Overview and Strategy Analysis of Technology-based Non-pharmacological Interventions for In-hospital Delirium Prevention and Reduction: Systematic Scoping Review

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Abstract

Background: Delirium prevention is crucial, especially in critically ill patients. Increasingly, non-pharmacological multicomponent interventions for preventing delirium are recommended and technology-based interventions have developed to support them. Despite the increasing number and diversity in technology-based interventions, there has been no systematic effort to create an overview.

Objective: The systematic scoping review was carried out to answer the following questions: (1) What are technologies currently used in non-pharmacological technology-based interventions for preventing and reducing delirium?, (2) What are the strategies underlying these currently used technologies?

Methods: A systematic search was conducted in Scopus and Embase between 2015 and 2020. A selection was made in line with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) . Studies were eligible if they contained any types of technology-based interventions and assessed delirium-/risk factor-related outcome measures in a hospital setting. Data extraction and quality assessment were performed using a predesigned data form.

Results: A total of 31 studies were included and analyzed focusing on the types of technology and the strategies used in the interventions. The review revealed eight different technology types and 14 strategies that were categorized into seven pathways: (1) restore circadian rhythm, (2) activate the body, (3) activate the mind, (4) induce relaxation, provide (5) a sense of security, (6) a sense of control, and (7) a sense of being connected. For all technology types, significant positive effects were found on direct and/or indirect delirium outcome. Several similarities were found across effective interventions: using a multicomponent approach and/or including components comforting psychological needs of patients (e.g., familiarity, distraction and soothing elements).

Conclusions: Technology-based interventions have a high potential when multidimensional needs of patients (e.g., physical, cognitive and emotional) are incorporated. The seven pathways pinpoint starting points for building more effective technology-based interventions. Opportunities were discussed for transforming the Intensive Care Unit (ICU) into a healing environment as a powerful tool to prevent delirium.

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Keywords: Intensive care unit, delirium, delirium prevention, delirium reduction, delirium treatment, technology, technology-based intervention, strategy, non-pharmacological, systematic scoping review

Introduction

Background

Delirium is an acute brain dysfunction with a disturbance in attention, awareness, and cognition [1], which is common, especially in critically ill patients. It occurs in about 40% of patients in the intensive care unit (ICU) [2] and in case of ventilated patients, the number goes up to about 65-80% [2,3]. Nonetheless delirium can be often underestimated due to differences in severity of illness in
populations and under-recognition of delirium [4][5]. Delirium is frequently associated with a significant increase of the ICU length of stay (LOS) [6], the risk of long-term cognitive impairments [7] and the 6-month mortality rates after leaving the ICU [8]. At the organizational level, delirium is associated with an increase in the cost of ICU care [9], ICU readmission [10], and mental stress of ICU nurses who take care of patients with delirium [11]. At the societal level, delirium costs up to $152 billion per year in health care in the United States [12]. Prevention of delirium may be the most effective way to avoid these negative outcomes. In case of in-hospital patients, at least 30-40% of delirium cases are preventable by reducing risk factors of delirium [13,14]. There are two types of interventions used for preventing delirium: pharmacological and non-pharmacological interventions (e.g., reorientation).

Non-pharmacological multicomponent interventions are recommended as a safe and promising way of preventing delirium over pharmacological interventions [15]. Non-pharmacological multicomponent interventions aim at reducing delirium risk factors that are modifiable by, for instance, promoting better sleep, early mobilization and cognitive training/stimulation [15]. In order to support the implementation of non-pharmacological interventions, several methods [16,17] have been introduced. As an example, the ABCDEF bundle provides practical ways to provide optimal care of ICU patients [16]. Despite the benefits of using these methods [18], there are still barriers, as the way in which non-pharmacological interventions are applied is often highly dependent on medical staff. Technology-based intervention might help to overcome these barriers. In this review, ‘technology’ is defined as equipment that is used or developed based on scientific knowledge for practical purposes. Ironically, while the ICU room has been one of the most technology-intensive places in hospitals, when it comes to delirium prevention, the use of technology-based interventions in the ICU room often remains limited to, for example, the use of earplugs [19].

With recent developments in technology, there is large potential for a diversity of technology-based interventions. Examples include a modified ICU room design providing, among others, a personalized light therapy system and noise reduction to support cognitive stimulation and a normal sleep-wake cycle of patients [20]. Another example is an interactive app using a conversational agent, which provides patients social interactions and medical advice [21]. The app enables personalized care for patients without frequent physical visits of bedside nurses. These examples showcase some of the possibilities that recent developments in technology can bring. However, understanding of how to optimize technology-based interventions are limited and therefore it is worthwhile to further and more systematically study the topic.

Prior work

Recently, several (systematic) reviews were performed to provide overviews and/or to highlight the potential of existing non-pharmacological interventions for preventing delirium [18,22–27]. However, none of the existing reviews focused exclusively on technology-based interventions for preventing delirium. Moreover, none of the previous reviews [24–26] provided information necessary for improving the design and development of new technology-based interventions. For instance, a vision outlining what is needed to build a better care environment for patients in the context of intensive care, and clear guidance for technology-supported improvements are lacking.

Goal of this study

To close this gap, this paper will provide a comprehensive review of technology-based interventions used for preventing and reducing in-hospital delirium. To our knowledge, it is the first systematic effort to provide such an overview. Taking a bottom-up approach, we will first investigate what types of technologies are used in current non-pharmacological interventions and how these interventions
contribute to delirium prevention and reduction in hospitalized patients. Second, we will identify underlying strategies of technologies applied in the technology-based interventions. Finally, following our analysis, we will discuss the limitations of current technology use and the opportunities for further research and development of technology-based interventions aimed at delirium prevention in ICU and for other hospitalized patients.

The systematic scoping review was conducted to answer the following questions: (1) What are technologies currently used in non-pharmacological technology-based interventions for preventing and reducing in-hospital delirium?, (2) What are the strategies underlying these currently used technologies? This review will provide insights in technologies that can be used for in-hospital delirium prevention and reduction, and suggest directions for future design and development of innovative technology-based interventions. We propose that incorporating these insights will optimize the use of technologies and enhance the effectiveness of technology-based interventions.

Methods
This systematic scoping review was conducted complying with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guideline [28]. The study protocol was registered on the international prospective register of systematic reviews (PROSPERO, CRD42020175874).

Search strategy
The search was conducted from the Scopus and Embase databases for studies that are written in English, and are published between the 1st of January 2015 and the 6th (Scopus) / the 13th (Embase) of January 2020. This time period was set to focus on the state-of-the-art technologies used following our scope for this review. The initial search was conducted with the terms delirium (deliri*) and technology (technolog*) but it did not result in a sufficient number of relevant studies. Samples of search terms were identified through the previous studies and extended through the search of index terms, medical subject headings (MeSH), and other technological terms used for other medical purposes. The following terms were used for the final search: 1) deliri*; 2) technolog*; 3) intelligen* OR automat* OR digital* OR computer OR computing OR robot*; 4) mobile OR app; 5) visual OR virtual OR VR OR video; 6) light* OR ambien* OR aroma* OR architect*; 7) sound* OR music* OR voice OR alarm; 8) cognitive training OR tracking OR game*; 9) 1 AND 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 (see Appendix 1 for full search strategy). Additional studies were sought through communication with experts. Only studies that are peer-reviewed and conducted with human subjects were included.

The title-abstract screening and the full-text review were performed by two reviewers (CK and EvdH) independently. Disagreements were discussed and reevaluated based on the main goal of the study. The reasons for excluding were recorded.

Eligibility criteria and study selection
The studies were included based on the eligibility criteria (See Table 1).

| Table 1 Eligibility criteria |
|-----------------------------|
| Criterion                   | Inclusion | Exclusion |

[unpublished, peer-reviewed preprint]
The main goal of this review is to find papers dealing with prevention and reduction of delirium in the ICU, but in order to not overlook the potential of a greater range of technology-based interventions, the search scope was not limited to the ICU department but included also other hospital departments (e.g., pediatric ICU, geriatric ward). We also included delirium from all age groups: from acute pediatric delirium to geriatric delirium, because they share a similar range of delirium symptoms [29]. Moreover, risk factors and recommended interventions across delirium in these groups are more or less same [30]. Although delirium varies into three subtypes, of which each have their own symptoms and courses [31], these subtypes were not applied in the eligibility criteria and the study selection as most studies did not specify them. We included studies focusing on incident delirium as well as prevalent delirium in order to address the full scope of delirium interventions. As we intended to explore all existing technology-based interventions supported by scientific evidence, we did not place any inclusion restrictions on the study design.

**Data extraction and quality assessment**

Data extracted from the studies included the primary author, year of publication, country of origin, publisher, summary of intervention content, applied technology, intervention goal, study design, type and number of participant, outcome measure, intervention outcome, key finding and limitation of study. The primary data extraction was performed by CK using the predesigned data extraction form and the extracted data was reviewed and confirmed by EvdH. Disagreements were resolved by discussions between CK and EvdH which included revisits of the relevant data by both authors.

To distinguish differences in the strength of evidence in the studies, a quality assessment was performed by CK using a predesigned assessment form (Appendix 2) and reviewed and confirmed by EvdH. Disagreements were resolved by follow-up discussions. However, none of the studies were excluded based on the quality assessment in our analysis as our goal in this review was to create an overview of existing technology-based interventions.

**Analysis**

First, all technologies used in the technology-based interventions were looked into and clustered per technology type: a total of eight categories was identified. Clustering was performed by CK and reviewed and confirmed by EvdH.
Next, to summarize strategies used in the technology-based interventions, goals and content summaries of each intervention were looked into: a total of 14 strategies was identified. These strategies were clustered and labelled based on the overarching theme: this led to the identification of seven pathways to delirium prevention. An extraction of 14 elements from each intervention was carried out by CK and clustering was performed independently by CK and two other experienced researchers (MR and BL). After each session, the results and disagreements were discussed by CK with either MR or BL, then the synthesis was finalized by CK.

**Results**

**Study selection**

The process of literature screening and selection is presented in the flow diagram (See Figure 1). After removing duplicates, a total of 1058 studies were screened. Among these, 67 studies were examined based on the full text and 31 studies met inclusion for the review.

**Figure 1** Flow diagram of study selection

- **1299 Records identified in databases**
  - 1034 Scopus
  - 265 EMBASE
- **6 Records identified through other sources**
- **1058 Records after duplicates removed**
- **1058 Records in title/abstract screen**
- **991 Excluded for not meeting eligibility criteria**
- **36 Excluded for**:
  - 13 were not original research
  - 6 did not involve technology
  - 4 with technologies not addressing patients
  - 5 were not focusing on delirium as a study variable
  - 3 were not about a hospital environment
  - 2 were not conducted with patients
  - 1 missed information about technology
  - 1 were only about delirium monitoring
  - 1 did not contain any measurable outcome
- **67 Potentially relevant articles for full-text review**
- **31 Articles included in review**
**Study characteristics**

The characteristics of 31 included studies are listed in Table 2. Most of the studies were conducted in the ICU (n=15, 48%) followed by hospital wards (n=13, 42%), and both ICU and hospital wards (n=3, 10%). The most common study population was adult patients (n=23, 74%). Seven studies were conducted with pediatric patients [32–38] and one study was conducted with both adult and pediatric patients [39]. Most studies were prospective studies (n=28, 90%), including randomized trial [32–48], pre-post/experimental [19,21,23,49–51], organizational case study [52], observational cohort [53] and pilot studies [54–56]. There were three retrospective studies [57–59](See Table 2 for further specification).

**Quality scores of included studies**

The assessed quality scores ranged from 1 [23,55] to 5 [32,35–38,45,47] (See Appendix 2). The average score was 3.258 with standard deviation of 1.264. A score lower than 3 was found in 10 studies [21,23,50–52,54–57,59]. Seven studies reached the maximum score of five [32,35–38,45,47].

The included studies were analyzed in two ways: firstly, focusing on extracting the different types of technologies in the interventions, and secondly, focusing on identifying strategies behind these interventions.

**Eight types of technologies currently used for preventing delirium**

A total of 31 technology-based interventions were identified (See Table 2 and Table 3). Eight categories were distinguished based on the type of technology used. These categories are: audio (7 studies), light (5), video/video game (5), virtual reality (VR) (3), sleep-aids (2), communication support (2), and others (2). Technologies used as a part of a multicomponent approach were grouped into a category multicomponent (5). The identified technologies varied from simple (e.g., earplugs, window blinds) to more advanced (e.g., dynamic light, VR) one. These technologies were used to complement conventional delirium treatments, rather than replace them, by reducing negative (psychosocial) consequences of environmental factors and their effects on patient experiences.
### Table 2 Characteristics of included studies classified into eight different technology types

| Author and Year | Main goal of Intervention                                      | Study Design                     | Patient Type | Total number of patients (Per group) |
|-----------------|-----------------------------------------------------------------|----------------------------------|--------------|-------------------------------------|
| **Audio (7) – Music / Voice message**                          |                                                                  |                    |                                        |
| Damshens 2018[39] | To improve mental state *                                        | Randomized Clinical Trial        | ICU (Pediatric & Adult) | 80 (I:40, C:40)                      |
| Lee 2017[38] | To reduce stress and anxiety                                     | Randomized Controlled Trial      | ICU           | 85 (I:41, C:44)                      |
| Johnson 2018[47] | To alter physiologic response                                   | Randomized Controlled Trial      | ICU/TOU       | 40 (I:20, C:20)                      |
| Sharda 2019[52] | To mitigate postoperative pain and anxiety *                    | Organizational Case Study        | ICU           | 202 (I:45, C:157)                    |
| Cheong 2016[54] | To enhance engagement, mood and to improve agitated behaviors * | Pilot Study (For Randomized Controlled Trial) | ICU          | 25 (I: 10, C: 25)                    |
| Byun 2018[32] | To activate positive psychological and behavioral responses and to reduce anxiety * | Double-Blind Randomized Controlled Trial | ICU (Pediatric) | 66 (I:33, C:33)                     |
| Munro 2017[48] | To support reorientation and to comfort patients *             | Three Group Prospective Randomized Controlled Trial | ICU *        | 30 (I:10, 12:10, C: 10)              |
| **Light (5) – Dynamic light / natural light**                  |                                                                  |                    |                                        |
| Estrup 2018[57] | To improve circadian rhythm *                                   | Retrospective Cohort Study       | ICU           | 183 (I:46, C:137)                    |
| Pustjens 2018[59] | To improve circadian rhythm *                                   | Retrospective Observational Study | CCU          | 748 (I:369, C:379)                   |
| Simons 2016[40] | To improve circadian rhythm and sleep *                        | Randomized Controlled Single-Centre Trial | ICU         | 734 (I:361, C:373)                   |
| Pothar-jaaroen 2018[41] | To improve sleep-wake cycle *                               | Single-Blind Randomized Controlled Study | ICU         | 62 (I:31, C:31)                     |
| Smonig 2019[53] | To reduce circadian rhythm disruption *                         | Prospective Single-Center Observational Study | ICU         | 179 (I:102, C:77)                    |
| **Video/video game (5) – Information / distraction**          |                                                                  |                    |                                        |
| Lee 2016[49] | To reduce preoperative anxiety *                               | Quasi-Experimental              | ICU           | 50 (I:25, C:25)                      |
| Kim 2015[33] | To reduce preoperative anxiety                                 | Prospective Randomized Control Trial | PACU (Pediatric) | 104 (I:34, 12:33, I3:37)        |
| Rodriguez 2019[34] | To reduce preoperative anxiety                                | Prospective, Randomized Trial   | PACU (Pediatric) | 52 (I:25, I2:27)                      |
| Waszynski 2018[42] | To reduce agitation in patients experiencing hyperactive or mixed delirium | Randomized Controlled Trial | Hospitalized ICU | 111 (I:34, 12:40, C: 37)      |
| Dwairej 2019[35] | To reduce preoperative anxiety                                 | Randomized Clinical Trial        | Day case surgery unit (Pediatric) | 128 (I:64, C:64)                    |
| **VR (3) – Information / distraction**                        |                                                                  |                    |                                        |
| Eijlers 2019[36] | To reduce pain and anxiety *                                   | Randomized Controlled Single-Blind Trial | Day case surgery unit (Pediatric) | 191 (I:94, C:97)                    |
| Ryu 2019[37] | To reduce preoperative anxiety                                 | Randomized Controlled Trial      | PACU (Pediatric) | 86 (I:41, C:39)                      |
| Suvajdzic 2019[56] | To reduce clinical anxiety and depression, and to support sleep and relaxation * | Pilot Test                      | ICU           | 10                                   |

**Sleep-aids (2)**

[unpublished, peer-reviewed preprint]
| Author          | Year     | Design                                                                 | Setting                  | Total (I:C) |
|-----------------|----------|-------------------------------------------------------------------------|--------------------------|-------------|
| Demoule         | 2017     | Randomized Controlled Trial                                            | ICU                      | 45 (1:23, C:22) |
| Van de Pol      | 2017     | Interrupted Time Series Design (Pre-and Post Intervention)             | ICU                      | 421 (I:210, C:211) |
| Garry           | 2016     | Pilot Prospective Trial                                               | ICU/CCU                  | 12          |
| Bott            | 2019     | Case Control Quasi-Experimental Pre-Post Randomized Controlled Trial   | Medical & Surgical unit  | 95 (1:41, C:54) |
| Lin             | 2018     | Prospective Blinded Randomized Trial                                 | PACU (Pediatric)         | 179 (I:89, C:90) |
| Giraud          | 2016     | Pilot Time-Cluster Randomized Controlled Study                          | ICU                      | 223 (I:115, C:108) |
| Arbabi          | 2018     | Quasi-Experimental                                                    | ICU                      | 148 (I:78, C:69) |
| Tovar           | 2016     | Prospective Pre-Experimental                                           | ICU                      | 49          |
| Rivosecchi      | 2016     | Prospective, Observational Improvement Pre-Post                        | MICU                     | 483 (I:253, C:230) |
| Mitchell         | 2017     | Single Randomized Trial                                               | ICU                      | 61 (I:29, C:32) |
| Zachary         | 2020     | Retrospective                                                          | Medical, Surgical /telemetry units | 4850 (I:2146, C:2704) |

Abbreviations: ACU, Acute Care Unit; CCU, Coronary Care Unit; ICU, Intensive Care Unit; MICU, Medical Intensive Care Unit; PACU, Post Anesthesia Care Unit; POSH, Perioperative Optimization of Senior Health; PtDD, Patients with Delirium and/or Dementia; TOU, Trauma Orthopedic Unit.

* With our minimal interpretation; † All patients are adults unless mentioned as pediatric patients; ‡ Intervention group; § Control group; ¶ About 10% was delirious at admission; ‡ Only delirious patients; ‡ Including ICU patients.
### Table 3: The content and effects of technology-based non-pharmacological interventions

| Author and Year | Summary of Intervention | Incidence of Delirium, N (%) | Duration of Delirium, Day (SD) | Effectiveness | Key Findings |
|-----------------|-------------------------|-------------------------------|-------------------------------|---------------|--------------|
| **Audio (7) – Music / Voice message** |
| **Damshenas 2018 [39]** | Music therapy: Listening to light instrumental music selected by a music expert for 45 min twice (once in the morning and once at night) for a day. | I: 15 (37.5%)<br>C: 16 (40%)<br>(p=.818) | - | X | No significant difference between the control and test group in terms of incidence of delirium. Significant lower use of two pain relievers (acetaminophen and diclofenac) in the test group. |
| **Lee 2017 [38]** | Music intervention: A single 30-minute session of listening to the slow beat music (60-80 BPM), selected by patients from predefined playlists, through headphones with the presence of physical nurse sitting at the bedside. The study was conducted to explore the anxiety-reducing effect of the intervention. | | - | - | Music intervention significantly reduced the anxiety and stress related measures (serum cortisol level, heart rate, Visual Analogue Scale for Anxiety etc.) of mechanically ventilated ICU patients. |
| **Johnson 2018 [47]** | Music intervention: Listening to simple repetitive, self-selected music with slow tempo (60-80 BPM), low pitch and repetitive rhythms for 60 min using an iPod and headsets, twice a day, over three days following admission. | I: 0<br>C: 0 | - | - | No delirium incidence in both the control and test group. Music intervention significantly improved pathophysiologic mechanisms that contribute to delirium; neurotransmitter imbalance, inflammation, and acute physiologic stressors in the test group. |
| **Sharda 2019 [52]** | Confusion Avoidance Led by Music (CALM) program: On postoperative day 1 patients got a music player and headphones with a personalized playlist based on a music assessment. Listening for at least 20 min twice a day was recommended, but patients had autonomy over the ultimate dose and frequency. | I: 17.8%<br>C: 28.7%<br>(p=.14) | - | X | CALM may impact incident delirium and optimize postoperative pain and anxiety. |
| **Cheong 2016 [54]** | Creative music therapy (CMT): Spontaneous music making with musical instruments, playing familiar songs of patient’s choice and music listening for 30 min once a day over two days. Based on individual’s profile and response to music, a certified music therapist modified techniques to meet patients’ need. | - | - | - | CMT can improve mood/emotion and engagement of patients with dementia and delirium. |
| **Byun 2018 [32]** | Mother’s recorded voice: Listening to either the recorded voice of a mother (11) or a stranger (12) through noise-cancelling headphones at the end of a surgery. The pre-recorded message with standardized text was repeated with 10 sec intervals and was continued until entering the PACU. | I1:8 (24.2%)<br>I2:20 (60.6%)<br>(p=.006) | - | O | Letting children listen to the sound of their mother in the recovery room reduced the incidence of emergence delirium. |
| **Munro 2017 [48]** | Automated reorientation: During the first 3 days at the ICU, patients either received an automated reorientation messages with a familiar (I1) or unfamiliar voice (I2), or no reorientation message at all (C). The message containing patient’s name and Delirium free day | I1:0.3 (0.48)<br>I1: 1.9 days (0.99)<br>I2: 2.1 days (1.07)<br>I2: 1.6 days (0.9)<br>C: 1.6 days (Not) | - | O | Reorientation through automated messages increased the number of delirium free days. A familiar voice was more effective in reducing delirium than an unfamiliar voice. |

https://preprints.jmir.org/preprint/26079 [unpublished, peer-reviewed preprint]
Information about the ICU environment (< 2 min long) was played during the day (9 am to 4 pm). No effect of the size, with parental presence at induction of anesthesia. No effect on the development of delirium.

**Light (5) – Dynamic light / natural light**

| Author          | Year | Description                                                                 | Intervention 1 | Comparison 1 | Result          | Description                                                                 |
|-----------------|------|------------------------------------------------------------------------------|----------------|--------------|-----------------|----------------------------------------------------------------------------|
| Estrup          | 2018 | Dynamic light: Exposure to the circadian light in which, the amount of blue light (460-480 nm) changes over time like natural light. The light intensity was varied from 50-4000 lux during daytime (between 6:00 and 20:30) and no blue light between 23:00 and 6:00. The exposure time of patients was varied from at least 24 hours to their total stay. | I: 30          | C: 28        | X               | Circadian light did not have an effect on the development of delirium.     |
| Postjens        | 2018 | Dynamic light: Exposure to an artificial daylight system with light intensity peak values of 750 lux at the eye level and a color temperature ranging from 2700 K to 6550 K. Patients were exposed as long as possible during daytime. The overall period was varied from 20 hours to 42.7 hours depending on a patient. | I: 20          | C: 19        | X               | Exposure to dynamic light did not reduce the incidence of delirium nor total hospital LOS. |
| Simons          | 2016 | Dynamic light: Exposure to the circadian light system with light intensity and color temperature peaks of 1700 lux and 4300K via conventional fluorescent tubes between 9:00 and 16:00 except for 11:30 and 13:30 (intervention group) and to the standard lighting settings of 300 lux and 3000 K (control group) during the ICU stay of patients (3-9 days). | I: 137         | C: 123       | X               | Dynamic light as a single intervention did not reduce the cumulative incidence and duration of delirium in the test group. |
| Pothara-jaroen  | 2018 | Bright light: Treatment with bright light therapy consisting of 5000 lux at 1.4 meter distance from patients' face between 9:00 and 11:00 for 3 days. Other treatment data (nasal cannula oxygen, drugs etc.) were analyzed. | I: 2           | C: 11        | X               | Bright light therapy reduced the incidence of delirium in the test group.   |
| Smonig          | 2019 | Natural light exposure: Exposure to natural light via windows from admission to the ICU until discharge (3-7 days). | I: 65          | C: 55        | X               | Admission to a single room with natural light via windows did not reduce the incidence of delirium, but a risk of agitation episodes and hallucinations.  |

**Video/video game (5) – Information / distraction**

| Author          | Year | Description                                                                 | Intervention 1 | Comparison 1 | Result          | Description                                                                 |
|-----------------|------|------------------------------------------------------------------------------|----------------|--------------|-----------------|----------------------------------------------------------------------------|
| Lee             | 2016 | Preoperative video information: Informative videos that explains preoperative procedures, operating room environment, and ICU environment on the day prior to surgery. | I: 3           | C: 5         | X               | The intervention was not effective on reducing delirium incidences but decreased the anxiety levels. |
| Kim             | 2015 | Video distraction and parental presence: In the pre-operative holding room before surgery, provision of: 4-min animated cartoon video (I1), parental presence (I2), or a video plus parental presence (I3). The primary study goal was to compare the effect of video distraction, parental presence, or combination of both on the preoperative anxiety reduction. | I1: 13         | I2: 13       | X               | All groups showed similar effect on the preoperative anxiety and none of them significantly reduced emergence delirium. |
| Rodriguez       | 2019 | Video distraction using varying screen size: Watching a movie in the preoperative area and through the induction of anesthesia. Patients chose | I1: 29.16%     | I2: 30.8%    | X               | The video distractions decreased the preoperative anxiety, regardless of the size, with parental presence at induction of anesthesia. No effect |
from one of 5 preselected age-appropriate movies using either a large bedside screen (I1) or a small tablet (I2). One parent accompanied a patient. The average time spent was 3.8 min (I1) and 4.5 min (I2). The primary study goal was to compare the effect of video distractions in different screen sizes on anxiety reduction.

| Study | Description | Video Intervention | Comparison | Results |
|-------|-------------|--------------------|------------|---------|
| Waszynski 2018 [42] | Simulated family presence and nature scene: Two types of video intervention for when agitation is present and the family is not: watching a one minute family video message plus usual care(I1) or watching a one minute nature video plus usual care(I2). The study goal was to examine the effect of family video message on agitation level. | I: M=11.06, SD=3.97 | C: M=10.25, SD=4.81 (p=.30) | The intervention significantly reduced anxiety. Yet the results did not reveal statistically significant difference in emergence delirium scores. |
| Dwairej 2019 [35] | Video game distraction and anesthesia mask practice: Combination of video distraction using a handheld video game (1-2 minute) before the transfer to operation room, anesthesia mask exposure, and shaping intervention. During anesthesia induction, parental presence is allowed but not standardized. In OR, nonmedical talks to distract the child. The study goal was to evaluate the effectiveness of the intervention on the preoperative anxiety. | I: 7.0(5.0-9.0) | C: 6.0(5.0-9.0) (p=.266) | The intervention did not have a beneficial effect on anxiety, pain, emergence delirium or parental anxiety. |
| VR (3) – Information / distraction | | | | |
| Eijlers 2019 [36] | Virtual Reality Exposure (VRE): Provision of a 15-minute highly immersive virtual reality experience of the operating theatre to get familiarized with the environment and general anesthesia procedures. The virtual environment was computer-generated, interactive and child friendly. | I: 16 (39%) | C: 14 (36%) (p=.773) | The intervention did not reduce the incidence and severity of emergence delirium, although it was effective in alleviating preoperative anxiety in children. |
| Ryu 2019 [37] | Preoperative immersive virtual reality tour of operating theater: Provision of a 4-minute virtual reality video for pediatric showing the operating theater and explaining the perioperative process using a popular animal character as a patient. The intervention was provided 1 hour prior to entering OR. The study goal was to examine the effect of the intervention on reducing the preoperative anxiety. | I: 0 (0%) | - X | |
| Suvajdzic 2019 [56] | Patient-centered VR system: Intervention consisting of two sessions (session 2 was hold at least 24 hours after session 1): i) a video instructing patients to enjoy the movie by moving their head to look around, followed by a 5-10- minute guided meditation in virtual nature scenes for breath control (Relax VR), ii) playing either Relax VR or fishing game (Bait!). | I: 0 (0%) | - X | The interventions did not result in clinically significant changes in pain, sleep, or vital signs. It seems likely that greater exposure to VR is more likely to produce a meaningful effect on patient physiology and sleep quality. |
| Sleep-aids (2) | | | | |
| Demoule 2017 [43] | Earplugs and eye masks: Use of earplugs and eye masks every night between 10 pm and 8 am from inclusion until ICU discharge (average 7 days). The study | I: 2 (7%) | C: 2 (6%) (p=1) | Interventions resulted in reduced long awakenings and increased deep sleep duration. Possibly the effect was at least partially |

Interventions resulted in reduced long awakenings and increased deep sleep duration. Possibly the effect was at least partially
goal was to evaluate the impact of the intervention on sleep architecture in ICU patients.

countered by the discomfort of wearing the devices.

**Van de Pol 2017**

| Nocurnal sound-reduction protocol: A protocol focusing on reducing noise in the night e.g., speaking and laughing quietly in the lobby, minimizing alarm volume, closing the door when the patient is not delirious, and providing earplugs at night. One-month of implementation phase. | Slope of delirium incidence | The protocol reduced the incidence of delirium. It significantly reduced delirium risk factors such as perceived nighttime noise and the use of sleep medication. Reported sleep quality was not improved. |
|---|---|---|
| I: -2.79% (p=0.02) | O | O |
| C: 0.91% (p=0.37) | | |
| Difference: -3.70% per time period (p=0.2) | | |

**Communication aids (2)**

**Garry 2016**

| Eye-tracking devices: Usage sessions (45min/session, 5 sessions on consecutive weekdays) were given, during which patients were prompted to spell out notes, to indicate their needs via picture sets and to play simple memory games. Patients were permitted to communicate with family, nursing staff and physicians outside the training sessions. | Day1:4 (33%) | The use of eye-tracking device positively affected patients’ happiness and ability to participate, yet did not show a significantly effect on patients’ confusion level or frustration. |
|---|---|---|
| Day2:1 (8%) | | |
| Day3/award | 0 | |

**Bott 2019**

| Bedside digital care coach avatar: 24-hour psychosocial and health care support through an embodied conversational agent (ECA) with an appearance of animated animal avatar. It checks patient status, assists communication, and offers psychological support during their stay at medical and surgical units (3-6 days). The average time spent with the ECA was 61 min per day. | I: pre12(41%)/post1(3%) | The use of the care coach avatar during hospitalization can reduce frequency of delirium, loneliness and falls among diverse hospitalized older adults. |
|---|---|---|
| C: 0 | O | O |

**Others (2)**

**Lin 2018**

| Eyepatch for visual preconditioning: Preventive treatment for pediatric patients undergoing ophthalmic surgery consisted of covering the eye with an eyepatch for at least 3 hours one day before surgery. | I:15 (16.9%) | The intervention significantly reduced preoperative anxiety and emergence delirium. Preoperative anxiety was found to be an independent risk factor of emergence delirium. |
|---|---|---|
| C:40 (44.4%) | O | O |
| (p<0.001) | | |

**Giraud 2016**

| Structured mirrors intervention: Protocol-driven mirrors intervention consisting of different mirrors to provide visual feedback about the environment, as reorientation tool, and to support self-awareness and explanation of medical/nursing procedures. The unit of randomization was a 2-week time period cluster. | I:20 (17%) | Use of the mirror intervention did not reduce delirium, but improved factual memory encoding. |
|---|---|---|
| C:17 (16%) | X | O |
| (p=0.705) | | (p=0.401) |

**Multi-component (5)**

**Arbabi 2018**

| Environmental changes and Liaison education: Environment with proper time cues, appropriate lighting for the time of the day during ICU stay (average about 5 days). Next to that allowing interactions with family members and medical staff, giving vision and hearing aids, preventing dehydration, and encouraging early mobilization. Training for medical staff on delirium management. | I: 30 (37.97%) | Multifactorial intervention (educational and environmental changes) was effective on reducing delirium rate in ICU and the duration of delirium. |
|---|---|---|
| I:26.18±3 | 5.38 | |
| C: 50 (72.46%) | C:35.84±3 | - |
| 9.31 | (p=0.001) | |
| (p=.01) | | |

**Tovar 2016**

| Environment with reduced environmental stressors: Nursing care guide to reduce environmental stressors such as noise and continuous | I: 3 (6.12%) | Multicomponent intervention focusing on reducing precipitating environmental factors was effective on |
|---|---|---|
| O | - | - |

https://preprints.jmir.org/preprint/26079 [unpublished, peer-reviewed preprint]
artificial light. Provision of active interactions with family members and medical staff, cognitive/sensory stimuli, and information about the environment. The post-test was performed after the guideline had been applied for five days.

| Rhosechii 2016 [23] | Nonpharmacological protocol: Nursing education bundled into the protocol consisting of Music, Opening blinds, Reorientation & Cognitive stimulation, Eye and Ear protocol (MORE) during ICU stay (Median 188.3 hours-control group, and 153.5 hours-intervention group). | I: 24 (9.4%) | I:16h (8-24) | C: 36 (15.7%) | C:20h (9.5-37) | O | The protocol reduced both duration and incidence of delirium. |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------------|---------------|----------------|---|------------------------------------------------------------------|
| Mitchell 2017 [46] | Multicomponent family delivered intervention: Family intervention consisting of orientation (memory clues: family pictures etc.), therapeutic engagement (cognitive stimulation: discussing current family life events etc.), and sensory (glasses, hearing aids in place/working). The intervention group was enrolled for median five days and the family members were asked to deliver the intervention at least once a day. The study goal was to access the feasibility and acceptability of the intervention for a designing a larger RCT. | I: 17 (59%) | I: 1.0 (2) | C: 18 (56%) | C: 1.0 (2) | X | Multicomponent family delivered intervention was not effective on reducing delirium incidence nor days of delirium. |
| Zachary 2020 [58] | Hospital Elder Life Program interventions (HELP): Geriatric intervention program consisting of reorientation, social stimulation, music therapy, games, mindfulness relaxation, mobilization, visual/hearing aids, sleep aids and nutrition support. Volunteer interventions were three times a day, took 20-30 min each time. | - | - | O | HELP reduced 30-day readmissions and hospital length of stay in the 70-85 age group. |

Abbreviations: ICU, Intensive Care Unit; LOS, Length of Stay; PACU, Post Anesthesia Care Unit; VR, Virtual Reality.

a Intervention group; b Control group; ' Direct effects: incidence and duration of delirium; ' Indirect effects: LOS, or delirium risk factors including but not limited to pain, anxiety, stress, mood, agitation and sleep deprivation.

Of the 31 identified studies, 23 studies analyzed the effect of the interventions on direct delirium-related outcome measures (incidence and duration of delirium). The other eight studies only assessed indirect outcome measures (e.g., LOS and precipitating risk factors of delirium such as anxiety).

Of the 23 studies that evaluated direct delirium-related outcome measures, nine studies showed a significant effect on decreasing incidence and/or frequency of delirium. The interventions in these studies involved diverse technologies across the categories: audio [32,48], light [41], sleep-aids [19], communication support [21], others [45], and multicomponent [23,50,51]. Of the 14 studies without significant effect direct outcome measures, 8 studies however show significant effects on delirium risk factors or symptoms including pain [39], anxiety [34,35,37,49], agitation [53], hallucination [53] and factual memory encoding [7].

Six of the eight studies using diverse technology-based interventions showed a significant effect on indirect outcome measures including anxiety [38], agitation [42], sleep deprivation [43], or ICU
readmission [58]. The technologies used in these studies were: audio [38,47,54], video/video game [42], sleep-aids [43] and multicomponent [58].

It is notable that across all technology categories, significant positive effects were found on direct and/or indirect delirium outcome measures. An explanation and further analysis of each category will follow.

a) Audio

The interventions using audio used either music or pre-recorded voice message. Music interventions involved, in general, slow tempo music with a duration between 20 minutes to 1 hour. The music was provided two or three times a day using a television audio system or headset. These interventions aimed at addressing anxiety [38,52], mood [54], pain [39,52], and engagement [54] for adult patients. Across these interventions, we found differences in the level of personalization and autonomy: the level of personalization varied from the provision of music pre-selected by a music expert, to the creation of a music playlist based on a patient’s own choice; the level of autonomy ranged from patients listening to music with dose and frequency pre-decided by a researcher, to patients deciding on dose and frequency. Interestingly, delirium incidence was reduced in the study with personalized music allowing patients autonomy [52]. While the majority of studies used a passive format, such as music listening, one study used a participatory format providing an interactive music therapy, and showed significant improvement in mood and engagement [54].

Pre-recorded voice messages contained mainly patient’s name and information about the care environment using either a familiar or unfamiliar voice. These interventions aimed to provide reorientation and a feeling of comfort. Two studies were carried out with different patient age groups: one with pediatric and the other with adult patients. The use of a pre-recorded voice message reduced direct delirium outcome in both groups [32,48]. Likewise, one of the studies showed that a familiar voice was more effective than an unfamiliar one [48].

b) Light

The interventions involving light used either a specially made light therapy system for dynamic/bright light or natural light through windows. Dynamic light interventions provided light consisting of diverse intensities (ranging from 50 Lux to 4000 Lux) and color temperatures (ranging from 2700 K to 6550 K) in the environment of patients [40,57,59]. The bright light intervention used high intensity of light (5000 Lux) for two hours a day [41] while the natural light intervention used natural light coming through windows [53]. All studies aimed at improving the patients’ circadian rhythm and were only tested on adult patients. Only the bright light intervention showed an effect on reducing incidence of delirium [41]. Possibly, most of the current light interventions are not effective in reducing direct delirium outcomes. Another possible explanation for why few studies found an effect on reducing incidence of delirium might relate to the amount of light (intervention) that patients actually received. In most studies, for example, the actual light intensity at patients’ eye level was not specified and/or the definite exposure time to light of each patient was not guaranteed as sedative patients were included that had their eyes closed [53,57,59].

c) Video/Video game

The interventions using video/video game were used for providing either information about the medical procedure prior to a surgery, or distractions with various contents including age-appropriate programs (e.g., cartoons), family messages or nature scenes through a handheld tablet or a specially made bedside screen. These interventions aimed to address anxiety or agitation and were effective in decreasing anxiety or agitation in all studies with either pediatric or adult patients [33–35,42,49]. Regarding direct delirium outcome measures, none of the studies showed a significant effect [33–
The interventions using VR technology provided either information about medical procedures, distraction, or sensory stimulation for patients. VR interventions used a head-mounted device and the VR content varied from a guided tour to the operating theatre, to the virtual scenes of real-world locations. The interventions were mainly used to address anxiety and/or to support restorative effect for both pediatric and adult patients [36,37,56]. The effects of using VR to provide information (a preoperative VR tour to the operating theatre) differed in the studies. Of two, one study showed a significant effect on reducing anxiety of pediatric patients [37]. For none of these studies, the use of VR resulted in any effect on delirium-related outcome measures [36,37,56].

e) Sleep-aids
The interventions related to sleep-aids were: wearable devices such as earplugs and eye masks [19,43], and environmental modifications such as closing doors and window blinds were applied [19]. They aimed at reducing noise and light during nighttime to improve sleep quality for adult patients. The application of both wearables and environmental modifications showed an effect on reducing incidence of delirium [19]. Next, the use of a wearable also showed an improvement in sleep quality [43]. It is notable that this study also highlights potential negative side-effects of using wearables on vulnerable patients due to experiencing discomfort.

f) Communication supports
The technologies used for communication supports were a conversational agent [21] and eye-tracking device [55]. They assisted adult patients to express their needs and/or to participate in psychosocial activities. Both types improved psychological well-being of patients by increasing happiness, ability to participate and by reducing loneliness. The conversational agent was used as a digital care coach providing communication means, human interaction, and companionship. This intervention reduced the frequency of delirium [21].

g) Others
In this category, we found rather simple forms of technologies used for diverse purposes: an eyepatch for experiencing what will happen after surgery [45], and a structured mirror to provide patients cognitive stimuli as a means to support mobilization and communication [44]. The eyepatch was used for pediatric patients and was effective in reducing emergence delirium [45]. The structured mirror intervention was for adult patients and improved their factual memory encoding [44].
h) Multi-component
Some interventions involved more than one technology as part of a non-pharmacological bundle for adult patients. Environmental modifications for noise reduction, cognitive stimulation, and reorientation reduced delirium incidences in three studies [23,50,51]. Zachary et al. (2020) had a similar focus and showed an effect on reducing 30-day readmission. In a small feasibility study, no significant effect was found on direct delirium outcome measures for the simple technology-based intervention involving family throughout different therapies such as orientation and cognitive stimulation [46].

Seven pathways to delirium prevention
14 strategies to prevent delirium were identified from the technology-based interventions of the included studies (See Table 4, See Table 5 for full description of 14 strategies).
Table 4 14 strategies used in the included technology-based interventions (0 – if a strategy is used)

| Strategy being explicitly mentioned by authors | Strategy being used but not explicitly mentioned by authors | Interpretation of strategy was made: activating physiological reaction (author’s words) -> soothing elements |
|-----------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| 1. Cognitive stimulation & training           |                                                         |                                                                                                   |
| 2. Companionship                              |                                                         |                                                                                                   |
| 3. Contextual cue (Reorientation)             |                                                         |                                                                                                   |
| 4. Daytime awakening                          |                                                         |                                                                                                   |
| 5. Distraction                                |                                                         |                                                                                                   |
| 6. Early mobilization                         |                                                         |                                                                                                   |
| 7. Easier communication                       |                                                         |                                                                                                   |
| 8. Engagement                                 |                                                         |                                                                                                   |
| 9. Familiarity                                |                                                         |                                                                                                   |
| 10. Good night sleep                          |                                                         |                                                                                                   |
| 11. Human interaction                         |                                                         |                                                                                                   |
| 12. Personalization                           |                                                         |                                                                                                   |
| 13. Psychological preparation                |                                                         |                                                                                                   |
| 14. Soothing Elements                         |                                                         |                                                                                                   |

| Reference                             | Use (O) | Reference                             | Use (O) | Reference                             | Use (O) | Reference                             | Use (O) | Reference                             | Use (O) |
|----------------------------------------|---------|----------------------------------------|---------|----------------------------------------|---------|----------------------------------------|---------|----------------------------------------|---------|
| Munro 2017[48]                         | O       | Potharajaroen 2018[41]                 | O       | Simons 2019[53]                        | O       | Van de Pol 2017[19]                   | O       | Van de Pol 2017[19]                   | O       |
| Potharajaroen 2018[56]                 | O       | Wazynski 2018[42]                     | O       | Wazynski 2018[42]                     | O       | Suvajdizic 2019[35]                   | O       | Suvajdizic 2019[35]                   | O       |
| Lee 2016[49]                           | O       | Rodríguez 2019[34]                    | O       | Dwarej 2019[35]                       | O       | Ryu 2019[37]                          | O       | Ryu 2019[37]                          | O       |
| Lee 2016[39]                           | O       | Estrup 2018[57]                       | O       | Estrup 2018[57]                      | O       | Eijlers 2019[36]                     | O       | Eijlers 2019[36]                     | O       |
| Lee 2016[39]                           | O       | Pustjens 2018[59]                    | O       | Pustjens 2018[59]                    | O       | Lee 2016[49]                         | O       | Lee 2016[49]                         | O       |
| Dubshens 2018[39]                      | O       | Johnson 2018[47]                     | O       | Johnson 2018[47]                     | O       | Kim 2015[33]                         | O       | Kim 2015[33]                         | O       |
| Kim 2015[33]                           | O       | Arbabi 2018[50]                      | O       | Arbabi 2018[50]                      | O       | Lin 2018[45]                         | O       | Lin 2018[45]                         | O       |
| Lin 2018[45]                           | O       | Bott 2019[21]                        | O       | Bott 2019[21]                        | O       | Giraud 2016[44]                      | O       | Giraud 2016[44]                      | O       |
| Giraud 2016[44]                        | O       | Tovar 2016[51]                       | O       | Tovar 2016[51]                       | O       | Mitchell 2017[46]                    | O       | Mitchell 2017[46]                    | O       |
| Mitchell 2017[46]                      | O       | Tovar 2016[51]                       | O       | Tovar 2016[51]                       | O       | Zachary 2020[58]                     | O       | Zachary 2020[58]                     | O       |
| Zachary 2020[58]                       | O       | Tovar 2016[51]                       | O       | Tovar 2016[51]                       | O       | Ryu 2019[37]                         | O       | Ryu 2019[37]                         | O       |
| Ryu 2019[37]                           | O       | Van de Pol 2017[19]                  | O       | Van de Pol 2017[19]                  | O       | Garry 2016[55]                       | O       | Garry 2016[55]                       | O       |
| Garry 2016[55]                         | O       | Bott 2019[21]                        | O       | Bott 2019[21]                        | O       | Giraud 2016[44]                      | O       | Giraud 2016[44]                      | O       |
| Bott 2019[21]                          | O       | Lin 2018[45]                         | O       | Lin 2018[45]                         | O       | Garry 2016[55]                       | O       | Garry 2016[55]                       | O       |

**a**Strategy being explicitly mentioned by authors  
**b**Strategy being used but not explicitly mentioned by authors  
**c**Interpretation of strategy was made: activating physiological reaction (author’s words) -> soothing elements
### Table 5  Descriptions of the 14 Strategies

| Strategy                  | Explanation                                                                 | Example                      |
|---------------------------|-----------------------------------------------------------------------------|------------------------------|
| 1  Cognitive Stimulation & Training | Stimulating patient’s brain activity to maintain and improve their cognitive capability and executive functions such as attention, memory, reasoning, and language. | Music, book                  |
| 2  Companionship          | Providing patients a sense of consistent social presence as a means to combat social isolation and loneliness. | Digital agent                |
| 3  Contextual Cue (Reorientation) | Providing patients contextual information such as time, date, and place to minimize confusion and anxiety coming from not knowing what’s going on and feeling lost. | Automated voice message, clock |
| 4  Daytime Awakening      | Supporting patients to stay physically and mentally activated during day so they can become tired enough to sleep at night. | Dynamic light                |
| 5  Distraction            | Redirecting patient’s focus away from distressing situation/condition such as pain, discomfort, fear and anxiety. | Music, video, VR             |
| 6  Early Mobilization     | Encouraging patients to move their body early enough to prevent muscle loss and other complications caused by lack of physical movement. | Structured mirror            |
| 7  Easier Communication   | Providing a means for patients to better express their needs especially when they are mechanically ventilated. | Eye-tracking device          |
| 8  Engagement             | Encouraging patients to be interested in and to be involved with what is happening. | Participatory music therapy   |
| 9  Familiarity            | Providing something that patients feel familiar with to help them feel safe, at ease and calm. | Mother’s voice, personalized music list |
| 10 Good Night Sleep       | Providing an environment that facilitates sleeping by removing disturbing elements such as sound and light noise, and by adding elements enhancing patient comfort and relaxation. | Earplugs                     |
| 11 Human Interaction (Social) | Providing patients warm human-like interactions to stimulate them socially and to help them feel being involved and being cared for. | Digital agent                |
| 12 Personalization        | Providing an option that reflecting patient’s preference. | Personalized music list      |
| 13 Psychological Preparation | Helping patients to feel prepared and confident by informing them what will happen in advance. | Virtual tour to the operation room |
| 14 Soothing Elements      | Helping patients to calm down and to manage stress and anxiety by providing an activity or environment that is soothing | Music, nature video          |

Subsequently, 14 strategies were clustered into seven pathways using a thematic analysis approach (See Figure 2). As such, the seven pathways might provide directions towards technology-based intervention(s) for delirium prevention.

The seven pathways and a short description of each pathway are:

1) **Restore the Circadian Rhythm** - helping patients to find a normal sleep-wake cycle to prevent sleep deprivation.
2) **Activate the Body** - supporting patients to regain physical strength and endurance.
3) **Activate the Mind** - supporting patients to prevent cognitive decline, to restore cognitive function, and also to minimize confusion, which can cause negative emotions such as anxiety, agitation and...
aggression.

4) Induce Relaxation - helping patients to stay in a positive psychological state, which prevents emotional distress, makes it easier to cope with their situation, and improves the patients’ physical state (e.g., through better sleep).

5) Provide a Sense of Security - supporting patients to feel reassured and safe so they can easily handle stress and emotional distress such as anxiety and fear that originate mainly from uncertainty and unfamiliarity.

6) Provide a Sense of Control - supporting patients by enhancing autonomy, empowerment and control over anxiety.

7) Provide a Sense of Being Connected - supporting patients to feel connected and socially engaged to prevent loneliness, depression and anxiety.

Three of the seven pathways outlined above—*Restore the Circadian Rhythm, Activate the Body, and Activate the Mind*—are in line with strategies recommended in the ABCDEF bundle [16]. The other pathways are not directly linked, yet are associated with important predictors of well-being used in psychology; *Induce Relaxation* links to coping strategies [60], and *Provide a sense of Security, Control, and Being Connected* are related to the universal psychological needs which are security [61], dominance [62] and relatedness [61]. The seven pathways therefore cover a broad range of delirium prevention strategies correlating physical, cognitive and emotional aspects as Figure 2 shows.
Discussion

The results of this review provided an overview and characteristics of technology-based interventions that have been used to prevent and reduce delirium. We also summarized the related strategies into seven pathways. These seven pathways include key elements for developing technology-based intervention for delirium prevention. From our analysis of the included studies and technologies, we next discuss limitations and opportunities for future research.

Limitations in the current technology use for preventing delirium

First, most technology-based interventions addressed only one or a few delirium risk factor(s). For instance, interventions that used a dynamic light system [40,59] aim to improve the patients sleep-wake cycle while interventions including video distraction [33,34,42] aimed to reduce anxiety of patients. Such approaches are not in line with the frequently recommended multicomponent approach, which effectively targets the multifactorial origin of delirium [15].

Second, most technology-based interventions were more momentary than continuous solutions. Although the length of stay in the ICU should be kept as short as possible, it can last from days to weeks. During this period, depending on the severity of their illness, patients are going through various clinical and emotional phases, and their needs are changing respectively. During various
activities (e.g., clinical checkup, therapy session, cleaning, resting and family visit), patients can experience diverse feelings (e.g., anxiety, fear, tiredness, worrying, relaxed and cheerful), and have different corresponding needs. In contrast to the heterogeneity of activities and patients’ needs throughout their ICU stay, the majority of included studies focused on a short period of time. For instance, the video and video game interventions were usually planned for less than 5 minutes [33–35,42,49], and the VR interventions were used for less than 15 minutes [36,37,56]. In order to minimize delirium risk factors, it is important to understand needs and concerns of patients throughout their whole ICU stay, and to develop preventive solutions that are more continuous and seamless. Importantly, knowledge as how to develop and implement a continuous solution throughout the ICU stay of patients is missing as none of the reviewed studies evaluated it.

Third, only a limited number of studies focused on the use of technology for improving the patients’ environment. Despite the negative influences of the stressors in the current ICU environment, such as overload of light and noise [63,64] on patients’ clinical progress, only a few studies [40,50,51,57,59] aim at optimizing the ICU environment. In contrast, most technologies used as interventions added extra sensory burden to the patients.

Last, the effect of some technologies can be improved by a more thorough understanding of (vulnerable) patients and context-dependent needs. Understanding the patient’s needs is crucial for delivering high quality care. However, sometimes the implementation of technology can be challenging and might result in a suboptimal match with the patients and context. For instance, in the study of bright light therapy, patients were sedated and had their eyes closed and this resulted in an insufficient amount of light exposure [40]. A use of wearable sleep-aid devices (earplugs and eye masks) on ICU patients can lead to potential discomfort limiting the effectiveness of the intervention [43].

**Further development of technology-based intervention for preventing delirium**

Despite limitations of current technology-based interventions, the potential of technology in delirium prevention is promising [20]. Reflecting on the identified limitations, the following recommendations are proposed for the future design and development of technology-based intervention for delirium prevention.

First of all, technology should not only support physical and cognitive functions but also support psychological and emotional needs. In the analysis, the proposed seven pathways described existing approaches for delirium prevention which cover multifaceted needs of patients. Yet, comparing the number of related strategies and studies included in each pathway, it is notable that in general, there are far more technology-based interventions aiming to support functions than to support needs. To take a more comprehensive approach, further development of technologies should aim at meeting patients’ needs by, for instance, providing a means to allow them more control over their situation, feel relaxed, safe and/or connected. Some examples are; an interaction device to enable ventilated patients to easily express their needs using gestures [65], a robotic pet that lets patient cuddle and helps them feel calm [66], or an intelligent alarm system contributing to a relaxing environment for ICU patients by controlling and harmonizing alarm sounds [67]. Another way to meet patients’ emotional and psychological needs can be found in the provision of (multi-)sensorial and cognitive stimuli. For instance, aromatherapy can be a way to support patients to feel relaxed through sensorial stimuli combining pleasant tactile pressure and aromatic fragrance [68]. For the stimuli, using nature
elements can be an interesting candidate as exemplified by previous cases [42,56] and other applications, examples are a VR therapy showing various nature sceneries [69], and a geriatric care environment adapting nature elements [70] to generate relaxation [69,70], increase social engagement and reduce restlessness [70].

Secondly, technology could create a healing environment for patients: a more context-aware, personalized and adaptive ICU. Despite emerging interest in patient-centered care, the review showed that such interactive technology is rare in the current ICU environment. Patient-centered care recognizes a patient as a unique individual and stresses the importance of care tailored to patients’ specific preferences, needs and values [71–73]. In order to better adapt patient-centered care, technology should be evolved in a way that: 1) it allows patients to take a more active role in their care process, for instance, by enabling them to be explicit about their specific needs, and 2) enables a care environment and service system to provide real-time interventions adapted to the patients’ profiles and their changing status/needs. Advances in technologies have made this feasible. Next to the modified ICU room [17] and the conversational agent [18] described in the introduction, the intelligent ICU concept enables autonomous monitoring of patients and the ICU environment over time using pervasive sensing [74]. Previously we pointed out that there were too few technologies aiming at improving patients’ environment despite its significant influence on patients. Luetz et al (2019) emphasized the potential of environment-related innovations, arguing that the ICU should be considered as a treatment tool [20]. In order to design a healing environment, future technology-based interventions should reinforce the main ingredients of patient-centered care: context-awareness, personalization and adaptability.

**Study limitations**

This study has some limitations. First, the review was conducted between 2015 and 2020 to focus on state-of-the-art technologies used for preventing and reducing delirium. Therefore, some technologies, which might have been introduced in the studies published before 2015 and have not been studied since then, were not included in this review.

Second, the search strategy made use of the combination of keywords describing different types of technologies and not the keyword ‘technology’ as this was not widely used in literature on delirium prevention and reduction. Although we tried to cover all the existing technology-related keywords, this search strategy might have left out some very rare types of technologies.

Third, the seven pathways were made based on the included studies only. Therefore, some approaches and strategies from the studies which did not meet our criteria were not included such as approaches and strategies related to pharmacological interventions or delirium detection only.

**Conclusions**

In this review, we provided an overview of technology-based interventions and proposed the seven pathways to delirium prevention based on evidence-based studies. These insights can be considered as starting points for transforming ICU’s into a healing environment, which might be well one of the most powerful non-pharmacological technology-based interventions for preventing delirium. Further research should generate a more in-depth and complete understanding of key components of a healing environment for patients, and on designing and developing technologies that can actualize it.
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Competing interests

None declared.

Abbreviations

ICU: Intensive Care Unit  
LOS: Length of Stay  
VR: Virtual Reality

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Supplementary Files
Figures
Flow diagram of study selection.

1299 Records identified in databases
- 1034 Scopus
- 265 EMBASE

6 Records identified through other sources

1058 Records after duplicates removed

1058 Records in title/abstract screen

991 Excluded for not meeting eligibility criteria

36 Excluded for:
- 13 were not original research
- 6 did not involve technology
- 4 with technologies not addressing patients
- 5 were not focusing on delirium as a study variable
- 3 were not about a hospital environment
- 2 were not conducted with patients
- 1 missed information about technology
- 1 were only about delirium monitoring
- 1 did not contain any measurable outcome

67 Potentially relevant articles for full-text review

31 Articles included in review
Overview of the 14 strategies grouped into seven pathways of delirium prevention, that are used in the technology-based interventions.
Multimedia Appendixes
Search strategy.
URL: http://asset.jmir.pub/assets/a2bfb051983ca21f66861c111fe92091.pdf

Quality assessment.
URL: http://asset.jmir.pub/assets/00f2dea078a5a10cd879e7a53bc47cbd.pdf

PRISMA-ScR checklist.
URL: http://asset.jmir.pub/assets/ced8f7649b5a91168ed55c56dde591d2.pdf
TOC/Feature image for homepages
