forum acusticum 2026
8-12 September · Graz, Austria

SPATIAL AUDIO AND IMMERSIVE AUDIO AS MODULATORS OF THERAPEUTIC MECHANISMS – AN INTEGRATIVE LITERATURE REVIEW

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Abstract

This paper explores the therapeutic potential of Spatial Audio and Immersive Audio in the context of mental health interventions. While a broad evidence base shows that audio-based approaches, including music listening, music therapy, and other sound-based interventions, can reduce pain, anxiety, stress, depressive symptoms, and fatigue, the additional contribution of spatial reproduction remains unclear. Using an integrative narrative approach, this review synthesizes evidence from media psychology, psychoacoustics, and clinical research on the relation between therapeutic mechanisms and the perceptual and physiological effects of Spatial Audio. Across audio-only, audiovisual, and interactive VR settings, spatial reproduction can improve localization and externalization, strengthen presence, immersion, attention, imagery, and emotional engagement, and elicit measurable physiological responses. Most findings are mechanism-oriented, and few clinical studies directly evaluate the effects of Spatial Audio on therapeutic outcomes. The available evidence indicates that Spatial Audio can intensify exposure-related activation, while immersive applications incorporating spatial sound can reduce tension, anxiety, and negative mood. Spatial Audio is therefore understood as a technological contributor to Immersive Audio and a modulator of therapeutic mechanisms rather than a stand-alone treatment. Its value depends on reproduction technology, sound design, content, audiovisual context, and the intervention goal. Future research should compare equivalent interventions and combine psychoacoustic, behavioral, physiological, and clinical outcome measures.

Keywords: *immersive audio, spatial, exposure therapy, mental health*

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1. Introduction

Music and audio are already used in clinical and health-related interventions. Systematic reviews report the beneficial effects of music interventions on pain, anxiety, medication requirements, fatigue, and psychosocial outcomes in surgical and cancer care [1], [2]. These findings establish audio as a relevant intervention medium, but do not investigate whether Spatial Audio provides benefits beyond musical content or conventional reproduction.

Spatial Audio is increasingly embedded in Virtual Reality (VR), Augmented Reality (AR), relaxation tools, and interactive health applications such as SonicTonic [3]. Emerging practice examples include hospital staff-wellness rooms using Immersive Audio [4], multisensory-immersive, nature-inspired Recharge Rooms [5], and audiovisual relaxation environments used during medical procedures [6], [7]. These applications receive growing practical interest, but typically combine sound with visual scenes, lighting, interaction, and other sensory elements; their reproduction technology and the specific contribution of Spatial Audio are rarely documented or evaluated independently. Consequently, observed outcomes cannot easily be attributed to spatial rendering itself.

This review therefore focuses on a more specific question: How can Spatial Audio modulate perceptual, cognitive, affective, and physiological mechanisms on which audio- and VR-based interventions may rely? It adopts an integrative narrative approach, bringing together evidence from psychoacoustics, media psychology, VR and AR research, and clinical research. The literature was selected for its conceptual and methodological relevance. Rather than cataloguing every health application that incorporates audio, the review prioritizes studies that clarify the reproduction technology, comparison condition, or relevant mechanism.

The reviewed studies are grouped into two categories according to their primary evidential contribution: clinical and exposure-related evidence, and mechanism-oriented evidence. Clinical and exposure-related evidence includes studies that evaluate therapeutic interventions, clinical outcomes, or exposure activation in treatment-relevant settings. Mechanism-oriented evidence examines perceptual, cognitive, affective, or physiological processes that may support therapeutic effects without directly testing therapeutic efficacy. The synthesis provides an overview of the therapeutically relevant mechanisms that Spatial Audio can influence.

Where reporting permits, studies are compared by listening setting, reproduction technology, comparison condition, and outcome type, with particular attention to whether effects can be attributed specifically to spatial reproduction.

2. Technical and Therapeutic Framework

Spatial Audio denotes technologies that reproduce direction, elevation, distance, movement, and room-related information. It includes binaural rendering for headphones, channel- and object-based audio rendering for loudspeaker systems, Ambisonics, and sound-field-based approaches [8]. Binaural systems consider head-related binaural cues and commonly convolve dry audio signals with binaural room impulse responses (BRIRs) to represent reflections and reverberation in addition [9]. Static rendering can create a three-dimensional scene without responding to movement, whereas head-tracked or position-dynamic rendering updates the scene so that virtual sources remains stable and spatially anchored in the surrounding environment. Enabling natural head movement through head-tracking supports the externalization of sound sources in binaural synthesis [10], [11]. However, the audio reproduction must provide sound source stability and motion coherence, e.g. during walking [12].

In auditory VR and AR, these processes can integrate virtual sound objects into a real or virtualized environment. Rendering method, room representation, HRTF individualization, and head-tracking are separable technical dimensions and can be designed in accordance with the desired Spatial Audio experience.

Neidhardt and Zerlik [13] provide an early example of position-dynamic auditory AR. The listener's position and head orientation were tracked, while dry source signals were convolved in real time with BRIRs corresponding to the current pose to place a virtual sound source in the listener's natural environment. Without an accompanying real reference, the virtual reproduction was frequently accepted as real, particularly by inexperienced listeners. Although the study did not examine therapeutic outcomes, it demonstrates that position-dynamic binaural rendering can create plausible and interactively explorable auditory scenes. This identifies plausibility, externalization, and the spatial stability of virtual sources as relevant perceptual targets for therapeutic applications.

The term Immersive Audio is used here as the broader experiential concept: Spatial reproduction can support immersion, while content, interaction, and the wider application context also contribute to the immersive experience [14]. Wycisk et al. [15] provide an empirical basis for distinguishing immersive experience from reproduction format. They presented the same musical excerpts in mono, stereo, and binaural 3D Audio and developed the Immersive Music Experience Inventory as a validated measure of immersive listening experience. The binaural 3D Audio versions received higher immersion ratings than the corresponding stereo and mono versions. These findings support the interpretation of Spatial Audio as a technological contributor to, rather than a synonym for Immersive Audio.

Therapeutic relevance follows from the mechanisms that spatial reproduction can influence. Slater's distinction between Place Illusion and Plausibility Illusion explains why users may respond realistically to mediated events without believing that they are literally real [16]. Auditory spatialization can strengthen this coherence by locating events around the listener and linking them plausibly to a scene. Spatialized sound can increase auditory presence [17]. Meta-analytic evidence further establishes VR exposure as an effective treatment medium and shows an association between presence and anxiety activation [18], [19]. Spatial Audio may therefore alter the perceptual and affective conditions under which therapeutic learning occurs. The expected pathway is indirect: rendering first changes localization, externalization, and perceptual coherence; these changes may then influence presence, attention, and activation, which may finally affect an intervention outcome.

3. Clinical and Exposure-Related Evidence

Grimaldos et al. [20] establish the broader therapeutic context by reporting promising effects of AR exposure for anxiety and related disorders, particularly specific phobias. Some interventions included event-related sounds or auditory feedback, but reproduction was not reported in enough detail to classify it as binaural, three-dimensional, or position-dynamic. Spatial Audio was not investigated as an independent component. The review supports the therapeutic relevance of mediated exposure while leaving the contribution of audio technology unresolved.

Brinkman et al. [21] provide an early direct comparison in an anxiety-relevant virtual wasp scenario. Mono, stereo, 5.1 Dolby Headphone Virtual Surround, and static HRTF-based binaural 3D Audio were presented through the same headphones with a fixed head position. In the audio-only condition, 3D Audio increased presence, spatial perception, and discomfort compared with mono and Dolby Headphone. In visual VR, adding sound increased presence and anxiety compared with silence, but 3D Audio did not significantly outperform stereo. The study therefore indicates that spatial rendering can intensify exposure-related experience, while also showing that its added value is context-dependent. It also separates two questions that are often conflated: whether sound improves an audiovisual scene, and whether a spatial format improves it beyond stereo.

Johnston et al. [22] provide the strongest direct therapeutic evidence for the contribution of Spatial Audio over stereo sound. Autistic young people with auditory hypersensitivity received repeated exposure to individually aversive sounds within a VR serious game. Crucially, both groups listened through headphones and used head-tracking: one received head-tracked binaural Spatial Audio and the other head-tracked stereo. The between-group difference can therefore be attributed more specifically to spatial rendering. The central outcomes were self-reported emotional responses to target and non-target sounds as well as tracked interactions with exposure-based game mechanics. Negative emotional responses to target sounds decreased, voluntary interactions increased, and the reduction in negative responses was significantly greater in the Spatial Audio group. The findings show that head-tracked binaural Spatial Audio can strengthen short-term exposure training. Importantly, the technology was evaluated within the coordinated context for which it was intended: a dynamic audiovisual VR environment with repeated exposure. Larger trials should examine the durability of these effects and their generalization to everyday listening environments.

Veling et al. [23] extend the clinical evidence from exposure to relaxation. In a randomized crossover trial, psychiatric outpatients used both: VRelax, which is an application combining immersive 360-degree nature environments, interactive elements, and Spatial Audio via headphones, and standard audio-based relaxation exercises during separate ten-day periods. Both interventions improved momentary affective states, but VRelax produced a significantly greater reduction in total negative affect, with greater reductions in anxiety and sadness and a greater increase in cheerfulness. The study therefore shows that an immersive audiovisual environment incorporating Spatial Audio can produce stronger immediate affective improvements than standard audio-based relaxation exercises in psychiatric care. Because VRelax combined Spatial Audio with visual immersion and interaction, it evaluates the technology as part of an integrated clinical application rather than as an isolated treatment component.

4. Mechanism-Oriented Evidence

The following studies extend the direct and exposure-related evidence by examining therapeutically relevant mechanisms across different levels of technological and contextual complexity: from controlled comparisons of spatial and conventional reproduction to integrated immersive applications.

Hendrix and Barfield [17] provide early controlled evidence that Spatial Audio can strengthen presence in audiovisual virtual environments. Across two experiments, spatialized sound was compared first with a condition without audio and subsequently with non-spatialized sound. Spatialized reproduction increased self-reported presence, strengthened the impression that sounds originated from specific locations within the virtual environment, and enhanced the perceived realism of interaction with the sound sources. It did not increase the overall realism of the virtual environment, indicating that its effect was specifically related to auditory presence and spatial interaction. The study therefore provides direct perceptual evidence for a pathway from spatially coherent reproduction to increased presence.

Rodero and Rodríguez-de-Dios [24] isolated binaural spatialization more clearly in an audio-only experiment. Two audio stories were produced as stereo and binaurally spatialized versions without adaptation to head movement. Binaural reproduction increased narrative engagement, mental imagery, enjoyment, and information recognition. Greater heart-rate deceleration and increased electrodermal activity additionally indicated stronger attention and arousal. The combination of self-report, recognition performance, and physiological measures demonstrates across subjective, behavioral, and psychophysiological levels that binaural spatialization can intensify cognitive and affective processing relative to stereo. Because both versions used the same narrative content, this is one of the clearest mechanism-oriented technology comparisons in the reviewed evidence.

Mavridou et al. [25] examined Spatial Audio enhancement in a more complex audiovisual and interactive VR setting. Participants experienced the applications *Job Simulator* and *Escape VR* with standard VR audio and with additional spatial and timbral processing. The enhanced condition combined complex Spatial Audio rendering with additional processing of dynamics, perceived loudness, and frequency response. The comparison therefore evaluated a combined spatial and timbral enhancement rather than binaural HRTF rendering alone. Although the applications contained spatially placed sound sources, the study does not specify whether tracked HMD pose for movement-congruent rendering was used.

The enhancement improved perceived audio quality, auditory involvement, and localization in *Job Simulator*, whose sound design contained clearly localizable, object-related sources. In *Escape VR*, auditory involvement increased across the complete scenario. During a salient helicopter and bombardment event, localization also improved, while physiological changes indicated time-limited modulation of valence, arousal, and heart-rate variability. The study shows that spatial and timbral enhancement can strengthen auditory involvement, localization, and affective activation, particularly when sound sources are clearly integrated with objects and salient audiovisual events.

These individual findings are supported by the broader literature survey of Stefanowska and Zieliński [26], which reports growing evidence that selected characteristics of Spatial Audio can influence listeners' affective responses. The authors distinguish technology-oriented studies, which examine specific properties of spatial reproduction, from technology-agnostic research that treats the audio implementation as an undifferentiated component of the experience. This distinction supports the interpretation of Spatial Audio as a design variable for emotional engagement and highlights the importance of identifying the spatial parameters responsible for therapeutically relevant effects.

Greenberg et al. [27] connect Spatial Audio more directly to stress regulation through *Prelude*, a web-based application combining ambient music, movable sound objects, and an interactive visual 3D environment. After using the application, participants reported reduced tension, state anxiety, and negative mood, with particularly strong tension reductions among participants reporting anxiety or depression. The study demonstrates the applied potential of Spatial Audio as part of an immersive environment for short-term stress and mood regulation. Because *Prelude* was evaluated as an integrated application across different playback devices, future controlled comparisons can determine the specific additional contribution of its spatial reproduction.

5. Synthesis: Therapeutic Mechanisms

Across the reviewed studies, a consistent pattern emerges: Spatial Audio can strengthen perceptual, cognitive, affective, and physiological processes relevant to audio- and VR-based interventions. The evidence can be organized into four interconnected mechanism clusters.

5.1. Presence, Plausibility, and Externalization

Spatial Audio can strengthen the perceptual credibility of mediated environments by improving localization, externalization, and spatial coherence. Spatialized sound increases auditory presence and the impression that sounds originated from specific locations in a virtual environment [17]. Binaural Spatial Audio receives higher immersion ratings than the corresponding stereo and mono versions [15]. In binaural synthesis, head-tracking and natural head movement support the externalization of virtual sound sources [10], [11] and position-dynamic BRIR-based rendering can create plausible and spatially stable virtual sources [12], [13]. Together, these findings indicate that spatially coherent reproduction can support presence and plausibility by embedding auditory events consistently within the surrounding environment.

5.2. Attention, Imagery, and Affective Activation

Spatial reproduction can also intensify cognitive and affective processing. Static binaural spatialization increases narrative engagement, mental imagery, enjoyment, and information recognition compared with stereo [24]. Heart-rate deceleration and electrodermal activity additionally indicated stronger attention and physiological arousal. In interactive VR, Spatial Audio improves auditory involvement, audio quality, and localization, together with event-related physiological changes [25]. Benefits were particularly evident when sound sources were clearly linked to objects and salient audiovisual events. These findings are consistent with a broader survey [26], which identifies Spatial Audio as a relevant design variable for listeners' affective responses.

5.3. Exposure Activation and Therapeutic Learning

Within exposure-based interventions, stronger presence, salience, and affective activation can increase engagement with therapeutically relevant stimuli. In Brinkman et al.'s audio-only condition, binaural 3D Audio increased presence, spatial perception, and discomfort compared with mono and Dolby Headphone 5.1 [21]. Johnston et al. [22] extended this mechanism into repeated therapeutic exposure: head-tracked binaural Spatial Audio produced greater reductions in negative emotional responses to aversive sounds than head-tracked stereo. Together, these studies suggest that Spatial Audio can both intensify exposure-related activation and, when incorporated into repeated exposure training, support beneficial short-term emotional learning.

5.4. Relaxation and Stress Regulation

Spatial Audio and 3D Audio have also been incorporated into applications designed to reduce negative affect and support relaxation. Veling et al. [23] found that VRelax, which combined immersive 360-degree nature environments, interactive elements, and 3D Audio via headphones, produced greater immediate reductions in total negative affect than standard audio-based relaxation exercises. Greenberg et al.'s interactive Spatial Audio application was associated with reduced tension, state anxiety, and negative mood, with particularly strong tension reductions among participants reporting anxiety or depression [27]. These findings show that immersive applications incorporating spatially organized sound can support affect regulation as well as exposure-related activation.

The variation across studies shows that the effects of Spatial Audio are shaped by its technical implementation, sound design, content, and application context. Static binaural reproduction already influenced attention, imagery, and arousal [24], while head-tracked and position-dynamic rendering additionally supported externalization, spatial stability, and interactive exploration [10], [11], [13]. The same capacity to increase perceptual coherence and engagement can therefore support different therapeutic goals, from controlled activation during exposure to affect regulation in restorative environments. Spatial Audio should not be understood merely as a reproduction format, but as a design framework through which sound sources, movement, environment, and intervention goals can be perceptually coordinated.

6. Research Gaps

Despite these promising findings, the available evidence does not yet determine which Spatial Audio implementations are most effective for particular therapeutic mechanisms and intervention goals. Spatial Audio is often embedded in complex audiovisual applications, while reproduction technology, movement adaptation, and room-related processing are insufficiently documented or not evaluated independently.

Bosman et al.'s review of 121 studies, including 21 in therapeutic contexts, confirms the broad relevance of audio for HMD-based VR [28]. Audio consistently increased perceived realism, while pleasantness was strongly influenced by the auditory environment and natural soundscapes were generally evaluated positively. Effects on presence were more variable. Because comparisons between different audio technologies were excluded from the review's outcome synthesis, the specific additional contribution of Spatial Audio remains an important research question.

Future research should therefore build directly on the positive findings identified here. Controlled studies should compare otherwise equivalent interventions using Spatial Audio and conventional reproduction and should examine which technical properties most effectively support specific therapeutic mechanisms. This requires a more differentiated evaluation of static and position-dynamic rendering, generic and individualized HRTFs, room-related rendering, loudspeaker- and headphone-based reproduction. Combining subjective experience with behavioral, physiological, and clinically relevant outcomes will clarify how Spatial Audio can be designed most effectively for exposure, stress regulation, relaxation, and other therapeutic applications.

7. Conclusion

The reviewed evidence supports Spatial Audio as a powerful technological modulator of therapeutically relevant mechanisms. Across audio-only, audiovisual, and interactive VR settings, spatial reproduction improved localization and externalization, strengthened presence, attention, imagery, and emotional engagement, and produced measurable physiological responses. In exposure-related applications, it intensified engagement with aversive stimuli and, in the most direct therapeutic comparison, produced greater reductions in negative emotional responses than head-tracked stereo. Spatial Audio and Immersive Audio have also been successfully integrated into applications associated with reduced tension, anxiety, and negative mood.

Its therapeutic value arises from the ability to coordinate auditory space, sound design, movement, and intervention context. Spatial Audio can therefore support different therapeutic goals: it can increase salience and activation where engagement with difficult stimuli is required, while also contributing to coherent and restorative environments for stress regulation and relaxation. The available findings provide a strong foundation for controlled, technology-specific clinical research and for the systematic development of Spatial-Audio-based health interventions.

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