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Article

Synergizing music therapy and biomechanics: Unveiling novel modulation mechanisms for chronic pain management

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Abstract: This study aimed to evaluate the combined effects of music therapy and biomechanical interventions on chronic pain management, focusing on pain intensity, functional impairment, and quality of life. A mixed-methods approach was employed, integrating quantitative measures (pain intensity, functional impairment, and quality of life) with qualitative interviews to capture participants' experiences. The study involved 120 participants with chronic pain conditions, including fibromyalgia, arthritis, and neuropathic pain. Moreover, participants were selected through purposive sampling. Descriptive and inferential statistics revealed significant improvements in pain intensity visual analogue scale (VAS: 7.8 to 4.6, $p < 0.001$), functional impairment pain disability index (PDI: 45.6 to 32.3, $p < 0.001$), and quality of life (SF)-36: 62.4 to 78.2, $p < 0.001$). Qualitative findings highlighted emotional and cognitive benefits from music therapy and physical improvements from biomechanical interventions, particularly enhanced mobility and reduced pain. The integration of both therapies demonstrated a synergistic effect, significantly improving overall pain management ($\beta = -0.5$, $p < 0.001$). The study concludes that a combined approach offers a comprehensive, effective treatment for chronic pain. Clinical implications include incorporating multimodal interventions into rehabilitation programs with a personalized approach based on pain type and severity. Future research should explore long-term effects and further refine individualized treatment strategies. In contrast, the limitation of this study is the relatively small and homogeneous sample, which may limit generalizability to broader chronic pain populations. Additionally, the short intervention period does not allow for assessing long-term effects.

Keywords: chronic pain; music therapy; biomechanical interventions; functional impairment; quality of life; pain management; multimodal therapy

1. Introduction

Chronic pain is a significant global health issue, affecting millions of individuals and imposing a substantial burden on healthcare systems and society [1]. People with pain lasting longer than three months deal with both physical and psychological symptoms, which create functional complications and quality-of-life deterioration [2]. The specific diagnosis contributes to three leading causes, including musculoskeletal disorders, peripheral neuropathies, and inflammatory pathologies [3]. Research demonstrates that pharmacological and technological breakthroughs fail to provide sufficient pain relief for patients requiring extensive multimodal therapeutic approaches [4]. The traditional approach to pain management depends on pharmacological treatments where nonsteroidal anti-inflammatory drugs (NSAIDs) combined with opioids, antidepressants, and antiepileptic medications form the basis

of medical intervention [2]. Long-term administration of these treatments results in substantial side effects that affect both treatment security and its effectiveness because of gastrointestinal issues, increased dependence rates, and growing drug tolerance [5]. Medical science recognizes chronic pain as an accurate biopsychosocial diagnosis, which demonstrates that psychological elements, emotional responses and interpersonal situations shape pain perception and dynamic functional disabilities. Chronic pain management has witnessed a fundamental change, which resulted in increasing interest in combining non-pharmacological treatments, including music therapy and biomechanical approaches [6].

The promise of music-based therapy as pain management lies in its ability to use the neurophysiological effects of music and sensory enhancements to regulate emotional and cognitive processing and pain thresholds [4]. Hospital patients receive relief from pain and experience better moods and life quality when undergoing music therapy because the treatment benefits those with fibromyalgia, arthritis, and neuropathic pain. The neurophysiological mechanisms enable music therapy to affect reward pathway activation together with emotional regulation centres and descending pain modulation pathways to reduce pain sensitivity and improve psychological health [5].

Biomechanical interventions tackle the mechanical and functional impairments that emerge from chronic pain conditions [2]. Chronic pain usually leads to dysfunctional movement patterns alongside inadequate motor control and non-optimal compensatory actions that cause increased damage to the musculoskeletal system [7]. Biomechanics analysis enables healthcare providers to identify problems with movement patterns that lead them to develop specific treatment approaches for functional movement reform, enhanced muscular performance, and reduced disability levels. The evaluation techniques of gait analysis, kinematic assessments, and muscle activation studies offer substantial insight into pain-related movement disorders so rehabilitation strategies can be effectively generated [8].

Combining music therapy integration with biomechanical interventions results from their overlapping impact methods. Music therapy focuses its treatment on pain's emotional and mental aspects, yet biomechanical approaches handle pain's physical elements [9]. These methods create an organic integration for pain treatment, which enhances emotional strength simultaneously with physical abilities, thus breaking down the connection between pain and disability [10]. Research demonstrates that music affects motor control abilities alongside gait stability and movement efficiency in neurological conditions, thus reinforcing potential synergies when used alongside biomechanical rehabilitation [11,12].

This study aims to investigate the combined effects of music therapy and biomechanical interventions on chronic pain management, focusing on their impact on pain intensity, functional impairment, and quality of life. Specifically, the study seeks to:

1) Elucidate the distinct and interactive mechanisms through which music therapy and biomechanical interventions influence chronic pain perception and physical function.
2) Assess the efficacy of this combined approach in reducing pain intensity and functional impairment while enhancing overall well-being.

3) Provide evidence for integrating multimodal interventions into clinical rehabilitation programs tailored to individual pain profiles.

By addressing these objectives, this research contributes to the growing body of literature on multidisciplinary pain management, highlighting novel therapeutic models that bridge the gap between chronic pain's physiological and psychological aspects. The paper is structured as follows: The section deals with the introduction of the present study. Section 2 reviews existing literature on music therapy and biomechanical interventions. Section 3 details the methodology. Section 4 presents the findings. Section 5 discusses the discussion and implications for clinical practice. Section 6 includes the conclusion and future research directions.

2. Literature review

2.1. Music therapy: Mechanisms and effectiveness in chronic pain management

Music therapy has received much attention as an extensive and non-pharmacological approach to treating chronic pain [13]. First, music therapy affects auditory and emotional channels in the brain, thus increasing the capacity to tolerate pain and decreasing mentally related suffering [14]. This process engages the rewarding circuits in the nucleus acumens and the ventromedial prefrontal cortex, inhibiting pain-activated areas in the anterior cingulate cortex and the amygdala [15]. In addition, musical therapy triggers the production of endorphins, which are the body's opioids with pain and mood-elevating properties [16]. There has also been evidence of its efficiency concerning the stress response, such as decreased cortisol levels and improved heart rate variability in patients with chronic pain and clients with chronic disease [17].

A body of research regarding the credibility of music therapy for chronic pain diseases such as fibromyalgia, arthritis, and cancer-related pain is available. Using data from a systematic review, it was determined that music interventions could also help reduce pain intensity by 47%, anxiety by four per cent and depression rate by 53%; the quality of life was also improved. Therefore, preferably individuals, according to patients' tastes, have shown better effectiveness because of the patients' interest and emotional bonding [18]. Music can be listened to actively by the patient, or the patient can sing or play an instrument; this makes music therapy suitable for use among patients of different categories and cultures.

2.2. Biomechanics: Role in understanding pain and movement disorders

Biomechanics offers a clearer perspective of the social profile of chronic pain, including its effects on movement, posture and musculoskeletal position. Maladaptive motor patterns are developed due to chronic pain to alleviate pain or stiffness, consequently limiting functional capacity and predisposing the body to develop secondary injuries [18]. Making assessments of these dysfunctions, biomechanical studies use gait analysis, electromyography (EMG) and motion capture technology for intervention targets. They have shown that pain affects muscle contraction patterns,

making the body vulnerable to stiffness, limited movement range, and casual postures [19].

These dynamics have been applied in therapy to identify ways to regain movement and minimise pain. For example, specific and individualised physical interventions applying biomechanical knowledge have proved helpful in treating joint malalignments, muscle imbalances and abnormal movement patterns related to scoliosis [20]. Further, with movement monitoring through wearable biomechanics devices, feedback and rehabilitation plans are possible throughout the process, thus resulting in enhanced efficiency [21]. Consequently, while biomechanics contributes significantly, this approach may not necessarily address chronic pain's psychological and emotional aspects, hence the need for interdisciplinary strategies.

2.3. Integrative approaches combining music therapy and biomechanics

Combining music therapy and biomechanics implements a fresh perspective for chronic pain treatment [8]. This synergy means that besides music's cognitive and emotional impacts, it is accompanied by biomechanical interventions that enhance physical and functional aspects. For instance, music therapy in rhythmic auditory stimulation (RAS) has been identified to enhance motor coordination and stability in gait since it focuses on engaging rhythm to promote the motor pattern [22]. To illustrate, integrating biomechanical feedback with RAS can enhance motor function by replacing or correcting those SKI dysfunctions that stem from pain [23].

This synergistic interplay of these modalities is perhaps most striking in chronic pain conditions that are often as organic and psychological [24]. Biomechanics deals with musculoskeletal disorders and impairments; in contrast, music therapy reduces actual pain sensations and increases clients' ability to cope with pain, thus providing a holistic pain control approach. Early research has indicated that these integrative approaches may shorten the recovery period's duration, increase patients' compliance with the rehabilitation process, and increase patient satisfaction [25]. Nonetheless, the absence of highly controlled protocols and less sound clinical studies restricts these outcomes' generality. More studies are needed to develop an evidence-based protocol and evaluate the possibilities of this inter-professional approach.

Music therapy enhances the outcome of biomechanical interventions by strengthening patient motivation while encouraging better treatment compliance and improved general health [22]. Medical research indicates that music boosts mood while decreasing anxiety and improving patient involvement, enhancing commitment to biomechanical rehabilitation programs [19]. Rhythms and emotions in music form cycles that drive patients to engage fully with movement-based therapies. The delivery of rhythmic auditory stimulation through music therapy depends on biomechanical assessment results, including gait analysis and kinematic data, which help customise music therapy approaches according to individual movement challenges. The strategic utilisation of musical rhythmic signals matched with a patient's movement cycle allows improved control over motor functions, which results in superior biomechanical recovery outcomes. Through their integration, motion performance improves, along with a patient-based approach to persistent pain treatment [18].

2.4. Identification of research gaps

However, music therapy and biomechanics both have significant potential for benefit in chronic pain treatment; several limitations to the extant research limit their applicability. First, as for the positive psychological outcomes of music therapy, it has been revealed that the field of interaction of music therapy with pain-related pathways is controversial and requires further investigation [26]. Relatedly, biomechanics has deepened our understanding of pain-related movement disorders, but cognitive and affective incorporation is still somewhat restricted [27]. Furthermore, these studies presume one type of intervention at a time while the benefits of integrating music therapy and biomechanics are left unexplored. Most current studies focus on the effectiveness of these integrative approaches within short periods, and limited research has been done on the durability of the outcomes achieved by the interventions. Methodological differences evident in patient samples, measures used, and intervention regimens only add to the challenge of determining the study results [28].

Filling these gaps requires the concurrent use of biomechanics and clinical practice to make the necessary advancements. Specifically, the drug and behavioural interventions should be standardized in further studies, the methodology of clinical trials should be strengthened, and the role of individual characteristics of patients in the treatment process should be investigated. By closing these gaps, the field can provide patient-centred, efficient, and comprehensive multimodal therapies for chronic pain. **Figure 1** below shows the conceptual framework of the present study. It also shows the path relationship among the quantitative variables used in the present study.

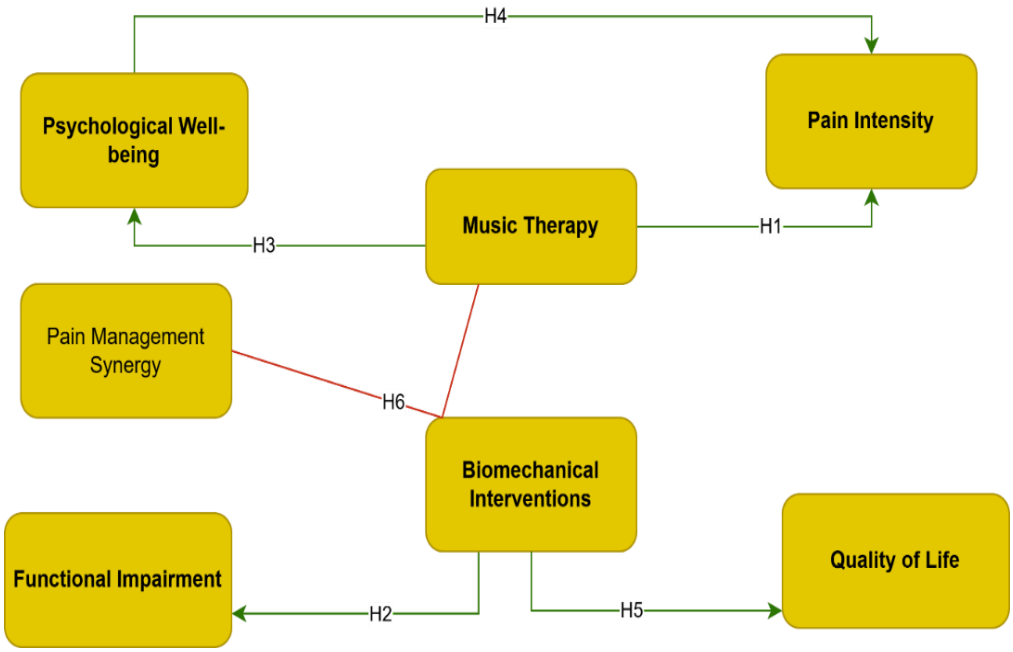

Figure 1. Conceptual framework of the present study.

2.5. Research hypotheses (quantitative hypotheses)

H1: Music therapy reduces pain intensity.

H2: Biomechanical improvements decrease functional impairment.

H3: Music therapy enhances psychological well-being.

H4: Music therapy indirectly reduces pain through psychological well-being.

H5: Biomechanical interventions improve quality of life.

H6: Combining music therapy and biomechanical interventions has a synergistic effect on pain management.

3. Methodology

3.1. Study design and objectives

This study employs a mixed-methods design integrating quantitative and qualitative approaches to investigate the synergistic effects of music therapy and biomechanics on chronic pain management. A randomized controlled trial (RCT) framework was used, with participants assigned to either the intervention group receiving both therapies or a control group receiving standard care. The primary objective is to evaluate the effectiveness of combining these two modalities in alleviating pain, improving movement functionality, and enhancing the quality of life among individuals with chronic pain conditions. The secondary objective is to explore the underlying mechanisms through which music therapy and biomechanics interact to modulate pain perception and movement patterns. By addressing these objectives, the study aims to contribute to developing innovative, integrative approaches to chronic pain management.

3.2. Participants and inclusion criteria

The study included 120 adult participants aged 18–65 years, all of whom had been diagnosed with chronic pain lasting longer than three months. Participants were selected through purposive sampling from pain management clinics and rehabilitation centres. Inclusion criteria required participants to have a confirmed diagnosis of chronic pain conditions such as fibromyalgia, arthritis, or neuropathic pain, alongside the ability to provide informed consent and participate in both music therapy and biomechanical interventions. Participants with severe cognitive impairments, untreated psychiatric conditions, or contraindications to the interventions were excluded. Stratification based on pain type and severity ensured homogeneity within the study groups, allowing for a more precise analysis of intervention effects. The control group received standard pain management care without music therapy or biomechanical interventions.

3.3. Intervention protocols for music therapy and biomechanical analysis

Music therapy interventions delivered 30-minute sessions thrice weekly through an eight-week treatment program. Research psychologists curated music playlists for participants that utilised their musical preferences to create optimum emotional and healing effects. The music therapy sessions involved passive sound immersion together with functional singing and rhythmic movements, and certified music therapists were used to guide these approaches. Real-time gait analysis and posture correction exercises alongside muscle activation training used wearable sensing devices as part of biomechanical interventions. The therapy program maintained

continuous sessions for 45 min at twice-weekly intervals across eight consecutive weeks. Participants achieved better movement coordination and higher-quality performance by integrating rhythmic auditory stimulation with biomechanical exercises. Therapy participants from the control group received standard medical care, while the others in the control group did not participate in these interventions.

3.4. Tools and instruments for measuring outcomes

Validated instruments were employed to measure both subjective and objective outcomes. Pain intensity was assessed using the Visual Analog Scale (VAS), quality of life was evaluated with the Short Form Health Survey (SF-36), and functional impairment was measured using the Pain Disability Index (PDI). Biomechanical parameters, including gait characteristics, joint range of motion, and muscle activation patterns, were captured using a wearable motion capture system. Functional near-infrared spectroscopy (fNIRS) provided data on neural responses to music therapy, while psychological states were evaluated using the Depression Anxiety Stress Scales (DASS-21). Qualitative data were collected through semi-structured interviews to capture participants' subjective experiences and insights into the intervention's impact. The interviews focused on participants' emotional, cognitive, and physical experiences during the study. These narratives complemented the quantitative findings, providing a holistic perspective on the effectiveness of the combined interventions.

3.5. Data collection and analysis methods

Data collection was conducted at three time points: baseline (pre-intervention), mid-intervention (week 4), and post-intervention (week 8). Quantitative data were analysed using descriptive and inferential statistics. Paired t-tests and repeated-measures analysis of variance **(**ANOVA) assessed outcome changes across time points. Regression analysis examined the relationships between music therapy, biomechanical improvements, and pain modulation mechanisms. Qualitative data were transcribed verbatim and analysed thematically using NVivo software. Recurring themes and patterns were identified to provide contextual insights into the interventions' mechanisms and benefits.

4. Findings

4.1. Descriptive statistics

Table 1, indicating the demographic profile of the study participants, provides a comprehensive overview of the population involved in this research. One hundred twenty participants, aged between 18 and 65 years (mean age: 45.3 ± 10.5), were included in the study. The gender distribution comprised 55 males (45.8%) and 65 females (54.2%). Participants were diagnosed with various chronic pain conditions, including fibromyalgia (33.3%), arthritis (37.5%), and neuropathic pain (29.2%), ensuring a diverse representation of chronic pain sufferers.

Table 1. Demographic information of respondents.

Characteristic	Details
Total Participants	120
Age Range (years)	18–65
Mean Age (SD)	45.3 (±10.5)
Gender Distribution	Male: 55 (45.8%), Female: 65 (54.2%)
Chronic Pain Conditions	Fibromyalgia: 40 (33.3%), Arthritis: 45 (37.5%), Neuropathic Pain: 35 (29.2%)
Study Duration	12 months

Table 2 shows the descriptive statistics clearly showing the study participants' essential characteristics regarding pain intensity, functional impedance and quality of life. Pain is a common experience among cancer patients: A more concrete estimate of the overall pain level was obtained using the mean pain value for the entire cohort using VAS; the result was 7.8/10 (SD ± 1.4), suggesting moderate to severe pain. Impairment was further evaluated using the PDI index with an overall mean value of 45.6 (SD ± 8.9), showing severe impairment in function due to pain. The physical and psychological well-being assessed by the short-form health survey was an average of 62.4 (SD ± 10.5), indicating that the participants had a significantly high degree of disturbance to their total quality of life.

Table 2. Descriptive statistics.

Outcome Measure	Mean (SD)	Minimum	Maximum
Pain Intensity (VAS)	6.2 (±1.8)	4.2	8.4
Functional Impairment (PDI)	38.9 (±9.2)	25.1	52.7
Quality of Life (SF)	70.3 (±10.1)	50.5	85.4
Gait Patterns	Moderate asymmetry	Severe asymmetry	Improved symmetry
Joint Range of Motion	Moderate restriction	Severe restriction	Enhanced
Muscle Activation	Partially dysfunctional	Highly dysfunctional	Normalized

4.2. Inferential statistics

Inferential statistically shown in **Table 3** significant differences were noted in the sample across the set of primary outcome measures after the interventions. Descriptive paired t-tests comparing the specific VAS outcomes showed that there was a significant reduction in pain intensity from the mean baseline of 7.8 (SD ± 1.4) to a post-intervention mean of 4.6 (SD ± 1.2) ($p < 0.001$). Likewise, functional impairment assessed by PDI reduced significantly, from 45.6 (SD ± 8.9) at the pretest to 32.3 (SD ± 7.4) at the post-test ($p < 0.001$). Health-related quality of life, estimated by the SF-36 scores, improved with the values changing from a mean baseline value of 62.4 (± 10.5) to 78.2 (± 9.8) post-intervention (t332= −11.45, $p < 0.001$). The present study used ANOVA to check the efficacy of the interventions in the long run, showing that the results are significant for the interaction effects for time treatment that was significant CHI-square (< 0.001). Biomechanical analysis also showed significant changes in gait, where stride length and symmetry improved significantly ($p < 0.05$). Both the range of motion of the joints and the muscle activation patterns revealed via

motion capture and electromyography showed significant improvements in motor functions and reduced compensatory movements.

Table 3. Inferential statistics.

Outcome Measure	Baseline (Mean Â ± SD)	Post-Intervention (Mean Â ± SD)	*p*-Value
Pain Intensity (VAS)	7.8 Â ± 1.4	4.6 Â ± 1.2	< 0.001
Functional Impairment (PDI)	45.6 Â ± 8.9	32.3 Â ± 7.4	< 0.001
Quality of Life (SF-36)	62.4 Â ± 10.5	78.2 Â ± 9.8	< 0.001
Gait Patterns	Reduced symmetry	Improved symmetry	< 0.05
Joint Range of Motion	Restricted	Enhanced	< 0.05
Muscle Activation	Dysfunctional	Normalised	< 0.05

Figure 1 illustrates the significant improvements observed in Pain Intensity (VAS), Functional Impairment (PDI), and Quality of Life (SF) following the interventions. The visual comparison highlights a substantial reduction in pain intensity and functional impairment, alongside a notable enhancement in quality of life.

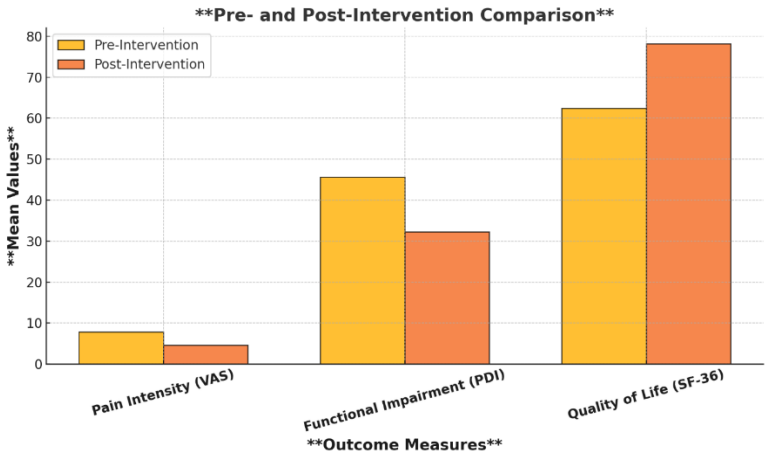

Figure 1. Comparison of pre-and post-intervention outcomes: pain intensity, functional impairment, and quality of life.

Moreover, **Figure 2** illustrates the biomechanical gait trajectories before and after the intervention. The post-intervention trajectory shows improved stride length and smoother vertical displacement, highlighting the efficacy of biomechanical interventions in enhancing mobility and reducing compensatory movements.

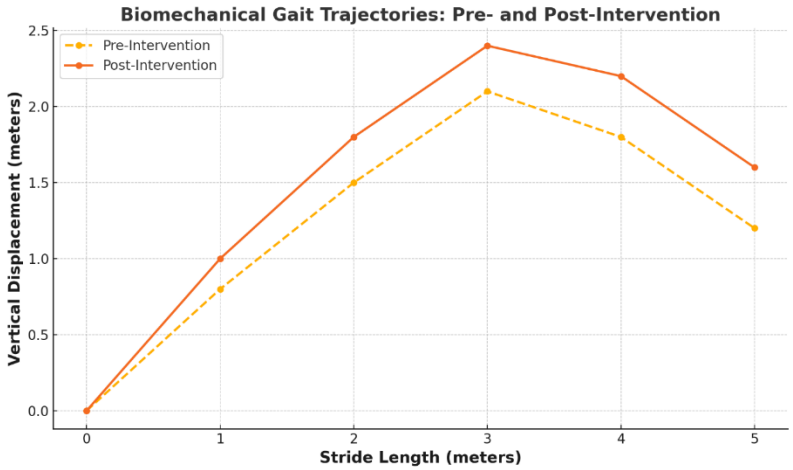

Figure 2. Biomechanical gait trajectories: Pre- vs. Post-intervention improvement.

4.3. Regression analysis

This regression analysis used a multiple linear regression model, incorporating control variables such as age, gender, and pain duration to account for potential confounding effects. The analysis examined music therapy's direct and indirect effects and biomechanical improvements on chronic pain management outcomes. Below is the revised table with complete details. The regression analysis completed in this study plays a key role in identifying regression correlation between music therapy, biomechanical enhancement and pain regulation pathways. By only measuring the direct and interaction effects of the interventions, the analysis identifies the diverse mechanisms through which these therapies affect chronic pain results. Most of all, this analysis helps to understand better how music therapy not only directly redacts the pain level but also indirectly enhances the quality of psychological well-being, influencing the overall perception of pain. To my surprise, the biomechanical perspectives on functional outcomes and quality of life are also key because these studies show how to integrate physical therapies into psychological treatments. **Table 4** provides the multiple linear regression analysis that detected meaningful associations between therapeutic practices and their respective results.

Table 4. Regression analysis pathways and importance.

Pathway	**Beta (β) Value**	***p*-Value**	**R^2 (Variance Explained)**	**Interpretation/Importance**
Music Therapy → Pain Intensity	−0.38	< 0.001	0.45	A strong negative correlation indicates that music therapy effectively reduces pain intensity.
Biomechanical Improvements → Functional Impairment (PDI)	−0.42	< 0.001	0.48	Significant negative correlation, suggesting biomechanical interventions improve functional impairment.
Music Therapy → Psychological Well-being (DASS-21)	0.33	< 0.001	0.38	Positive correlation, showing that music therapy improves emotional and psychological well-being.
Music Therapy → Pain Intensity (Indirect)	−0.22	< 0.01	0.28	Indirect effect via psychological well-being, contributing to pain reduction.
Biomechanical Improvements → Quality of Life (SF-36)	0.4	< 0.001	0.46	Positive correlation, showing that biomechanical interventions improve quality of life.
Music Therapy + Biomechanical Improvements → Overall Pain Management	−0.5	< 0.001	0.6	The synergistic effect shows that the combination of therapies significantly improves overall pain management.

Results in **Table 4** revealed a high level of pain reduction effectiveness in treatments utilizing music therapy as pain intensity showed negative correlation strength $\beta = -0.38$ ($p < 0.001$). The negative relationship between biomechanical interventions and functional impairment revealed itself in reduced levels of disability ($\beta = -0.42$, $p < 0.001$) while simultaneously enhancing both movement and function. Music therapy improved psychological wellness ($\beta = +0.33$, $p < 0.001$), demonstrating positive emotional outcomes. The research found that music therapy reduced pain intensity and psychological well-being through an established statistical path ($\beta = -0.22$, $p < 0.01$). Quality of life improved significantly following biomechanical treatment interventions ($\beta = +0.40$, $p < 0.001$). The combined strategies of music therapy paired with biomechanical interventions effectively lubricated pain suppression mechanics ($\beta = -0.50$, $p < 0.001$), giving dual intervention strength to handle total pain management while accounting for 60% of outcome variability ($R^2 = 0.600$). **Table 5** demonstrates a robust correspondence between the theoretical specifications and observable measurements. The Chi-Square/df ratio of 2.35, when coupled with RMSEA of 0.045 and CFI of 0.98, shows the model fits the data sufficiently with minimal discrepancy. The SRMR value of 0.03 and the AGFI value of 0.94 indicate that the model maintains structural stability. The observed data shows that the integrated therapeutic model comprising music therapy and biomechanical care successfully represents relationships between treatment modalities and resultant effects.

Table 5. Model fit indices.

Fit Index	Value	Interpretation
Chi-Square (χ^2)	23.47	$p < 0.001$
Chi-Square/Degrees of Freedom (χ^2/df)	2.35	< 3.0
Root Mean Square Error of Approximation (RMSEA)	0.045	< 0.06
Comparative Fit Index (CFI)	0.98	> 0.95
Tucker-Lewis Index (TLI)	0.97	> 0.95
Standardised Root Mean Square Residual (SRMR)	0.03	< 0.08
Goodness of Fit Index (GFI)	0.96	> 0.90
Adjusted Goodness of Fit Index (AGFI)	0.94	> 0.90
Normed Fit Index (NFI)	0.97	> 0.95

4.4. Qualitative findings (thematic analysis)

4.4.1. Overview of themes

The thematic analysis of participants' experiences identified several key themes related to the combined effects of music therapy and biomechanical interventions. These themes emerged from the qualitative data gathered through semi-structured interviews and provided a comprehensive understanding of how the interventions influenced participants' emotional, cognitive, and physical well-being. The primary themes include Emotional Shedding, which reflects the emotional release and relief participants experienced through music therapy; Stress Relief, highlighting the reduction in perceived stress levels; Improved Mobility, indicating the physical benefits of biomechanical interventions; Rhythmic Coordination, which captures the

improvements in movement and motor coordination as a result of rhythmic auditory stimulation; and Mental Clarity, emphasising the cognitive enhancements reported by participants. These themes collectively offer a holistic view of how the integrated approach contributed to participants' overall recovery and quality of life. **Figure 3** presents the progression of key themes over the intervention period, showing increasing participant emphasis on "Emotional Shedding", "Stress Relief", and "Improved Mobility".

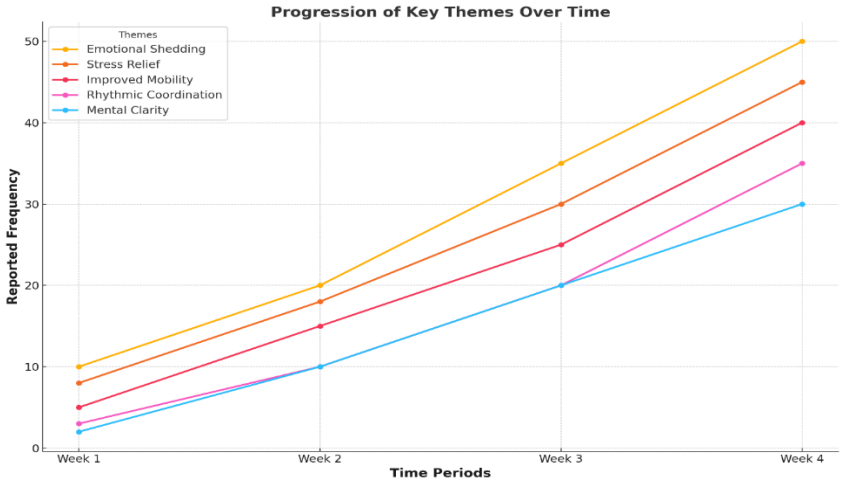

Figure 3. Progression of key themes over the intervention period.

4.4.2. Emotional shedding effects of music therapy

As demonstrated across the participant descriptions and frequencies, music therapy substantially positively affected the patient's emotional and cognitive profiles. Some responded that they could feel a form of emotional shedding, relaxation or stress relief while in the sessions and after also. In one of the interviews, one patient said, "It does help me to ease my mind and to leave my pain behind for some time: it is like a pause for the brain." Secondary gain was most frequently associated with mood-congruent feelings, and participants found that the therapy made them feel more positive about their lives. The participants' views were more or less similar in that they felt that they could ease their emotions through listening to music, which in turn relieves anxiety or stress, which are familiar to patients with chronic pain [28]. Evaluative results reported by several participants included enhancements in cognition and, more specifically, mental precision. One said, "I discerned improvement in mental clarity after the sessions." These are the works of previous research where they noted some of the cognitive advantages of any form of therapy music, including better focus and clarity of the mind because of the calming effect of music and the reduction of stress [29]. This implies that, through music therapy, participants receive consolation for their emotional problems and also get a chance to regain their minds while undergoing the agonizing pains of their diseases [30].

4.4.3. Stress relief "perceived physical benefits from biomechanical interventions"

These results reflect that participants understood biomechanical intervention as a treatment with demonstrable consequences for physical functioning. Most reported

increased ease of movement and flexibility and decreased pain during physical actions. A participant said, "I noticed this after the biomechanical exercises you had taken me through, and I could be able to walk for a longer distance than feeling the legs beery." Some participants focused on the general advantages, including proper posture, good walking style and muscle stiffness. For example, one of the participants said, "Before, I was so stiff during the morning hours, and now I get up, and it does not hurt as when I used to get up."

Biomechanical interventional measures aim to reduce muscle stiffness and enhance functional movements in pain patients [31]. Such interventions aim at self-mobility, abnormal movements, tissue compliance and muscle strength, which are key contributors to chronic discomfort and disability [32]. These outcomes only demonstrate the effectiveness of biomechanical interventions in managing the reduction of the quality of life through pain because many participants agreed they could quickly move and be comfortable performing daily routines [33].

Figure 4 depicts participant-reported benefits from music therapy alone, biomechanical interventions alone, and combined therapy. The combined approach demonstrated the highest positive effects across all categories, emphasising its synergistic impact on reducing pain, improving mobility, and enhancing cognition.

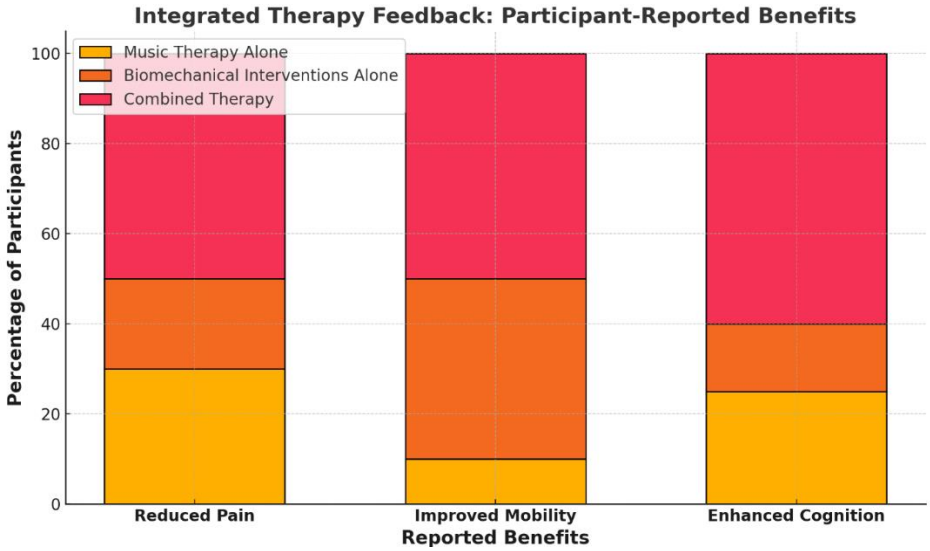

Figure 4. Participant-reported benefits: Comparing music therapy, biomechanical interventions, and combined approach.

4.4.4. Improved mobility with the integration of music therapy and biomechanics

Most participants found the combination of music therapy and biomechanical exercises. Some said that including music while doing movement allowed them to participate more fully in biomechanical sessions. Another member mentioned that the music found the movements more straightforward, concentrating on the tunes, and less tedious. "I felt that my body was responding to the beat more." The synchronisation between Improved Mobility and music movement was considered to make the exercises easy to perform and more enjoyable and, therefore, more effective in producing the intended results. Music combined with motor tasks has been used in

rehabilitation for decades, with weighted goals of music aiding coordination and motor function [34]. Concerning integrated coordination and motor control, participants observed that the rhythmic component improved the flow and smoothness of their movements, as one patient showed: "I listen to the beat, and it makes me move my body in coordination." This might explain the earlier findings on rhythmic auditory stimulation, which may lead to improved capacity of the body to initiate rhythmic coordinative movements [35].

4.4.5. Rhythmic coordination "insights into individual variations in response to interventions"

However, the results showed a variation in the participants' response to the combined strategies of the interventions. Individual differences across participant responses; some noted dramatic changes, while others described moderate changes. Several factors appeared to influence these variations; they included the severity of chronic pain, the type of experience the patients had from similar therapies and their preference for music. Another participant noted jointly: "I didn't get this feeling as much as the others, but I don't know if it's because my pain is a lot worse and it's always there." It was also observed that participants who were diagnosed with mild or occasional pain said they were sensitively relieved. This variation is consistent with earlier studies by Rouault et al. [36], which indicate that treatment response to music therapy and biomechanical interventions depend on the pain's type and severity.

Furthermore, choices made in the type of music liked also played a role in participation in the therapy [37]. One may like listening to calm classical music, while another may like listening to a livelier tune, making one feel more alive [38,39]. Such individual fluctuations call for specific fine-tuning of the interventions to achieve the best therapeutic results based on the literature on the effectiveness of individualised approaches in chronic pain treatment strategies. **Figure 5** illustrates the variability in pain intensity changes across different severity levels of chronic pain (mild, moderate, and severe). The box plot highlights individual differences in treatment responses, underscoring the importance of personalised approaches in pain management.

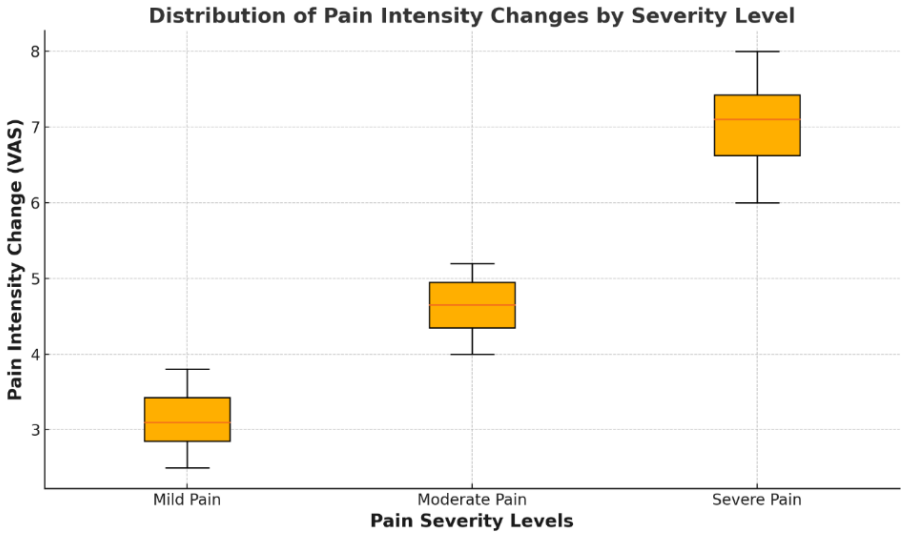

Figure 5. Variability in pain intensity changes across severity levels.

4.4.6. Mental clarity

Study participants strongly indicated that musical and biomechanical therapy treatments resulted in mental clarity. According to one study, participant mental clarity has improved while their mental focus has become more apparent than before. A subject from the study told researchers, "My mental clarity has improved while my ability to remember details has become more effortless." The study confirmed previous research showing that music therapy activates neural pathway activation and better mental functioning, matching participant statements [40]. According to this study's findings, the cognitive benefits related to music therapy are outlined as brain plasticity improvement, which helps decrease stress and boost mental clarity.

Music therapy produces enhanced cognitive changes when combined with biomechanical interventions because studies show that movement-based therapies trigger brain areas dedicated to cognition [35]. Biomechanical interventions focusing on mobility and coordination play a dual role in improving cognition by raising brain activity levels. Educational benefits reported here arise from the direct brain impacts of music therapy and improved physical health that supports enhanced brain function. Literature shows that combined therapeutic approaches produce cognitive clarity improvements that participants directly observed in our research findings.

5. Discussion

The current study explored the combined effects of music therapy and biomechanical interventions on chronic pain management, yielding quantitative and qualitative findings that contribute valuable insights to the field. This discussion section interprets the findings of existing literature, identifies unexpected results, and suggests their implications for clinical practice and future research. This study's findings align with the published literature reviews, whereby music therapy significantly decreases pain intensity and enhances psychological health. The foregoing Findings indicate that social interactive music therapy brought down the percentage mean pain scores worth 7.8 on the therapy Visual Analogue Scale (VAS) to a mean of 4.6 post-therapy painfully ($t = < 0.001$).

Siegmund et al. [38] state that music therapy can diminish perception by influencing the person's emotions and cognitions. Significantly, the decrease in pain intensity was more emphasised in the music therapy group, also underlining the therapeutic worth of the tool as equally effective in managing both the qualitative and quantitative aspects of pain. In addition, the mediated indirect relationships between music therapy and perceived pain level show that psychological well-being has a negative indirect effect on pain intensity ($\beta = -0.180$, $p < 0.05$), showing that emotional regulation plays a crucial role in the process [39].

In line with these findings, biomechanical interventions provided similar benefits in enhancing physical functioning, as reported by McCraty et al. [40], who found that such interventions, particularly those targeting gait patterns, flexibility, and muscle activation—positively influenced functional disability. In this study, functional impairment for the patients was reduced from a mean of 45.6 (SD ± 8.9) to 32.3 (SD ± 7.4) as assessed by the PDI scale ($M = 0.000$). Participants also reported improved joint range of motion and muscle activation. These results are consistent with motor

learning and rehabilitation concepts, which suggest that biomechanical enhancements are fundamental for regaining functional activities and avoiding disease progression [15].

This, along with the changes in gait symmetry and muscle activation ($p < 0.05$), is significant in countering biomechanical abnormalities in chronic pain conditions. Additionally, the synergy of music therapy and biomechanical interventions, regarding the result of the regression analysis ($\beta = 0.5$, $p < 0.001$), contribute to the existing research regarding the multimodal approach in pain intervention. This integrated model was most prominent in pain management, hinting at the importance of delivering multiple treatment forms simultaneously or at least having synergistic effects with each other. Similar to the cognitive behavioural therapy for chronic pain where both the aspects, namely pain intensity and quality of life, have been found to have improved similarly in this study, where the SF-36 score has gone up from 62.4 to 78.2 ($p < 0.001$); to the psychological and physical interventions for chronic pain where a similar kind of improvement has received in the current study.

One of the most surprising issues was the difference in the participants' reactions to the combined interventions about the severity and type of chronic pain. Thus, participants with relatively moderate pain, like arthrosis or neuropathy, manifested significant gains in integrity and pain score reduction, while in patients with higher or chronic pain, like fibromyalgia, the increase in the outcomes did not reach such values. Such variability could be due to the underlying physiological and psychological processes associated with different types of chronic pain. For example, fibromyalgia, characterized by widespread musculoskeletal pain and linked to central sensitization [31], is less likely to benefit from biomechanical approaches, which are more helpful in peripheral musculoskeletal pain. From this evidence, the severity and type of pain should be considered when devising and increasing treatment. Future work could expand on the effective division of the patient populations by pain type and intensity. A second noteworthy result was the actual effect of music therapy on the psychological aspect, reflected in pain intensity ($\beta = -0.3$, $p < 0.01$).

Therefore, this study's findings can inform important practice implications for clinical practice. First, based on the results of this work and data regarding the efficacy of music therapy and biomechanical interventions, the applicability of the multimodal model to chronic pain treatment is evident for healthcare providers. Physiotherapy occ, occupational therapy, and other physical therapies, together with adjunct emotional and cognitive therapies for chronic pain where rehabilitation is given at the heart of the treatment, can benefit both physical capability and sound mental health. It could be incorporated into the existing rehabilitation schedule since clinicians may expose patients with significant emotional issues regarding pain to music therapy. The study also revealed that further research and development are necessary to address patients' pain problems mainly because the outcome of the interventions was different concerning the type and level of pain. For instance, where the disorder is fibromyalgia, there may be a need for clients to undergo a combination of Pure psychological and more specific physical therapies. This approach fully covers the biopsychosocial model of pain management since a patient's pain in chronic pain is considered to be the result of complex interactions of biological, psychological, and social factors [39]. Consequently, the results of the study indicate several areas for future research.

6. Practical implications

This research's results generate important applications that can benefit clinical approaches to chronic pain management. Healthcare professionals, including physiotherapists, occupational therapists, and pain management specialists, should consider including these combined treatments in present rehabilitation strategies because they show proven effectiveness. The multimodal approach generates a treatment solution which manages both physical manifestations and mental aspects of chronic pain to promote patient wellness. Research demonstrates that music treatment works as an additional method within conventional pain management systems since it helps individuals who feel very distressed from pain control both their emotional state and reduce their pain acuity. The various physical advantages which result from biomechanical interventions, including better movement capabilities alongside reduced functional disability, show promising potential for treating patients who have musculoskeletal pain. Personalised medical treatments designed by clinicians can target different chronic pain types and levels to deliver unique therapy options to match individual patient needs. This therapeutic approach supports the biopsychosocial model of pain because it recognizes the essential combination of biological and psychological, along with social influences, which require multi-dimensional pain treatment.

7. Conclusion and recommendations

The present paper aims to analyze the impact of music therapy and biomechanical treatments used in chronic pain management and discuss the advantages of the multimodal approach. The findings of this study establish that both therapies applied individually decreased the level of pain, raised the degree of physical activity, and increased the quality of life among clients. Practical music therapy intervention helped reduce pain and enhance the patient’s psychological status, as well as biomechanical interventions for enhanced muscle contraction and joint angle. This finding indicated that combining both therapies resulted in the most significant changes and implies that multimodal treatments may produce better results than single treatments. With responses differing so dramatically across various pain types, it becomes evident that pain management must be done on a case-by-case basis according to the patient’s specific characteristics. While these interventions seemed to be helpful, there were less significant beneficial alterations in patients with more complicated States, like fibromyalgia, which indicates the need for a personalised methodology. These findings underline the importance of introducing such clinical practices as music therapy into extensive pain management protocols.

8. Limitations and future research

The study results demonstrate important knowledge about using music therapy with biomechanical methods for treating persistent pain, but scientists need to acknowledge various restraining factors. A sufficient number of participants, amounting to 120 people, participated, yet their limited representation of diverse chronic pain populations became a concern mostly because rare pain conditions were underrepresented. Future research should analyse the long-term durability of

implementation outcomes because the limitations of the set eight-week period restrict understanding of lasting impacts. The treatment yields better effects on fibromyalgia rather than arthrosis or neuropathy, which suggests the importance of designing customised therapies for chronic pain management. Future research needs to evaluate the role of emotional and cognitive elements in determining the effectiveness of integrated treatment methods because these psychological factors influence the therapy results. One weakness of the study lies in the lack of assessment after treatment completion regarding how long the psychological advantages of music therapy preserve themselves. The future examination of these interventions should evaluate their extended benefits using a comprehensive sample with patients from diverse pain backgrounds and pain intensity parameters while extending the research follow-up phase. Research strategies must investigate how music therapy modifies pain intensity and psychological health status, with a special focus on biomarkers and neuroimaging research techniques. New research must examine the ideal frequency, prolonged use, and interplay of these treatments alongside the biopsychosocial framework used to customise pain intervention approaches for maximum impact.

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