate group exercise therapy among hospitalized older adults, with minimal adverse effects for the participants and with minimal setup difficulties for the untrained health professionals [57].

Building on the success demonstrated by earlier application of VR in general medicine, this technology has also emerged as a promising, targeted non-pharmacological strategy for preventing delirium in intensive care unit (ICU) settings. A recent systematic review and meta-analysis of randomized controlled trials encompassing 764 critically ill patients demonstrated that VR-based interventions were associated to a 44% reduction in the overall incidence of delirium compared to patients who received standard hospital care [58]. Across the protocols included in this review, researchers employed different audio-visual environments and exercises, most notably, family-recorded videos [59], nature meditation sceneries [60], grip games [61], real life locations [62] and cognitive games [63]. These immersive sessions would be administered once or twice daily for 15 to 20 minutes. Across these interventions, a common underlying mechanism present was the provision of consistent multisensory stimulation, which may help counteract sensory deprivation and cognitive disorientation frequently observed in hospital settings. Beyond mitigating cognitive decline, the evidence suggests that these virtual spaces may provide profound psychological benefits, including significant reductions in patient anxiety and depressions and improvements in subjective sleep quality.



Figure 2: Example of Cognitive and Grip VR Game [64].

Despite the promising results already obtained in the fields of virtual reality and postoperative delirium prevention, existing interventions have predominantly focused on generic relaxation scenarios, cognitive exercises or prerecorded audiovisual content. Although these interventions may provide cognitive and emotional benefits and may become a more widely adopted prevention strategy in the future, limited attention has been given to the possibility of using virtual reality as a tool to better effectively familiarize patients to the specific clinical environment in which they will recover after surgery.

Given how environmental change and spatial disorientation can act as a catalyst for delirium prevention, the recreation of the postoperative recovery setting represents a relatively unexplored application of virtual reality within this context. This gap provides the rationale for present study.

1.3 Motivation

The present study proposes the development and implementation of a dedicated immersive virtual reality environment specifically designed for elder patients scheduled for oncological surgery. Integrated directly into the preoperative prehabilitation phase, this targeted virtual environment will depict the hospital ward in which patients will wake up and recover following surgery. The objective is to provide patients with spatial awareness of their new surroundings prior to surgery, while simultaneously delivering proactive cognitive stimulation and psychological optimization, thereby effectively preventing the onset of postoperative delirium or significantly reducing the severity and duration of its clinical symptoms.

2. Methodology

2.1 Methodological Framework

This dissertation follows an interdisciplinary methodological approach that integrates principles from healthcare, immersive technologies and experience-oriented design, while loosely following the development-based methodology of the Stanford Biodesign framework [65]. At its core, this work primarily consists of the design and construction of an immersive VR environment intended for elder oncological patients scheduled for surgical procedures, followed by its preliminary evaluation by health professionals with have direct clinical experience in delirium management.

This work is built on three interrelated disciplinary pillars. First, with respect to clinical medicine, the work is situated within perioperative geriatric oncology, where physiological vulnerability and hospital-related stressors place the older surgical patient population at increased risk of postoperative delirium. From a neuropsychological perspective, the intervention is based on the mechanisms of cognitive orientation and spatial awareness, and is therefore meant to familiarize the targeted patient population with their postoperative environment. Finally, from a human-computer interaction standpoint, the development prioritises usability, comfort, accessibility for elder adults and the minimisation of cognitive and sensory overload, ensuring that interaction with the virtual system remains immersive, safe and effective.

The methodological process involved an initial digital modelling of clinical spaces, the integration of interactive virtual assets into the virtual environment and the iterative refinement of the immersive experience based on the feedback gathered from the aforementioned healthcare professionals.

The VR environment was developed with specific objectives in mind, including the reduction of perioperative anxiety, given that psychological stress can be a trigger for postoperative delirium, the enhancement of spatial awareness and familiarity prior to the surgery, guided mild cognitive stimulation and the reduction of sensory and environmental disorientation commonly experienced in postoperative settings, all developed and selected with the overall goal of preventing postoperative delirium.

To evaluate the prototype, the participating health professionals completed a questionnaire comprising both rating-scale questions and open-ended questions. This approach enabled for both quantitative and qualitative assessment of the prototype based on usability, comfort, clinical relevance and feasibility, providing a comprehensive preliminary evaluation of its potential clinical value.

2.2 Clinical Context and Requirements

2.2.1 Clinical Problem Identification

Older surgical oncology patients represent a clinically vulnerable population in perioperative care due to a multitude of factors, primarily advanced age, the burden associated with oncological disease and its treatment and surgical stress. Consequently, postoperative delirium remains a frequent and clinically relevant complication, further complicated by its fluctuating presentation and tendency to go undiagnosed in the early stages of acute hospitalisation. This renders early preventive approaches especially relevant in perioperative pathways where rapid changes in cognitive status may occur frequently.

This vulnerability is further compounded by the unfamiliarity of the postoperative hospital environment, in which patients are exposed to new surroundings, routines and care processes, whilst still recovering both physically and cognitively. In older adults, these changes may lead to difficulties with orientation and adaptation during recovery.

2.2.2 User-Centred Needs Assessment

Regarding the patients, they present several functional and perceptual limitations, such as reduced sensory acuity and cognitive fatigue, among others, that influence how the VR environment should be designed. Additionally, older patients may have limited experience with digital technologies, such as VR equipment, therefore the interaction with the immersive environment must be simple, intuitive and it must not require any prior technical knowledge.

Furthermore, psychological factors, such as preoperative anxiety stemming from both the upcoming surgery and the uncertainty surrounding the recovery period, must be considered, as they may influence the patient's overall recovery. Accordingly, the VR environment must promote familiarity with the patient's postoperative surroundings. Finally, physical fatigue and reduced endurance are also common characteristics of this patient population, particularly among those undergoing cancer treatment, meaning that the immersive experience should be designed to require minimal physical effort.

2.2.3 Clinical Constraints

The implementation of virtual reality-based protocols in hospital environments introduces several practical constraints that must be considered. For instance, infection control requirements are particularly relevant, requiring that all hardware components be compatible with disinfection protocols and be safely usable by multiple users. A further critical constraint is the session duration, as prolonged exposure to VR environments can result in negative side effects, such as dizziness, nausea, disorientation, postural instability and fatigue [66], particularly among inexperienced users.

Additionally, these interventions must be delivered effectively in short, structured sessions that don't interfere with standard perioperative care routines.

A further relevant factor is physical positioning, as many patients in the perioperative phase are required to remain seated or in bed. Therefore, all interactions must be fully compatible with seated use and must avoid any requirement for physical movement. Finally, the patient must be supervised during the intervention, to ensure their safety and enable immediate assistance in the event of discomfort or adverse reactions.

Collectively, these clinical constraints directly informed the design and implementation decisions adopted during the development of the virtual environment and its corresponding protocol and questionnaire.

2.3 Development Process

The development of the virtual reality environment followed an iterative and interdisciplinary process, combining clinical input from healthcare professionals with technical development in immersive technologies and user-centred design principles. The initial stage focused on collecting the necessary information to guide the construction of a functional prototype. Reference material was collected from the intermediate care unit and included photographs, videos, architectural floor plans and audio recording of the clinical environment.

Based on these references, the virtual environment was designed with the objective of recreating the postoperative recovery setting as accurately as possible. This process focused on reproducing the organisation of the physical space, including furniture, and medical and technological equipment present, along with other environmental elements, such as light and noise, considered relevant for patient familiarisation and orientation. Particular attention was given to ensuring that the recreated environment remained clinically representative while also accounting for the usability requirements and potential limitations of the target population.

Following development of the initial prototype, an intervention protocol and a set of feedback questionnaires were developed to support the preliminary assessment of the virtual environment. These were designed to collect both quantitative and qualitative feedback regarding usability, comfort, realism, clinical relevance, simplicity and potential applicability within the context of postoperative delirium prevention.

Following the development of the protocol and questionnaires, the prototype was presented to healthcare professionals with experience in the care of patients with postoperative delirium. Their feedback provided valuable insight into aspects requiring improvement and into how suitable and relevant the virtual environment can be. Based on the feedback obtained during this evaluation phase, several improvements were made to enhance the overall realism and quality of the virtual environment.

2.4 Clinical Environment Characterisation

The virtual environment was grounded in a detailed analysis of the intermediate care unit in which patients stay and recover following oncological surgery. The unit's blueprint, shown in Figure 3, comprises a large open bay, a connecting corridor and several smaller adjacent rooms. Recovering patients are exclusively accommodated in the open bay, and consequently this space constituted the central focus of the development phase. As the corridor is visible from the open bay, it was also included in the virtual environment to preserve spatial continuity. The smaller rooms were excluded from the virtual environment, as these areas are used exclusively by healthcare professionals and not by patients.



Figure 3: Hospital Unit Blueprint – Open Bay (red) and Corridor (blue).

As shown in Figure 4, the open bay is divided into two sides. The side adjacent to the windows is where the patients recover and the side adjacent to the corridor contains some desks for health professionals.



Figure 4: ICU Open Bay.

Within the patient-recovery side of the open bay, there is sufficient equipment and infrastructure to accommodate up to eight beds. Privacy curtains are mounted on a ceiling-mounted railing, following a regular, repeated configuration aligned with the ceiling beam structure and wall pillar structures. The ceiling lights and the ceiling-mounted vacuum suction system also follow the same configuration. As shown in Figure 5, the side walls are also visible: one is green and unoccupied, while the other is blue and features several power outlets, small tables, two television sets, a chair and an armchair. The images also illustrate the difference in floor texture.



Figure 5: Open Bay – Patient Side.

Identical equipment is repeated at each bed station. On the left side, there are several Perfusor Syringe Pumps, designed to safely and accurately administer infusions to the patient. Additionally, there are also several small objects, such as a medical glove box, hand sanitizer, and a waste disposal bin, among others. On the right side, there is a vital signs monitor connected to a TV. On both sides, there are drawers and a tray for any equipment necessary. Each bed is equipped with a pillow and a blanket and side railings that can be raised to prevent patient falls. Finally, depending on its position

within the room, each bed has a window behind it, through which solar panels, foliage and nearby buildings are visible in the background.



Figure 6: Open Bay – Bed Station.

The medical equipment described above, namely the monitoring and infusion systems, are connected to the patient via the hand. A peripheral intravenous catheter is inserted and secured with a transparent adhesive dressing. A pulse oximeter is also placed on one of the patient's fingers, connecting them to the vital signs monitor, as shown in Figure 7. This was also incorporated into the virtual environment, as the patient's hands may be visible during the virtual reality intervention in place of the controllers. This detail was deliberately included because patients may attempt to remove the adhesive upon waking from surgery. Therefore, by previously exposing them to this visual cue within the virtual environment, patients become familiarised with it in advanced, which may reduce the likelihood of catheter removal.



Figure 7: Patient monitoring and IV access setup.

On the side of the open bay opposite to the patients, there are two blue and white desks for the use of health professionals, equipped with computers, monitors, keyboard and mouse, and a printer positioned nearby. Behind these desks, there are two blue cabinets separated by a fridge, with one cabinet featuring a medication storage and dispensing unit mounted on top. Several windows are also present, through which the corridor is visible.



Figure 8: Open Bay – Health Professionals Side.

To the right of these desks, there is another blue cabinet (seen in Figure 9), adjacent to a small water fountain, two waste bins and the door to the dirty utility room. This room was excluded from the virtual environment as patients do not have access to it. Further to the right, there is a television on a rolling stand, identical to the one shown in Figure 8, along with a projector screen and several armchairs. A noticeable change in floor pattern is also present.



Figure 9: Open Bay – Health Professionals Side – Right Side.

As previously mentioned, the open bay features two distinct floor patterns: a simple white pattern on one side and a more complex pattern on the other, as shown in Figure 10.



Figure 10: Open Bay – Floor Pattern.

As shown in the blueprint (Figure 3), the open bay has identical two exit doors. Figure 11 shows that the double doors each have a small window, but only one has a handle.



Figure 11: Open Bay – Exit Double Doors.

Finally, the corridor has several doors on the left, as shown in the blueprint. It is largely empty, features a tiled floor pattern, and some foliage is visible through the main window. In addition, windows on the right side provide a view of the open bay, as shown in Figure 12.

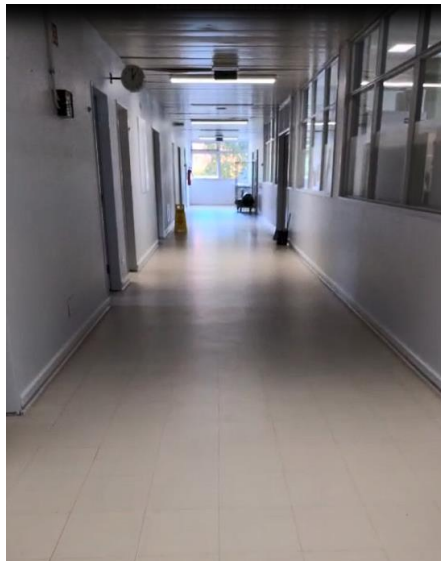


Figure 12: Corridor

Both the open bay and the corridor are illuminated through a combination of natural light, entering through the windows, and artificial lighting, from ceiling-mounted LED light fixtures. From an acoustic perspective, there is a continuous background noise, comprising conversations, staff movement throughout the unit, medical equipment use and other ambient noises. The audio recordings collected were used to recreate the auditory atmosphere within the virtual environment.

2.5 Hardware and Software Tools

The immersive experience was designed for the Meta Quest 3 headset, which was selected due to its high-resolution displays, wireless operation with a long battery life, portability, ease of deployment and use and reduced setup requirements, making it suitable for prospective use in clinical environments and straightforward to configure for healthcare professionals.

The virtual environment was developed using Unity. This software was selected for several reasons, including its comprehensive and mature native support for XR (Extended Reality) workflows, rapid prototyping capabilities, extensive developer documentation, straightforward debugging and seamless deployment pipeline to Android-based standalone head-mounted displays, such as the Meta Quest 3. Three-dimensional assets and environmental elements were created using Blender, an open-source modelling software commonly used for the creation of 3D assets. To accelerate development and improve the overall realism of the environment, a combination of custom-created assets and externally sourced assets was used. Several models, textures and environmental elements were obtained from online asset repositories and modified to better reflect the characteristics of the actual postoperative ward. A complete list of the software packages, external assets and custom-developed assets used during the development of the virtual environment is provided in Appendix A.

As mentioned previously, audio recordings from the hospital unit were integrated into the environment to enhance realism and improve environmental familiarity. These files were processed and adapted for use within the virtual environment. Measures were also taken to slightly distort the recorded voices in order to preserve anonymity.

In addition to the headset itself, the Meta Horizon app was used to connect the Meta Quest 3 to an external device, provided both devices were connected to the same Meta account. This functionality allowed the healthcare professional to supervise the intervention and observe the virtual environment from the patient's perspective in real time, thereby improving their ability to guide patients through the intervention.

2.6 Design Approach and Rationale

The design of the virtual environment was guided by the objective of creating a calm, slower-paced, recognizable and easily interpretable representation of the postoperative recovery setting. The environment was developed as an easy-to-use familiarisation tool to support patient orientation prior to surgery.

A central design consideration, previously discussed, was the reduction of uncertainty regarding the postoperative recovery period. Given that unfamiliar surroundings can contribute to anxiety and disorientation in older adults, both of which can predispose patients to postoperative delirium, the virtual experience was designed to allow patients to explore the developed space, comprising the open bay and the corridor. This approach exposes patients to their future surroundings, which may facilitate adaptation and reduce psychological distress.

As older oncological patients may be more susceptible to cognitive overload, unnecessary visual elements, clutter and distracting stimuli were minimized, with an emphasis on clear spatial organization and an easily interpretable visual layout. This was intended to reduce cognitive demand during exploration of the virtual environment. The same principle guided the design of the overall atmosphere, which was intended to avoid excessive stimulation. Noise and lighting conditions were calibrated to remain realistic while avoiding excessive sensory complexity that could induce discomfort in patients. These design decisions ensured that the virtual environment could be easily navigated by older patients, in line with the clinical objective of reducing anxiety and promoting preoperative orientation.

2.7 Virtual Environment Structure and Content

When the intervention begins, meaning when the patient views the virtual environment for the first time, patients begin positioned next to the bed, facing the health professionals' side of the open bay, similar to what they will see upon waking up after surgery. As patients are able to move throughout the environment, they are positioned at an eye level between standing and lying down, which is already relatively high, considering the beds are themselves raised.

The interaction design of the virtual environment was intentionally kept simple and minimally physically demanding. Patients are seated in a rotating chair, allowing them to look around freely by rotating either their head or the chair. To navigate around the virtual environment, patients use the left controller's joystick. The decision to minimise interaction complexity was made based on the characteristics of the target population.

Patients are able to move freely and at their own pace within the virtual environment. No predefined route is imposed, and patients are able to view both the open bay and the corridor from any viewpoint within the virtual environment. Several small objects, such as a medical glove box, hand sanitizer, and a waste disposal bin, can be manipulated, by grabbing and releasing them using the grip button (which can be seen in Figure 13), although this interaction is not required for completion of the protocol or for movement within the virtual environment. No tasks, objectives or gamification elements are present in the virtual environments as the primary focus is on observation and familiarization.



Figure 13: Trigger and Grip Buttons on Meta Quest 3 Controllers [67].

For the patient to become fully familiarized with the room, they should be able to recognize the open bay layout, understand the location and organization of various furniture and medical equipment, identify how to navigate from the open bay to the corridor, and recognize various secondary environmental features, such as ambient sounds and lighting conditions. The duration of the virtual reality session is approximately 15 minutes, although this duration is flexible, given the absence of a fixed route or mandatory sequence of actions. The session may be concluded when the supervising healthcare professional determines that the patient has already achieved the objectives of the intervention or if the patient experiences any discomfort or other side effects related to the intervention.

2.8 Ethical Considerations

Prior to the beginning of the evaluation phase, ethical approval was obtained from the Ethics Committee of the IPO Porto Research Center (CI-IPOP) (process number CI-IPOP 12-2026). The study was conducted according to applicable ethical principles for research involving human participants. All healthcare professionals involved in the evaluation were informed about the objectives and procedures of the study and consented before voluntary participation. All collected data were handled anonymously.

2.9 Evaluation Methodology

Before implementing these interventions with patients and testing their effectiveness, it was important to have health professionals evaluate the prototype and provide feedback. Twelve health professionals, all of whom were nurses (including two clinical nurse specialists and one nurse manager), with direct experience in managing postoperative delirium in the intermediate care unit on which the virtual environment was based, were recruited to evaluate the prototype and provide feedback.

During the evaluation procedure, the health professionals were shown how to set up the virtual environment as they would when conducting the intervention with a patient. Then they explored the virtual environment, not for the purpose of familiarization with their surroundings, but rather to evaluate it as thoroughly as possible, for as long as they deemed necessary. They subsequently completed the questionnaire specifically developed for the participating health professionals. A questionnaire for patients, along with a simplified version, was also developed to support future evaluations.



Figure 14: Health professional evaluating the virtual reality prototype.

The evaluation instrument for the participating health professionals consisted of a structured questionnaire divided into three sections: perceived realism of the virtual environment, usability of the system [68], and usability of the VR experience [69]. The questionnaire included 25 Likert-scale items (1 = strongly disagree; 5 = strongly agree) and four open-ended questions addressing prior experience with immersive virtual reality, realism, missing elements, and general feedback. The scale included both positively and negatively worded items, such that for some questions a lower score indicated a better outcome. These items were treated accordingly during analysis to ensure consistent interpretation. Then, from the System Usability Scale [68] scores for each question, one point is removed. Then they are added up and multiplied by 2.5, resulting in a final score ranging from 0 to 100. Values between 80 to 100 indicate excellent usability, scores between 68 and 80 indicate above-average usability, scores between 50 and 68 indicate poor usability, and scores below 50 suggest significant usability problems. The complete questionnaire is provided in Appendix B.

The questionnaire developed for patients, available in Appendix C, was adapted from the health-professional questionnaire, modifying the elements regarding clinical realism and fidelity of equipment to prioritise the subjective experience of the virtual reality intervention, including perceived preparedness for hospitalisation and postoperative recovery, anxiety reduction, and overall understanding of the hospital environment. Finally, a simplified version of this questionnaire, available in Appendix D, was developed to avoid overwhelming patients with questions and elicit honest and direct feedback.

Quantitative data were analysed through the calculation of mean values and standard deviations, to summarise central tendency and variability across responses. Qualitative responses were thematically reviewed to identify recurring patterns, suggestions and usability issues. All feedback was considered in the refinement of the prototype.

3. Results

3.1 Visual Fidelity Assessment of the Virtual Environment

The following section presents a visual comparison between the real intermediate care unit and its corresponding representation within the developed virtual environment, with the aim of illustrating how the physical environment and its key elements were reproduced within the virtual simulation. In addition to the overall spatial organisation of the unit, this comparison also includes patient bed stations, medical equipment, environmental features, furniture and other elements that affect the patient's postoperative experience. Furthermore, beyond the visual elements, the virtual environment also incorporated audio recordings collected from the open bay and the corridor.

Beginning with the overall spatial organisation of the unit, the general layout and proportions of the open bay were reproduced as shown in Figure 15.



Figure 15: Real intermediate care room (left) and corresponding virtual environment (right).

At a closer level, the patient side of the main room, including the privacy curtains, ceiling structure, side walls and general arrangement, was reproduced as shown below.





Figure 16: Real patient-side view of the open bay (left) and corresponding virtual environment (right).

Each individual bed station and its associated medical equipment were also recreated in the virtual environment, preserving the same spatial organisation and equipment arrangement observed in the real hospital unit. In three of the virtual environment's bed stations, human models were added to the beds to represent other recovering patients.



Figure 17: Real view of the bed station (top) and corresponding virtual environment (bottom).

At the patient level, the monitoring and intravenous access systems were also reproduced within virtual environment, as shown below.

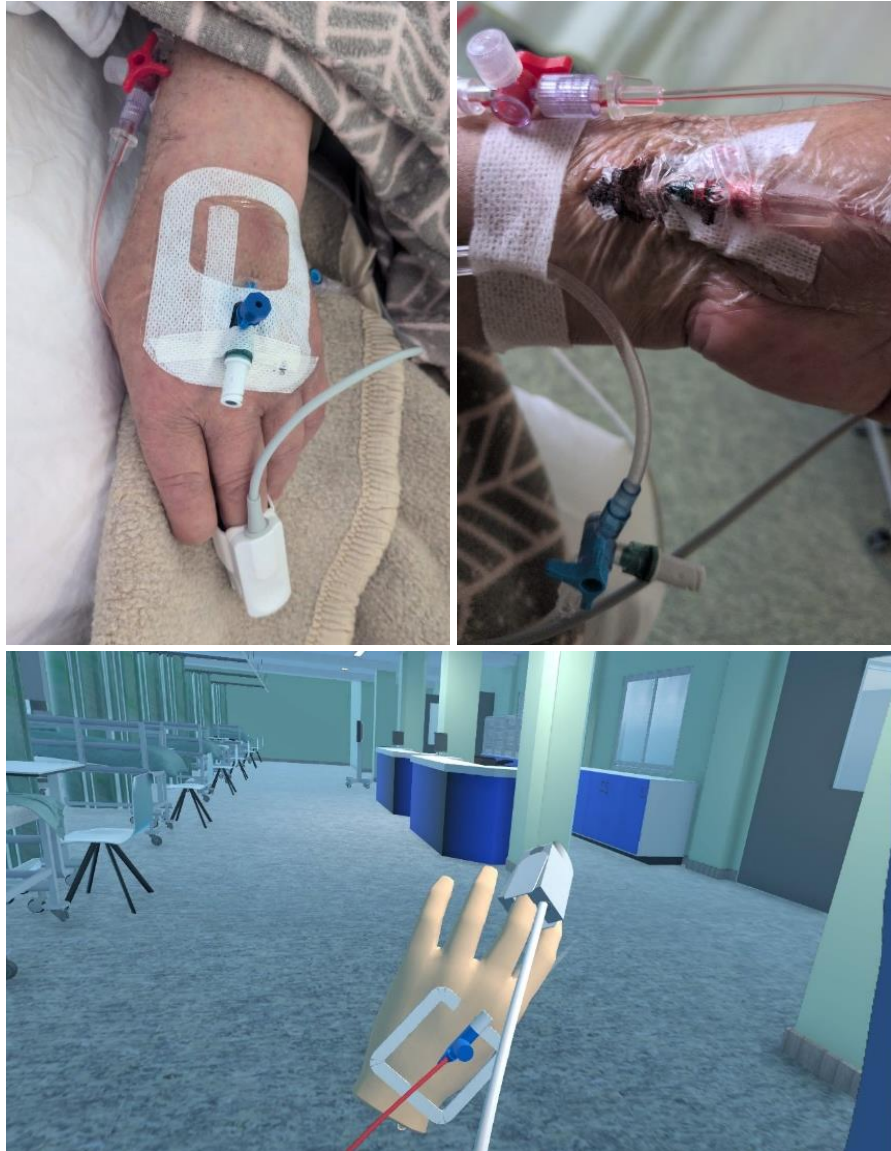


Figure 18: Real view of the patient monitoring and IV access setup (top) and corresponding virtual environment (bottom).

On the opposite side of the room, the health professionals' workstation area, comprising the desks, monitors, cabinets, small water fountain, and medication storage unit, was represented below in Figure 19. Behind both desks, two human models were incorporated to represent the health professionals typically present in the real ward.



Figure 19: Real health professionals-side view of the open bay (left) and corresponding virtual environment (right).

The two distinct floor patterns present in the open bay were also reproduced within the virtual environment, as shown below.

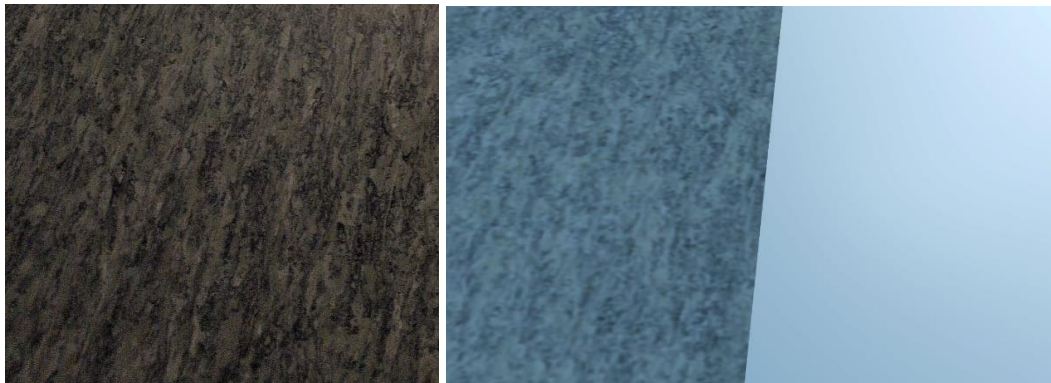


Figure 20: Real view of the open bay's floor pattern (left) and corresponding virtual environment (right).

The exit double doors were also included within the virtual environment, as shown below.



Figure 21: Real view of the double exit doors (left) and corresponding virtual environment (right).

Finally, the corridor, which is visible from the open bay, was also included within the virtual environment, as shown below.



Figure 22: Real view of the corridor (left) and corresponding virtual environment (right).

3.2 Questionnaire Results

This section presents the quantitative and qualitative results obtained from the questionnaires completed by the twelve participating health professionals following their evaluation of the virtual reality prototype. Of the participating group, only one reported prior experience with immersive virtual reality technologies, while the remaining had no previous experience. A further participant reported a pre-existing history of vertigo, which did not prevent participation in the evaluation of the virtual environment, but may have influenced their results, and was noted as a relevant consideration for future patient screening.

3.2.1 Perceived Realism and Clinical Fidelity

The first section of the questionnaire focused on the perceived realism and clinical fidelity of the virtual environment, with its results summarized in Table 2.

Domain	Sentence	Mean $\pm$ SD
Spatial Realism	1. The dimensions, proportions and overall layout of the virtual environment correspond to the real hospital unit.	4.50 $\pm$ 0.65
Clinical Fidelity	2. The visible medical equipment (e.g., bed, monitors, IV stands) is accurately represented.	4.42 $\pm$ 0.65
Patient's Perspective	3. The field of vision and perspective in the virtual environment accurately portray what a real patient goes experiences.	4.58 $\pm$ 0.86
Physical Environment	4. The lighting, colours and textures in the environment seem realistic and familiar.	4.67 $\pm$ 0.62
Visual Safety	5. I did not identify any unrealistic visual elements, distortions, or graphical errors that could cause confusion or agitation in a geriatric patient.	4.25 $\pm$ 0.72
Practical Relevance	6. I consider the level of detail in this virtual environment to be appropriate and useful for familiarising a patient with the real intermediate care unit prior to admission.	4.50 $\pm$ 0.50

Table 2: Realism evaluation of the Virtual Environment.

3.2.2 System Usability Scale

The second section of the questionnaire assessed the usability of the system using the System Usability Scale [69], with results summarised in Table 3. The negatively worded items are marked with an asterisk.

Sentence	Mean $\pm$ SD
1. I think I'd like to use this system frequently.	4.33 $\pm$ 0.62
2. I thought the system was unnecessarily complex. *	4.42 $\pm$ 1.04
3. I thought the system was easy to use.	3.58 $\pm$ 0.86
4. I think I'd need an expert to help me use the system. *	2.58 $\pm$ 1.26
5. I consider the different functions of the system to be well integrated.	4.25 $\pm$ 0.72
6. I thought there was too much inconsistency in this system. *	4.58 $\pm$ 0.64
7. I would imagine that most people would learn to use this system very quickly.	3.17 $\pm$ 0.99
8. I found the system very cumbersome to use. *	3.67 $\pm$ 1.18
9. I felt very confident using the system.	4.25 $\pm$ 0.92
10. I needed to learn a lot of things before I could get going with this system. *	3.83 $\pm$ 1.14

Table 3: System Usability Scale [69].

The total score of the System Usability Scale scores equates to 71.65, which puts it in the above-average usability bracket.

3.2.3 Virtual Reality System Usability Scale

The third and final quantitative section of the questionnaire comprised nine items assessing the usability of the virtual reality experience [70], with results summarised in Table 4. The negatively worded items are marked with an asterisk.

Sentence	Mean $\pm$ SD
1. The system responded appropriately to my interactions, without noticeable delays.	4.42 $\pm$ 0.64
2. I believe that the virtual reality system provides clear feedback in response to my interactions.	4.33 $\pm$ 0.45
3. I continued to make mistakes or encounter errors while using the virtual reality system. *	3.17 $\pm$ 1.28
4. I could clearly understand the information presented in the virtual environment.	4.50 $\pm$ 0.65
5. I believe the system is intuitive, easy to learn, and designed so that most people can adapt to it quickly.	3.75 $\pm$ 0.92
6. I believe it is easy to correct errors made during virtual reality experiences.	4.33 $\pm$ 0.62
7. I enjoyed the virtual reality experience.	4.33 $\pm$ 0.94
8. I experienced dizziness, motion sickness, or headaches during the virtual reality experience. *	3.25 $\pm$ 1.42
9. During the virtual reality experience, I experienced mental overload, such as tension, frustration, and time pressure. *	4.25 $\pm$ 1.01

Table 4: Virtual Reality System Usability Scale [70].

3.2.4 Qualitative Responses

Following the presentation of the quantitative results, the qualitative responses gathered from the open-ended section of the questionnaire are summarised below.

First, regarding elements perceived as less realistic or requiring correction prior to any intervention with a patient, the majority of participants either left this section blank or indicated that no corrections were needed. It should be noted that some responses lacked sufficient detail to allow for clear interpretation, including one answer that mentioned the patient's bed and another answer that mentioned the overall available space, both lacking further elaboration. One participant noted that the environment felt appropriately adjusted to reality, while another highlighted that the virtual reality environment was much quieter than the real ward, noting that ringing telephones, monitor alarms, and noise caused from people talking and supply trolleys moving missing from the virtual environment. The absence of visual or auditory cues representing staff movement and locomotion throughout the unit was also mentioned.

Subsequently, when asked whether any important equipment or details were absent from the virtual environment, again most participants indicated that nothing was missing. The elements identified as absent included the entrance door leading from outside the unit to the unit's hallway, windows between the corridor and open bay, adjustments to lighting and noise, and the patient

support table. Although this comment was not formally recorded, another participant also mentioned the absence of two clocks, one in the open bay, near to the entrance, close to the first beds, and another in the corridor.

Finally, when asked for general comments and suggestions, one participant suggested changing the controller assigned to the virtual character's movement from the left hand to the right hand. Another participant noted that the virtual environment became slower and more unstable when an external device was connected to the headset via the Meta Horizon app, while another expressed a desire for additional opportunities to test the prototype before its use with patients. Finally, another participant verbally noted recognizing a colleagues' voice among the audio recordings in the virtual environment.

These responses from the questionnaire were used to inform improvements to the virtual environment, outlined in the following section.

3.3 Virtual Environment Improvements

There were several improvements made to the virtual environment that fell into three categories: visual adjustments, audio enhancements and general performance improvements aimed at making the experience run more smoothly.

Among the additional visual elements introduced was the entrance door to the corridor. Although in the real hospital unit, the glass is transparent, the glass in the virtual environment was made opaque, to avoid revealing unmodelled areas that are not a part of the intermediate care unit and to which patient do not have access.

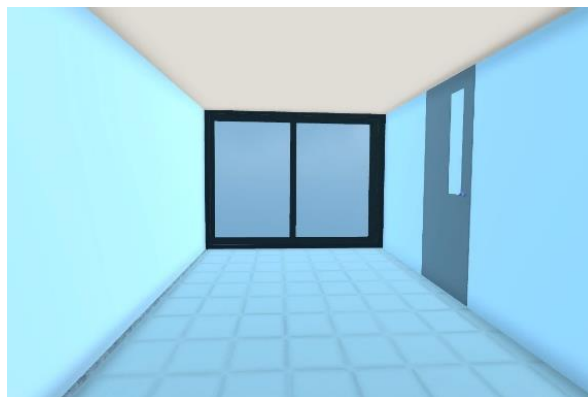


Figure 23: Entrance door.

In the virtual corridor, one of the two previously identified missing clocks was added. Its real-world counterpart is visible in the top-left portion of the left-hand image in Figure 25.

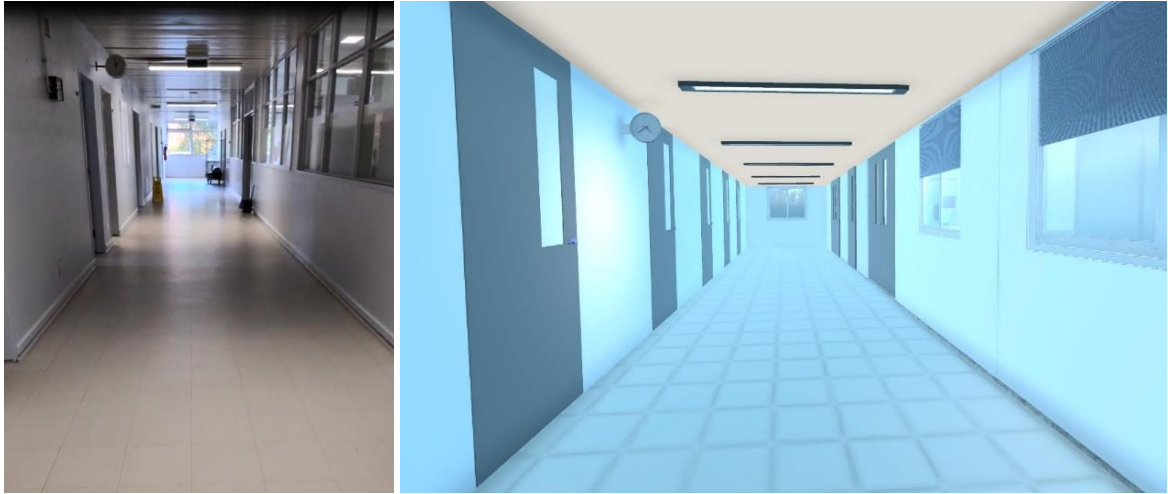


Figure 24: Real view of the corridor showing the clock (left) and corresponding updated virtual environment (right).

In the virtual open bay, the second missing clock was added. Its real-world counterpart is visible in the top-left portion of the left-hand image in Figure 26.



Figure 25: Real view of the open bay showing the clock (left) and corresponding updated virtual environment (right).

In the area adjacent to the health professional's desks, three distinct elements were incorporated into the updated virtual environment. The patient support cart, visible in the bottom right corner of the real environment in Figure 27 (top left), was absent from the original virtual environment (top right) and was subsequently added to the updated version (bottom). A telephone was added to one of the desks, intended for use as an audio cue within the virtual environment. Finally, the two ceiling-mounted LED lights above the desks, which were missing from the original virtual environment, were also incorporated into the updated version.



Figure 26: Real view of the health professionals' desk area (top left), original virtual environment (top right) and updated virtual environment (bottom).

Similarly, on the health professional's side of the open bay, the missing windows were added, as shown below.



Figure 27: Real view of the health professionals' side – right side (left) and corresponding updated virtual environment (right).

Finally, in each bed stations featuring a human model, a vital signs interface was added to the vital signs monitor, as shown below.

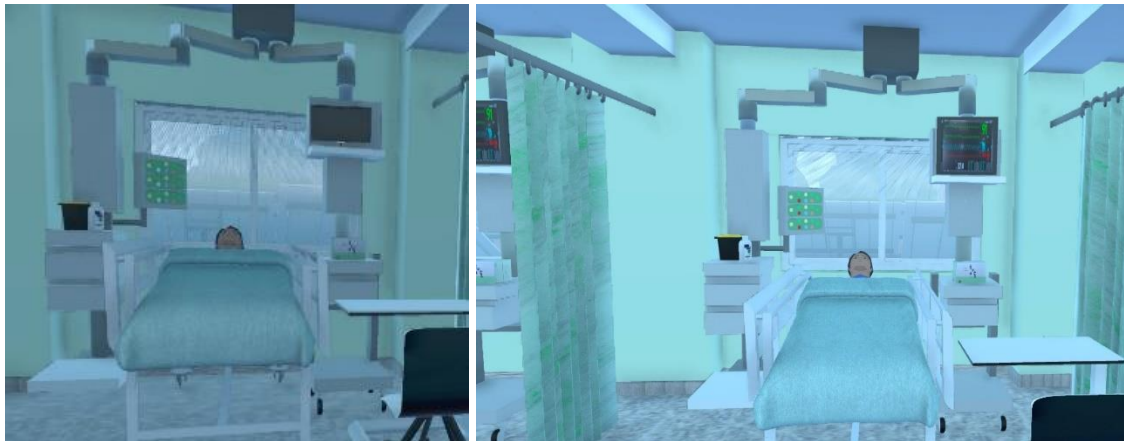


Figure 28: Bed station on the original virtual environment (left) and on the updated virtual environment (right).

In terms of audio enhancements, there were several changes made. First, the audio recordings from the corridor and the open bay were further distorted, ensuring that no individual's voice remained recognisable. Next, a cardiac monitor tone was added to the vital signs monitors in the bed stations featuring a human model and a telephone-ringing sound was also added to the telephone on one of the health professionals' desks, which started after 60 seconds, playing for 15 seconds and then replaying after 150 seconds. Finally, an additional another track of people talking was added to the open bay.

In terms of lighting changes, in addition to the previously mentioned two ceiling-mounted LED lights above the health professional's desks, the skybox was modified to better represent the natural light seen typically observed in the open bay, which is considerably brighter than what was seen in the original virtual environment. Finally, some non-visual elements were removed in an effort to improve overall performance and ensure a smoother and more stable experience.

4. Discussion

4.1 Overall Assessment of the Prototype

Before delving into the results from the prototype's external evaluation by the health professionals, it is important to conduct an initial analysis of the developed prototype, based on various characteristics, particularly the visual fidelity shown in Figures 15 through 23. This comparison provides an initial assessment of how successfully the virtual environment reproduced the key spatial, visual and equipment-related characteristics of the real intermediate care unit, prior to external validation.

Overall, the visual recreation of the intermediate care unit demonstrates a close correspondence with the real clinical environment across the key areas reproduced within the virtual environment. The general spatial organisation of the open bay, including the arrangement of the bed stations, the separation between the patient and the health professionals' areas, and the connecting corridor was successfully represented within the virtual environment, with the recognisable characteristics of the real hospital unit accurately represented. Similarly, the individual elements, such as the bed stations, the monitoring and intravenous access systems, the health professionals' workstation area, the floor patterns, and the exit doors, were all successfully reproduced within the virtual environment, collectively contributing to an environment that closely reflects the visual and spatial experience of a post-operative patient waking up in the intermediate care unit.

Alongside with the visual dimension of the virtual environment, the audio component is also critically important for ensuring immersiveness and, consequently, intervention effectiveness [59]. The incorporation of the audio recordings from the real intermediate care unit further contributed to the overall realism and immersiveness of the virtual environment. Additionally, the movement system is simple and intuitive to use, allowing older adults to navigate the virtual environment without requiring prior experience with virtual reality or other digital technologies.

However, the virtual environment is not without its limitations. Certain minor objects were not represented, such as elements visible in the bed stations, the cabinets behind the desks, and certain information posters on the wall. A further limitation identified during use of the virtual environment was occasional image instability during navigation. This occurred during rapid head movements, or when simultaneous head movement and joystick-based movement inputs occurred. Although this limitation did not impede interaction with the virtual environment, it may have impacted visual comfort and the overall stability of the immersive experience.

While this initial assessment provides a positive indication of the virtual environment's success at reproducing the main characteristics of the real intermediate care unit, the external evaluation by health professionals with experience in the real hospital unit, discussed in the following sections, provides a more clinically focused and unbiased perspective on the prototype's realism, usability, and overall feasibility.

4.2 Quantitative Assessment

4.2.1 Realism and Clinical Fidelity

The results presented in Table 2 indicate a consistently positive assessment of the virtual environment across all domains. First, the spatial realism domain, which assessed whether the dimensions, proportions and overall layout of the virtual environment were accurately represented, received a score of 4.50 ± 0.64 , suggesting that the spatial organisation reproduced within the virtual environment was closely aligned with participants' understanding of the real unit. Similarly, the clinical fidelity domain, which assessed if the visible medical equipment was accurately represented, received a score of 4.42 ± 0.65 , indicating that the equipment reproduced within the virtual environment was perceived as a credible representation of that found in the real hospital unit.

The patient's perspective domain, which assessed whether the field of vision and perspective during the intervention accurately portrayed the patient experience, received a score of 4.58 ± 0.86 , among the highest scores of this section. Given the central aim of the prototype and the intervention, this result is especially relevant, as it suggests viewing the environment from a patient's position was perceived as authentic by individuals familiar with the real unit. The physical environment domain, which assessed whether the lighting, colours and textures in this environment appeared realistic and familiar, received the highest score in this section at 4.67 ± 0.62 , indicating that the general visual atmosphere was successfully developed and well received.

The visual safety domain, which assessed whether the participants identified unrealistic visual elements, distortions, or graphical errors that could induce confusion or agitation in geriatric patients, received a score of 4.25 ± 0.72 , the lowest score of this section. Although certain minor visual elements may still require refinement, this result remains favourable, reflecting the overall success of the virtual reconstruction of the intermediate care unit.

Finally, the practical relevance domain, which assessed whether the participating health professionals considered the level of detail within the virtual environment appropriate and useful for familiarising patients with the real intermediate care unit prior to admission, received a score of 4.50 ± 0.50 , directly supporting the prototype's intended application as a preoperative familiarisation tool.

4.2.2 System Usability Scale

The results presented in Table 3, obtained using the System Usability Scale [67], indicated an overall positive assessment, though with more variable evaluation of the prototype's usability compared to the previous results. The final total score obtained was 71.65, which put in the above average usability bracket.

Several items received high scores, reflecting an overall favourable perception of the system, with results ranging from 4.25 to 4.58. Participants felt that the system's functions were well integrated, did not perceive it as overly complex or inconsistent, felt confident using it and reported a high willingness to use it frequently in interventions with preoperative patients.

However, other items, related to intuitiveness and the learning curve, received relatively lower scores. Four of these items, with scores ranging from 3.17 to 3.83, addressed whether the system was easy to use, whether first-time users would learn to use it quickly, the extent of prior learning required for participating health professionals to use the system in patient interventions and whether the system felt cumbersome to use. Finally, the item assessing whether expert assistance would be required to operate the system received a score of 2.58 ± 1.26 , the lowest in this section. Although this is a negatively worded item, the relatively low mean and the high standard deviation suggest that most participants would require assistance to set up the intervention and the equipment, at least during initial use. This suggests that additional initial guidance may be beneficial before the intervention begins, allowing patients to become comfortable with the controllers and familiar with the basic interaction mechanics of the system.

Considered collectively, these results suggest that, although the system's overall design and functionality were positively received, uncertainty remains regarding how quickly and intuitively a first-time user might adjust to the system and how steep the learning curve may be, whether for health professionals setting up the intervention or for patients encountering the virtual environment for the first time.

4.2.3 Virtual Reality System Usability Scale

The results presented in Table 4, obtained using the Virtual Reality System Usability Scale [68], indicate an overall positive evaluation, with most items scoring highly.

Several items received particularly high scores, reflecting a positive reception of the core experience, with scores ranging from 4.33 to 4.50. Participants reported that the system responded appropriately and without delays, provided clear feedback, allowed for a clear understanding of the information presented, rendered errors made by participants easy to correct, and was generally enjoyable.

However, two items received relatively lower scores. The first item, which assessed whether the system was intuitive, easy to learn, and designed for rapid adaptation by most users, received a score of 3.75 ± 0.92 , mirroring the more negative findings identified in Table 3. The second item, which assessed whether participants made mistakes or encountered errors while using the virtual environment, received a score of 3.17 ± 1.28 , which is understandable, considering that most participants had little to no prior experience with virtual reality technologies.

Finally, the two items relating to potential adverse effects of the virtual reality experience produced divergent results. The item assessing whether participants experienced dizziness, motion sickness or headaches during the virtual reality experience, received a score of 3.25 ± 1.42 , which may occur when participants use virtual reality technologies for the first time or when visual instability increases. The other item assessed whether participants felt mental overload, such as tension, frustration, or time pressure, during the virtual reality experience, and received a score of 4.25 ± 1.01 , indicating that, for most participants, this was not a significant issue.

Taken together, these results suggest that the core virtual reality experience was positively received, although the recurring theme of intuitiveness and learning curve, alongside the variability

observed regarding possible adverse effects, highlights specific areas warranting further attention, especially considering the characteristics of the intended patient population.

4.3 Implications for the Target Population

It is important to reinforce that only one of the twelve participating health professionals had prior experience with virtual reality technologies, meaning the usability results reflect a first-time user perspective, which is especially relevant given that the target population is also likely to have little to no prior experience with this technology. Accordingly, the recurring concerns regarding intuitiveness and the steep learning curve identified may be representative of how a patient encountering the virtual environment for the first time might respond. Additionally, as previously noted, one participant reported a pre-existing history of vertigo, which may have influenced their responses, particularly regarding the dizziness-related item. This factor should be considered for future evaluations.

These usability findings can also be interpreted in light of the clinical constraints described in the methodology. Given that the target population for whom this intervention is intended to consist of older adults, who are likely to have little to no experience with virtual reality, and that the intervention is structured around short, fifteen minutes sessions that require minimal physical effort, the lower scores relating to initial adaptation to the virtual environment are not entirely unexpected. Furthermore, the intervention is designed such that the patients are supervised by a healthcare professional throughout the session, allowing for immediate assistance in the event of difficulties. The potential for side effects associated with virtual reality exposure further underscores the importance of supervision by a healthcare professional during the intervention, particularly given the physiological vulnerability of patients during the perioperative period [8]. For future implementations, this supervision requirement could potentially be addressed through the development of simplified guidance protocols or automated safety features that allow healthcare professionals to support the intervention without incurring extensive additional workload.

4.4 Qualitative Assessment and Prototype Refinement

The qualitative feedback collected from the open-ended section of the questionnaire provided additional insight beyond the numerical scores, highlighting specific elements that affected the overall realism and familiarity of the virtual environment, and that directly influenced the subsequent improvements to the prototype.

Regarding elements perceived as less realistic, the relative quietness of the virtual environment compared to the real hospital unit was mentioned repeatedly. The absence of background noises, such as ringing telephones, monitor alarms and conversations was identified as a noticeable gap in the prototype's auditory realism. This underscored the importance of auditory cues, not only as a factor contributing to immersion, but also as a cognitive cue that contributes to patients' sense of place and routine, similar to how reorientation protocols function [34]. In response to this feedback, a cardiac

monitor tone, a telephone ringing sound and ambient conversation audio were added to the open bay within the virtual environment, addressing this concern regarding auditory realism [37] [38].

Similarly, the missing clocks, which also function as cognitive cues [34], represented another missing element within the virtual environment. Both clocks were subsequently added in the virtual environment, directly reflecting the role of clocks as cognitive anchors within reorientation protocols [34]. Other missing elements included the windows and the entrance door, which, although they had little impact on the high realism scores reported in the participant's questionnaires, were also added. Beyond the elements identified through qualitative feedback, additional elements, including the vital signs interface, the patient support cart, and the missing ceiling-mounted LED lights, were also added, further narrowing the gap between the prototype and the real unit. The skybox was also adjusted to better reflect the natural lighting conditions, building on the already-high scores obtained for the physical environment domain in Table 2.

The other comments, regarding controller configuration, image and external-device stability, and future testing opportunities, also provided useful guidance to refine practical aspects of the intervention's implementation, particularly regarding how healthcare professional may supervise and accompany patients throughout the virtual reality exposure. Finally, an informal observation by a participant who recognised a colleague's voice raised an important consideration regarding privacy, as well as regarding the possibility of a patient recognizing a known individual's voice. Consequently, the existing audio recordings were further distorted such that individual voices were no longer recognizable, whilst still preserving the overall auditory atmosphere of the unit. Finally, some non-visual elements were removed from the prototype to improve overall performance and ensure a smoother experience, which is important given the scores related to image stability and the adverse effects of virtual reality exposure.

4.5 Relation to Existing Literature

Previous studies investigating virtual reality as a tool for delirium prevention predominantly focused on interventions based on relaxation, cognitive stimulation, distraction or prerecorded audiovisual content [59] [60] [61] [63] [63]. Although these approaches have demonstrated promising effects in reducing the delirium incidence among critically ill patients [58], they have generally not targeted patient's relationship with their future clinical environment. Instead, they aimed to regulate psychological state or provide cognitive engagement, without addressing the uncertainty and unfamiliarity associated with recovering in an unknown hospital setting.

As previously noted, the present study extends this application of virtual reality by recreating the specific intermediate care unit where patients will recover after oncological surgery. This shifts VR towards environmental preparation and patient familiarisation with the postoperative setting, aligning with existing evidence supporting the role of environmental orientation and reorientation-based strategies in delirium prevention [34] [35] [36].

The results obtained from the evaluation provide preliminary support for the feasibility of this approach. The high scores related to realism and clinical fidelity suggest that the virtual environment's recreation was successful, which is a prerequisite for effective patient intervention. Accordingly, the

findings suggest that the software and hardware used are capable of supporting the creation of clinically relevant immersive environments.

The usability results provide preliminary evidence that this type of environment-specific VR intervention could be practically integrated into perioperative care. Although certain areas requiring improvement were identified, the overall positive evaluation from health professionals suggests that the system may be used effectively within a clinical context.

Overall, these findings suggest that environment-specific virtual reality familiarisation could represent a complementary approach within broader non-pharmacological delirium prevention strategies. Rather than replacing established interventions, this approach could potentially be integrated as an additional component within multicomponent prevention models, which have consistently demonstrated greater effectiveness than isolated interventions [41].

4.6 Current Limitations

This project and its findings are subject to several limitations. First, the evaluation was conducted exclusively with health professionals, rather than patients. Although the participants had direct experience with postoperative delirium management and were familiar with the represented clinical environment, they do not share the same cognitive, sensory or emotional characteristic as older oncological patients undergoing surgery. Consequently, their perception of realism, usability and comfort may differ from how the intervention would be experienced by the target population.

Additionally, the evaluation focused primarily on the prototype's realism, clinical relevance and usability rather than directly assessing its influence on patient outcomes. As such, the results do not provide evidence regarding the intervention's effectiveness in reducing anxiety, improving postoperative preparedness or influencing delirium incidence. Instead, these findings represent an early-stage contribution supporting the technical feasibility, acceptability and potential clinical applicability of this approach.

Finally, the inclusion of the participant reporting vertigo symptoms within the overall analysis may have influenced the evaluation outcomes, particularly regarding comfort-related aspects and adverse effects of the virtual reality experience. However, this response was retained, as it provides relevant insight into potential challenges associated with implementing the intervention among individuals with increased susceptibility to VR-related discomfort.

4.7 Future Work

First, the updated prototype should be re-evaluated by health professionals to assess whether the implemented improvements resulted in increased realism, usability and clinical fidelity. Additional health professional evaluations could also provide broader feedback and further refine the system before testing with patients.

Further technical improvements should also be made to address aspects identified during the evaluation, including image stability during navigation, interaction accessibility, controller configuration and real-time supervision mechanisms in particular, as patients should be supported and monitored without negatively affecting the immersive experience.

Following successful validation with health professionals, the next stage should involve evaluation with the intended patient population using the developed patient questionnaires, to assess patient acceptance, perceived preparedness, anxiety-related outcomes and, ultimately, whether preoperative familiarisation with the postoperative environment contributes to delirium prevention strategies.

5. Sustainable Development Goals (SDG)

The United Nations Sustainable Development Goals (SDGs) provide a global framework for achieving a better and more sustainable future for all. They comprise 17 goals [70] to address the world's most pressing challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice.

Within the context of healthcare and immersive technology, research must transcend isolated clinical metrics to address broader global priorities. By developing a non-pharmacological, virtual reality-based intervention to mitigate postoperative delirium, this dissertation directly intersects with the socio-economic and health equity targets outlined in the global agenda.

The specific Sustainable Development Goals addressed in this work are:

SDG 3 Ensure healthy lives and promote well-being for all at all ages;

SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all;

SDG 10 Reduce inequality within and among countries.

SDG	Target	Contribution	Performance Indicators and Metrics
3	4	The application of an immersive VR environment for preoperative familiarization reduces disorientation and unfamiliarity, key psychological triggers of postoperative delirium in geriatric oncology patients. By lowering perioperative anxiety and supporting cognitive stability, the intervention perioperative mental well-being and reduces the risk of long-term cognitive decline and morbidity.	Reduction in postoperative delirium incidence rate.
			Reduction in the difference between preoperative and postoperative cognitive assessment.
	8	A scalable, non-pharmacological VR-based prevention strategy reduces delirium complications, prolonged hospital stays and healthcare resource consumption. By improving recovery efficiency, the financial and logistic burden caused by postoperative delirium will be partially relieved.	Reduction in average length of stay in the Intermediate Care Unit.
			Reduction of direct operational cost per patient from reduced bed-days and nursing workload.
	d	The project strengthens proactive management of geriatric delirium risk by proposing an additional prevention strategy.	Increase in percentage of successful and independent nursing deployments of the VR protocol.

8	8	Preventing hyperactive delirium reduces stressful and unpredictable clinical situations caused by agitation, falls and overall disorientation. An additional postoperative delirium prevention strategy would support safer working environments and improve conditions for frontline nursing staff.	Reduction in nursing staff perceived stress.
			Increase in workplace safety scores.
10	2	Delirium is often associated with a reduction in quality of life, cognitive function and independence in older adults, which leads to their isolation. An additional postoperative delirium prevention strategy supports continued participation of elderly patients in family and community life.	Improvement in cognitive and functional independence scores at different time periods post-discharge.
			Increase in percentage of patients returning to independent preoperative living arrangements without cognitive deficits.

Table 5: Sustainable Development Goals.

6. Conclusion

This dissertation set out to develop and preliminarily evaluate an immersive virtual reality environment intended to familiarise geriatric oncological patients with the intermediate care unit prior to surgery, as a non-pharmacological strategy for the postoperative delirium prevention. To this end, an interdisciplinary approach was adopted, combining principles from clinical medicine, neuropsychology and human-computer interaction, and loosely following the development-based methodology of the Stanford Biodesign framework. The prototype was constructed through the detailed reconstruction of a real intermediate care unit, encompassing its spatial organisation, medical equipment, environmental features and auditory atmosphere, using accessible software (Unity and Blender) and commercially available (the Meta Quest 3 headset). The resulting environment was subsequently submitted to a preliminary evaluation by twelve health professionals with direct clinical experience in postoperative delirium management.

The prototype's development process was successful in reproducing the key spatial, visual and auditory characteristics of the real clinical environment, and the preliminary yielded positive results across realism, clinical fidelity and usability domains. These findings support the technical and practical feasibility of the proposed approach and suggest that environment-specific virtual reality familiarisation represents a promising addition to existing non-pharmacological delirium prevention strategies. Importantly, the qualitative feedback gathered also proved in guiding an iterative refinement process, through which several aspects of the prototype, including its auditory realism and visual completeness, were further improved.

This work also demonstrated that a credible and usable virtual environment could be developed using accessible and affordable tools and hardware, without requiring substantial institutional resources. This is a particularly relevant finding from a translational perspective, as it suggests that similar environment-specific interventions could be feasibly replicated and adapted across other clinical units and institutions, without the technical or financial barriers often associated with the implementation of immersive technologies in healthcare. The iterative, feedback-driven development process, informed by the evaluation results, led to a series of targeted improvements that enhanced the prototype's realism, auditory atmosphere, and overall performance. Although the evaluation was limited to health professionals and to a small sample size, the results nonetheless provide a meaningful first step towards validating this approach and advancing towards patient testing.

Nonetheless, this work has limitations that should be considered when interpreting its findings. The evaluation was conducted exclusively with health professionals rather than the intended patient population, and focused primarily on realism, clinical relevance and usability rather than directly assessing patient-centred outcomes. Future work should therefore prioritise evaluation with the target patient population, as well as longer-term studies capable of assessing the intervention's clinical impact on anxiety, preparedness and delirium incidence.

Postoperative delirium remains a significant clinical and socioeconomic burden, and its prevention continues to rely on multicomponent, non-pharmacological approaches. The present study explores a novel and targeted application of virtual reality that, if validated in future clinical studies, could complement existing prevention strategies by addressing environmental disorientation, a

relatively unexplored contributor to postoperative delirium. By shifting the focus of virtual reality interventions from generic relaxation or distraction towards a more targeted, environment-specific form of preoperative familiarisation, this work contributes a novel perspective to the growing body of literature on immersive technologies in perioperative care and lays the groundwork for future research aimed at turning this approach into clinical practice.

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8. Appendix

8.1 Appendix A – Assets and Packages Used in the Virtual Environment

8.1.1 Unity Asset Store Packages

Name	Purpose	Publisher
MIX FURNITURE PACK	Furniture and room assets	ZNS3D
Door Texture Pack	Textures	Cheese Animal Productions
School assets	Infrastructure	A.R.S T:
Computer Devices	Workstation Equipment	Maximalist
Yughues Free Architectural Materials	Textures	Nobiaux / Yughues
World Materials Free	Textures	Avionx
Free Stylized Textures	Textures	LowlyPoly
FREE Stylized PBR Textures Pack	Textures	Lumo-Art 3D
30 Stylized Textures FREE	Textures	Billion Mucks
Modern LED Lighting Pack	Lighting	PolyKebap
Bed Wood Oak PBR	Pillows	AK STUDIO ART
Furniture Low poly pack	Textures	DIABULUSKIRA
Office Pack - Free	Office Equipment	nappin
Pack Gesta Furniture #1	Furniture	Gest
Korean_Style_Bar	Monitors and Cardboard Boxes	Canmu
Free Sockets and Switches	Sockets	Boxx-Games Assets

Name	Purpose	Publisher
Waste Can PBR	Waste Bins	AK STUDIO ART
Plastic Trash Bins	Small Waste Bins	SpaceZeta
BrickTown Assetack	Background Buildings	Loafbrr
Jejungwon Hopsital	Trees	Gwangju Arts & Culture Humanities Story Platform
Russian buildings pack	Background Buildings	MadMedicSoft
Russian buildings lowpoly pack	Background Buildings	MadMedicSoft
Simple City pack plain	Background Buildings	255 pixel studios
City Voxel Pack	Background Buildings	PoèMe
Urban Skyscrapers	Background Buildings	misha virtual
High Quality Solar Panel	Solar Panels	Padia 3D
Small Pack Furniture	Furniture	OneProgram's
npc_casual_set_00	Human Models	Chepatack
PolyPeople Series - Hospital [Free]	Nurse Models	Simply Poly Lab
Low Poly Character Pack	Human Models	Floreswa
Furniture Mega Pack - Free	Furniture	dlgames
Apartment Kit	Background Buildings	Brick Project Studio
Realistic Tree 9 [Rainbow Tree]	Trees	Pixel Games
Low-Poly Office Set #1 [+140 Models] [VNB]	Office Equipment	VNB Productions

8.1.2 BlenderKit Assets

- Hospital Bed - asset_base_id:bcd8529e-4a8d-406c-bb1c-88fd62af21fc asset_type:model;
- Blanket - asset_base_id:9baa9480-d651-4a99-9ea4-ac256ab4a6d7 asset_type:model;
- Pillow - asset_base_id:8845e9d1-5b28-4018-a33e-385dff50997 asset_type:model;
- Blinds - asset_base_id:a2b796fb-59d2-4bf6-b964-457b746460d2 asset_type:model;
- Fridge - asset_base_id:a132333c-96e2-4076-9d7c-1e8d09226ebd asset_type:model;
- Sanitizer - asset_base_id:9e271174-a865-496c-8a88-e64bb5eec721 asset_type:model;
- Water Fountain - asset_base_id:41d8499b-d8f4-4baa-8f1d-4c0b44111fd0 asset_type:model.

8.1.3 Custom-Developed Assets

- Air Duct;
- Cabinet;
- Desk;
- Armchair;
- Chair;
- Cart;
- Plastic Tray 1;
- Plastic Tray 2;
- Perfusor Syringe Pumps;
- Double Doors;
- Bed Station Structure;
- IV;
- Oximeter;
- Wall and Window;
- Shelf;
- Wheel;
- Waste Bin Trolley;
- Television;
- Power Outlet.

8.2 Appendix B - Health Professional's Questionnaire

Nome: _____

Data: _____

Categoria Profissional: _____

A. Experiência prévia com Realidade Virtual

Avaliação de realismo da UCIB - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Domínio	Afirmação	1	2	3	4	5
Realismo Espacial	1. As dimensões, proporções e a disposição geral do quarto virtual correspondem à realidade da UCIB.	()	()	()	()	()
Fidelidade Clínica	2. Os equipamentos médicos visíveis (ex: cama, monitores, suportes de soro, calhas de gases) estão representados com precisão.	()	()	()	()	()
Perspetiva do Doente	3. A linha de visão e a perspetiva a partir da cama do doente refletem fielmente aquilo que um doente real experiencia.	()	()	()	()	()
Ambiente Físico	4. A iluminação, as cores e as texturas do ambiente (paredes, chão, janelas) parecem realistas e familiares.	()	()	()	()	()
Segurança Visual	5. Não identifiquei elementos visuais irreais, distorcidos ou "erros gráficos" que possam causar confusão ou agitação num doente geriátrico.	()	()	()	()	()
Relevância Prática	6. Considero que o nível de detalhe deste ambiente virtual é adequado e útil para familiarizar previamente um doente com a UCIB.	()	()	()	()	()

Escala de Usabilidade do Sistema - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Afirmação	1	2	3	4	5
1. Eu penso que gostaria de utilizar este sistema com frequência.	()	()	()	()	()
2. Eu achei o sistema desnecessariamente complexo.	()	()	()	()	()
3. Eu achei o sistema fácil de usar.	()	()	()	()	()
4. Eu penso que precisaria de ajuda de um especialista para usar o sistema.	()	()	()	()	()
5. Eu considero que as diferentes funções do sistema estão bem integradas.	()	()	()	()	()
6. Eu acho que existe demasiada incoerência no sistema.	()	()	()	()	()
7. Eu imagino que a maioria das pessoas aprenderia a utilizar este sistema rapidamente.	()	()	()	()	()
8. Eu achei o sistema muito complicado de utilizar.	()	()	()	()	()
9. Senti-me confiante ao utilizar o sistema.	()	()	()	()	()
10. Eu teria de aprender muitas coisas antes de poder utilizar o sistema corretamente.	()	()	()	()	()

Escala de Usabilidade do Sistema de Realidade Virtual - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Afirmção	1	2	3	4	5
1. O sistema respondeu bem às minhas interações, como esperado, sem atrasos.	()	()	()	()	()
2. Acredito que o sistema de realidade virtual fornece feedback claro sobre as minhas interações.	()	()	()	()	()
3. Continuei a cometer erros/falhas durante a utilização do sistema de realidade virtual.	()	()	()	()	()
4. Consegui compreender claramente as informações apresentadas no ambiente virtual.	()	()	()	()	()
5. Acredito que o sistema é intuitivo, fácil de aprender e concebido de forma a que a maioria das pessoas consiga-se adaptar facilmente a ele.	()	()	()	()	()
6. Acredito que é fácil corrigir erros cometidos durante experiências de realidade virtual.	()	()	()	()	()
7. Gostei da experiência de realidade virtual.	()	()	()	()	()
8. Senti tonturas, enjoo de movimento ou dor de cabeça durante a experiência de realidade virtual.	()	()	()	()	()
9. Durante a experiência de realidade virtual, senti sobrecarga mental, como tensão, frustração e pressão de tempo.	()	()	()	()	()

B. Que elementos do quarto virtual lhe pareceram **menos realistas** ou precisam de ser corrigidos antes de mostrarmos aos doentes?

C. Há algum equipamento ou detalhe importante do quarto real que esteja **em falta** na simulação e que um doente devesse ver?

D. Comentários ou sugestões adicionais:

8.3 Appendix C - Patient's Questionnaire

Inquérito de Avaliação – “Prevenção de Delirium em Pacientes Geriátricos através de Realidade Virtual”

Nome: _____

Data: _____

Gênero: _____

Idade: _____

A. Experiência prévia com Realidade Virtual:

Escala de Usabilidade do Sistema - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Afirmação	1	2	3	4	5
1. Eu penso que gostaria de utilizar este sistema com frequência.	()	()	()	()	()
2. Eu achei o sistema desnecessariamente complexo.	()	()	()	()	()
3. Eu achei o sistema fácil de usar.	()	()	()	()	()
4. Eu penso que precisaria de ajuda de um especialista para usar o sistema.	()	()	()	()	()
5. Eu considero que as diferentes funções do sistema estão bem integradas.	()	()	()	()	()
6. Eu acho que existe demasiada incoerência no sistema.	()	()	()	()	()
7. Eu imagino que a maioria das pessoas aprenderia a utilizar este sistema rapidamente.	()	()	()	()	()
8. Eu achei o sistema muito complicado de utilizar.	()	()	()	()	()
9. Senti-me confiante ao utilizar o sistema.	()	()	()	()	()
10. Eu teria de aprender muitas coisas antes de poder utilizar o sistema corretamente.	()	()	()	()	()

Escala de Usabilidade do Sistema de Realidade Virtual - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Afirmção	1	2	3	4	5
1. O sistema respondeu bem às minhas interações, como esperado, sem atrasos.	()	()	()	()	()
2. Acredito que o sistema de realidade virtual fornece feedback claro sobre as minhas interações.	()	()	()	()	()
3. Continuei a cometer erros/falhas durante a utilização do sistema de realidade virtual.	()	()	()	()	()
4. Consegui compreender claramente as informações apresentadas no ambiente virtual.	()	()	()	()	()
5. Acredito que o sistema é intuitivo, fácil de aprender e concebido de forma a que a maioria das pessoas consiga-se adaptar facilmente a ele.	()	()	()	()	()
6. Acredito que é fácil corrigir erros cometidos durante experiências de realidade virtual.	()	()	()	()	()
7. Gostei da experiência de realidade virtual.	()	()	()	()	()
8. Senti tonturas, enjoo de movimento ou dor de cabeça durante a experiência de realidade virtual.	()	()	()	()	()
9. Durante a experiência de realidade virtual, senti sobrecarga mental, como tensão, frustração e pressão de tempo.	()	()	()	()	()

Experiência Global de Realidade Virtual - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Afirmação	1	2	3	4	5
1. A experiência virtual ajudou-me a sentir mais preparado para estar internado na UCIB.	()	()	()	()	()
2. A visualização do quarto reduziu a minha ansiedade em relação ao ambiente hospitalar.	()	()	()	()	()
3. O ambiente virtual foi muito imersivo.	()	()	()	()	()
4. A experiência pareceu natural.	()	()	()	()	()
5. Os elementos visuais eram fáceis de ver.	()	()	()	()	()
6. A navegação no ambiente virtual foi simples.	()	()	()	()	()
7. O equipamento foi confortável de utilizar.	()	()	()	()	()
8. A duração da experiência foi adequada.	()	()	()	()	()
9. Compreendi melhor como será o ambiente hospitalar.	()	()	()	()	()
10. Reconheço melhor os equipamentos que poderei encontrar.	()	()	()	()	()

B. Comentários ou sugestões adicionais:

8.4 Appendix D - Patient's Questionnaire - Simplified

Nome: _____

Data: _____

Gênero: _____

Idade: _____

A. Experiência prévia com Realidade Virtual:

Experiência Global de Realidade Virtual - Assinale a sua concordância com as frases abaixo indicadas (1 – Não concordo nada; 5 – concordo totalmente)

Afirmação	1	2	3	4	5
1. Senti-me confortável durante a experiência.	()	()	()	()	()
2. O equipamento foi confortável de usar.	()	()	()	()	()
3. Senti-me calmo(a) durante a experiência.	()	()	()	()	()
4. A experiência ajudou a reduzir a minha ansiedade sobre o internamento.	()	()	()	()	()
5. Os elementos visuais eram fáceis de ver.	()	()	()	()	()
6. A navegação no ambiente virtual foi simples.	()	()	()	()	()
7. Senti tonturas, stress, enjoo ou desconforto físico.	()	()	()	()	()
8. A duração da experiência foi adequada.	()	()	()	()	()
9. Compreendi melhor como será o ambiente hospitalar.	()	()	()	()	()

Comentários ou sugestões adicionais:

Prevention of Delirium in Geriatric Patients using Virtual Reality

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