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Effects of Sound Interventions on the Mental Stress Response in Adults: A Scoping Review

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Abstract

Background: This scoping review explores the effects of various sound interventions, including music, natural sounds, and speech, on stress response in adults.

Objective: The review identifies key therapeutic factors, including sound type, individual listener characteristics, and environmental factors. As part of our review, we synthesize evidence of the body's response to sound interventions and highlight current research gaps.

Methods: A systematic search was conducted using databases such as PubMed, Web of Science, Scopus, and PsycINFO, focusing on studies from 1990 to the present. Eligible studies included randomized controlled trials, clinical trials, and laboratory experiments that measured stress through physiological markers (e.g., heart rate variability, cortisol) and self-reports. Data from 34 studies were included, and thematic analysis was conducted to categorize the factors influencing the effectiveness of sound interventions.

Results: Findings suggest that music, especially classical and self-selected pieces, effectively reduces physiological stress markers, including heart rate variability, blood pressure, and cortisol levels. Non-musical sounds, such as nature sounds and calming voices, also demonstrate stress-relief potential, though research in this area is less comprehensive. While most sound interventions demonstrated positive effects, some studies reported adverse responses, suggesting that sound can induce stress as much as mitigate it. The outcomes were significantly affected by context factors, such as personal preferences, delivery methods, cultural context, etc., which emphasizes the importance of personalized interventions.

Conclusions: Sound interventions offer promising non-invasive methods for stress reduction. This review suggests a future focus on addressing the gaps in research on non-musical sound interventions and further investigation of the neural mechanisms underlying stress responses to sound.

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Original Manuscript

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Protocol Registration:
The review protocol has been published with the international registered report identifier (irrid): DERR1-10.2196/54030.

Keywords:
stress; mental stress; anxiety; sound therapy; music therapy; psychoacoustics; expressive sounds; stress reduction; stress management; stress relief; stress markers; relaxation; personalized therapy

Introduction

Sound plays a fundamental role in human life, influencing communication, emotional regulation, and environmental awareness. Beyond its basic functions in speech and music, sound can modulate psychological and physiological states [01, 02]. Auditory stimuli, including natural sounds, music, and human voices, have been shown to evoke a range of emotional responses and affect stress levels [03]. Recent research has explored the therapeutic potential of sound-based interventions, particularly in managing stress and promoting relaxation [04]. Much evidence documented sound integrative impact on the psycho-emotional and physiological outcomes, which makes it helpful for treating stress-related conditions, such as pain syndromes or anxiety [05, 06, 07,].

Music and music therapy

Sound therapy techniques have gained prominence over the past decades, with a significant emphasis on music as a primary form of sound stimulation. One of the early definitions of music describes it as "*humanly organized sound*" [08], but there are several alternative perspectives debating this definition [09]. For example, M. Taut proposed to consider music as a complex, time-ordered, and rule-based sensory language [10]. Similar to language, music constitutes a universal part across all human cultures, made up of individual sounds that are structured and layered [11]. The healing effects of music on the mind and body resonate with ancient cross-cultural beliefs [12]. Nowadays, music therapy incorporates various elements of music, such as melody, rhythm, tempo, dynamics, and pitch, along with activities like songwriting, improvisation, and singing, to promote patients' physical and mental well-being.

Non-musical sound therapies

Despite the widespread popularity of music, evidence indicates that other sound types, including natural noises, chanting and speech, can also exert therapeutic effects. For example, listening to poetry has been shown to alleviate symptoms of anxiety and stress [13, 14, 15]. Moreover, in various therapeutic frameworks, the quality of communication is often considered a crucial factor. The effectiveness of treatment hinges not only on the specific technique or theoretical knowledge but also on the establishment of a trusting and intimate rapport between the client and the therapist. Ackerman and Hilsenroth indicate that human-rated factors such as warmth, interest, and curiosity contribute positively to the development of a strong therapeutic alliance [16]. Therapists use different vocal styles depending on the session's phase, aligning their voice to meet the emotional and therapeutic needs of the interaction [17]. However, distinguishing the impact of content from that of speech acoustics in poetry or therapeutic conversations presents a challenge. A comprehensive understanding of the factors that contribute to the therapeutic influence of sound remains to be elucidated.

Mechanisms of sound therapy

The theoretical foundation of how sound interventions can yield therapeutic change and positive outcomes encompasses multiple levels, with the most prominent factor being the learned cognitive response shaped by cultural context [18].

Four-level model

Clements-Cortés and Bartel proposed a four-level model, suggesting that sound can trigger a response due to a set of learned associations that vary from person to person. A particular tone or sound can activate meaningful memories and evoke emotions associated with recalled events [18]. This phenomenon, known as music-evoked autobiographical memory recall, activates related brain networks, potentially inducing shifts in mood and emotional responses [19]. Other responses to sounds are closely linked to our inborn perceptive patterns. Music, characterized by organised vibrations and rhythms, reflects early learned responses. This forms the foundation of our reactions to music — fast music feels exciting, while slow music feels calming. Similarly, louder sounds are associated with strength and boldness, while quieter sounds seem weaker and softer [18].

These principles extend to non-musical sounds: slower tempo-rhythmical structure, such as a gentle voice or soft breeze, can feel calming, while faster or louder sounds, like a storm and thunder, can create higher arousal, excitement or urgency [20,21]. In addition to inborn and early learned responses, situational emotional learning also shapes sound perception. Bliss-Moreau, Barrett, and Owren demonstrated that voices can gain emotional meaning through past experiences, influencing how quickly participants respond to emotionally charged words based on their prior associations [22].

Levels 3 and 4 of the Clements-Cortés and Bartel model encompass responses to sound that are not the result of cognitive processing or learning, but rather occur at a vibrational, rhythmic structure. Level 3 focuses on neural oscillatory coherence, where neurons fire in synchrony in response to rhythmic stimulation of the senses (auditory, visual, tactile), which can lead to various beneficial effects. Level 4 suggests that music and sound can activate mechanisms at the cellular level, potentially influencing everything from neurons to bone and blood cells [18]. Michael Thaut indicates that the brain responds to sound rhythms through involvement, where the listener's mood aligns with the emotional context conveyed in the sound. This occurs due to acoustic resonance, where the brain naturally synchronizes with the rhythm stimuli [23].

Role of context and common therapeutic factors

In practical applications, it is crucial to consider collateral factors that influence the perception of sound. The effectiveness of music as an art therapy method also depends on the surrounding environment and common factors applicable across creative therapies. These factors include being present in the moment, experiencing a predictable environment, feeling personally connected, developing social skills, finding meaning, feeling motivated, experiencing emotional release, and being actively engaged. Music therapy enhances therapeutic alliance and group processes through playful interactions, shared experiences, musical attunement, synchronicity, and dialogue. Musical engagement also modulates one's sense of time and space, fostering a state of flow or providing distraction from stress-inducing thoughts [24]. Another framework for understanding how any therapy, including music therapy, facilitates positive changes is the Mediator and Moderator model [25, 26]. This model takes into consideration external factors that affect the strength or direction of the relationship between treatment and the outcome. Moderators may include client or therapist characteristics (e.g., gender, ethnicity, experience), the format of the treatment (individual vs. group, in-person vs. online), or the treatment frequency (once vs. twice a week) [27, 28].

Objective and contribution of this review

This scoping review aims to analyze literature on sound interventions targeting stress response and stress related conditions in adults in laboratory experiments, clinical trials and randomized controlled trials (RCT). We also aim to identify sound interventions that have not been sufficiently studied and require further investigation.

We incorporated investigations focusing on responses of the hypothalamic-pituitary-adrenal (HPA) axis and the autonomic nervous system (ANS) as indicators of stress, supplemented by self-reported data and introspective surveys as markers of emotional stress. Our primary outcome of interest is the neural mechanisms underpinning the therapeutic influence of sound. Also, we are interested in the comparison of delivery methods and sound sample choices for understanding the therapeutic factors of sound for stress reduction.

This study marks a conceptual shift in research of sound therapeutic effects by moving beyond music-focused framework to consider non-musical acoustic interventions using human voices or environmental sounds. This broader perspective opens new possibilities for stress management strategies. By highlighting how diverse sounds can serve for therapeutic changes, this review encourages future studies to explore non-musical sounds more rigorously, and investigate how personal, cultural or environmental contexts can interact with various sound types.

Moreover, this shift is expanding sound therapeutic potential to services like classical therapeutic methods that use speech and conversation as primary tools. For instance, it is possible consider the impact of vocal acoustics, such as tone or rhythm, within psychotherapy sessions to enhance emotional attunement and therapeutic alliance.

Additionally, this concept can become a basis for the new technological development. It is possible to bring into the light, track and analyse vocal elements in real time, allowing therapists to adapt their approach based on the client's stress markers. Environmental sound tracking also holds potential for improving well-being, as ambient soundscapes could be monitored and adjusted to promote relaxation for everyday environments. This broader perspective encourages innovative approaches that personalize sound to individual needs.

Methods

The objectives, inclusion criteria and methods of analysis for this review were specified and documented in a protocol [29].

Research questions

This scoping review was guided by the Population-Concept-Context (PCC) framework, recommended for constructing clear objectives and eligibility criteria in scoping reviews [30]. The PCC framework in this study focuses on the population of interest (adults experiencing stress), the concept (therapeutic sound interventions), and the context (various settings in which sound interventions are applied for stress reduction). Through careful refinement, we formulated the following research questions (RQs) to guide the entire review process:

- **RQ1:** What are the therapeutic factors of sound in the case of reducing stress response and stress-related conditions in human adults? For instance, it might be rhythm, sentiment, environmental context, personal preferences or background, etc.

- **RQ2:** The secondary research questions will clarify body responses (physiological effects measured by biomedical technologies and devices), associated with sound interventions in stressful conditions.

Search strategy and query string

This scoping review employed a systematic search strategy across four key medical and interdisciplinary databases: PubMed, Web of Science, Scopus, and PsycINFO (or EBSCOhost). As far as the neurobiology of music and sound therapy emerged as a separate field in the 1990s, the search strategy covers the research from 1990 till the present day. The search aimed to capture studies addressing the effects of sound interventions, such as music therapy and guided relaxation, on stress reduction in adults. The complete query string formulated for this purpose was as follows: "(stress OR anxiety OR relax*) AND ("sound therapy" OR "music therapy" OR "guided relaxation" OR "guided meditation" OR hypno* OR ASMR OR MBSR) AND (prosody OR song OR poetry OR voice OR paralinguistics OR paralanguage) NOT (children OR infants OR animal OR teen)."

Using the operator "AND" we combined three key fields to comprehensively capture relevant literature. (1) Mental Stress or Relaxation Indicators: Terms like "stress," "anxiety," and "relax*" were included to identify studies focused on both stress-related conditions and relaxation as therapeutic outcomes. (2) Sound-Based Interventions: This field targeted interventions where sound is essential, encompassing “sound therapy,” “music therapy,” “guided relaxation,” “guided meditation,” “hypno*,” “ASMR,” (Autonomous Sensory Meridian Response) and “MBSR” (Mindfulness-Based Stress Reduction). (3) Voice and Paralinguistic Elements: We included terms such as “prosody,” “song,” “poetry,” “voice,” “paralinguistics,” and “paralanguage” to capture studies examining the acoustic characteristics of speech and natural language as therapeutic components. The exclusion criteria were applied using the “NOT” operator to filter out studies on children, infants, animals, and adolescents, ensuring a focus on adult populations.

This structured approach aims to capture a comprehensive range of studies, not only focusing explicitly on sound-based therapies but also those involving therapeutic aspects of speech and vocal elements. By broadening the scope in this way, we aim to explore potential blind spots in sound therapy research, particularly in the therapeutic roles of natural speech and paralinguistic features alongside traditional music-based interventions.

Study selection

The process of how citations and full-text reports reviewed, included, and excluded is shown in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Flow Diagram (Figure 1). The first author, a clinical psychologist, led all aspects of the review, including literature search, extraction, screening, and data analysis. The second author, a psychology researcher, assisted in the literature search and extraction and performed screening independently. Disagreements were resolved through discussion and consensus with other authors of the research consortium.

A two-step process was followed for study selection. First, we screened citation titles, abstracts, and keywords, classifying each citation as “include,” “exclude,” “unclear,” or “duplicate.” In the second step, full-text reports for citations marked “include” and “unclear” were reviewed to make a final decision on inclusion or exclusion. Reference management and screening were conducted in Rayyan, a web-based application for systematic review management. Inclusion and exclusion criteria presented in tables 1 and 2 respectively. These criteria ensure a focused review on adult populations using diverse passive sound interventions for stress relief, with an emphasis on studies providing measurable physiological data.

Figure 1. PRISMA flow chart

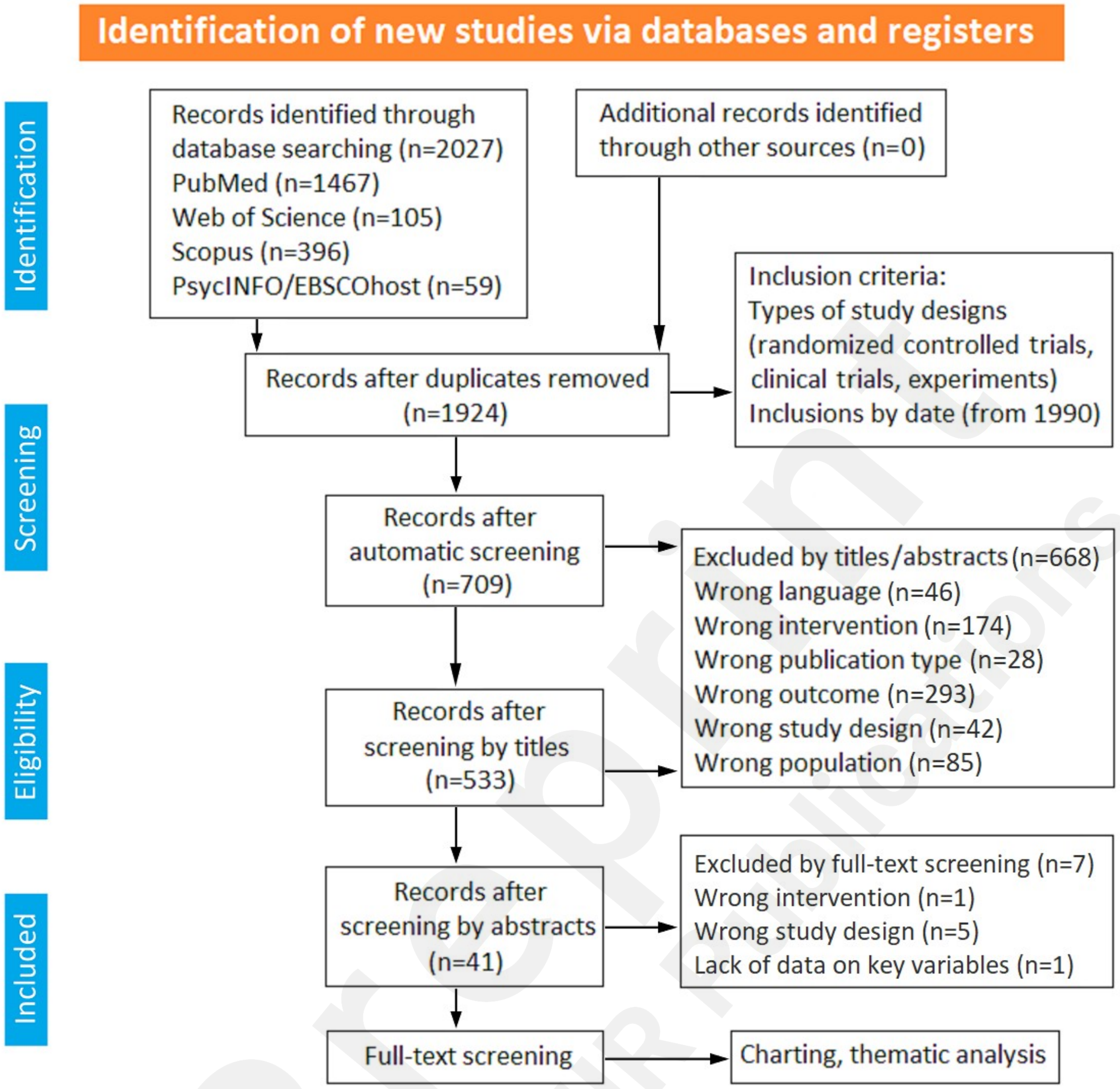

Table 1. Inclusion criteria

Criteria	General description	Detailed examples
Population	Human adults, exposed to stress-related conditions. Both clinical and healthy populations	Anxiety, reactive depression, crises and emergency cases, grief, loss, basic needs deprivation, burnout, occupational hazards
		Experimental stress
Intervention type	All types of passive sound interventions	Listening to instrumental music, songs, poetry, human voices, and nature sounds
		Sound-based therapies, including music therapy, acoustic stimulation during relaxation, meditation, and hypnotic induction
Outcome measurements	Studies that assess stress-relief effects through physiological measures	e.g., heart rate variability, salivary cortisol, electrodermal activity, neuroimaging markers
	Studies that combine both physiological measurements	e.g., perceived stress scale, state anxiety inventory, Beck's anxiety inventory

	and self-reported stress levels	
Study design	Randomized controlled trials	
	Clinical trials	
	Laboratory experiments	
Publication type	Peer-reviewed original research articles published in English	

Table 2. Exclusion criteria

Criteria	General description	Detailed examples
Population	Participants under 18 years of age	
	Animals	
	Individuals with hearing disabilities	
Health conditions	Conditions for which stress is not the original cause	Pain syndromes
		Psychotic episodes
		Chronic neurological disorders, such as Alzheimer's or Parkinson's disease
		Age-related cognitive changes
		Autism spectrum disorders
		Tinnitus, Hyperacusis
Outcome measurements	Studies relying solely on questionnaires or self-reports without physiological measurement data	
Intervention type	Active sound interventions, including improvisation, music composition, drumming, singing, poetry writing or chanting, etc.	
	Mixed interventions when sound combined with other non-related therapeutic interventions such as aromatherapy, massage, etc.	
	Mono interventions: studies in which sound (usually an unclearly defined piece of music) represented the only intervention, and the absence of sound represented the comparator	

Data extraction

After initial screening according to the chosen criteria, two reviewers independently evaluated the full-text articles. Key information was summarized in tables 3 and 4 and included the following items:

1. Authors & year of publication - indicating the first author and publication year.
3. Country of origin - specifying the country where the study was conducted
4. Concept - specifying the main idea and hypothesis of the study
5. Population - specifying the sample size and population type (e.g., nurses, students, patients with specific diagnosis, etc.).
6. Study type - for instance, randomized controlled trials, clinical trials, or laboratory experiments.
7. Intervention type (groups)- indicating the type of sound stimulation as described in the article (e.g., music, voice, nature sounds, etc.). In most cases, the separation of participants into groups is based on the intervention. This is where we get information about both the types of sound interventions and the participant grouping.
8. Outcomes and measurements - specifying the target condition or issue that the sound stimulation aims to impact, and how it was measured including both physiological measures and self-reports of subjective experience (e.g., measurements of stress hormones, heart rate variability, anxiety scale,

emotional state questionnaires etc.).
9. Key findings related to the scoping review questions - indicating the primary results, such as clinical outcomes, body-mind responses, effectiveness, etc.

Thematic Analisys Method

The thematic analysis for this scoping review followed Braun and Clarke's reflexive thematic analysis framework [31], employing an inductive approach to identify key therapeutic factors of sound interventions on stress reduction. The analysis began with a familiarization phase, in which the first two authors thoroughly reviewed and familiarized themselves with the data extracted from each included study. This initial stage focused on understanding the study concept and intervention types.

Following familiarization, an open coding process was conducted across the entire dataset, centering on essential elements such as sound characteristics, and individual outcomes. This coding identified basic elements like music styles, sentiment, basic physical elements (rhythm, frequency), environmental context, and personal context as core factors within the data. Related codes were then grouped into preliminary categories, organizing the themes based on factors influencing the effectiveness of sound interventions. Three broad categories emerged from this process: (a) *Sound per se*, capturing sound characteristics independent of the listener; (b) *Personal Factors*, which focused on listener-dependent characteristics, including musical education, cultural background, personal preferences, and stress history; and (c) *Environmental Factors*, covering aspects of sound delivery, such as live versus recorded sound, use of headphones or broadcast sound, and interactions with medical staff or researchers during the session.

Within the category of *Sound per se*, which proved to be the most widely researched, nine sub-categories were developed to reflect specific sound types and qualities. The first three of them (I-III) related to music, including different styles, sentiment (such as cheerful versus sad music), and elementary characteristics (such as tempo-rhythm), the next three (IV-VI) outlined non-musical sounds (e.g. white noise, nature sounds, and human voices), and three others (VII-IX) related to the comparison of musical and non-musical sounds. Initially, the category "Environmental Context" included sub-categories like "live vs. recorded sound" and "presence of supportive personnel," while "Personal Preferences" encompassed elements like "music genre" and "cultural background." At the same time, due to the modest number of articles assigned to these themes, we decided not to overload the chart and did not include these subcategories in the final edition. In addition, it was important for us to add three extra categories for outcomes that were out of the main pattern or for negative outcomes. These were mixed samples ("mix"), relaxing effects of the absence of sound ("0"), and negative, stressful sound effects ("-").

During the thematic refinement stage, categories and sub-categories were iteratively adjusted through regular team discussions and codebook updates, enhancing internal coherence and consistency across the themes. As the thematic map took shape, each category was further refined and defined to ensure clarity and distinctiveness. This thematic framework not only provided a structure for categorizing therapeutic factors and mechanisms of sound interventions but also revealed patterns in the literature and highlighted gaps for future research. As shown in the Results section, some categories have little research, suggesting areas for future studies. We found that in most of the studies reviewed, the hypotheses and groupings were based on the type of sound intervention. This means that the groups typically reflect the type of sound being tested. In some cases, there were more than two types of sounds. If the categorization was unclear or debated, we referred to the study's concept and research question to identify the primary focus of authors. For instance, if a study had three groups, 'cheerful music,' 'sad music,' and 'white noise', we would place it in the 'musical sentiment' sub-category, since the study's focus is on musical emotion rather than comparing music to non-musical sounds."

Results

The systematic database search obtained 2027 records. After removing duplicates, 1924 records remained for further review. Screening of titles and abstracts led to the exclusion records that did not meet the chosen criteria, such as unsuitable languages, inappropriate outcomes, interventions, etc. Full-text review of the remaining 41 records revealed that 7 did not meet the inclusion criteria due to various reasons, including wrong intervention (n=1), wrong study design (n=5) and lack of data on key variables (n=1). Finally, a total of 34 studies were considered eligible for inclusion in the analysis. These studies were randomized controlled trials (n=22), experiments (n=9), and pilot studies (n=3). The search process is outlined in the PRISMA flowchart (Figure 1).

Table 3. Overview of the included studies by country of origin, concept, population and study type

	Author, year	Country	Concept	Population	Study type
1	Umemura, M, 1998 [… 32]	Japan	Classical music may promote relaxation by influencing heart rate variability compared to rock music or noise.	6 university students, age 21 - 26	Experimental study
2	Chafin, S, 2004 [… 33]	USA	Listening to classical music may improve blood pressure recovery after a stressful task compared to silence or other music styles.	75 healthy participants	Experimental study
3	Labbé, E, 2007 [34]	USA	Listening to classical or self-selected relaxing music reduces anxiety, anger, and physiological arousal after stress compared to heavy metal music or silence.	56 college students	RCT
4	Uğraş, GA, 2018 [35]	Turkey	All types of music can reduce preoperative anxiety, with Classical Turkish music being the most effective.	180 patients undergoing surgery	RCT
5	Gulnahar, Y, 2020 [36]	Turkey	Listening to music reduces anxiety during dental implant surgery, with Turkish music and classical music potentially being most effective.	80 dental implant surgery patients, age 40 - 70	Prospective, observational RCT
6	Paszkiel, S., 2020 [37]	Poland	Relaxing music and Autonomous Sensory Meridian Response music may reduce stress levels faster than silence or rap music. Rap music may even worsen stress compared to silence.	9 healthy females, age 22	Pilot study
7	Hirokawa, E, 2003 [38]	Japan	High-uplifting and low-uplifting music may have different effects on immune function, neuroendocrine responses, and emotional states after a stressful task.	18 Japanese college students	Experimental study
8	Sokhadze, EM, 2007 [39]	USA	Both pleasant and sad music may improve physiological recovery after stress (viewing stressful images) compared to white noise. White noise may not enhance recovery.	29 healthy subjects	Experimental study
9	Suda, M, 2008 [40]	Japan	Major mode music reduces stress more than minor mode music.	10 graduate students	Experimental study
10	Wiwatwongwana, D, 2016 [41]	Thailand	Music may reduce anxiety in patients undergoing cataract surgery. Binaural beat audio may offer additional benefits over music alone.	141 patients undergoing cataract surgery under local anesthesia	Prospective, double-blind RCT
11	Opartpunyasarn, P, 2022 [42]	Thailand	Binaural beat audio may reduce anxiety in patients undergoing fiberoptic bronchoscopy compared to plain music or no music.	112 patients undergoing fiberoptic bronchoscopy	Prospective RCT
12	Lee-Harris, G, 2018 [43]	UK	Meditative Binaural Music may be effective for relaxation, with effects potentially differing by age.	30 (15&15) subjects, age 18 – 25 & 50 – 80	RCT
13	Gantt, MA, 2017 [44]	USA	Binaural beat technology (theta waves) embedded in music may be more effective than music alone in reducing cardiovascular stress response in military personnel with post-deployment stress.	74 military service members with post-deployment stress	Double-blind RCT
14	Calamassi, D, 2022 [45]	Italy	Listening to music at 432 Hz and at 440 Hz may reduce anxiety and stress biomarkers, compared to a no-music control group.	54 emergency nurses	Double-blind RCT
15	Sharma, S, 2021 [46]	India	Indian classical music with incremental tempo and octave variations promotes better anxiety reduction.	21 male undergraduate medical students	Crossover RCT
16	Singh, VP, 2009 [47]	India	Both music and progressive muscle relaxation are effective in reducing anxiety and dyspnea in hospitalized COPD patients. Music may be more effective than PMR for reducing anxiety.	72 hospitalized COPD patients with recent exacerbation	RCT
17	Tang, HY, 2009 [48]	USA	Audio relaxation programs may be effective for short-term blood pressure reduction in older adults, potentially more effective than listening to Mozart.	41 older adults	RCT
18	Lin, MF, 2011 [49]	Taiwan	Music therapy and verbal relaxation are effective in reducing anxiety induced by chemotherapy.	98 patients with cancer under chemotherapy	RCT
19	Lee, EJ, 2012 [50]	Germany	Both monochord sounds and progressive muscle relaxation can reduce anxiety and improve relaxation during chemotherapy.	40 patients with gynecologic cancer under chemotherapy	RCT
20	Warth, M, 2016 [51]	Germany	Live music therapy may be more effective than a pre-recorded mindfulness exercise in improving cardiovascular health for terminally	84 palliative care patients	RCT

			ill patients through its influence on the autonomic nervous system.		
21	Koehler, F, 2022 [52]	Germany	Music therapy may be more effective than mindfulness in reducing subjective distress in palliative care patients. Both interventions may reduce stress biomarkers.	104 palliative care patients	RCT
22	Radstaak M, 2014 [53]	Nether-lands	Listening to self-chosen relaxing or happy music after stress may improve mood but delay systolic blood pressure recovery.	123 healthy subjects	Experimental study
23	Leardi, S, 2007 [54]	Italy	Music therapy, especially patient-selected music, may reduce stress response during day surgery compared to no music.	60 patients undergoing day surgery	RCT
24	Miller, M, 2010 [55]	USA	Music may influence endothelial function, potentially improving vascular health.	10 healthy subjects, average age 35.6	Crossover RCT with counterbalancing
25	Imbriglio, TV, 2020 [56]	Canada	Guided music listening with relaxing music or a participant's favorite music may decrease muscle activity and bruxism episodes in chronic myalgia, while stressful music may increase them.	14 women with chronic myalgia & 15 pain-free women	Experimental study
26	Gelatti, F, 2020 [57]	Italy	Live harp music may be more effective than recorded harp music in reducing preoperative stress, fear, heart rate, and blood pressure.	46 patients undergoing day surgery	Pilot, quasi-experimental study
27	Bro, ML, 2019 [58]	Denmark	Live music may reduce anxiety during chemotherapy compared to pre-recorded music or standard care.	143 newly diagnosed lymphoma patients	Multi-center RCT
28	Lee, KC, 2011 [59]	Taiwan	Both headphones and broadcast music can effectively reduce preoperative anxiety in adult surgical patients.	167 patients undergoing surgery without premedication	RCT
29	Kumari, 2023 [60]	India	Broadcast and headphone music playing may vary anxiety-relieving effect for patients awaiting surgery.	150 healthy subjects	Experimental study
30	Lai, HL, 2012 [61]	Taiwan	Music intervention with a nurse present is more effective than recorded music alone for improving psycho-physiological health in cancer patient caregivers.	34 female cancer patient caregivers	Crossover RCT
31	Janelli, LM, 2004 [62]	USA	Listening to preferred music may reduce negative behaviors in physically restrained patients.	30 physically restrained patients, age 65-93	Pilot study
32	Kang, JG, 2008 not founf yet [63]	South Korea	Blocking noise, but not music, reduces bispectral index scores during propofol sedation in noisy operating rooms.	63 patients undergoing total knee replacement surgery, age 55 - 75	Prospective, single- blind RCT
33	Tsivian, M, 2012 [64]	USA	Music with headphones may reduce pain perception and anxiety during prostate biopsy compared to control or headphones alone.	88 men undergoing transrectal ultrasound prostate biopsy	Prospective RCT
34	Gingras B, 2014 [65]	Austria	Repetitive drumming with shamanic instructions may affect subjective experiences and cortisol levels compared to instrumental meditation music.	39 subjects inexperienced in shamanic journeying	Experimental study

Thematic Analysis Results

Thematic analysis of the included studies revealed several key factors contributing to the effectiveness of sound interventions. These factors can be categorized into three main categories: sound per se, personal factors, and environmental factors (Figure 2).

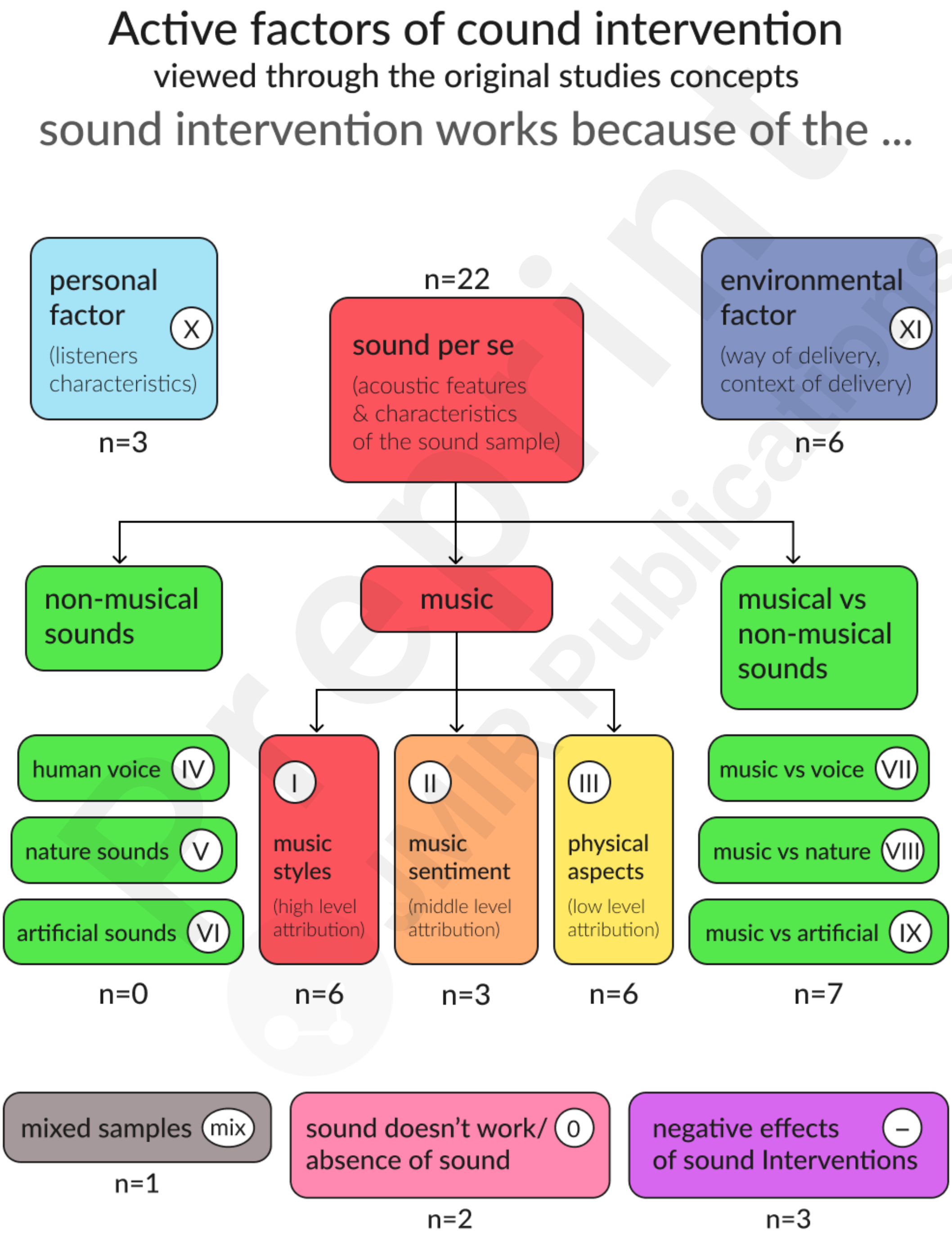

Figure 2. Thematic analisys results

Majority of the identified articles focused on the characteristics of sound per se (n=22). For example, studies investigating music interventions often explored different music styles (n=6), music sentiment (n=3), and physical aspects such as frequency or tempo (n=6).

Regarding non-musical sounds within our predefined inclusion criteria, we found publications comparing musical interventions with a variety of voice-assisted interventions (n=7). However, no studies were found that focused narrowly on non-musical sounds for stress-relief in adults, or comparing different sound characteristics beyond the concept of musical intervention.

Within the personal factors category, listener characteristics (n=3) were identified as influencing intervention outcomes. Environmental factors, such as the way of delivery and context of delivery, were also considered (n=6).

Additionally, the analysis identified a small number of studies (n=1) that explored mixed samples of sounds, and a few that shifted their focus from sound to silence (n=2) or reported negative effects of sound intervention (n=3).

Information on key findings for comparing the effectiveness of different sound intervention factors is summarized in Table 4.

Table 4. The effects of sound interventions

	Author, year	**Interventions (groups)**	**Category**	**Outcomes (measurments)**	**Key findings**
				Sound per se – music styles	
1	Umemura, M, 1998	(1) Classical music, (2) Rock music, (3) Noise, (4) Rest.	I	Heart rate variability (Mayer Wave related Sinus Arrhythmia (MWSA) and Respiratory Sinus Arrhythmia (RSA) components) and subjective comfort levels (psychological evaluation).	Classical music reduced variability in heart rate components (MWSA and RSA) compared to rest, suggesting a potential relaxation effect. Rock music and noise increased MWSA and decreased RSA, potentially indicating a stress response. Subjectively, classical music was associated with comfort, while rock music and noise were associated with discomfort. Changes in MWSA correlated with comfort levels, suggesting a link between heart rate variability and perceived comfort.
2	Chafin, S, 2004	(1) Classical music, (2) Jazz music, (3) Pop music, (4) No sound (control).	I	Systolic blood pressure measured pre- and post- stressful task.	Listening to classical music resulted in significantly lower post-task systolic blood pressure compared to silence. Other music styles did not show significant benefits for blood pressure recovery.
3	Labbé, E, 2007	(1) Classical music, (2) Self-selected relaxing music, (3) Heavy metal music, (4) No sound (control).	I	Emotional state (anxiety and anger) and physiological arousal (pre- and post-intervention)	Listening to self-selected or classical music significantly reduced negative emotions and physiological arousal compared to heavy metal music or silence.
4	Uğraş, GA, 2018	(1) Turkish classic music, (2) Western music, (3) Natural sounds, (4) No sound (control).	I	State-Trait Anxiety Inventory (STAI-S) for anxiety, Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Heart Rate (HR), and Cortisol levels measured pre- and post-music intervention.	All music types significantly reduced anxiety (STAI-S), systolic blood pressure (SBP), and cortisol levels compared to pre-intervention. Natural sounds reduced diastolic blood pressure (DBP), and Classical Turkish music showed the most significant reductions in DBP and HR. All music was effective in reducing preoperative anxiety, with Classical Turkish music being the most beneficial.
5	Gulnahar, Y, 2020	(1) Turkish Classic music, (2) Classical music (Vivaldi), (3) Slow rock music, (4) No sound (control).	I	Pre- and post-intervention anxiety using the Corah's Dental Anxiety Survey, blood pressure, heart rate, and oxygen saturation.	All music groups showed reduced anxiety compared to controls. Turkish music and classical music were significantly more effective in anxiety reduction compared to slow rock music.
6	Paszkiel, S., 2020	(1) Rap music, (2) Relaxing music, (3) ASMR music. (4) No sound (control).	I —	(1) Electroencephalography (EEG) - alpha wave activity, (2) Blood pressure, (3) Heart rate, (4) Subjective stress perception questionnaires.	Relaxing music and ASMR reduced stress level faster than silence. Rap music increased stress level compared to silence.
				Sound per se – music sentiment	
7	Hirokawa, E, 2003	(1) High-uplifting music, (2) Low-uplifting music, (3) No sound (control).	II —	(1) Salivary secretory IgA (S-IgA) level, (2) Active natural killer (NK) cell level, (3) T lymphocyte subsets (CD4+, CD8+, CD16+), (4) Dopamine, norepinephrine, and epinephrine levels (pre- and post-intervention),	Results were inconclusive, but trends suggested: (1) Low-uplifting music may increase feelings of well-being, (2) High-uplifting music may increase norepinephrine and liveliness, decrease depression, (3) Silence may decrease active NK cells. Music classification is important for understanding music's influence on these responses.

				(5) Emotional state questionnaires (pre- and post- intervention).	
8	Sokhadze, EM, 2007	(1) Subjectively pleasant music, (2) Sad music, (3) White noise, (4) No sound (control).	II	(1) Electroencephalography - frontal and temporal activity, (2) Skin conductance, (3) Heart rate, (4) Heart rate variability, (5) Facial capillary blood flow, (6) Respiration rate (measured pre- and post- stressful images and during recovery interventions).	Both pleasant and sad music improved recovery on most measures compared to white noise (heart rate, respiration rate, blood flow). White noise did not enhance recovery. Both music types positively influenced cardiovascular and respiratory activity during recovery. The "undoing hypothesis" (positive emotions aid recovery from negative emotions) was partially supported.
9	Suda, M, 2008	(1) Major music, (2) Minor music, (3) No sound (control).	II	Salivary cortisol levels (endocrine stress marker) and optical topography (brain activity).	Major mode music resulted in lower salivary cortisol levels (stress marker) compared to minor mode music. This suggests music can induce emotional responses like happiness, potentially linked to stress reduction.
				Sound per se – physical characteristics	
10	Wiwatwongwana, D, 2016	(1) Binaural beat music, (2) Plain music, (3) No sound (control).	III	State-Trait Anxiety Inventory (STAI) score (pre- and post-intervention), systolic blood pressure, heart rate (measured at admission, surgery start, and 20 minutes after surgery).	Both music with and without binaural beats reduced anxiety (STAI score) and systolic blood pressure compared to the control group. Binaural beat music showed an additional decrease in heart rate compared to plain music or the control group. Binaural beat audio embedded in music may have some advantages over music alone for reducing anxiety during cataract surgery.
11	Opartpunyasarn, P, 2022	(1) Binaural beat music (2) Plain music (3) No sound (control).	III	State-Trait Anxiety Inventory (STAI) score (pre- and post-bronchoscopy), blood pressure, heart rate, and sedative use.	Patients in the binaural beat group showed a significantly greater reduction in anxiety (STAI score) compared to plain music and no music groups. They also experienced a decrease in blood pressure but an increase in heart rate. Binaural beat audio may be effective for reducing anxiety before bronchoscopy.
12	Lee-Harris, G, 2018	(1) Meditative music with binaural beats, (2) Meditative music without binaural beats, (3) Low-arousal classical music, (4) High-arousal classical music,	III	Self-reported emotional state (arousal and positivity) and physiological arousal (measured but not specified in the abstract).	The effect of listening to Meditative Binaural Music was comparable to listening to calm classical music. Younger adults showed a stronger decrease in self-reported arousal with MBM with binaural beats compared to low-arousal classical music. Older adults showed a preference for low-arousal classical music for feeling comforted, followed by MBM. These results suggest age may influence how music affects relaxation.
13	Gantt, MA, 2017	(1) Music with embedded theta binaural beats (BBT), (2) Music alone.	III	Heart rate variability (HRV) measured before and after intervention to assess changes in sympathetic and parasympathetic nervous system activity. Daily self-reported stress levels recorded in diaries.	Music with binaural beats led to a decrease in low-frequency HRV (indicating reduced sympathetic response) and an increase in high-frequency HRV (indicating increased parasympathetic response) compared to music alone. The binaural beats group also reported lower daily stress levels compared to the music-only group. Overall, music with BBT showed promise in reducing physiological and psychological stress markers in military personnel with post-deployment stress.
14	Calamassi, D, 2022	(1) Listen to 440 Hz music during break, (2) Listen to 432 Hz music during break, (3) Usual break activities (control).	III	(1) State-Trait Anxiety Inventory (STAI-X1), (2) Heart rate, (3) Respiratory rate, (4) Systolic and diastolic blood pressure, (5) Pain and productivity (Likert scale).	All groups showed a reduction in anxiety after the break. Listening to 432 Hz music showed the greatest reduction in anxiety and additionally reduced respiratory rate and systolic blood pressure. Music at 440 Hz reduced anxiety but showed no significant physiological benefits in this study.
15	Sharma, S, 2021	(1) varying music (VM) with incremental tempo/octave changes, (2) stable music (SM) without variations, (3) No sound (control).	III	Anxiety (Beck's Anxiety Inventory, State-Trait Anxiety Inventory), EEG (electroencephalography) for brainwave activity, ECG (electrocardiography) for heart rate variability (HRV).	Significant anxiety reduction only in the VM group. VM showed decreased low-frequency brainwaves and midline power (reduced default mode network activity) compared to silence. VM also showed more balanced brain activity compared to SM. HRV remained stable during music interventions. The authors propose VM induces a "controlled mind wandering" state leading to anxiety reduction.
				Sound per se – music vs human voice	
16	Singh, VP, 2009	(1) Self-selected music, (2) Audio instructions (Progressive Muscle Relaxation).	VII	(1) State-Trait Anxiety Inventory (Spielberger's inventories), (2) Dyspnea, (3) Systolic and Diastolic Blood Pressure, (4) Pulse Rate, (5) Respiratory Rate (pre- and post-intervention).	Both music and Progressive Muscle Relaxation significantly reduced anxiety, dyspnea, systolic blood pressure, pulse rate, and respiratory rate. However, the music group showed greater reductions in anxiety compared to the Progressive Muscle Relaxation group. Music and Progressive Muscle Relaxation are effective for reducing anxiety and physiological measures in hospitalized chronic obstructive pulmonary disease (COPD) patients, with music potentially being more effective for anxiety reduction.
17	Tang, HY, 2009	(1) 12-minute audio relaxation program, (2) 12-minute Mozart	VII	Blood pressure (systolic and diastolic) measured at each intervention session and at one-month and three-month	Both groups showed significant reductions in blood pressure after the intervention. The audio relaxation group showed a greater reduction in systolic blood pressure than the Mozart group. Blood pressure reductions

		andante.		follow-up.	were not sustained at one- and three-month follow-up. Audio relaxation may be more effective than music for short-term blood pressure reduction in older adults.
18	Lin, MF, 2011	(1) One-hour session of music therapy, (2) 30 minutes of guided verbal relaxation, (3) Usual care.	VII	State anxiety (Spielberger State-Trait Anxiety Instrument), emotional distress (Emotional Visual Analog Scale), and physiological responses (skin temperature, heart rate, and consciousness level) before and after chemotherapy.	Music therapy was more effective than verbal relaxation or usual care in reducing post-chemotherapy anxiety and increasing skin temperature. Patients with high initial anxiety benefited more from music therapy than those with normal anxiety. Both interventions showed some effectiveness within 30 minutes.
19	Lee, EJ, 2012	(1) monochord sounds (MC), (2) progressive muscle relaxation (PMR).	VII	(1) Spielberger's State Anxiety Inventory for Anxiety, (2) Questionnaires on physical and psychological states, (3) EEG data pre- and post-intervention.	Both MC and PMR groups showed significant improvements in anxiety, physical and psychological state. EEG data showed increased posterior theta and decreased midfrontal beta-2 activity in both groups, indicating relaxation. The MC group also showed a decrease in alpha band activity compared to PMR. Both interventions were effective for reducing anxiety and improving relaxation, with potentially different underlying neural mechanisms.
20	Warth, M, 2016	(1) Live music therapy. (2) Pre-recorded mindfulness exercise.	VII	Vagally mediated heart rate variability and blood volume pulse amplitude measured over time to assess autonomic nervous system response.	Both groups showed improvements over time, but music therapy led to significantly greater reductions in vascular sympathetic tone (BVP-A). This suggests music therapy may be more effective in managing pain and stress symptoms in palliative care. Baseline pain levels influenced patient response, highlighting its importance in treatment planning. Music therapy's impact may be related to the therapist-patient relationship in addition to the music itself.
21	Koehler, F, 2022	(1) Three sessions of music therapy, (2) Three sessions of mindfulness training.	VII	(1) Subjective distress rating scale (pre- and post- intervention), (2) Salivary cortisol and alpha-amylase levels (pre- and post-intervention), (3) Heart rate and heart rate variability.	Music therapy showed a greater reduction in subjective distress compared to mindfulness. Both interventions led to reductions in cortisol and heart rate, but no significant differences between groups were found for these or other stress biomarkers.
22	Radstaak M, 2014	(1) Self-chosen relaxing music, (2) Self-chosen happy music, (3) Audiobook, (4) Silence (control).	VII	(1) Mood questionnaires, (2) Subjective arousal and rumination questionnaires, (3) Systolic and diastolic blood pressure, heart rate.	Listening to self-chosen relaxing or happy music improved mood compared to control conditions. No significant effects on subjective arousal or rumination. Both relaxing and happy music groups showed delayed systolic blood pressure recovery compared to control conditions.
				Personal factors	
23	Leardi, S, 2007	(1) New age music, (2) Choice of music from four styles, (3) Control group (standard operating room sounds).	X	Plasma cortisol levels and subpopulations of lymphocytes (natural killer cells) measured before, during, and after surgery.	Both music groups showed decreased cortisol (stress hormone) levels during surgery compared to the control group. Patients who chose their music (group 2) had significantly lower postoperative cortisol levels than those who listened to new age music (group 1). Natural killer cell levels (immune function) decreased during surgery in the music groups and increased in the control group. Patients listening to new age music (group 1) had lower levels of natural killer cells during surgery compared to the control group.
24	Miller, M, 2010	(1) Listening to self-selected joyful or anxiety-provoking music for 30 minutes, (2) Watching video to induce laughter and listening to audio for relaxation.	X	Endothelial function was measured by brachial artery flow-mediated dilation before and after each intervention.	Joyful music increased flow-mediated dilatation (blood vessel dilation), while anxiety-provoking music decreased flow-mediated dilatation. The increase in joyful music was comparable to improvements seen with exercise or medication.
25	Imbriglio, TV, 2020	(1) relaxing music, (2) favourite music, (3) stressful music, (4) pink noise	X —	(1) Electromyographic activity in the right masseter muscle to measure muscle effort: (a) posture, (b) spontaneous awake bruxism episodes, (2) Duration and frequency of awake bruxism episodes.	Relaxing music and favorite music decreased muscle effort during awake bruxism in chronic temporomandibular disorders by 26% and 44%, respectively. Stressful music increased muscle effort. Guided music listening with selected music may be a promising non-invasive treatment for chronic temporomandibular disorders.
				Environmental factors	
26	Gelatti, F, 2020	(1) Live harp music intervention, (2) Recorded harp music control.	XI	(1) Self-reported fear and stress levels (pre- and post-intervention), (2) Blood pressure (pre- and post-intervention), (3) Heart rate (pre- and post-intervention).	Both live and recorded harp music significantly reduced fear. Live harp music was more effective in reducing heart rate and diastolic blood pressure compared to recorded music.
27	Bro,	(1) 30 minutes of patient-	XI	Anxiety measured by Spielberger's	Live music showed a borderline statistically significant reduction in anxiety

	ML, 2019	preferred live music, (2) 30 minutes of patient-preferred pre-recorded music, (3) Standard care.	X	State Anxiety Inventory, blood pressure, pulse rate, nausea, vomiting, serum catecholamine levels, and health-related quality of life. Musical Ability Test was used to assess if musical ability influenced anxiety.	compared to standard care. Pre-recorded music had no significant effect. No significant changes were observed in secondary outcomes. Musical ability did not influence the effect of music.
28	Lee, KC, 2011	(1) Headphone music therapy, (2) Broadcast music therapy, (3) Control (no music).	XI	(1) Visual Analogue Scale for anxiety (pre- and post-intervention), (2) Heart rate variability (pre- and post-intervention).	Both headphones and broadcast music significantly reduced visual analog scale scores (anxiety) compared to the control group. No significant difference was found between headphones and broadcast music for reducing anxiety. Broadcast music offers an alternative to headphones for reducing preoperative anxiety while considering infection control.
29	Kumari , 2023	(1) Headphone group (2) Broadcast group, (3) Control	XI	(1) Pre-operative anxiety by visual analog scale (2) Heart rate variability	The average heart rates of the broadcast group, head- phone group and control group were not significantly different. The mean anxiety score of the control group was significantly higher than that of the headphone group and the broadcast group. Time-domain heart rate variability was not significantly different. There was a significant difference in high frequency HR variability among the three groups. LF in the broadcast group was significantly lower than the control group indicates there was less tension of the sympathetic nervous system in the broadcast group. Both headphones and broadcast music are effective for reducing the preoperative patient's anxiety in the waiting room. Thus, when headphones are not available or not appropriate, speakers can be an effective substitute.
30	Lai, HL, 2012	(1) Music with Nursing Presence, (2) Recorded Music.	XI	(1) Blood volume pulse amplitude and heart rate variability, (2) Depression, anxiety, and sleep quality measured pre- and post-intervention, (3) Participant evaluation of music.	Both interventions improved anxiety, depression, and blood volume pulse amplitude. Music intervention with a nurse led to greater reductions in anxiety and improved ease of falling asleep compared to recorded music. Participants preferred music with a nursing present and found it to be more harmonious and friendly. Both interventions were beneficial, but music with a nursing presence provided a more positive experience.
31	Janelli, LM, 2004	(1) Preferred music out of restraints, (2) No music out of restraints (control), (3) Preferred music in restraints.	XI	Observation of positive and negative behaviors during the music intervention phase.	Listening to preferred music showed no significant decrease in negative behaviors or increase in positive behaviors for patients in restraints. Patients out of restraints with preferred music had higher positive behavior scores and lower negative behavior scores, suggesting some potential benefit.
Absence of sound					
32	Kang, JG, 2008 not founf yet	(1) Blocking noise with earplugs (silence group), (2) Patient- selected music (music group), (3) Exposure to ambient noise in operating room (noise group).	O	Bispectral index measured seven times during surgery, along with ambient noise levels.	Blocking noise with earplugs reduced bispectral index scores compared to exposure to ambient noise during specific surgical procedures creating high noise levels. Music was not significantly different from noise exposure. Blocking noise may be more effective than music for reducing sedation levels during surgery with high background noise.
33	Tsivian, M, 2012	(1) Music with headphones, (2) Noise-cancelling headphones only, (3) Control group with no intervention.	O	Pain and anxiety scores (questionnaires) and physiological parameters (blood pressure) before and after the procedure.	Pain scores were the lowest in the music group. No significant changes in anxiety scores were observed. Patients in the music group showed a smaller increase in diastolic blood pressure after the procedure compared to the other groups, suggesting a reduced physiological stress response.
Mixed samples					
34	Gingras B, 2014	(1) Repetitive drumming & shamanic instructions, (2) Repetitive drumming & relaxation instructions, (3) Instrumental meditation music & shamanic instructions, (4) Instrumental meditation music & relaxation instructions.	mix	(1) Salivary cortisol concentration measured pre- and post-intervention, (2) Self-reported mood questionnaire pre- and post-intervention, (3) post-experiment questionnaire on subjective experiences.	All groups showed a decrease in cortisol regardless of music or instructions. Repetitive drumming with shamanic instructions led to specific subjective experiences (heaviness, decreased heart rate, dreamlike experiences) compared to drumming with relaxation instructions. Cortisol response may not be sensitive to the specific intervention (shamanic vs relaxation instructions).

Sound per se

The “sound per se” category encompasses studies focused on the direct impact of various sound types on psychological and physiological outcomes, independent of personal or environmental factors. This category is divided into sub-categories based on music styles, music sentiment, and the physical aspects of music, examining how specific genres, emotional tones, and sound structures influence stress-related markers. Non-musical sounds were also considered.

Music styles

In the "sound per se - music styles" category, studies have consistently shown that different music types can influence relaxation and stress reduction. Umemura et al. (1998) found that classical music reduced heart rate variability, indicating relaxation, while rock and noise had the opposite effect, increasing stress markers. Chafin et al. (2004) observed that classical music significantly lowered systolic blood pressure following a stress task, while other music styles did not. Labbé et al. (2007) demonstrated that listening to classical or self-selected relaxing music effectively reduced anxiety and physiological arousal compared to heavy metal or silence. Uğras et al. (2018) reported that all music styles reduced preoperative anxiety, with Classical Turkish music being the most beneficial. Similarly, Gulnahar et al. (2020) showed that Turkish and classical music reduced anxiety during dental procedures more effectively than other styles. Lastly, Paszkiel et al. (2020) found that relaxing music and ASMR decreased stress levels more quickly than silence, whereas rap music increased stress. These findings highlight the calming effects of classical and relaxing music styles across different contexts.

Music sentiment

In the "sound per se - music sentiment" category, research has focused on the impact of different music sentiments on stress recovery. Hirokawa et al. (2003) suggested that high-uplifting music might enhance mood by increasing norepinephrine levels, while low-uplifting music could potentially boost feelings of well-being. Sokhadze et al. (2007) found that both pleasant and sad music improved physiological recovery from stress more effectively than white noise, indicating that positive emotions generated by music might aid in stress recovery. Suda et al. (2008) demonstrated that major mode music led to lower salivary cortisol levels compared to minor mode music, implying that music in a major mode may induce emotional responses like happiness, which are closely linked to stress reduction. These findings indicate the potential at music sentiment for stress recovery and mood regulation.

Physical characteristics of music

In the "sound per se - physical characteristics" category, studies investigated how specific musical features or elements affect stress and anxiety outcomes. Wiwatwongwana et al. (2016) found that binaural beats reduced anxiety and systolic blood pressure more effectively than plain music during cataract surgery. Opartpunyasarn et al. (2022) showed that binaural beat music significantly reduced anxiety and blood pressure in bronchoscopy patients. Lee-Harris (2018) reported that meditative binaural music had comparable effects to calm classical music, with age influencing preferences. Gantt et al. (2017) found that binaural beat technology reduced stress by altering heart rate variability in military personnel. Calamassi et al. (2022) demonstrated that listening to 432 Hz music lowered anxiety and improved respiratory rate more effectively than 440 Hz music. Finally, Sharma (2021) reported that music with tempo/octave changes reduced anxiety and decreased low-frequency brainwaves, reduced default mode network activity, more balanced brain activity compared to stable music without variations.

Music vs human voice

In the "music vs human voice" category, studies evaluated the relative effectiveness of music and voice-based interventions on anxiety and physiological responses. Singh et al. (2009) found that both music and progressive muscle relaxation reduced anxiety and physiological markers in COPD patients, with music showing greater effectiveness. Tang et al. (2009) reported significant reductions in blood pressure after both audio relaxation and music interventions, with audio relaxation showing a greater impact. Lin et al. (2011) demonstrated that music therapy was more effective than verbal relaxation or usual care in reducing anxiety and physiological responses in cancer patients undergoing chemotherapy. Warth et al. (2016) observed that live music therapy led to greater improvements in vagally mediated heart rate variability compared to a pre-recorded mindfulness exercise, highlighting its potential for stress management. Finally, Lee et al. (2012) found that both music and progressive muscle relaxation improved anxiety and relaxation in cancer patients, with EEG data suggesting different neural mechanisms for each intervention.

Personal factors

The "personal factors" category examines how individual characteristics, preferences, and personal involvement influence the effectiveness of sound interventions. Leardi et al. (2007) found that patients who selected their own music during surgery had lower cortisol levels postoperatively and higher immune function compared to those exposed to standard operating room sounds or new age music. Miller et al. (2010) showed that joyful music improved endothelial function (flow-mediated dilatation), while anxiety-inducing music decreased flow-mediated dilatation, with the effects comparable to those achieved through exercise or medication. Imbriglio et al. (2020) reported that guided music listening with relaxing or favourite music reduced muscle effort during awake bruxism episodes in temporomandibular disorders patients, whereas stressful music increased muscle tension increase. This category highlights the importance of tailored interventions, showing that factors such as personal music selection, emotional connection, and the listener's psychological state can modulate physiological and emotional outcomes. Studies within this category emphasize that the success of sound-based interventions often depends on aligning the experience with the individual's preferences and emotional needs.

Environmental factors

The "environmental factors" category focuses on the influence of delivery methods and contextual conditions on the effectiveness of sound interventions. This category explores how the medium of delivery (e.g., live versus recorded music, broadcast versus headphone playback) and environmental settings (e.g., presence of supportive personnel) shape physiological and emotional outcomes. Gelatti et al. (2020) found that live harp music was more effective than recorded harp music in reducing heart rate and blood pressure during surgery. Bro et al. (2019) reported a borderline reduction in anxiety with live music during chemotherapy, while pre-recorded music showed no significant effect. Lee et al. (2011) and Kumari (2023) found that both headphone and broadcast music reduced preoperative anxiety, with no significant difference between the two methods, suggesting that broadcast music can be an alternative when headphones are unavailable. Lai et al. (2012) demonstrated that music interventions with a nurse present improved anxiety, sleep quality, and depression more effectively than recorded music alone. Janelle (2004) observed no significant changes in the behaviour of restrained patients who listened to preferred music but noted that patients who were not restrained and listened to music had higher rates of positive behaviour. The findings underscore that not only the sound itself but also how and where it is delivered plays a critical role in maximizing the benefits of sound-based interventions.

Mixed samples

In the "mixed samples" category, we included only one article. This intervention is considered mixed because it combines both musical (drumming and music) and voice (shamanic and relaxation guidance) elements represented simultaneously. Gingras (2014) compared the effects of repetitive drumming with shamanic instructions, relaxation instructions, and instrumental meditation music on cortisol levels and subjective experiences. The study found that all groups showed a decrease in cortisol regardless of the intervention, but repetitive drumming with shamanic instructions led to unique subjective experiences, such as feelings of heaviness and dreamlike states, compared to drumming with relaxation instructions.

Absence of sound

In the " absence of sound" category, studies examined the effects of blocking noise compared to music interventions. Kang et al. (2008) found that blocking noise with earplugs reduced bispectral index scores more effectively than exposure to ambient noise during surgery, while music had no significant difference from noise blocking. This suggests that noise reduction may better aid sedation under noisy conditions. Tsivian et al. (2012) reported that music with headphones reduced pain perception during prostate biopsy compared to noise-canceling headphones or no intervention. Although anxiety scores remained unchanged, patients in the music group showed smaller increases in diastolic blood pressure, indicating a reduced physiological stress response.

Negative effects

In the "Negative" category, studies reported increases in stress markers resulting from specific sound interventions. Hirokawa et al. (2003) found that listening to both high- and low- uplifting music decreased salivary secretory IgA (S-IgA) levels, indicating reduced immune function, while silence led to a slight increase in S-IgA. Imbriglio (2020) observed that stressful music increased muscle effort during awake bruxism episodes, highlighting the potential for certain music to exacerbate physical stress responses. Rap music increased stress level compared to silence. Paszkiel et al. (2020) indicated that rap-style music increased stress markers compared to silence. These findings suggest that some sound interventions may have unintended adverse effects on physiological conditions.

Discussion

Principal Findings

This scoping review synthesizes current research on the effects of sound interventions on stress reduction in adults, highlighting key factors that contribute to their therapeutic potential. The analysis revealed that music, particularly classical and self-selected relaxing music, consistently demonstrates a capacity to reduce both physiological and psychological markers of stress. Non-musical sounds, including nature sounds and prosodic features of human speech, showed promise but were less commonly studied. As to body responses, studies frequently reported positive effects on heart rate variability, blood pressure, cortisol levels, and self-reported anxiety. Furthermore, limited research using brain imaging demonstrated that sound interventions could modulate neural activity associated with emotional regulation, suggesting a neurobiological mechanism underlying the stress-relieving effects. Overall, these findings highlight sound therapy’s potential in stress management and underscore the need for further exploration of diverse sound types and individualized approaches.

Therapeutic Factors of Sounds

The results of this review indicate that sound therapy operates through multiple mechanisms. First, it engages emotional systems to reduce stress. Sentiment**,** or the emotional tone of the sound, plays a significant role: calming and positive emotional tones, such as those found in classical or soothing music, are frequently associated with reductions in anxiety and stress markers. Tempo-rhythm also emerged as a key factor, with studies showing that slower, steady rhythms often promote relaxation by modulating heart rate and respiratory patterns, while faster tempos can increase arousal. The influence of binaural beats and tempo variations further underscores the importance of this factor in modulating stress responses. These findings align with the four-level model of sound therapy proposed by Clements-Cortés and Bartel, which suggests that sound can impact stress both through learned associations and inherent biological mechanisms.

One key takeaway from this review is the nuanced role of personal factors in determining the effectiveness of sound interventions. Studies that allowed participants to select their preferred music, for example, demonstrated better outcomes in terms of stress reduction than those where music was pre-selected. This underscores the importance of individual preferences, emotional involvement, and past experiences in shaping responses to sound therapy. Personalization may thus be crucial in optimizing the therapeutic potential of sound interventions.

Environmental factors, such as the method of sound delivery, also play a significant role. Live music therapy, for example, appears to have stronger effects on stress markers than pre-recorded music, likely due to the interactive and dynamic nature of live performances. Similarly, interventions that involve a supportive human presence, such as a nurse during a music session, further enhance the therapeutic effect.

We remain cautious about identifying the most effective therapeutic factors in sound therapy due to variability in how studies approach comparisons. Some studies focus on fine-grained distinctions in basic characteristics, such as rhythm or frequency spectrum, while others compare broader intervention clusters, such as music versus guided meditation. This difference in levels of generalization complicates direct comparisons. Key therapeutic factors consistently identified include tempo-rhythm, sentiment (emotional tone), frequency range, and environmental context, personal preferences, delivery method which are primarily studied within the framework of music therapy. Although it is possible to extrapolate these basic characteristics, such as sentiment and rhythm, from music to other sounds, like speech, there may be underlying differences in how these factors operate. For example, while rhythm in music typically follows a structured, repetitive pattern, rhythm in spoken voice can be more dynamic and context sensitive. Further research is needed to understand how these factors may or may not transfer across sound types, providing therapeutic effect whether applied in musical or non-musical contexts.

Body Responses to Sounds

The review highlights several physiological responses associated with sound interventions in stressful conditions, measured using various biomedical technologies. Heart rate variability and cortisol levels were among the most frequently assessed markers, with multiple studies indicating that calming interventions, such as soothing music or guided relaxation, can balance autonomic nervous system responses, leading to higher HRV and lower cortisol levels. Other commonly measured physiological indicators included blood pressure, electrodermal activity, and respiratory rate, which collectively reflect physiological responses to stress. These metrics were typically recorded using devices like electrocardiograms for HRV, blood pressure monitors, and salivary samples for cortisol.

Additionally, some studies utilized advanced neuroimaging techniques, such as EEG, to observe brain activity changes in response to sound interventions. This review included limited studies utilizing brain imaging, generally focused on brain activity associated with emotional regulation. For instance, some EEG data showed increased posterior theta and decreased midfrontal beta-2 activity, indicating stress relief. Another study suggested an increase in alpha wave activity, also associated with relaxation, following music and guided relaxation interventions. These neurophysiological findings support the notion that sound therapy can modulate brain activity linked to stress and emotional processing, providing a neurobiological basis for its therapeutic effects.

Identified Research Gaps

Despite these promising findings, several gaps in the literature were identified. There is a clear need for more research on non-musical sound interventions, particularly human voice-based therapies and natural soundscapes. Studies comparing different types of sound interventions, beyond the binary classification of music versus silence, are limited. Additionally, more research is required to understand the negative or side effects of sound interventions and the optimal conditions for their application.

The fragmentation of the research field and reliance on fragmented concepts are also noteworthy. For instance, several studies emphasize the benefits of classical music over other styles, though it remains unclear what specific factors, aside from the researchers' personal preferences and cultural backgrounds, account for the perceived effectiveness of one style over another. Considering the limited investigation into personal factors, future studies could be designed to compare the effects of the same music on both native listeners and foreigners unfamiliar with one or another musical tradition, rather than focusing on comparisons between different regional styles.

In general, individual factors, such as personal preferences, cultural background, and prior exposure to sound therapy, have not been thoroughly examined. Future studies should consider these factors to develop more personalized sound interventions tailored to individual needs.

Another gap is the relative lack of brain imaging studies. There is still limited knowledge about the neural mechanisms underlying sound therapy's effects. Expanding neuroimaging research in this field could offer deeper insights into how different types of sounds impact neuronal activity related to emotional regulation and stress processing, particularly in real-time applications of sound therapy in stress management.

Strengths and limitations

One of the key strengths of this scoping review is its comprehensive approach to synthesizing evidence across a variety of sound interventions and stress markers. By including diverse studies, such as randomized controlled trials, clinical trials, and laboratory experiments, the review offers a broad perspective on how different types of sound, from music to natural sounds and human voices, can influence stress response in adults. This wide scope provides a valuable foundation for understanding the generalizability of sound interventions in stress management. The review also emphasizes the importance of personal, environmental, and delivery factors, shedding light on the nuances of how sound interact with different listeners and environments.

Another strength lies in the focus on psychophysiological outcomes. By including studies that measure stress through biomarkers like heart rate variability, cortisol levels, and blood pressure, alongside self-reported emotional states, the review provides a holistic view of how sound interventions impact both body and mind. This dual focus strengthens the findings by bridging subjective experiences with objective physiological evidence.

However, this review also has some limitations. One notable limitation is our focus on the researchers' interpretations without direct access to the actual sound samples. As evidenced by the data comparison, sound can produce both positive and negative effects, depending on its characteristics. Numerous factors may influence these effects simultaneously. For instance, comparing a heavy metal composition with a Mozart lullaby, it is reasonable to expect differences in style, and emotional tone, and frequency spectrum simultaneously. If these compositions were placed in their typical performance contexts, such as a concert hall for the classical music versus a stadium with amplified sound and a large, excited audience for the metal piece, the listening environments would likely impact the physiological response of listener significantly. Therefore, our framework primarily addresses how current papers conceptualize and investigate sound. A potential direction for future research would be to obtain the sound pieces used in original studies and systematically analyse them.

Another limitation is the variability in study designs and methodologies, which makes it challenging to directly compare findings across different sound interventions. Differences in participant populations, intervention durations, sound types, and stress measurement techniques create inconsistencies that limit the ability to draw definitive conclusions about the most effective sound intervention strategies.

Additionally, the review does not fully address the long-term effects of sound interventions, as most studies focus on short-term stress relief. The lack of longitudinal data makes it difficult to assess the sustainability of these interventions over time and their potential cumulative benefits for stress management.

Conclusion

While the therapeutic potential of sound interventions in reducing stress is evident, the effectiveness of these interventions is shaped by a combination of personal, environmental, and sound-related factors. Future studies should focus on expanding the scope of sound types studied, exploring personalized approaches. Sound-based interventions offer a non-invasive approach to stress management. Continued exploration of their mechanisms and optimal applications will be key to opening their full potential in both clinical and non-clinical settings.

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Data Availability

Data sharing is not applicable to this article as no data sets were generated or analyzed during this study.

Authors' Contributions

Marina Saskovets performed conceptualization, data curation, formal analysis, investigation, methodology, project administration, visualization, and writing (original draft, review and editing). Irina Saponkova handled data curation, investigation, validation, visualization, and writing (original draft, review and editing). Zilu Liang contributed to conceptualization, funding acquisition, methodology, project administration, resources, supervision, validation, and writing (review and editing).

Conflict of interest

None declared.

Abbreviations

RCT - Randomized Controlled Trials
HPA - Hypothalamic-Pituitary-Adrenal (axis)
ANS - Autonomic Nervous System
PCC - Population-Concept-Context (framework)
RQ - Research Questions
ASMR - Autonomous Sensory Meridian Response
MBSR - Mindfulness-Based Stress Reduction
PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses
MWSA - Mayer Wave related Sinus Arrhythmia
RSA - Respiratory Sinus Arrhythmia
STAI - State-Trait Anxiety Inventory
SBP - Systolic Blood Pressure
HR - Heart Rate
HRV - Heart Rate Variability
EEG - Electroencephalography
ECG - Electrocardiography
S-IgA - Salivary secretory IgA
NK - Natural Killer (cell)
BBT - Theta Binaural Beats
VM - Varying Music
SM - Stable Music
MC - Monochord Sounds
PMR - Progressive Muscle Relaxation
COPD - Chronic Obstructive Pulmonary Disease

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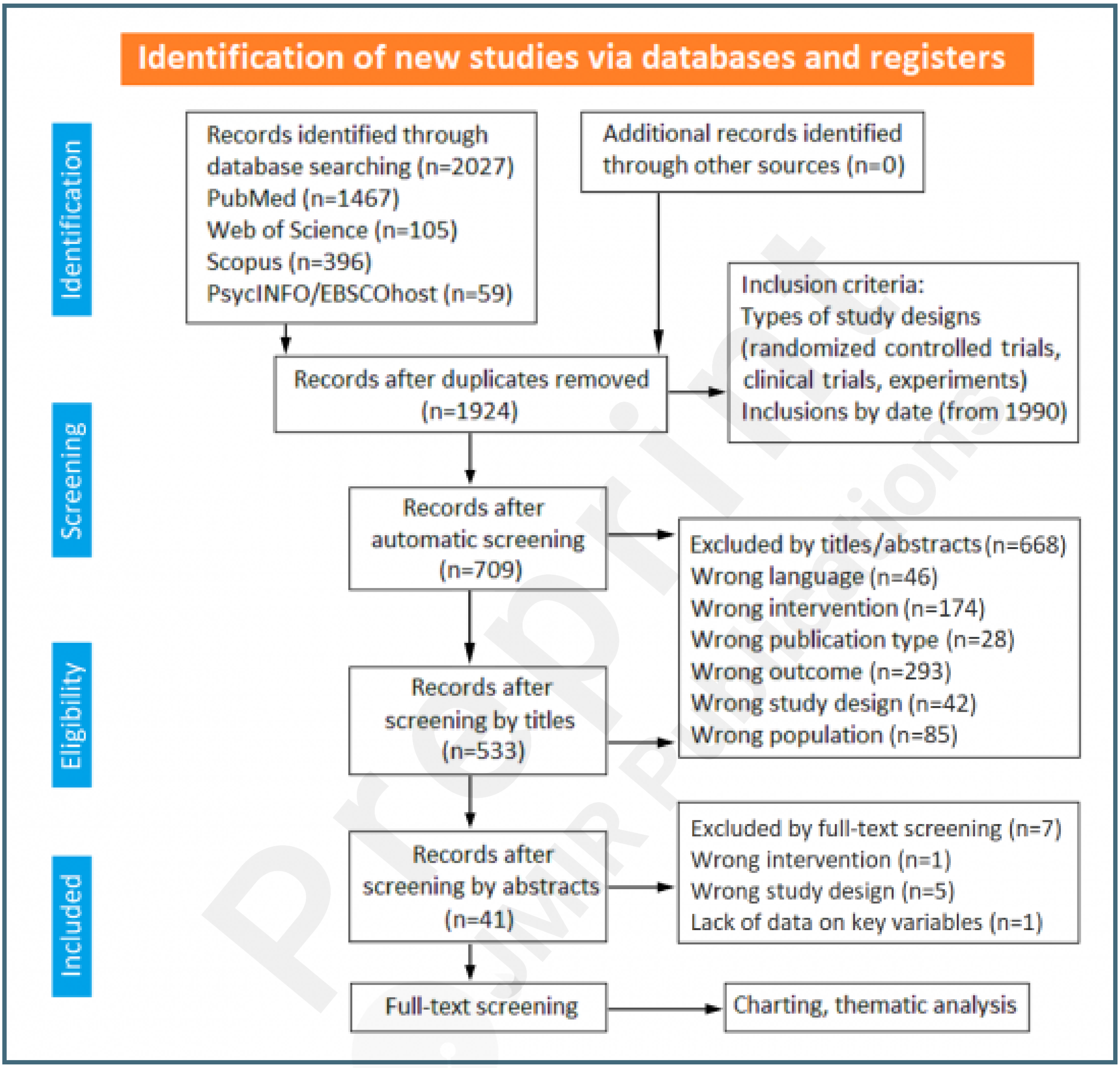
Supplementary Files

Figures

PRISMA flow chart.



Thematic analysis results.