

The Use of Music and Virtual Reality in Health Contexts: A Scoping Review

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Abstract

The integration of virtual reality (VR) and music is gaining attention in therapeutic and rehabilitative fields for its potential role in health-related interventions. This scoping review maps how music and VR have been combined across health contexts. Using databases such as PubMed and Scopus, peer-reviewed studies published between January 2009 and 15 February 2024 were analyzed following established review reporting procedures. Forty-five studies were reviewed, covering diverse patient populations, including those with neurological impairments and emotional disorders. The mapped literature reports outcomes related to patient engagement, motor function, stress reduction, emotional satisfaction, feasibility, and usability. However, because intervention methods and patient needs vary, and because the included studies are heterogeneous in design, population, and outcome measures, the findings should be interpreted as evidence mapping rather than definitive evidence of clinical effectiveness. By mapping the current evidence, this review may support future research and clinical practice by helping to refine VR and music interventions for specific health contexts, patient populations, and therapeutic goals.

Keywords: virtual reality; music-based interventions; health contexts; scoping review

1. Introduction

An increasing number of individuals are affected by neurological disorders according to the Global Burden of Disease Study [1]. Specifically, more than three billion individuals globally are affected by neurological disorders, among which the most prevalent include stroke, migraine, Alzheimer's disease, tension-type headache, and others. Neurological disorders may result from damage to, or disease affecting, the central nervous system. These neurological conditions may cause motor, sensory, cognitive impairment and may also impact patient behavior, leading to prolonged rehabilitation programs with multifaceted tasks [2].

The neurorehabilitation process involves both medical based interventions and non-pharmacological approaches [3]. All the aforementioned diseases have an impact on the quality of life of patients. Recently, to tackle this issue, there has been a growing emphasis on non-pharmacological approaches, such as music therapy and virtual reality which are frequently utilized as complementary treatment for individuals with neurological disorders such as cognitive and motion impairments.



Academic Editor: Paolo Bellavista

Received: 17 June 2026

Revised: 27 July 2026

Accepted: 28 July 2026

Published: 31 July 2026

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The beneficial effect of musical intervention on behavior, cognitive psychosocial domains, and in neurological disorders, stems from researchers' findings that music triggers neural processes [4]. Music is a structured sound that contributes to neural plasticity and strengthens neural connections by stimulating sensory, cognitive, motor, and emotional centers in the human brain. [5].

Music therapy is defined by the American Music Therapy Association (AMTA) as *"the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program"* [6]. The World Federation of Music Therapy (WFMT) further describes it as *"the professional use of music and its elements as an intervention in medical, educational, and everyday environments with individuals, groups, families, or communities who seek to optimize their quality of life and improve their physical, social, communicative, emotional, intellectual, and spiritual health and wellbeing"* [7]. Overall, both definitions highlight the broad scope of music therapy, which can facilitate stress reduction, enhancement of communication, emotional expression, and improvement of quality of life. Moreover it can alleviate pain, promote physical rehabilitation, support in neurodegenerative diseases such as Alzheimer.

A specific approach, known as Neurologic Music Therapy (NMT) consists of twenty evidence-based techniques for neurologic rehabilitation. According to the handbook of neurologic music therapy, music is an organized "auditory language" which engages different brain functions as perception, cognition, motor and it can be utilized for retraining of brain injury [8].

Virtual Reality (VR) has developed into a groundbreaking technology. Many studies try to investigate the effects of VR on patients and as a diagnosis tool [9]. VR refers to a computer-generated environment that reproduces or simulates aspects of real-world locations or situations through visual, auditory, and sometimes other sensory inputs. By employing specialized electronic equipment, users are able to interact with this immersive environment in a manner that gives the impression of physical presence and engagement [10,11]. The two types of existing VR are immersive and non-immersive, using different equipment for simulation.

For non-immersive experience, visual display with computer or game consoles may be used and also peripheral inputs such as keyboards, mice and controllers for the game [12]. In immersive VR experience participants have the opportunity to engage with their surroundings through sensory stimuli and physical movements. Equipment used in immersive VR is virtual headsets or head mounted displays. In order to create a realistic environment, visual, auditory stimuli and occasionally tactile methods were used in the literature [12–14]. In VR users are engaged in a simulated environment whereas Augmented Reality (AR) adds virtual elements like images, text, sound, and graphics onto the user's real-world both visual and auditory experience [15,16]. According to studies, VR seems to be used for therapeutic purposes and has an impact on similar health conditions as music therapy. Specifically, it was used for pain management, mental health, stroke rehabilitation, fatigue, and other health-related applications [14,17,18].

Recent developments in music therapy research highlight the growing integration of technology into rehabilitation practices. The Nordic Journal of Music Therapy's special issue on Technology and Arts in Rehabilitation (2025) showcases advances such as digital instruments, immersive virtual and extended reality, biofeedback systems, and assistive technologies. These innovations expand opportunities for creative expression and active participation, while also fostering neuroplastic changes, encouraging interdisciplinary approaches, and broadening opportunities for recovery and client participation [19–22]. The interest of utilizing music interventions in different health conditions and the proliferation of technology leads to the use of technology-based music interventions [23,24]. Indeed,

there is an ever-increasing number of research studies using VR and music interventions in rehabilitation process and their results are promising. Consequently, this study aims to map the literature on the combined use of virtual technologies with music-based components in rehabilitation and broader health-related contexts. The present scoping review identifies the types of interventions, technical configurations, application areas, outcome domains, and evidence gaps reported in the existing literature. This framing is particularly appropriate for an emerging and heterogeneous research area in which populations, technologies, intervention functions, and outcomes vary substantially across studies.

The rest of this paper is organized as follows: Section 2 reviews related research relevant to the present scoping review. Section 3 outlines the methodology, explains the rationale for the review, and presents the research questions. Section 4 summarizes the findings of studies and highlights the main insights of the outcomes. Section 5 offers a discussion of the challenges identified during the particular review as well as suggesting future research directions. Finally, Section 6 concludes with a summary of findings in this research.

2. State of the Art

The undeniable power of SLRs, surveys, and meta-analyses toward the research progress is reflected by the fact that several studies of this type can be found in the literature varying from health, security and environment to stock market and software applications [25–29]. As mentioned in the Introduction, during the last years, several studies investigated the potential of VR and music for rehabilitation and therapeutic purposes. For this reason, a number of representative literature reviews, surveys, and meta-analyses summarizing the effect of either VR or music within healthcare are presented in the following paragraphs.

Focusing first on the field of VR, this disruptive technology shows potential as an intervention during rehabilitation, particularly as highlighted in a systematic review that investigates its usability and effectiveness of virtual reality treatment as complementary therapy in different rehabilitation settings [30]. Similarly, a scoping review by Carroll et al. [31] identified 65 studies utilizing VR technology (including AR/VR interventions, 2D video and non-interactive environments) in older adult population with physical or cognitive impairment but also healthy participants. The VR-based interventions contributed to enhanced wellbeing by reducing anxiety and depression symptoms and further supported improvements in physical activity, balance, memory, and attention. Moreover, a recent systematic review by Li et al. [32] identified 30 studies that investigated the impact of VR-based interventions on physical and mental health of older adults residing in long-term care facilities. VR-based approaches appear promising, especially regarding their ability to deliver individualized and autonomous training. According to this review, although physical improvements were evident, outcomes related to mental health remain inconclusive. However, as highlighted in another review by Emmelkamp and Meyerbröker [33], the use of VR in mental health has expanded beyond symptom alleviation to include its use as an assessment tool across a plethora of disorders including post-traumatic stress disorder, attention deficit hyperactivity disorder, psychosis, autism spectrum disorder, substance use disorders, and eating disorders. The most robust evidence for VR interventions exists in the treatment of specific phobias, social anxiety disorder, and panic disorder with agoraphobia.

Respectively, several surveys and reviews have been performed on the implementation of music therapy in healthcare. Notably, a realist review conducted by McConnell and Porter [34] identified 51 studies, and their findings indicate the impact of music therapy on physical, psychological, emotional, and spiritual dimensions of suffering among patients receiving palliative care. Moreover, a recent review conducted by Teesa Lomax (2024) [35] suggests that the adjunctive use of music therapy alongside treatment as usual offers

short-term benefits for individuals with depression compared to treatment as usual alone. Additional positive effects were observed in anxiety reduction and functional enhancement. In the specific review, five intervention comparisons were explored for participants with depression: music therapy versus treatment as usual (TAU), music therapy and TAU compared to TAU alone, music therapy compared to other psychotherapy approaches, active music therapy compared to receptive music therapy, and music therapy compared to pharmacologic treatments. Extending previous findings on music therapy in rehabilitation, the review by Liang et al. [36] provides further evidence of its effectiveness in the context of general surgery. Specifically, music therapy was shown to reduce negative emotional states, contribute to pain relief, and promote stabilization of vital signs in preoperative, intraoperative, and postoperative nursing care.

A contribution that is particularly close to the scope of the present work is the narrative review by Danso et al. [37], which focused on the combined relevance of virtual reality and music therapy in the specific context of post-stroke neglect rehabilitation. Their review highlighted that the integration of immersive technologies with music-based therapeutic elements may offer useful opportunities for supporting rehabilitation engagement and intervention delivery in this clinical area. However, their work was intentionally limited to neglect rehabilitation and followed a narrative review design.

Another highly relevant recent contribution is the review by Tuominen and Saarni [14], which examined the use of virtual technologies with music in rehabilitation. Their work is closely aligned with the present topic because it focuses on the intersection of virtual technologies, music, and rehabilitation, and highlights this combination as an emerging area of research. In particular, their review shows that music has been combined with different virtual technologies in rehabilitation-oriented applications, including systems designed to support motor, cognitive, emotional, or engagement-related outcomes. Their contribution is therefore important for establishing the relevance of studying music and virtual technologies together, rather than as two separate intervention domains.

By summarizing the key findings from the aforementioned reviews, it is evident that VR-based and music-based interventions have often been investigated separately, while fewer reviews have focused on their combined use. Previous work has provided valuable evidence on VR interventions, music therapy, and specific combinations of virtual technologies with music in rehabilitation. In particular, Danso et al. [37] addressed the specific case of VR and music therapy in post-stroke neglect rehabilitation, while Tuominen and Saarni [14] provided a broader rehabilitation-focused review of virtual technologies with music. The present scoping review complements these contributions by extending the scope beyond rehabilitation alone and mapping a broader set of health contexts, including psychiatric and mental health applications, pain and perioperative support, cognitive and neurodevelopmental applications, feasibility and usability studies, and healthy-participant studies with health-related objectives. In addition, the present review provides a wider descriptive synthesis of intervention types, virtual technology modalities, music-related components, roles of music, participant characteristics, outcome domains, and cross-mapping patterns between health conditions, VR intervention types, and music intervention categories. Therefore, the present review aims to extend existing work by mapping how VR and music-based interventions have been combined across health contexts.

3. Materials and Methods

3.1. Data Sources and Methods

The present work follows the procedures of scoping reviews, which are suitable when the purpose is to examine the extent, range, and characteristics of evidence in a

heterogeneous or emerging field, rather than to estimate pooled intervention effects [38]. Accordingly, the aim of the present review is to map how music-based components are combined with virtual technologies in health-related contexts. The reporting of the review was informed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [39]. The completed PRISMA-ScR checklist is provided as Supplementary File S1. In addition, the study selection process was summarized using a PRISMA 2020-style flow diagram [40]. The eligibility structure was aligned with the PCC framework commonly used in scoping reviews [41]:

- i. *Population/Participants*: clinical populations, rehabilitation-related users, or healthy participants when the intervention was relevant to rehabilitation, training, therapy, or health-related outcomes.
- ii. *Concept*: combined use of VR and related virtual technologies with music-based or auditory components in health-related contexts. The review mapped two distinct dimensions: the virtual-technology modality (e.g., virtual environments, serious games, virtual videos, virtual musical instruments, AR/XR, or VR 3D audio) and the music-related component (e.g., music listening, music therapy, music production, combined listening/production, natural or environmental sounds, auditory feedback, or sonification).
- iii. *Context*: rehabilitation, neurorehabilitation, motor or cognitive training, stress or anxiety management, pain or perioperative support, neurodevelopmental applications, and related clinical, quasi-clinical, or feasibility contexts.

A comparator group was not required for inclusion because the purpose of the review was to map the available evidence rather than to synthesize comparative treatment effects. Therefore, controlled studies, uncontrolled pilot studies, feasibility studies, case studies, and healthy-participant studies were eligible when they addressed the combined use of virtual technologies and music-based interventions in a relevant health-related context.

The present scoping review addresses the following research questions:

1. In which health contexts have music and virtual reality been combined?
2. What types of virtual or immersive technologies are used in the included studies?
3. What role does music play within the virtual or immersive interventions?
4. Which outcome domains have been reported in the included studies?
5. What gaps can be identified in the existing literature?

The databases used as data sources for the present scoping review were PubMed and Scopus, which are well-established and extensively used in other reviews [26,42]. According to the eligibility criteria, articles had to be written in English. The time period was from 1 January 2009 to 15 February 2024. This decision was made because the scoping review needs to be informed about the latest advancements in this field.

3.2. Study Selection

In order to select the primary studies from the literature, the first step includes the search string selection. As stated in the work of Spanos and Angelis [26], this is an iterative process that takes into account a predetermined number of primary studies and refines the final search string with the goal of identifying the majority, if not all, of the known studies. Preliminary combinations of specific terms returned very limited records when combined. For this reason, broader core terms were retained to support the scoping objective of mapping the available literature across health contexts. Hence, the search keywords used in the titles or abstracts in the PubMed and Scopus databases for the present study were: ‘virtual’ AND ‘music’ AND (‘therapy’ OR ‘remedy’ OR ‘treatment’).

Moreover, the selection of studies based on the following eligibility criteria:

3.2.1. Inclusion Criteria

- (1) written in English
- (2) published between January 2009 and 15 February 2024
- (3) providing results (qualitative or quantitative)
- (4) combining music-based components with virtual technologies in health-related contexts

3.2.2. Exclusion Criteria

- (1) Systematic reviews and book chapters
- (2) studies that are limited to theoretical or conceptual discussions without actual implementation or outcome data
- (3) studies that included one of the two intended interventions

Title/abstract screening, full-text assessment, and data extraction were conducted by the first author and checked by the second author. Unclear cases regarding study eligibility or data charting were discussed between the two authors until consensus was reached. A total of 509 records were identified through PubMed ($n = 107$) and Scopus ($n = 402$). Before screening, 105 duplicate records were removed, leaving 404 records for title/abstract screening. During this screening stage, 231 records were excluded as not relevant to the scope of the review. The remaining 173 reports were sought for retrieval. Of these, 36 reports were not retrieved, and 137 reports were assessed for eligibility. After eligibility assessment, 92 reports were excluded for predefined reasons: reviews ($n = 24$), book chapters or webpages ($n = 10$), and studies whose interventions or results were not relevant to the review scope ($n = 58$). Finally, 45 studies were included in the review, corresponding to 45 reports of included studies. The study selection process is depicted in Figure 1.

3.3. Data Extraction and Charting Process

The data extraction and charting process included information on the year, country, source, publication type, and authors of each included study. Additional information was extracted on the study design, sample characteristics, health condition or application context, research objectives, virtual reality technology, role of music within the intervention, any additional intervention components, methodological approach, reported outcome domains, statistical measures where available, and main findings.

Consistent with the scoping-review objective, the extracted information was used to descriptively map how music and virtual reality have been combined across health contexts rather than to estimate pooled clinical effectiveness. Particular attention was given to the health context, type of virtual or immersive technology, role of music, study design, sample size, presence or absence of a control group, reported outcomes, and evidence gaps. No formal study-level risk-of-bias assessment was conducted.

3.4. Data Synthesis and Evidence Mapping

Given the breadth and heterogeneity of the included studies, a quantitative meta-analysis was not appropriate. The extracted data were therefore synthesized narratively and descriptively. Descriptive statistics, tables, and figures were used to map study characteristics, health contexts, intervention categories, virtual technology modalities, the role of music within the interventions, outcome domains, and evidence gaps. This approach is consistent with the purpose of a scoping review, which is to clarify the extent, range, and structure of an evidence base rather than to estimate a pooled effect size or determine comparative clinical effectiveness.

3.5. Tools Used for Data Analysis

Zotero was used to organize citations and studies during the selection and screening process, while Microsoft Excel was used for data extraction, descriptive statistics, and figure generation.

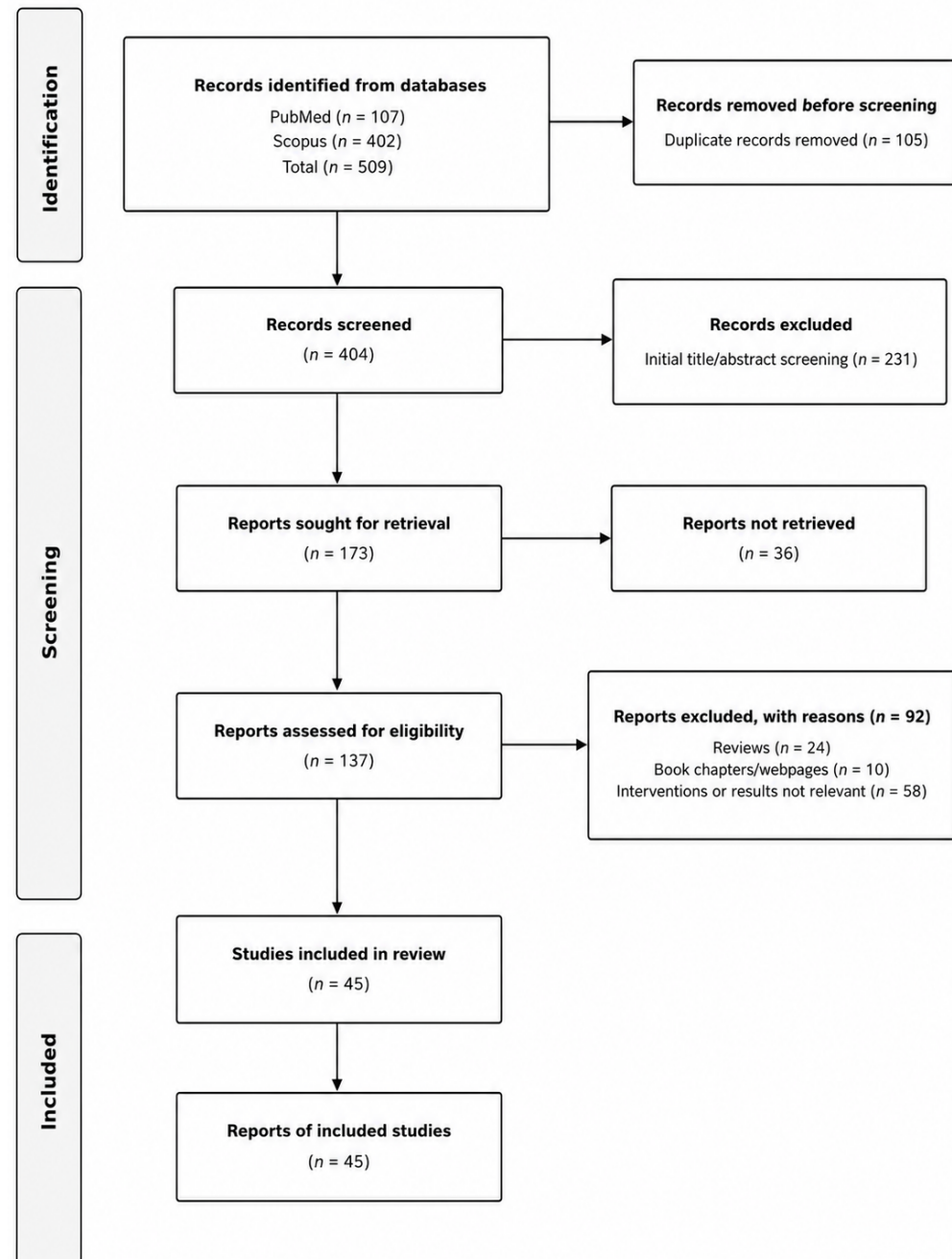


Figure 1. Study selection flow diagram.

4. Results

This section details the findings from the scoping review. Overall, 45 studies have been identified and extracted. The data extracted from the 45 studies included: names of authors, publication dates, countries that studies took place, publication sources, types, study designs, study settings, research objectives/aims, music interventions, virtual technologies, other interventions, methodologies, statistical measures, effects and significance.

Table 1 lists the main publication characteristics of the primary studies, namely the author names, the publication source, the publication type, the year of publication, and

finally, the article number, which is a unique identifier that will be used for the remaining analysis. Starting the analysis with the authors, the author list contains a total of 271 distinct authors, with some appearing more than once. More specifically, Adjorlu, A. and Vermetten, E. appear three times (in a16, a25, and a41 for Adjorlu and a5, a30, a33 for Vermetten), while Nijdam, M. J. appear twice in a5 and a33. This indicates that while the majority of authors are unique, three authors prepared more than one research study in the field of VR combined with music.

Table 1. The publication characteristics.

Authors	Publication Source	Publication Type	Year	Article No.
Yi Qin, Huayu Zhang, Yuni Wang, Mei Mao, Fuguo Chen [43]	IEEE Conference on Multimedia Information Processing and Retrieval (MIPR)	Conference	2020	a1
Marina Giannarakis, Nektarios Moumoutzis, Yiannis Papatzakis, Elias Kourkoutas, Katerina Mania [44]	IEEE Global Engineering Education Conference (EDUCON)	Conference	2021	a2
Boulay Mélodie, Benveniste Samuelc, Boespflug Sandra, Jouvelot Pierre, Rigaud Anne-Sophie [45]	Technology and Health Care	Journal	2011	a3
Gökhan Ince, Rabia Yorganci, Ahmet Ozkul, Taha Berkay Duman, Hatice Köse [46]	Journal on Multimodal User Interfaces	Journal	2021	a4
Marieke J. van Gelderen, Mirjam J. Nijdam, Eric Vermetten [47]	Frontiers in Psychiatry	Journal	2018	a5
Kirwan, N. J., Overholt, D., & Erkut, C. [48]	Sound and Music Computing Conference	Conference	2015	a6
Barclay, S. A., Klausning, L. N., Hill, T. M., Kinney, A. L., Reissman, T., & Reissman, M. E. [49]	Sensors	Journal	2023	a7
Rubijesmin Abdul Latif, Rozita Ismail [50]	Intelligence and Interactivity for Future Computing	Journal	2015	a8
Geiser, N., Kaufmann, B. C., Knobel, S. E. J., Cazzoli, D., Nef, T., & Nyffeler, T [51]	Cortex	Journal	2024	a9
Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., ... & Bordin, A [52]	Neurorehabilitation and Neural Repair	Journal	2010	a10
Zhu, L., Tian, X., Xu, X., & Shu, L. [53]	IEEE MTT-S International Microwave Biomedical Conference (IMBioC)	Conference	2019	a11
Adamovich, S. V., Fluet, G. G., Mathai, A., Qiu, Q., Lewis, J., & Merians, A. S. [54]	Journal of NeuroEngineering and Rehabilitation	Journal	2009	a12
Tamplin, J., Loveridge, B., Clarke, K., Li, Y., & J Berlowitz, D. [55]	Journal of Telemedicine and Telecare	Journal	2020	a13
Kanehira, R., Ito, Y., Suzuki, M., & Hideo, F. [56]	International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery (ICNC-FSKD)	Conference	2018	a14
Touil, N., Pavlopoulou, A., Momeni, M., Van Pee, B., Barbier, O., Sermeus, L., & Roelants, F. [57]	International Journal of Clinical Practice	Journal	2021	a15
Pedersen, L. B., Adjorlu, A., & Bauer, V. [58]	Sound and Music Computing Conference	Conference	2022	a16
Heyse, J., Carlier, S., Verhelst, E., Vander Linden, C., De Backere, F., & De Turck, F. [59]	Applied Sciences	Journal	2022	a17
Luo, Z., Durairaj, P., Lau, C. M., Katsumoto, Y., Do, E. Y. L., Zainuddin, A. S. B., & Kawauchi, K [60]	IEEE International Conference on Virtual Reality (ICVR)	Conference	2021	a18
Fonteles, J. H., Serpa, Y. R., Barbosa, R. G., Rodrigues, M. A. F., & Alves, M. S. P. L. [61]	IEEE International Conference on Serious Games and Applications for Health (SeGAH)	Conference	2018	a19
Zondervan, D. K., Friedman, N., Chang, E., Zhao, X., Augsburg, R., Reinkensmeyer, D. J., & Cramer, S. C. [62]	Journal of rehabilitation research and development	Journal	2016	a20
Perez, P., Vallejo, E., Revuelta, M., Redondo Vega, M. V., Guervós Sánchez, E., & Ruiz, J [63]	ACM International Conference on Interactive Media Experiences	Conference	2022	a21

Table 1. Cont.

Authors	Publication Source	Publication Type	Year	Article No.
Seinfeld, S., Bergstrom, I., Pomes, A., Arroyo-Palacios, J., Vico, F., Slater, M., & Sanchez-Vives, M. V. [64]	Frontiers in psychology	Journal	2016	a22
Zhou, T., Wu, Y., Meng, Q., & Kang, J. [65]	Frontiers in psychology	Journal	2020	a23
Baur, K., Speth, F., Nagle, A., Riener, R., & Klamroth-Marganska, V. [66]	Journal of NeuroEngineering and Rehabilitation	Journal	2018	a24
Bauer, V., Adjorlu, A., Pedersen, L. B., Bouchara, T., & Serafin, S. [67]	ACM Symposium on Virtual Reality Software and Technology	Conference	2023	a25
Covarrubias, M., Aruanno, B., Cianferoni, T., Rossini, M., Komarova, S., & Molteni, F. [68]	International Conference on NeuroRehabilitation (ICNR)	Conference	2019	a26
Corrêa, A. G. D., de Assis, G. A., do Nascimento, M., & de Deus Lopes, R. [69]	Disability and Rehabilitation: Assistive Technology	Journal	2017	a27
Keshavarz, B., & Hecht, H. [70]	Applied Ergonomics	Journal	2014	a28
Latif, R. A. [71]	International Conference on Computer and Information Sciences (ICCOINS)	Conference	2018	a29
Roy, M. J., Bellini, P., Kruger, S. E., Dunbar, K., Atallah, H., Haight, T., & Vermetten, E. [72]	Frontiers in Virtual Reality	Journal	2022	a30
Gu, L., Sun, B., Liu, L., Li, Y., Zhang, Q., & Yang, J. [73]	IEEE International Conference on Intelligence and Safety for Robotics (ISR)	Conference	2021	a31
Sooriyaghandan, I. V., Mohamad Jailaini, M. F., Nik Abeed, N. N., Ng, B. H., Yu-Lin, A. B., Shah, S. A., & Abdul Hamid, M. F. [74]	BMC Pulmonary Medicine	Journal	2023	a32
van Veelen, N., Boonekamp, R. C., Schoonderwoerd, T. A., van Emmerik, M. L., Nijdam, M. J., Bruinsma, B., ... & Vermetten, E. [75]	Frontiers in Virtual Reality	Journal	2021	a33
Gür, E. Y., & Apay, S. E. [76]	Midwifery	Journal	2020	a34
Martí-Hereu, L., Navarra-Ventura, G., Navas-Pérez, A. M., Fernández-Gonzalo, S., Pérez-López, F., de Haro-López, C., & Gomà-Fernández, G. [77]	Enfermería Intensiva	Journal	2024	a35
Shahab, M., Taheri, A., Mokhtari, M., Shariati, A., Heidari, R., Meghdari, A., & Alemi, M. [78]	Education and Information Technologies	Journal	2022	a36
Alexanian, S., Foxman, M., & Pimentel, D. [79]	Frontiers in Rehabilitation Sciences	Journal	2022	a37
Taneja, A., Vishal, S. B., Mahesh, V., & Geethanjali, B. [80]	International Conference on Signal Processing, Communication and Networking (ICSCN)	Conference	2017	a38
Araujo-Duran, J., Kopac, O., Campana, M. M., Bakal, O., Sessler, D. I., Hofstra, R. L., ... & Ayad, S. [81]	Anesthesia & Analgesia	Journal	2024	a39
Sun, M., Bu, Q., Hou, Y., Ju, X., Yu, L., Lim, E. G., & Sun, J. [82]	International Conference on Multimodal Interaction	Conference	2023	a40
Adjorlu, A., Barriga, N. B. B., & Serafin, S. [83]	Sound and Music Computing Conference (SMC2019)	Conference	2019	a41
Baka, E., Kentros, M., Papagiannakis, G., & Magnenat-Thalmann, N. [84]	Learning and Collaboration Technologies	Conference	2018	a42
Cameirão, M. S., Pereira, F., & i Badia, S. B. [85]	International Conference on Virtual Rehabilitation (ICVR)	Conference	2017	a43
Lin, X., Mahmud, S., Jones, E., Shaker, A., Miskinis, A., Kanan, S., & Kim, J. H. [86]	Annual Computing and Communication Workshop and Conference (CCWC)	Conference	2020	a44
Buzzi, M. C., Buzzi, M., Maugeri, M., Paolini, G., Paratore, M. T., Sbragia, A., ... & Trujillo, A. [87]	HCI International	Conference	2019	a45

Continuing the analysis of the publication characteristics, regarding publication source, the list contains 41 distinct publication sources. The Sound and Music Computing Conference is the source with the most publications (3), while the Journal of NeuroEngineering

and Rehabilitation and *Frontiers in Psychology* appear 2 times. This indicates that the included studies were published across a wide range of sources, although some venues appeared more frequently than others. Similarly, concerning the publication type, almost half of the studies (20) have been published in conference papers while the other half (25) in journals. The balance between the types of publications reveals that the research in this specific field is disseminated through both types of academic venues. Conference papers usually present preliminary findings, whereas journals provide more comprehensive and validated research.

Finally, with respect to the publication year, the overall period encompasses studies between January 2009 and 15 February 2024 to capture developments in this field. It is evident that the majority of publications fall within the period from 2017 to 2024. Specifically, in 2018 and from 2020 to 2022, 6 studies were published each year. In 2019, there were 4 publications, while 2017, 2023, and 2024 each saw 3 publications. However, the number of studies identified for 2024 should be interpreted with caution, because the search was completed on 15 February 2024. Therefore, the publication-year distribution likely underestimates the most recent growth of this research field. From 2009 to 2011 and in 2014 there was one publication per year which increased to 2 publications per year in 2015 and 2016. It is worth mentioning that there were no publications in 2012 and 2013. Overall, this time analysis shows that there is much more research activity in the field of VR and music combination for rehabilitation during the recent years, as depicted graphically in Figure 2.

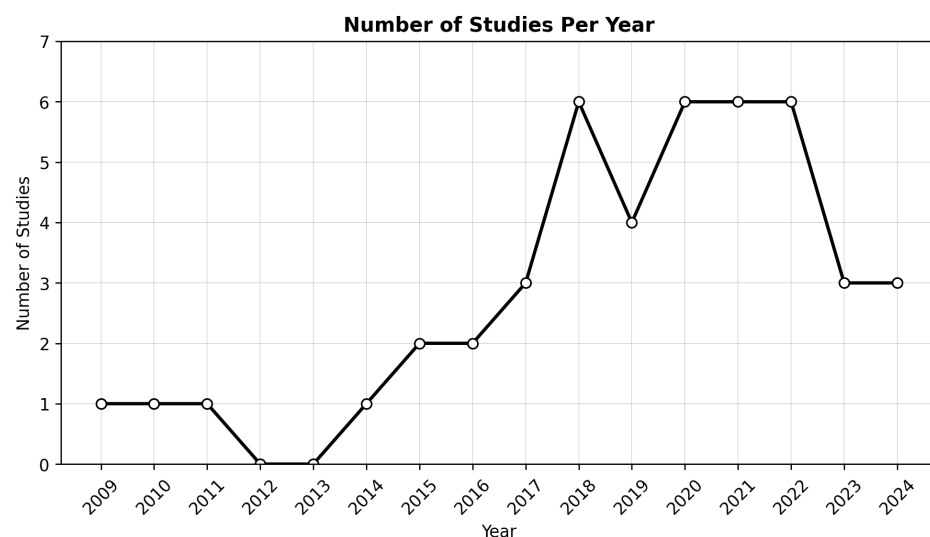


Figure 2. Number of studies per Year.

Table 2 presents the characteristics of the sample in each of the 45 primary research works, providing valuable information about the country of study, the environment (clinical or community), and the sample description. The first column represents the different countries existing in the scoping review. As reflected in Figure 3, with respect to the geographic origin of the studies, the majority of them are from Europe, accounting for 21 studies. This is followed by Asia with 13 studies and North America ranks third with 5 published studies. South America contributed 2 studies, while in two cases, the geographic location of the research was not specified. Additionally, Australia contributed 1 study and 1 study was classified as international due to its execution across multiple locations simultaneously. The aforementioned shows that there is research activity in different global regions, led by European countries, with notable but smaller contributions from other regions.

Table 2. Sample Characteristics.

Country	Environment	Sample Description	Article No.
China	Community	Seventy-three (30 males, 43 females) ages: <12 years (1 person), 13–18 years (6 people), 19–28 years (16 people), 29–40 years (10 people), 41–50 years (6 people), 51–66 years (16 people), >66 (18 people). Four groups.	a1
Greece	Community	4 children: 3 male, 1 female (2 diagnosed with ADHD, and 2 without ADHD), ages: 8–12 years	a2
France	Clinical	7 (4 women, 3 men, mean age 88.5)	a3
Turkey	Community	1st scenario: 20 students (10 women-10 men, average ages: 25.5. 2nd scenario: 8 participants (4 men-4 women with average age 23.5) they participated and in the first scenario. 3rd Scenario: 20 participants (10 women-10 men, average age : 23.1, did not participate in scenario 1 and 2)	a4
Holland	Community	3 patients	a5
Ireland	Community	4 (2 male, early twenties participants and 2 therapists)	a6
United Emirates	Community	16 healthy (7 females-9 males, mean age 21.69 ± 0.6 years)	a7
Malaysia	Community	28 participants (14 males-14 females, ages 19–22)	a8
Switzerland	Clinical	28 patients (15 women-13 men, mean age 72.64)	a9
Italy	Community	36 participants (24 female-12 male, mean age 80 years). Final sample completed intervention 31 participants	a10
China	Community	13 students (20–30 years old)	a11
USA	Community	4 subjects: with hemiparesis after stroke (mean age 51.5 years), with mild or moderate impairment (according to Chedoke McMaster Stroke Assessment), with minimal to moderate spasticity (according to Modified Ashworth Scale), with stroke began from 11 months to 7 years.	a12
Australia	Clinical	6 participants (5 male-1 female) with mean age 43.5 and spinal cord injury	a13
Japan	Community	8 university students	a14
Belgium	Clinical	48 patients (27 females 21 males—mean age 49 years)	a15
Denmark	Community	25 healthy children (9 years old)	a16
Belgium	Clinical	4 patients with brain injury unilateral spatial neglect (USN), >12 years old, six months after injury and 3 with left side neglect and one with right side.	a17
Singapore	Clinical	11 participants (7 male-4 female) after stroke, 69.45 mean age	a18
Brazil	Community	4 participants: 2 children (ages: 7 & 8), 2 adults (ages 27 & 28 years old)	a19
USA	Community	17 participants with hand impairment after stroke conventional group (8): 5 male-3 female mean age: 59 years & Music Glove group (9): 4 female-5 male, mean age: 60 years	a20
Spain	Community	16 patients (12 female-4 male, mean age: 87.8 years)	a21
Spain	Community	40 patients (music group: 12 females-8 males Mean Age : 27.15 years, Non-Music Group: 15 females-5 males Mean age: 25.40 years)	a22
China	Clinical	70 patients (36men-34 women, mean age: 48.2 years)	a23
Switzerland	Community	16 (10 males-6 females, mean age: 27.2 years)	a24
France	Clinical	13 children with autism (10 male-3 female with mean age: 10.46), 4 children verbal-6 “limited verbal abilities”-3 “minimal to non-verbal abilities)	a25
Italy	Clinical	10 healthy (4 female-6 male ages between 18–23 years) in the preliminary tests and in the main test the sample was with Individuals undergoing mental health rehabilitation	a26
Brazil	Clinical	19 healthy (1 male and 18 female therapists)	a27
Germany	Community	93 participants (50 female-43 male) but 20 participants didn’t complete the experiment	a28
Malaysia	Community	30 (15 males-15 females) healthy students at university in Malaysia, (ages between 19–25 years) assigned into 3 groups	a29
USA	Community	20 Individuals (10 males and 10 females), Mean age: 45.1 years. 16 participants completed the intervention	a30
China	Community	32 participants (20 males-12 females, mean age: 23.2 years)	a31
Malaysia	Clinical	80 patients (40 each group, mean age: above 67 years for intervention group and 64 years for control arm group))	a32

Table 2. *Cont.*

Country	Environment	Sample Description	Article No.
-	Community	3 (two male-one female)	a33
Turkey	Clinical	273 pregnant women (55 in B, C, D group and 54 in A, E group)	a34
Spain	Clinical	20 patients (12 male-8 female, mean age: 64 years)	a35
Iran	Community	5 children (male), mean age: 7.09 years	a36
International (Asia, USA, Africa)	Community	90 participants (56 males, 33 females, 1 not say)	a37
India	Community	20 students (14 males-6 females, ages 18–21 years)	a38
USA (Ohio)	Clinical	106 individuals (in VR group: 27 females from 52 mean age 66 years, in 2D group: 25 from 46 were females with mean age 63 years)	a39
China	Clinical	2 patients	a40
Denmark	Community	4 participants (male, ages: 18–20 years) with social anxiety, diagnosed with ASD	a41
Greece	Clinical	3 participants (2 female-1 male, ages: 32–52 years)	a42
Portugal	Clinical	13 participants: 7 in VR group (2 females & 5 males, ages: 57–83 years), 6 in Control group (3 females & 3 males, ages: 42–86 years)	a43
USA	Community	19 participants (16 males-3 females, mean age: 17.7 years)	a44
-	Community	4 children (ages: 11–15 years)	a45



Figure 3. Number of studies per country.

Continuing with the analysis of the environment, in the literature there are the clinical and the community environment. In medical studies, a clinical environment refers to research conducted in healthcare settings like hospitals, clinics, or specialized medical institutions, involving patients who are typically seeking treatment, and the research is usually performed under controlled conditions. In contrast, a community environment is centered on everyday spaces like homes, schools, or workplaces and participants are generally members of the broader population, not limited to those seeking medical treatment. Regarding the study settings of the present scoping review, these include 17 studies conducted in a clinical environment, while the remaining 28 studies carried out in a community environment. This finding, as reflected in Figure 4 shows that this kind of intervention (VR with music), which belongs to the category of non-pharmacological interventions, was most commonly reported (> 60%) in a broader community environment.

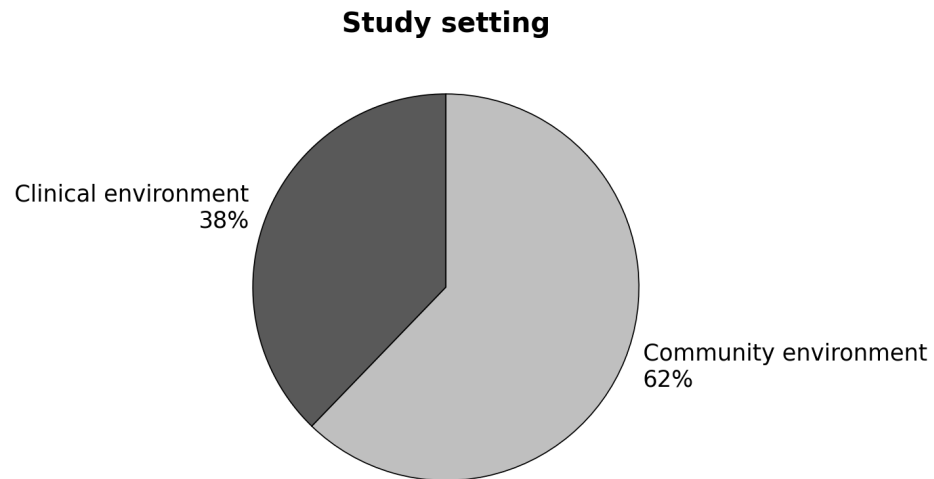


Figure 4. Summary of study settings.

Finally, the sample characteristics of the primary studies were summarized, including sample size, gender, age, country, and study setting. Across the 45 studies included in this scoping review, the total number of participants was 1380. Gender information was reported for 1320 participants: 783 were female, 536 were male, and one participant did not self-identify within the binary categories of male or female. For the remaining 60 participants, gender information was not reported. Age was reported heterogeneously across the included studies. The largest identifiable age group was 19–28 years, with approximately 750 participants. This was followed by participants aged over 65 years ($n = 201$), those aged 41–50 years ($n = 150$), 51–65 years ($n = 64$), under 12 years ($n = 50$), and the 13–18 and 29–40 age groups, with 29 participants each. However, these age summaries should be interpreted cautiously because several studies reported broader age ranges rather than mutually exclusive age categories. These included participants reported as 18–59 years ($n = 10$), over 12 years ($n = 4$), 35–44 years ($n = 21$), 45–55 years ($n = 10$), 25–34 years ($n = 46$), over 60 years ($n = 106$), 35–52 years ($n = 3$), and 42–86 years ($n = 15$). Overall, the mapped sample characteristics indicate a diverse participant pool in terms of age, gender, and study setting. There was a slight female majority among the total sample, while younger adults and older adults were both substantially represented. Because demographic reporting was not fully consistent across all studies, the demographic summaries are presented as descriptive mapping information rather than as exact population-level estimates. Detailed study-level sample information, including country, environment, sample description, and article number, is provided in Table 2.

Table 3 summarizes the study characteristics of the 45 included studies, including the virtual-technology modality, the music-related or auditory component, the health condition or application context, the measurement tools, and the reported finding. The reported finding is used descriptively and should not be interpreted as a formal assessment of clinical effectiveness.

Starting with the VR interventions, out of the 45 studies reviewed, 10 utilized virtual serious games as a therapeutic intervention. Virtual serious games are interactive digital games designed with a primary purpose beyond entertainment, often used for education, training, or therapy. Among these 10 studies, three also used robotic equipment to support the rehabilitation process. Moreover, nine studies employed virtual videos as a virtual reality (VR) intervention. Virtual videos as a VR intervention involve immersive experiences designed to stimulate users through realistic or simulated environments. Additionally, 17 studies incorporated virtual environments. Compared with virtual videos, virtual environments usually involve a higher degree of user interaction and engagement within

the simulated setting. Finally, eight studies integrated virtual musical instruments, which simulate through VR the playing of actual instruments, and only one study employed a VR 3D audio system, which is an immersive sound technology that simulates how sound behaves in a three-dimensional space, allowing users to perceive the direction, distance, and movement of sounds and enhancing realism and spatial awareness within the virtual environment. Overall, this analysis highlights the variety of VR interventions identified in the reviewed studies identified in the reviewed studies, with five different approaches. The most common were virtual environments and virtual serious games, used in 17 and 10 studies, respectively (Figure 5).

Table 3. Study characteristics.

VR Intervention	Music Intervention	Health Condition	Measurement Tool	Reported Finding	Article No.
VR 3D audio	Audio Music Listening (2D Audio & 3D Audio in fast/slow tempo)	Healthy (intended for Stress)	Human body metrics (galvanic)	Positive	a1
Virtual Musical Instrument	Music Production (Musical Rhythms with VR Drum)	Attention Deficit Hyperactivity Disorder (ADHD)	Questionnaires, Game metrics	Positive	a2
Virtual Serious Game	Active Music Therapy (Playing melodies in virtual keyboard)	Dementia (Alzheimer mild to moderate)	Game metrics, Questionnaires and Observation	Positive	a3
Virtual Game (VR robot/VR avatar playing drum)	Music Production (imitate drum rhythms with Motions)	Healthy (intended for Special needs)	Questionnaires, Observation, Game metrics	Positive	a4
Virtual Environment	Audio Music Listening (participants preference)	Posttraumatic Stress Disorder (PTSD)	Questionnaire (PCL-5)	Positive	a5
Virtual Musical Instrument	Music Therapy (Voice Improvisation with 5 tonic tones)	Intellectual Disability	Observation	Neutral	a6
Virtual Serious Game	Audio Music Listening (Songs combined with moves)	Healthy (for kinetic)	Human Body metrics	Positive	a7
Virtual Environment	Audio Music Listening (nature & Zikr sounds)	Stress	Questionnaires, Interviews	Positive	a8
Virtual Video	Audio Music Listening (one of these: Classic, Pop, Country, traditional Swiss folk music, or Jazz)	Visual Neglect	Human Body metrics (Records eye movements with video oculography)	Positive	a9
Virtual Environment	Music Therapy (listening to music)	Memory Impairment	Questionnaires (Neuropsychological tests)	Positive	a10
Virtual Video	Audio Music Listening (Western & New Century Music)	Stress	Human Body Metrics (EEG signals recordings), Questionnaires, (SAM scale emotional responses)	Positive	a11
Virtual Musical Instrument (piano)	Music Production (VR piano)	Stroke (hemiparesis)	Game metrics. Human Body metrics (tests for motion impairment, Wolf Motor Function Test (WMFT) & Jebsen Test of Hand Function (JTHF))	Positive	a12
Virtual Environment	Music Therapy (Singing)	Spinal cord	Questionnaires, Interviews	Positive	a13

Table 3. Cont.

VR Intervention	Music Intervention	Health Condition	Measurement Tool	Reported Finding	Article No.
Virtual Video	Music Therapy (Audio music listening including Healing, favorite, white noise)	Stress	Human Body Metrics, Questionnaires	Positive	a14
Virtual Video	Audio Music Listening	Surgery (hand)	Questionnaires	Positive	a15
VR Environment	Music Therapy (Sounds of Musical Instruments)	Autism	Observation, Interviews	Positive	a16
Virtual Musical Instrument	Music Therapy (Neurologic Music Therapy Technique—Musical Neglect Therapy)	Spatial Neglect	Game metrics, Interviews	Positive	a17
Virtual Serious Game	Audio Music Listening (Sounds of Musical Instruments)	Stroke	Human Body Metrics (Canadian Occupational Performance Measure (COPM) & Fugl-Meyer Assessment—Upper Extremity (FMA-UE), Questionnaires, Game metrics	Neutral performance, Positive satisfaction	a18
Virtual Serious Game	Music Production (Playing notes/songs combined with gestures)	Repetitive strain injury (RSI)	Game metrics, Questionnaires	Positive (entertainment and completed all levels of 3 tasks)	a19
Virtual Serious Game (robotic equipment)	Music Production (Music rhythms & audio feedback combined with hand-finger exercises)	Stroke (motor-hand)	Human Body Metrics (Box and Block Test, Nine Hole Peg Test) & Questionnaires (stroke scale, depression scale), Interviews (Motor Activity Log (QOM & AOU), Action Research Arm Test)	Positive	a20
Virtual Video	Audio Music Listening	Cognitive Impairment (depression)	Questionnaires	Positive	a21
Virtual Video	Audio Music Listening (Instrumental)	High Anxiety	Human Body Metrics [galvanic skin-electrodermal activity (EDA) & Electrocardiogram (ECG)] Questionnaires	Positive	a22
Virtual Environment	Audio Music Listening (hospital sounds)	Hospital Anxiety (chronic disease)	Human Body Metrics, Questionnaires	Neutral	a23
Virtual Serious Game (Robotic Equipment)	Music Production (rhythm, melody, tempo, harmonies linked to movements, sonification)	Healthy (for arm motor rehabilitation)	Game metrics, Questionnaires (Intrinsic Motivation Inventory, Borg Scale)	Positive	a24
Virtual Musical Instrument	Audio Music Listening (Instrumental sounds)	Autism	Questionnaires, Observation	Positive	a25
Virtual Environment	Music therapy (with harp)	Mental recovery post stroke	Questionnaires	Positive	a26
Virtual Serious Game	Audio Music Listening (musical instrumental sounds MIDI)	Healthy (for physical and cognitive disabilities)	Questionnaires	Positive	a27
Virtual Video	Audio Music Listening (relaxing: instrumental, neutral: pop music, stressfulness music: electronic music)	Visually Induced Motion Sickness (VIMS)	Questionnaires	Positive	a28

Table 3. Cont.

VR Intervention	Music Intervention	Health Condition	Measurement Tool	Reported Finding	Article No.
Virtual Environment (Immersive)	Audio Music Listening (nature sounds, zikr sounds)	Stress	Human Body Metrics, Interview	Positive	a29
Virtual Environment	Audio Music (favorite songs)	PTSD	Questionnaires [PCL-5, Neurobehavioral Symptom Inventory (NSI), Patient Health Questionnaire Depression module (PHQ-9), e Insomnia Severity Index (ISI)]	Positive	a30
Virtual Environment	Audio Music (nature sounds/ relaxing music)	Stress	Human Body Metrics (EEG, EDA electrodermal activity), Questionnaires (PANAS)	Positive	a31
Virtual Environment	Audio Music (Instrumental music)	Bronchoscopy Surgery	Questionnaires (Satisfaction, Visual Analogue Scale, State-Trait-Anxiety-Inventory)	Positive	a32
Virtual Environment	Audio Music (neutral)	PTSD	Interview, Human Body Metrics, Observation	Positive	a33
Virtual Video	Audio Music (classical music)	Labor	Interviews, Questionnaires (VAS, VRS-Verbal rating scale)	Positive	a34
Virtual Environment	Audio music (natures sounds/binaural beats)	Intensive care	Questionnaires (STAI, Satisfaction)	Positive	a35
Virtual Musical Instrument	Audio music (Drum and Xylophone sounds)	Autism	Game metrics, Questionnaires, Observation	Positive	a36
VR Environment	Audio music (low pitches, slow tempo)	Healthy	Questionnaires [POMS-Profile of Mood States & SPEC—Spatial presence Experience Scale]	Mixed	a37
Virtual Environment	Audio music (piano and other instrumental music)	Mental stress	Game metrics (GO NOGO TASK), Questionnaires (PANAS)	Positive	a38
Virtual Video	Audio Music (binaural audio)	Hip Surgery	Human Body Metrics (opium consumption-medical records, antiemetic medication), Questionnaires [Pain Scores (numeric pain scale), patient usability scale, mobility scale, Routine pain, Pain Outcomes Questionnaire Short Form (POQ-SF)]	Neutral	a39
Virtual Musical Instrument	Music production (create melodies in xylophone and rhythms in drums)	Stroke	Game metrics	Positive	a40

Table 3. Cont.

VR Intervention	Music Intervention	Health Condition	Measurement Tool	Reported Finding	Article No.
Virtual Environment	Audio music + sing (favorite songs)	Autism	Questionnaires [Liebowitz Social Anxiety Scale (LSA), Witmer Singer presence questionnaire (PQ), Immersive Tendency Questionnaire (ITQ)]	Positive	a41
Virtual Serious Game	Neurologic Music Therapy techniques: TIMP & PSE	Stroke (arm paretic)	Questionnaires (stress & self-efficacy), Game metrics	Positive	a42
Virtual Environment (Immersive)	Audio Music (favorite songs)	Stroke	Game metrics, Human Body Metrics [(Fugl-Meyer Assessment Test for Upper Extremities (FM-UE), Chedoke Arm and Hand Activity Inventory (CAHAI)], Questionnaires (Montreal Cognitive Assessment (MoCA), Bells test Barthell Index	Positive	a43
Virtual Serious Game	Music Therapy (Playing Xylophone, drums, piano)	Stress anxiety	Questionnaires	Positive	a44
Virtual Musical Instrument	Music production (Piano)	Autism	Game metrics, Observation	Positive	a45

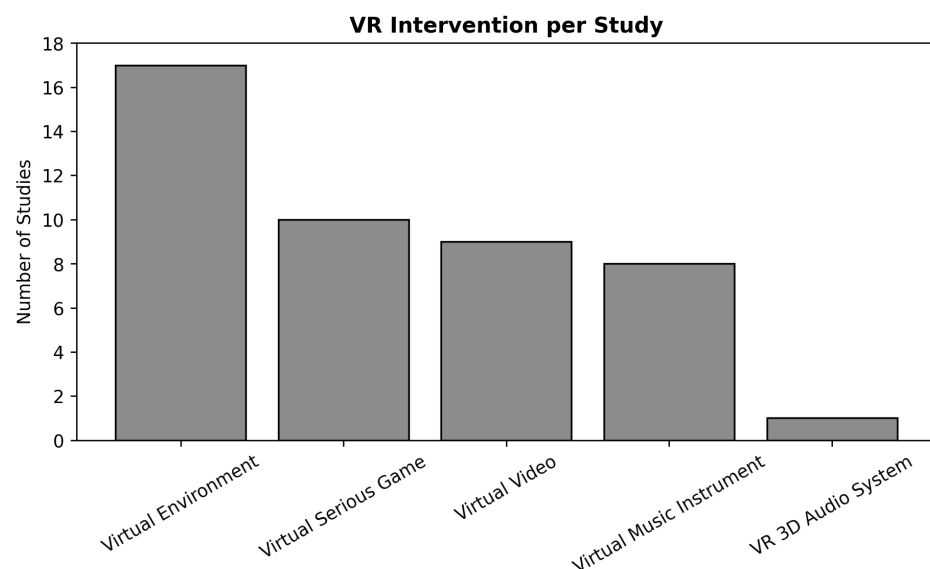


Figure 5. Summary of VR interventions.

Before continuing with the analysis of the music interventions, it should be noted that music therapy may include both active and receptive approaches. Active approaches involve direct musical participation, such as improvising, singing, playing musical instruments, or other forms of music-making, whereas receptive approaches involve listening to live or recorded music within a therapeutic process [88–90]. In the present review, however, the broader term music-based interventions is used because not all included studies delivered music within a formal music therapy relationship or by a credentialed music therapist. Several studies used music primarily as a technological, interactional, or environmental component of the VR intervention, such as background music, music listening outside a

formal therapy context, rhythmic cueing, auditory feedback, sonification, or interaction with virtual musical instruments. For this reason, the synthesis distinguishes formally delivered music therapy, including active and receptive approaches, from broader uses of music embedded within virtual or immersive systems. From the 45 studies analyzed, the vast majority, 26 studies (57.8%), employed audio music listening as the primary musical intervention. Depending on the study's sample and objectives, the type of music varied, including nature sounds, participants' favorite songs, instrumental music, and different music genres. Additionally, 10 studies used music therapy and only two of them utilized techniques from the neurologic music therapy (NMT), such as Therapeutic Instrumental Music Performance (TIMP) and Patterned Sensory Enhancement (PSE). Finally, in 8 studies, participants actively produced music, creating melodies or rhythms using virtual musical instruments, with the most common being the xylophone, drum, and piano, or through game-based platforms. In some cases, the intervention involved a combination of music production and physical movement, facilitated by the use of robotic equipment. One study employed a mixed musical intervention by combining audio music listening and music production. In summary, there are three distinct music intervention categories, with two of them, audio music listening and music therapy, being observed in the majority of the studies (36 out of 45), as depicted graphically in Figure 6.

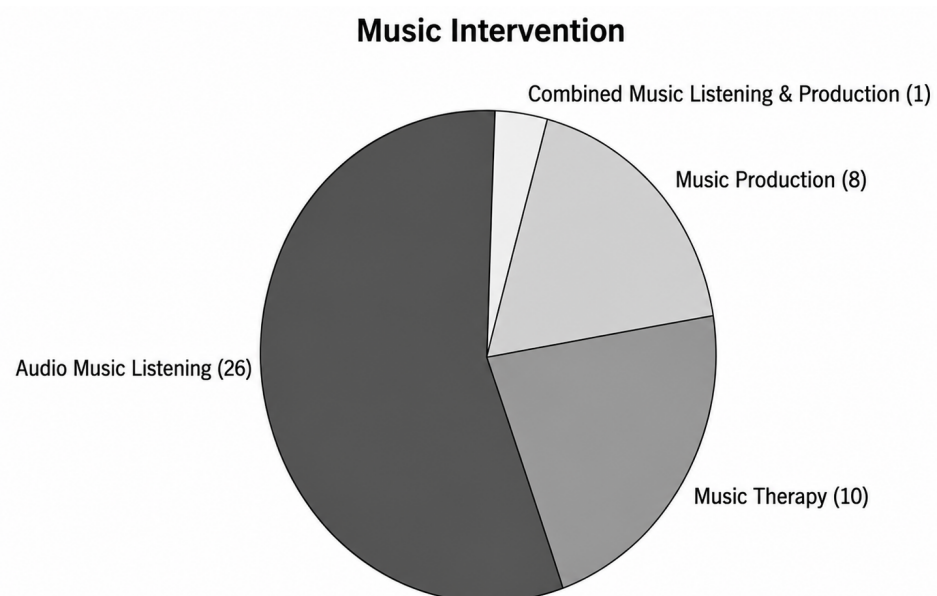


Figure 6. Summary of music interventions.

Regarding the analysis of the health condition in which the combination of VR and music has been applied, the studies were categorized according to their main population or application context. This resulted in the identification of three studies related to cognitive impairment, including Alzheimer's disease, dementia, memory problems, and cognitive difficulties. Seven studies focused on neurodevelopmental disorders, covering conditions such as autism, attention deficit disorder, and intellectual disabilities. Twelve studies examined psychiatric and mental health conditions, with the majority addressing various forms of anxiety, including hospital-induced anxiety, PTSD, and related conditions. Six studies involved a healthy sample, although these studies may still provide useful insights for future applications in populations such as children with special needs or patients with mobility limitations. An additional eleven studies focused on neurological conditions, such as stroke, spatial neglect, spinal cord injury, and visually induced motion sickness, with several of these studies addressing motor rehabilitation. Four studies involved surgical,

obstetric, or procedural contexts, including surgery, bronchoscopy, labor, and hip surgery, while two studies examined musculoskeletal disorders or intensive-care unit populations. Overall, this distribution shows that the combined use of VR and music has been explored across a heterogeneous range of health contexts rather than within a single clinical area. This diversity supports the scoping-review approach, as the aim is to map the breadth of existing applications and reported outcomes rather than to estimate a pooled clinical effect across comparable studies. This diversity is depicted in Figure 7.

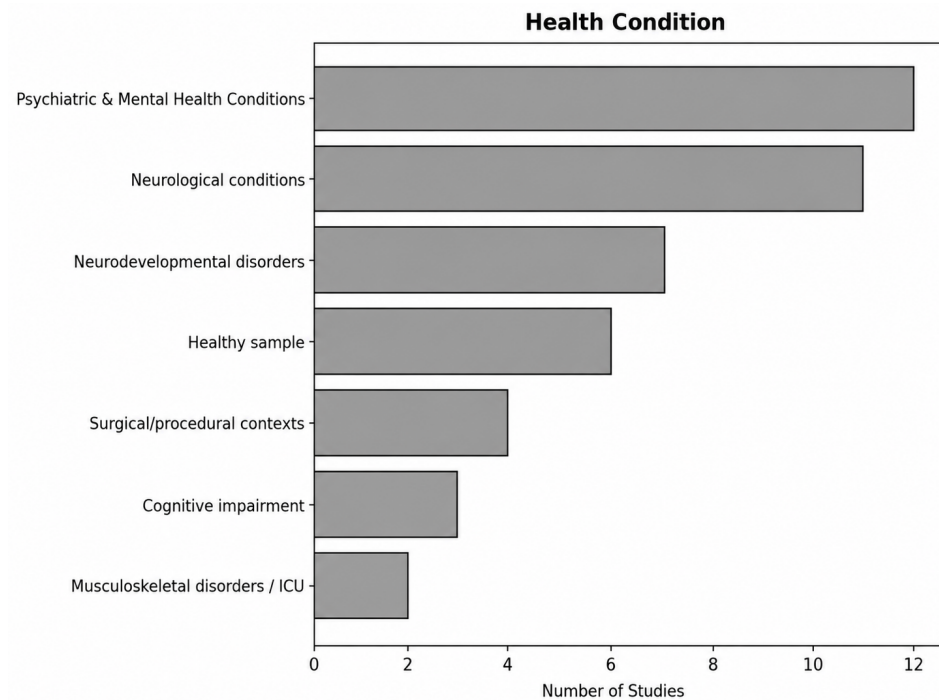


Figure 7. Summary of health conditions.

Beyond the separate frequency distributions, the categories were also examined descriptively in relation to each other in order to better map how VR, music, and health contexts were combined across the included studies. First, the relationship between health condition and music intervention showed that psychiatric and mental health studies were mainly associated with audio music listening (10/12, 83.3%), with only two studies using music therapy (2/12, 16.7%). Neurological conditions showed a more balanced distribution across audio music listening (4/11, 36.4%), music therapy (4/11, 36.4%), and music production (3/11, 27.3%). Neurodevelopmental disorder studies also showed a mixed pattern, including audio music listening (2/7, 28.6%), music therapy (2/7, 28.6%), music production (2/7, 28.6%), and one combined music listening and production intervention (1/7, 14.3%). This suggests that music was not used in a single uniform way across health contexts, but was adapted according to the population, therapeutic aim, and intervention setting.

Second, the relationship between health condition and VR intervention showed that different health contexts tended to involve different technological configurations. Psychiatric and mental health studies were mostly linked to virtual environments (8/12, 66.7%) and virtual videos (3/12, 25.0%), which together accounted for 11 out of 12 studies (91.7%) in this category. Neurodevelopmental disorder studies were mainly associated with virtual musical instruments (5/7, 71.4%), whereas neurological studies showed the widest technological spread, including virtual environments (3/11, 27.3%), virtual serious games (3/11, 27.3%), virtual videos (2/11, 18.2%), and virtual musical instruments (3/11, 27.3%). This pattern is particularly relevant for the technological scope of the review, as it shows

that the field does not rely on one dominant VR modality but includes several forms of virtual and immersive implementation.

Third, the relationship between VR intervention and music intervention showed that virtual environments were most often combined with audio music listening (12/17, 70.6%), while virtual videos were also mainly combined with audio music listening (8/9, 88.9%). In contrast, virtual serious games were more frequently associated with active or therapy-oriented music uses, including music production (4/10, 40.0%) and music therapy (3/10, 30.0%). Similarly, virtual musical instruments were mostly linked to music production (4/8, 50.0%), while two studies used music therapy (2/8, 25.0%) and two used audio music listening (2/8, 25.0%). Overall, these cross-mapping patterns support the interpretation of the reviewed literature as a heterogeneous set of VR–music applications rather than a single uniform intervention type.

In the reviewed studies, 40 out of 45 studies reported positive findings in relation to their specific objectives, while the remaining studies reported neutral, mixed, or outcome-dependent findings. However, this count should be interpreted descriptively and not as evidence of overall clinical effectiveness, because the included studies differed substantially in terms of populations, intervention designs, outcome measures, and methodological approaches.

5. Discussion

5.1. Interpretation of the Mapped Intervention Patterns

This scoping review mapped how music and virtual reality have been combined across health contexts. The purpose was not to determine clinical effectiveness through pooled evidence synthesis, but to describe where this combination has been explored, which VR technologies and music interventions have been used, how music is embedded within the virtual intervention, which outcome domains have been reported, and what gaps remain in the literature. This distinction is important because the included studies were highly heterogeneous in terms of populations, health contexts, VR modalities, music interventions, study designs, outcome measures, and reporting detail.

The mapped evidence suggests that audio music listening was the most frequently used music intervention in combination with VR. This may be explained by its practical advantages: it can be implemented with limited technical resources, standardized across participants, and adapted to different virtual environments and health contexts. However, the prominence of audio music listening should not be interpreted as evidence that it is the most effective approach. Rather, it indicates that listening-based music components have been the most commonly explored and most easily integrated within VR interventions.

Across stress-, anxiety-, PTSD-related, pain-related, and perioperative contexts, music was often used as a background, relaxation, or emotional regulation component. Studies in these areas commonly reported outcomes related to relaxation, stress reduction, emotional response, pain perception, or comfort. In contrast, studies involving neurological, motor-rehabilitation, cognitive, and neurodevelopmental contexts more often used music in a more active, structured, or interactive way, including music therapy, music production, rhythmic support, attentional guidance, or interaction through virtual musical instruments. This suggests that the role of music within VR varies according to the population, therapeutic aim, and type of virtual technology used.

The role of music selection also appears to be an important factor in how VR and music interventions are experienced and delivered. Studies using self-selected music [47,72,75] reported that personalization may support immersion, emotional relevance, and memory processing. These studies suggest that when participants are able to select or co-create the auditory stimuli, engagement may increase and avoidance behaviours may decrease,

which is particularly relevant in trauma- and PTSD-related contexts. By contrast, when standardized calming music was employed [79], the emphasis was placed less on personal meaning and more on supporting relaxation and physiological stress regulation through steady pulse, predictable melodic lines, and stable dynamics. These findings suggest two possible pathways through which music may contribute to VR interventions: personalized, emotionally salient music may support memory-related and engagement processes, whereas standardized soothing music may support relaxation and stress reduction.

The way music is mapped into the VR experience also varied across the included studies and may help explain differences in reported outcomes. In some interventions [50,65], music or sound was used as background audio to enrich the sense of presence, realism, or environmental context, such as hospital ward sounds or natural environments. Other studies [47,85] incorporated music in a more interactive or session-structured manner, for example by using trauma-related music followed by neutral music to mark closure, or by alternating VR training sessions with and without personalized music. These examples suggest that when music is connected to specific phases of the intervention, such as initiation, engagement, or closure, it may support not only immersion but also the structure and acceptability of the therapeutic session.

The degree of participant control over the music component also remains underexplored. Some studies [72,75] allowed participants to bring or select their own music, thereby giving them some influence over the VR environment. This approach may support a sense of agency, authenticity, presence, and engagement. In contrast, studies where music was pre-selected and passively delivered [65,79] offered greater consistency across participants and experimental conditions, but provided less opportunity for personalization. Future studies should therefore report more clearly whether music is self-selected, therapist-selected, or protocol-defined, and should examine whether different levels of participant control are associated with differences in engagement, acceptability, or reported outcomes.

A closer look at studies combining VR video or immersive visual environments with music further illustrates that the role of auditory input differs across intervention goals. In Geiser et al. [51], music was used as spatially directed auditory motion cues rather than as passive background music. The auditory stimulus shifted from the intact right hemispace toward the neglected left side, thereby aiming to guide attention into the neglected field. The study reported that auditory motion stimulation reduced neglect-related outcomes to a degree comparable with visual motion stimulation, while combining auditory and visual stimulation did not produce additional benefits. In this case, the relevance of the music component was related to its directional and task-related mapping rather than to relaxation.

By contrast, Touil et al. [57] integrated relaxing background music into an immersive VR undersea environment combined with hypnotic suggestions for relaxation and breathing. In this case, the auditory input was not interactive or user-controlled, but was embedded within the relaxation protocol to support calmness during anesthesia preparation. Similarly, Seinfeld et al. [64] used relaxing background music within a height-exposure VR task, where music functioned as an emotional regulation layer during an anxiety-provoking virtual scenario. These studies suggest that background relaxing music may support distraction, comfort, or emotional regulation in perioperative and anxiety-related contexts, although the available evidence does not allow firm conclusions about comparative effectiveness.

Taken together, these examples show that music is embedded in VR interventions in different ways. Spatially directed auditory cues may be used to support attentional guidance in neglect-related rehabilitation, whereas background relaxing music may be used to support relaxation, distraction, or emotional regulation in anxiety- or perioperative contexts.

Notably, these interventions generally relied on protocol-defined auditory input rather than real-time participant control. This highlights an important gap for future research: studies should examine whether greater participant agency over music parameters, such as selection, tempo, genre, switching, or triggering auditory cues, can improve engagement, acceptability, or specific health-related outcomes. Overall, the available evidence suggests that the contribution of music within VR depends on how the auditory design is aligned with the intervention goal, but stronger and more comparable studies are needed before firm conclusions can be drawn.

This interpretation also clarifies the contribution of the present review in relation to previous work. For example, Danso et al. [37] focused specifically on VR and music therapy in post-stroke neglect rehabilitation. In contrast, the present scoping review maps the combined use of music and VR across broader health contexts and highlights how music is embedded within VR interventions through different roles. At the same time, the review shows that formal music therapy and broader uses of music within VR systems are not always clearly distinguished in the included studies. This represents an important reporting gap, since clearer descriptions of the music component, its therapeutic rationale, and its role within the VR environment are needed to support more comparable future research.

5.2. Synthesis in Relation to the Research Questions

Regarding the first research question, the mapped evidence shows that music and VR have been combined across a wide range of health contexts rather than within a single clinical area. The included studies covered cognitive impairment, neurodevelopmental disorders, psychiatric and mental health conditions, healthy samples, neurological conditions, surgical or procedural contexts, and musculoskeletal or intensive-care settings. This distribution supports the scoping-review approach, as the field is broad and emerging, with applications ranging from rehabilitation and cognitive support to anxiety reduction, pain-related support, perioperative care, feasibility testing, and user-experience evaluation.

Regarding the second research question, the review identified several VR intervention types, including virtual environments, virtual serious games, virtual videos, virtual musical instruments, and VR 3D audio. The additional descriptive synthesis in the Results showed that different health contexts tended to involve different technological configurations. Psychiatric and mental health studies were mainly linked to virtual environments and virtual videos, while neurodevelopmental disorder studies were mainly associated with virtual musical instruments. Neurological studies showed a broader technological spread, including virtual environments, serious games, virtual videos, and virtual musical instruments. This finding is relevant to the technological contribution of the review, because it shows that the field is not based on one dominant VR modality but includes several forms of virtual and immersive implementation.

Regarding the third research question, music was not used as a single homogeneous component across the included studies. Audio music listening was the most frequent music intervention category, followed by music therapy, music production, and one combined music listening and production intervention. The cross-mapping patterns showed that psychiatric and mental health studies were mainly associated with audio music listening, whereas neurological conditions showed a more balanced distribution across audio music listening, music therapy, and music production. Neurodevelopmental disorder studies also showed a mixed pattern, including audio music listening, music therapy, music production, and combined music listening and production. These patterns indicate that music was used in different ways depending on the population, therapeutic aim, and VR modality.

Regarding the fourth research question, the included studies reported a wide range of outcome domains. These included engagement, motivation, relaxation, stress and anxiety

responses, emotional satisfaction, pain or perioperative outcomes, motor performance, cognitive or attentional responses, usability, feasibility, acceptability, and user experience. However, these outcome domains should not be treated as equivalent. Feasibility, usability, engagement, and satisfaction outcomes provide important information about acceptability and implementation, but they do not have the same evidential meaning as clinical outcomes such as motor function, pain reduction, cognitive response, or stress reduction. Therefore, positive findings reported across studies should be interpreted as mapped outcome trends rather than as definitive evidence of clinical effectiveness.

Regarding the fifth research question, the main evidence gaps concern heterogeneity, reporting quality, and evidence maturity. Many studies used small samples, exploratory designs, feasibility-oriented protocols, or limited follow-up. In addition, the description of the VR modality, the music intervention, the rationale for the selected music, the degree of user interaction, and the outcome measures was not always sufficiently detailed. These gaps limit the ability to compare studies directly and make it difficult to determine which VR–music combinations are most appropriate for specific health contexts or therapeutic goals.

Overall, the synthesis indicates that the reviewed literature should be understood as a heterogeneous set of VR–music applications rather than as one uniform intervention type. This interpretation is consistent with the descriptive Results, where the studies were mapped by health condition, VR intervention type, music intervention category, demographic characteristics, and cross-mapping patterns. It also explains why strong claims about effectiveness are not appropriate at this stage, despite the fact that many studies reported positive findings in relation to their own objectives.

5.3. Limitations and Future Directions

This scoping review has several limitations. First, the database search covered the period from January 2009 to February 2024. References published after the search date were used only as background literature to contextualize the continuing relevance of the topic and were not included in the evidence base or synthesis. Therefore, more recent studies may not be represented in the mapped literature. Second, the search focused on peer-reviewed studies indexed in PubMed and Scopus and did not include grey literature. Therefore, technical reports, theses, prototype descriptions, and other non-indexed materials relevant to emerging VR technologies may not have been captured. Future broader searches should also consider databases such as IEEE Xplore, ACM Digital Library, Web of Science, Embase, PsycINFO, CINAHL, and the Cochrane Library.

A further limitation concerns the heterogeneity and maturity of the evidence base. The included studies varied substantially in populations, health contexts, VR technologies, music interventions, outcome measures, study designs, intervention durations, and follow-up reporting. For this reason, no meta-analysis, pooled effect-size estimation, confidence-interval synthesis, sensitivity analysis, reporting-bias assessment, certainty-of-evidence grading, or formal study-level risk-of-bias assessment was conducted. Instead, study characteristics were charted descriptively to contextualize the mapped evidence. As a result, this review cannot provide definitive conclusions about the comparative effectiveness of specific VR and music intervention combinations.

Future studies should report both the VR and music components more systematically. For the VR component, this includes the type of virtual environment, degree of immersion, interaction mechanism, feedback modality, and whether the intervention uses video, serious games, virtual instruments, or other immersive systems. For the music component, this includes whether music is delivered as listening, formal music therapy, music production, rhythmic cueing, feedback, personalization, or active interaction. Future studies should also distinguish more clearly between feasibility outcomes, such as usability, engagement,

adherence, and satisfaction, and clinical outcomes, such as motor function, pain reduction, cognitive response, or stress reduction.

Safety and tolerability indicators should also be reported more systematically. This is particularly important for VR-based interventions, where cybersickness, dizziness, fatigue, sensory overstimulation, adherence, dropout, and user discomfort may affect both feasibility and clinical applicability. In addition, the inclusion of conference proceedings should be considered when interpreting the evidence base. Conference papers are valuable in a scoping review because emerging VR systems, prototypes, serious games, and interaction designs are often first reported in conference venues. However, they may provide less mature clinical evidence than full journal articles, often because of shorter reporting, smaller samples, limited follow-up, and less detailed methodological description.

At present, the substantial heterogeneity of populations, intervention designs, VR technologies, music interventions, and reported outcomes makes a rigorous effectiveness-oriented systematic review difficult to conduct. However, the growing number of studies in this emerging field suggests that such a review may become feasible in the future, once a larger and more comparable body of controlled evidence is available. Such future work could more appropriately assess intervention effectiveness, risk of bias, and the strength of evidence for specific VR and music combinations in defined health contexts.

6. Conclusions

This scoping review mapped how VR and music have been combined across health contexts, including rehabilitation, cognitive and neurodevelopmental applications, stress- and anxiety-related contexts, pain or perioperative support, and feasibility or usability studies. The included literature suggests that VR and music have been explored in relation to engagement, motivation, relaxation, motor and cognitive rehabilitation, emotional response, and user experience. However, these findings should be interpreted as mapped trends rather than as definitive evidence of clinical effectiveness, because the studies varied substantially in populations, intervention designs, VR modalities, music interventions, outcome measures, and methodological maturity.

A central finding of the review is that music is not used as a single uniform component within VR interventions. Instead, it may function as background or relaxation support, rhythmic cueing, attentional guidance, feedback, personalization, formal music therapy, music production, or active interaction. This diversity highlights the need for clearer reporting of both the VR and music components, including the therapeutic rationale, degree of user interaction, personalization strategy, safety and tolerability indicators, and outcome domains assessed.

Overall, VR and music represent promising complementary elements in health and rehabilitation interventions, but stronger and more consistently reported evidence is needed before definitive clinical recommendations can be made. At present, the heterogeneity of the field makes a rigorous effectiveness-oriented systematic review difficult to conduct. As the number of controlled and comparable studies increases, such a review may become feasible and could more appropriately assess effectiveness, risk of bias, and the strength of evidence for specific VR–music combinations in defined health contexts.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/s1>, File S1: PRISMA-ScR Checklist.

Author Contributions: Conceptualization, A.K., G.S., C.K., F.V., A.N. and K.V.; methodology, A.K. and G.S.; investigation, A.K.; data curation, A.K. and G.S.; writing—original draft preparation, A.K.; writing—review and editing, G.S., C.K., F.V., A.N. and K.V.; supervision, G.S. and C.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This research did not require ethics committee or IRB approval. This research did not involve the use of personal data, fieldwork, or experiments involving human or animal participants, or work with children, vulnerable individuals, or clinical populations.

Data Availability Statement: No new primary datasets were generated during the current study. The review was based on data extracted from previously published studies. The extracted data table and data-charting/coding scheme are available from the corresponding author upon reasonable request, according to journal requirements.

Conflicts of Interest: The authors declare no conflicts of interest.

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