New technologies at the service of thermal medicine for chronic pain: Crenomusic-care.

for the Inter-University Diploma in Medical Practices in Thermal Spas 2025

by Luc Brun PhD

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# Abstract :

**Introduction:** Thermal medicine, a centuries-old technique, is effective in treating numerous conditions, particularly musculoskeletal pain. Digital technologies and other emerging innovations are playing an increasingly important role in healthcare. Recent publications have described the impact of digital therapies (DTx) using music on pain and anxiety. The diffusion of sounds and then music underwater has been extensively studied scientifically and could be of interest as a complementary treatment technique. Speakers designed for transmitting music in aquatic environments are available.

**Objective:** To study the feasibility and effect of underwater music listening (tympanic and retrotympanic listening) during a thermal spa treatment for patients suffering from chronic pain.

**Method:** A prospective, single-center observational study of volunteer patients undergoing rheumatological spa treatment (Balaruc-les-Bains thermal spa). Each patient received one or more sessions called "Crenomusic-care." The subject is immersed in the thermal pool, lying down with their body and ears submerged for tympanic and also retrotympanic listening (via the temporal bone). The Music Care© application (music listening using the "U" technique, lasting 20 minutes) is used for musical relaxation and broadcast underwater by the Aquamusique© system (4 waterproof speakers submerged in the thermal water pool). The primary outcome of the study is the assessment of pain level, measured before and after the session using a numerical rating scale (NRS 0 to 10). The secondary outcome is the anxiety level (NRS) measured before and after the session. Statistical analysis uses Wilcoxon signed-rank tests.

**Results:** 22 patients (17 women), with a mean age of 64.6 years, participated in the study. The number of sessions varied from 1 to 3 per patient, depending on their availability. More than half of the patients were in their first week of treatment (59.1%), and 54.6% received 3 sessions. Half of the patients suffered from lower back pain. From the first session, a significant reduction in pain level was observed, decreasing from 3.8±2.3 before the session to 1.4±1.9 after the session, corresponding to a 64% decrease ($p=0.0014$). A greater decrease was observed with subsequent sessions (71% and 90%, respectively). Similar results were demonstrated for anxiety levels, with a 58% decrease during the first session (-1.6±2.0, $p=0.0005$).

**Conclusion:** We have demonstrated the feasibility of underwater listening to a musical relaxation sequence during spa therapy for patients suffering from chronic pain. Pain and anxiety appear to decrease after each session. It will be necessary to confirm the encouraging results of this pilot study with a randomized controlled trial involving a larger number of participants.

# Introduction :

Thermal medicine is a centuries-old, non-pharmaceutical medical treatment technique that has been regulated in France since the 18th century (Royal Academy of Medicine, then National Academy of Medicine). There are 12 therapeutic approaches, and recent controlled studies have demonstrated its effectiveness in improving numerous chronic conditions and the long-term quality of life of treated patients (1,2,3).

Music therapy likely dates back to the origins of humanity, so deeply is music ingrained in civilizations and how it accompanies human beings throughout their lives (even before birth, in the womb). The properties of music have led medical specialties to use listening to music in a wide variety of disciplines: pain management, anxiety and depressive syndromes, neurological diseases, and numerous functional disorders (sleep, fatigue, hyperactivity, etc.)(4,5,6,7). The company Music-Care has developed a digital solution that allows for listening to music according to standardized modalities and the musical tastes of patients. Randomized studies have demonstrated its effectiveness in improving symptoms of rheumatological and neurological conditions, as well as in pain management (8,9). A 2011 study conducted at the Allevard thermal baths examined the effects of weekly Music-Care® sessions during a spa treatment program for patients suffering from fibromyalgia. A reduction in pain was noted at each session, and a potentiation effect was even observed over time. The same results were observed for anxiety (10).

Music is generally listened to through the air, but the propagation of sound in water allows for listening to music while immersed, not only through the eardrum but also through the temporal bone for retrotympanic listening (direct activation of the cochlea). Thus, since 1992, a handful of pioneers in the field have created a system for playing music in aquatic environments. The concept of "musical massage" arose from observing the effects of music on the human body when subjected to underwater listening, both tympanic and bodily. An amplifier transmits the music into a pool using a series of speakers specifically designed for this purpose. Noel Canivenq (Aquamusique®) defined the concept of "tympano-amniotic" listening to describe the effects of this underwater musical experience on the human brain (11,12). For the purposes of this work, we will use the term "retro-tympanic" listening.

The aim of this study is to demonstrate the feasibility of listening to a musical relaxation sequence underwater using the Music-Care® App during a spa treatment. We have therefore named this study "Crenomusic-care". We will also observe the effects on pain and anxiety.

# Methodology:

**Study design:** Single-center prospective observational study

**Study location:** Balaruc-les-Bains thermal spa (Occitanie, France)

**Population description:** We are studying subjects admitted to the spa for rheumatological spa treatment. The number of subjects must be greater than 20 to perform statistical calculations. Pain must be present (Numerical Rating Scale ≥ 3) to demonstrate a clinically relevant difference. After providing informed consent, the spa guest volunteers and agrees to the use of their anonymized data. They agree to swim in the pool according to the spa's regulations.

**Intervention procedure:** The pool water is thermal water at a temperature of 32°C, allowing for a comfortable 20-minute bath.

We offer simultaneous group sessions**.**

The subject is interviewed by an investigator to collect administrative and medical data: this is part 1 of the data collection process. His musical tastes are discussed with him to ensure they are compatible with the selection of Music Care® sessions that will be used (see Appendix 3). He is then immersed in the thermal pool (1.30 m deep; 32°C): lying down with his ears submerged and buoyancy aided by a floating object (a "noodle"). The goal is to achieve the deepest possible relaxation to support the session. The body and ears are immersed for tympanic and retrotympanic listening. The patient is free to float as he pleases to enjoy his session without any other stimulation. He is advised to close his eyes.

The aquatic music diffusion system uses two 50W shell-shaped speakers and two 70W AquAirmusic speakers with a dedicated amplifier and DSP (Digital Sound Processing). The four waterproof Aquamusique® speakers *(see photo 1)* are installed in the pool, allowing for the diffusion of pre-selected musical sessions into the water. An investigator is present in the pool to observe the subjects' reactions and ensure their safety. Physical contact with the investigator is avoided as much as possible.

The crenomusic-care session lasts 20 minutes.

Afterward, the participant leaves the pool, and data for Part 2 is collected.

A single subject can participate in several consecutive sessions, thus serving as their own control over multiple sessions.

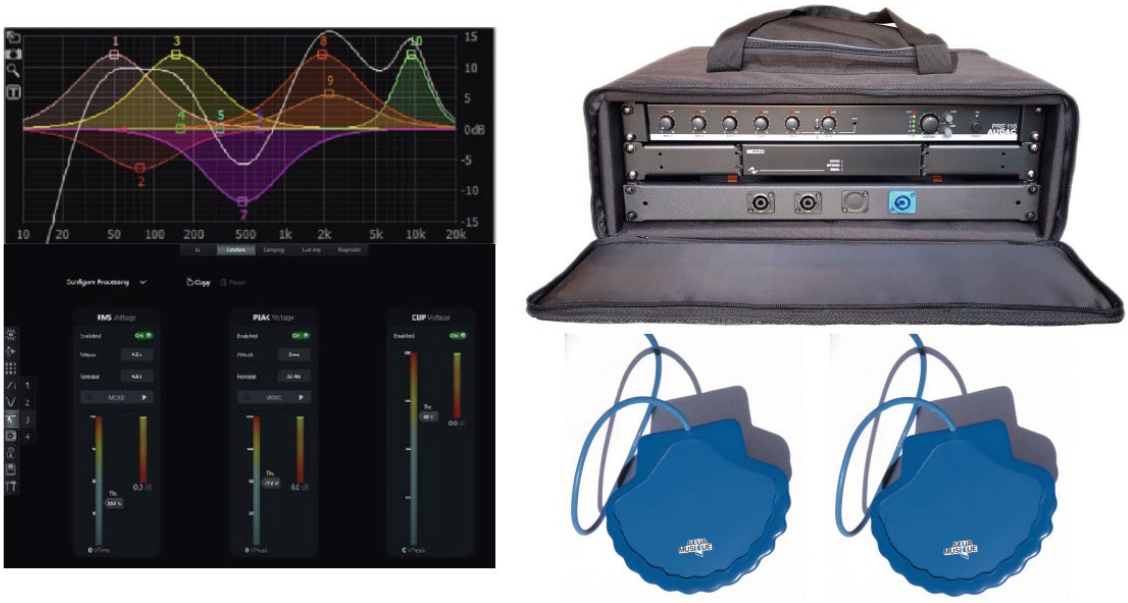

Photo 1. The Aquamusic system used for Crénomusic-Care

**Parameters analyzed:**

**Part 1 (before the session):**

Signed patient agreement: informed consent and image rights

Demographic data

Medical history, treatments, associated care protocols within the program, indication for the program.

Which week of the program are you in?

Have you previously experienced Music Care®?

Do you listen to music regularly?

Do you play an instrument?

Do you use music to relax or stimulate yourself?

Do you experience any pain? If so, where?

Numerical pain scale before: from 0 (no pain at all) to 10 (the most excruciating pain imaginable)

Do you have difficulty relaxing? Yes No

Numerical anxiety scale before: from 0 (no anxiety at all and perfectly relaxed) to 10 (the most intense psychological tension imaginable)

Name of the Music Care® session used.

**Part 2 (After the session)**

Numerical pain scale after session: 0 to 10

Numerical anxiety scale after session: 0 to 10

Session satisfaction using the Likert scale: Not satisfied; moderately satisfied; satisfied; very satisfied

Would you recommend this treatment to others? Yes or No

Observations made during the session by the investigator

Patient's comments

**Statistical Analysis:**

Primary outcome measure: reduction in pain between before and after the session.

Secondary outcome measures: reduction in anxiety, session satisfaction.

The primary outcome measure of the study is the assessment of pain level, measured before and after the session using a numerical rating scale (NRS 0 to 10). The secondary outcome

measure is the anxiety level (NRS) measured before and after the session. Statistical analysis uses Wilcoxon signed-rank tests.

For subjects undergoing several consecutive sessions: to assess the evolution of pain and anxiety during the first and subsequent sessions, a repeated measures mixed effects model (MMRM) is used. The MMRM provides relatively unbiased estimates in the presence of certain types of missing data (MCAR, MAR) and accounts for intra-patient correlation. Mean pain and anxiety levels, along with their confidence intervals, are estimated for the entire population using a model with sessions as the fixed effect.

To assess the impact of multiple sessions on the evolution of pain and anxiety, the "session" event was considered a fixed effect. By making the event a fixed effect, it will be possible to estimate whether the baseline score in the first session differs from the score at the start of the second session, which amounts to analyzing the significance of the MMRM intercept. Subsequently, it will be assessed whether the slope during the first session and subsequent sessions is statistically different from 0 (i.e., whether there is a change in pain and anxiety levels over time).

Several variance-covariance matrix structures were tested (no structure, compound symmetry, first-order autoregressive) to determine the most suitable model, choosing the one that minimized the two criteria: AIC (Akaike's information criterion) and BIC (Bayesian information criterion). The absence of structure was chosen as the most appropriate.

# RESULTS

## 1. Preliminary test period

A first test session was conducted on March 8, 2025, in the thermal water pool of Balaruc-les-Bains with 8 test subjects: 2 consecutive 20-minute sessions.

50% were already familiar with Music Care®.

100% regularly listen to music.

62.5% use music to relax or stimulate themselves.

3 people (37%) play an instrument.

Only 1 person reported not experiencing pain, and 50% had difficulty relaxing.

Average pain level before the session: 4/10

Average pain level after the session: 0.6/10

Average anxiety level before the session: 2.25/10

Average anxiety level after the session: 0.12/10

7 subjects were very satisfied, one was satisfied, and 100% would recommend Music Care® to their friends and family.

| **Comments from test participants:** |
| --- |
| Avoid songs with lyrics as they break the relaxation zone. |
| "Well-being, pain relief" |
| Pay attention to the bass levels (3 people) |
| Be careful of drifting in the pool (subjects colliding with each other) |
| "I felt like I was flying" |
| "Aquatic sensation like being in amniotic fluid," |
| "like being in my mother's womb" |

This preliminary study allowed us to make the correct adjustments for the group sessions *(see photos 2A and 2B)*:

• Placement of the speakers in the pool

• Positioning of the subjects in the water and buoyancy aids ( foam board, inflatable vest, etc.)

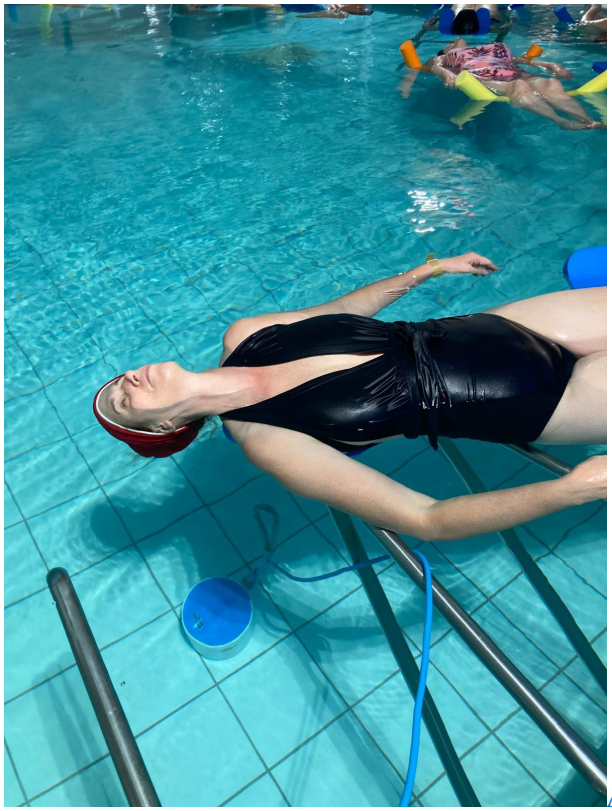 A

Photo 2. The subject's positioning in the Balaruc thermal water pool (2A and 2B). The presence of a caregiver in the pool ensures the participants' safety..

Aquamusique® speakers in immersion (2A)

B

## 2. Crénomusic-care : résults

Twenty-two patients participated in the study: 17 women and 5 men. The average age was 64.6 years.

The number of sessions varied from 1 to 3 per person: 12 subjects completed 3 consecutive sessions (54.6%), 4 had 2 sessions, and 6 had only one session. These variations in the number of sessions per subject were related to the patients' availability on the proposed days and times.

More than half of the patients were in their first week of treatment (59.1%). Six patients were in their second week and 3 in their third week. Half of the patients had a dual focus on rheumatology and phlebology.

**Medical history:** *(see Table 1)*

8 patients suffer from chronic lower back pain (36.3%), 6 from osteoarthritis in multiple locations (27.2%), and 9 from post-surgical pain (40.9%): 3 lumbar spinal fusions, 1 hip replacement, 3 cancers, and 1 fracture.

Other notable medical histories include: fibromyalgia, chronic insomnia, migraine, osteoporotic fractures, inflammatory rheumatic diseases (PMR and AS), cervical spondylotic myelopathy, and severe dystonia.

| Medical History | N= | percentage |
|---|---|---|
| **Arthrosis** | 6 | 27.2 |
| **Low back pain** | 8 | 36,3 |
| **Post surgical chronic pain** | 9 | 40,9 |
| **fibromyalgia** | 1 | 4 ,5 |
| **Insomnia** | 1 | 4,5 |
| **migraine** | 1 | 4,5 |
| **Ostéoporotic fracture** | 2 | 9 |
| **Inflammatory rheumatism** | 2 | 9 |
| **Cervical spondylotic myelopathy** | 2 | 9 |
| **Severe upper limb dystonia** | 1 | 4,5 |
| **depression** | 2 | 9 |

Table 1. The medical history of spa visitors

**Treatments** : *(see table 2)*

Five patients are taking paracetamol and two are taking NSAIDs.

One patient is on immunosuppressants for ankylosing spondylitis and on strong morphine (oxycodone 10 to 40 mg per day).

Two patients are on antidepressants and one is taking Rivotril. One patient is undergoing hormone therapy for gynecological cancer.

| Medicine treatment | N= | percentage |
|---|---|---|
| acetaminophen | 5 | 22,7 |
| NSAID | 2 | 9 |
| opioids | 1 | 4.5 |
| Antidepressant | 2 | 9 |
| Clonazepam | 1 | 4 ,5 |
| hormone therapy | 1 | 4,5 |

Table 2. Medicine treatments

Two participants were already familiar with the Music Care app, having participated in the preliminary testing phase in March 2025. All the others had never experienced music therapy. The majority regularly listen to music to relax or energize themselves (90.9%). Only two play a musical instrument (9%).

**Pain before the intervention**: *(see Table 3)* One participant reported not experiencing any pain before starting the study but wanted to participate because of its effect on anxiety.

Pain reported before the first session included:

Lumbar spine: n=15 (68.1%)

Cervical spine: n=7 (31.8%)

Thoracic spine: n=8 (36.4%)

Lower limb: n=14 (63.6%)

Upper limb: n=11 (50%).

Before the sessions, the average pain score on the numerical scale (from 0 to 10) is significant: 3.8 plus or minus 2.6. 4 patients have a NRS <=3 before the first session (low pain) and 5 patients have high pain with NRS>=7.

| Pain location | N= | percentage |
|---|---|---|
| Low back | 15 | 68 ,1 |
| leg | 14 | 63,6 |
| arm | 11 | 50 |
| Upper back | 8 | 36,4 |
| Cervical spine | 7 | 31,8 |

Table 3. Pain location

**Pre-intervention anxiety:**

Anxiety is a secondary study parameter; it is often associated with chronic pain, and its consideration is important in overall treatment. Thirteen participants reported having difficulty relaxing (59%). The average numerical anxiety score before the first intervention was 2.8 ± 2.4.

**Music Care® sessions listened to:**

The first group session involved 12 participants for the Lullaby session.

The second involved 18 participants for the Keneya session.

The third involved 20 participants for the Kanou session.

All sessions lasted 20 minutes.

**Comparison before and after the sessions:** *(see Figures 1 and 2)*

From the first session, a significant reduction in pain level was observed, decreasing from 3.8 ± 2.3 before the session to 1.4 ± 1.9 after the session, corresponding to a 64% decrease ($p = 0.0014$). A more significant decrease was observed over the course of the sessions (71% and 90%, respectively). Furthermore, pre-session pain scores decreased during successive sessions.

Similar results were demonstrated for anxiety levels, with a 58% decrease during the first session (-1.6±2.0, $p=0.0005$).

The repeated measures mixed-effects model showed a significant change in pain levels over the sessions ($p=0.0219$). A similar result was observed for anxiety ($p=0.0382$). Thus, the patients' pain and anxiety levels appear to decrease over the course of the sessions.

Note: For anxiety during sessions 2 and 3, no significant difference was found, despite what can be seen in the graph (Figure 2). This is because the graph represents means, while the test was performed on medians due to the small sample size.

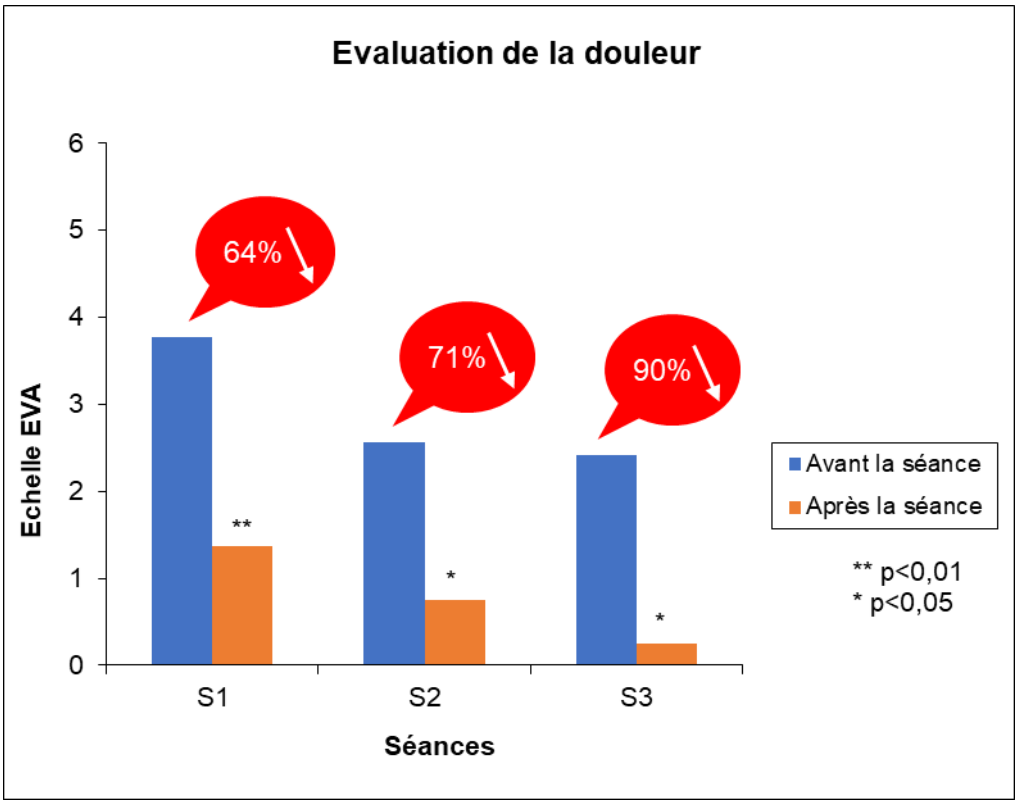


Fig.1 Pain scores (EN 0 to 10) before and after sessions S1= session 1 (Lullaby), S2= session 2 (Keneya) , S3= session 3 (Kanou)

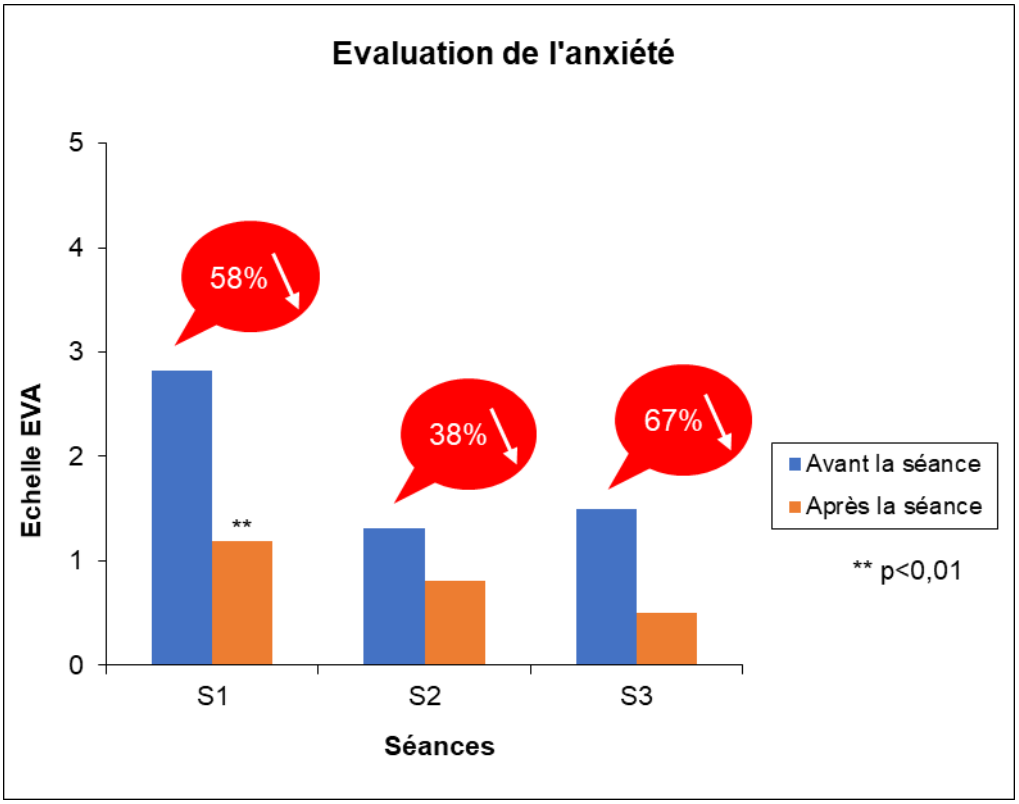


Fig.2 Anxiety Scores (EN 0 to 10) before and after each session. The decline is significant for the first session but not for sessions 2 and 3.

**Satisfaction scores:**

Most spa-goers are satisfied or very satisfied with the technique: *(see table 4.)*

| Satisfaction score | N= | percentage |
|---|---|---|
| **Not satisfied** | 1 | 4,5 |
| **Moderatelly satisfied** | 1 | 4.5 |
| **satisfied** | 4 | 18,2 |
| **Very satisfied** | 15 | 68,2 |
| **No comment** | 1 | 4,5 |

Table 4 : satisfaction scores

The majority (95.4%) would recommend this treatment to their friends and family if they were to undergo a rheumatological spa treatment.

**Difficulties encountered:**

Finding the correct, comfortable position with proper immersion of the body and head is essential. Some spa-goers took time to achieve this optimal buoyancy. Six spa-goers reported neck pain related to the cervical extension position.

Contact between spa-goers during group sessions: Some spa-goers were bothered by the drift caused by the water's movements. They sometimes came into contact with other spa-goers, but only one complained about this. We largely resolved the problem by turning off the filtration system during the session. This also reduced the background noise from the operating jets.

Sound diffusion in the water: Two spa-goers were bothered by the bass: one different spa-goer at each session. Disturbed by high-pitched sounds: 1 participant in session 1.

Disturbed by the volume: 1 participant in session 2; 4 participants in session 3.

Disturbed by percussion: 3 participants in session 2; 1 participant in session 3.

Musical selection and group sessions: The Music Care system was not used according to standard recommendations, particularly regarding selection based on participants' musical tastes. Because the study design required group sessions, we were unable to accommodate individual session preferences.

One participant complained of irritation of the external auditory canal and sought medical advice after the first session. However, she wished to continue the study due to the pain relief experienced after the first session. We authorized her to continue with a topical treatment.

All participants were instructed to rinse their external auditory canals with water. During the last session, a patient experienced a worsening of pre-existing dental pain. However, she continued until the end.

**Verbatim from crenomusic-care participants:**

I didn't need to take morphine. I felt hypnotized.

I felt like I was floating as I fell asleep after the second session.

It's nirvana. The night was longer than usual. My brain is no longer focused on the pain. I have a sensation of flying, of being outside my body. A feeling of nothingness, what a relief.

I traveled, I was transported to Africa, to the ends of the earth, with the animals in Tanzania, surrounded by zebras and giraffes… It was the best treatment of the entire spa retreat (2nd week of treatment). I felt like flying, like a bird, like I was in the air, gliding. I also felt like I was holding my breath underwater, like I was diving. I felt like I was falling asleep, I wanted to turn onto my side and grab my duvet, then I remembered I was in the water… I had a good night's sleep, no pain when I woke up. I didn't need sleeping pills last night.

I didn't need them. I had a good night's sleep; I fell asleep easily, which is unusual for me…

Less stiffness this morning when I woke up.

Sometimes underwater music creates a pleasant vibration throughout my spine.

Two patients reported a re-experiencing of this sensation when they had dry sound therapy sessions after their first crenomusic-care session.

# DISCUSSION :

## 1. The study context: The Balaruc-les-Bains spa resort

First things first, let's begin by describing the Balaruc-les-Bains spa resort, which welcomed us for this unique experience. Pindar, the Greek poet (518-438 BC), attributes the emergence of the thermal waters of Balaruc to Athena, so that Heracles could rest and recharge before going to fetch the bulls of Geryon and bring back the golden apples from the Garden of the Hesperides. Could Heracles have been the first spa-goer in Balaruc-les-Bains?

In the 11th century, the Montpellier School of Medicine relied on treatments with thermal waters for its foundation, its development, and its influence in the new world of medicine. It was one of his students, in 1579, who authored a monograph on the waters and therapeutic uses of Balaruc-les-Bains: Dr. Nicolas Dortoman (successor to Antoine Saporta at the Faculty

of Medicine in Montpellier (1574), physician to Charles IX, first physician to Henry IV, and professor at the University of Montpellier) (13).

With approximately 55,000 spa visitors per year, Balaruc is the leading thermal spa resort in France.

The average age of spa visitors is 69. 37% are men and 63% are women. The officially recognized specializations are rheumatology and phlebology.

Drawed from a depth of between 120 and 404 meters at a natural temperature between 37°C and 49°C, it is one of the hottest and most mineral-rich thermal waters in Languedoc. Its water is said to be 100,000 years old and originates from the limestone plateaus of Aumelas and the Gardiole massif, 2,000 meters underground.

The waters of Balaruc-les-Bains have analgesic, anti-inflammatory, sedative, anxiolytic, and restorative properties. They come from deep springs, rich in bicarbonate and trace elements, in their original marine environment.

The thermal water is richly mineralized (11g/l): chloride, sodium, calcium, sulfate, and magnesium.

| Cation | Concentration (mg/l) |
|---|---|
| Calcium | 560 |
| Magnesium | 380 |
| Sodium | 3700 |
| Fer | 0.10 |
| Manganèse | 0.042 |
| Aluminium | 0.02 |
| Arsenic | 0.005 |
| Lithium | 0.18 |
| Strontium | 4.2 |

Table 5. Concentration of cations in the thermal water of Balaruc-les-Bains

| Anions | Concentration (mg/l) |
|---|---|
| Bicarbonate | 500 |
| Chlorure | 6800 |
| Sulfate | 900 |
| Fluor | 0.35 |
| Brome | 0.7 |

Table 6. Concentration of anions in the thermal water of Balaruc-les-Bains

Among the facilities, the Balaruc-les-Bains establishment has a thermal water pool with a temperature between 32 and 33°C, which is used for our study. *(see photo 3).*

Photo 3. The thermal water pool in Balaruc les Bains (Crénomusic-care study)

The spa resort of Balaruc-les-Bains is the site of numerous studies on thermalism. Current research focuses on cyanobacteria and microalgae in the thermal waters and their therapeutic properties.

The framework of our study likely introduces a bias regarding the effectiveness of the results. Indeed, spa-goers are accustomed to the thermal water pool, and the treatments provided generate comfort and analgesia. The environment and the presence of the thermal baths are also reassuring and may contribute to reducing anxiety.

# 2. Additive Effect of Music Therapy and Thermal Medicine

## 2.1 Music and Treatment

Music has been known since antiquity to relieve pain and other unpleasant symptoms. At the end of the 19th century, some dentists using music played on a phonograph observed a decrease in the intensity of pain, anxiety, complaints, and the frequency of nausea. In 1960, these observations were confirmed by Gardner, who published a large-scale study of 5,000 patients in the journal "Science," demonstrating that listening to music during dental surgery reduced pain in 90% of patients (14). Since then, similar results have been reported for various types of acute and chronic pain (15). Chosen for its pleasantness to the patient, music can reduce the overall sensation of pain (16).

Music therapy is gradually finding its place as a complementary technique in medical practice. More recently, thanks to brain imaging and experimental and clinical studies, we are beginning to understand the mechanisms involved in the relationship between music and pain. The main modes of action have thus been identified: these are the same mechanisms underlying the different dimensions of pain (17).

- The sensory component: by triggering counter-stimulation of afferent fibers, thus referring to the "Gate Control" theory;

- The cognitive component: by diverting attention, often by creating images (recalling a situation, recognizing the timbre of an instrument, etc.) and by diverting thoughts away from the pain;

- The affective component: by modifying mood associated with states such as depression or anxiety, thereby reducing tension and negative emotions linked to these states;

- The behavioral component: by acting on muscle hypertonia and psychomotor activity (the urge to dance or move when listening to upbeat music);

- Psycho-social by intervening in the reduction of the chronic pain phenomenon: the music being chosen according to the personal tastes of the patient, it makes it possible to respond to the demand for individual listening *(see Figure 3)* (18).

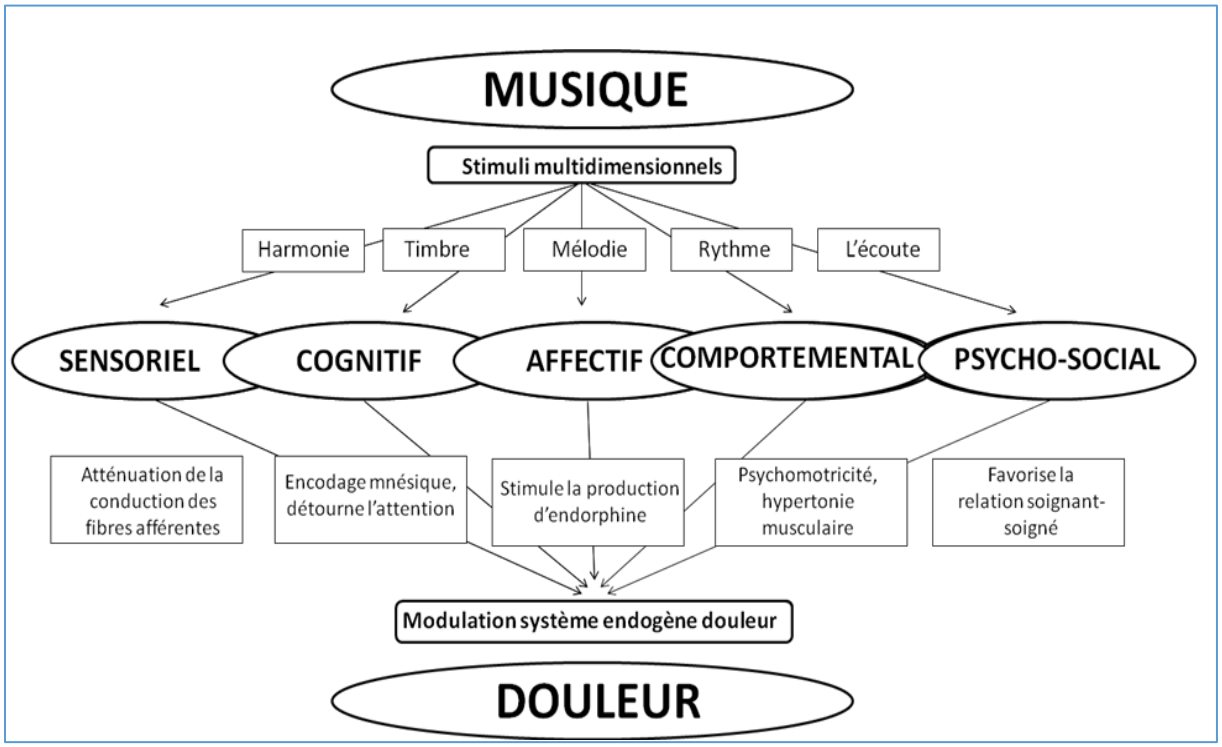


Figure 3. Main psychophysiological modes of action of music therapy

### 2.2 Key parameters of therapeutic musical sequences

**Relieving pain: at what tempo?**

The tempo of music plays an important role in synchronizing with heart and respiratory rates. A slower tempo is associated with calmness, while an faster tempo is associated with stimulation. A slow tempo, around 60 beats per minute, induces a state of relaxation, whereas a fast tempo, around 180 beats per minute, brings patients back to a state of alertness.

It has recently been shown that music is more likely to relieve pain when its tempo is in harmony with our natural internal rhythm (heart rate) (20).

**How to tune instruments?**

The tuning of instruments can also play a role in health. According to the results of recent controlled studies, tuning instruments to 432 Hz is more effective at reducing anxiety than tuning to 440 Hz (the current standard for music) (21,22). The sequences offered by the Music Care® medical device incorporate this new tuning into their composition.

### 2.3 Literature Data

The effects of Music Care® have been demonstrated in various clinical situations to reduce anxiety and pain in people suffering from a range of conditions.

In the context of chronic pain, the results of a randomized controlled trial show an impact on reducing pain intensity (VAS) ($p<0.001$) and, in particular, on the use of anxiolytics and antidepressants. This study was conducted on 87 patients with: lower back pain (n=22),

fibromyalgia (n=22), an inflammatory condition (n=22), or a neurological condition (n=21). During hospitalization, the intervention group (n=44) received at least two daily musical interventions via the digital application between days 0 and 10, in addition to their usual treatment, and continued to use the application at home until day 60. The proportion of patients taking anxiolytics in the music therapy group decreased from 90.9% at day 0 to 42.9% at day 60 (-5%). In the control group, these proportions were 79.1% at day 0 and 66.7% at day 60 (-16%), respectively (8).

Another randomized controlled trial conducted with patients suffering from chronic lower back pain showed that the proportion of patients experiencing improvement increases with the number of sessions. 76% of patients reported improvement after the first music therapy session, 73% after the second, 88% after the third, and 94% after the fourth session (16).

Music Care® can also be administered in surgical settings or to support unpleasant or painful procedures. A randomized study of 310 patients was conducted for cataract surgery under local anesthesia. The reduction in intraoperative hypertensive episodes (indicative of anxiety and procedural pain) was significant, with 21 episodes recorded in the Music Care® arm (13.6%) versus 82 in the control arm (52.9%) ($p<0.01$). A significant decrease in anxiety and sedative (midazolam) injections during the operation was observed (23).

# 3.Additive effect of underwater listening to music intervention in healthcare

## 3.1 Background

Manual massage has analgesic properties linked to several peripheral and central neurological mechanisms. By combining warm water with mechanical hydro-massage, the 20th century democratized the benefits of underwater massage, which became completely independent of the previously indispensable hand. Following in the footsteps of Mr. Jacuzzi's invention, the company Aquamusique had the idea of replacing the action of these air bubbles and water currents on the human body with music.

Its founder, Noël Canivenq, describes this new relaxation technique: “During an underwater music session, the Aquamusique® speaker diffuses the benefits of music into our bodies;

– The reclining position, with the body immersed up to the ears in warm water, prepares the mind for rest, as if in a state of pre-sleep in bed;

– The subjective dimension of music promotes muscle relaxation thanks to the distracting effect of listening to music;

– The membrane of the underwater speaker acts as a kind of substitute for the eardrum and transmits the sound wave directly to the cochlear fluids of the inner ear as a vibration, while amplifying the sound through tympanic bone conduction;

– At the same time, other areas are directly affected independently of the ear. An undecoded vibratory form of the sound signal propagates, via the fluid that makes up our body, a global massage beyond the known range of musical perception.

During intrauterine life, the individual is immersed in a sonic aquatic world, the amniotic fluid. This capacity for bodily listening is forgotten after birth but does not disappear entirely. The underwater membrane speaker could reactivate this

prenatal listening. This new listening is called "amniotympanic" by Noël Canivenq. For him, the simultaneous conjunction of this dual listening, both tympanic and bodily, creates the conditions for a new perception of music: musical massage. In thermal medicine, this type of treatment could be compared to pool relaxation, a treatment regularly used in spa resorts.

In 2008, Etienne Oury, a sound engineer, wrote a thesis on the perception of underwater sound (24). He concluded that sound is perceived via transcranial bone conduction underwater *(see inset).*

**Conclusions of Mr. Etienne Oury's thesis, "Underwater Sound Perception,"** (24)

Underwater perception is felt physically. Vibrations are felt throughout the body.

Sound is perceived in the skull. Localization seems difficult.

The spectral rendering is modified compared to our usual aerial listening habits, and it depends on the depth and the listener's position in the pool:

➢ There is a bump in the midrange at the surface.

➢ Bass frequencies are reinforced at the bottom of the pool.

Some music is rendered better than others:

➢ Timbral nuances are poorly reproduced.

➢ Wide dynamic ranges cannot be rendered.

The perception of dynamic range is limited underwater.

Sound excerpts with clearly defined left/right sources are recognizable.

Stereophonic sound, compared to monophonic sound, creates a sense of spaciousness and enhances listening comfort.

The "classical" perception (via the ears) plays a role in underwater localization:

➢ It amplifies low frequencies

➢ It provides a greater sense of space

➢ It affects accuracy and definition.

In 2009, an experiment was conducted on patients with cerebral palsy, and the results were spectacular in terms of behavioral changes during the sessions: improved self-confidence, reassurance for those initially afraid of water, improved interpersonal interactions, and improved mood. 70% of the subjects had completed their individual projects after several days of sessions (11).

For the first time, we present a medical study conducted with the Aquamusique® system *(see photo 1)*. The reclining position and the release from gravity through buoyancy encourage

relaxation and a sense of calm. The muffling of certain frequencies observed by Mr. Oury was noted by several subjects. The terms "relaxation" and "weightlessness" frequently appeared in the comments.

It would be interesting to analyze the different components of this underwater listening experience. Indeed, the musical vibration is transmitted to the immersed body as a whole (somatic vibration perceived by the body surface via the mechanoreceptors of the skin) and also to the auditory system via the tympanic route and via the retrotympanic route (via the petrous bone).

## 4. The Crénomusic-care experiment in the thermal water pool of Balaruc-les-Bains

In this original study, we combined therapeutic music listening (using the Music Care® digital solution) with underwater speakers (using the Aquamusique® system) in the Balaruc-les-Bains thermal pool with 22 spa guests (50 sessions in total). The experiment was conducted over three consecutive days.

We had to adapt to the conditions of the thermal spa's operating season, taking into account the pool's and staff's availability: the sessions took place at the end of the day, when the guests were finishing their treatments. Several sessions were possible for guests who were available at that time. Most of those who participated in a session wanted to continue, and recruitment continued throughout the three days.

The Balaruc thermal water is highly mineralized, with a NaCl concentration that provides good buoyancy, which is conducive to relaxation in a reclining and submerged position. The 32°C temperature was perfectly suited to the treatment, which induces a state of relaxation and immobility during a 20-minute immersion *(see photo 2)*. The participants were already familiar with the aquatic environment and the facilities, which facilitated their participation in the study. We quickly resolved any positioning issues in the water thanks to the expertise of Mr. Noël Canivenq, who has been operating the Aquamusique® system for over 20 years. This is crucial, as the subject must feel confident, fully immersed, and relaxed to fully benefit from the session.

Our initial experimental phase (test phase on March 8, 2025) allowed us to fine-tune the subjects' positioning in the pool and to identify the musical sequences from the Music Care® web app that ensured good sound diffusion in the aquatic environment.

We were surprised by how easily the spa guests adopted the technique as soon as they entered the pool and heard the first notes of music, given that sound is only perceived when the head is submerged (through bone conduction followed by eardrum conduction).

The study population corresponds to the spa-goers of Balaruc-les-Bains: average age 64.6 years and a majority of women (77% in our study). All subjects were undergoing a rheumatological spa treatment. The spa environment, with its expected benefits, is likely a source of bias in the observed results regarding pain and anxiety in our study.

We experienced a side effect in one patient who complained of an ear infection after the first session but wished to continue given the benefits she felt. We subsequently advised patients to rinse their external auditory canals with tap water after each session.

One patient experienced a toothache that worsened during the session, and indeed, the aquatic musical vibrations can increase dental pain. This will be a contraindication in the future.

The Music Care® solution was used unconventionally, as we were unable to allow each patient to choose their musical style. We conducted group sessions using tracks with good aquatic diffusion (this is not the case for all tracks, especially those with a lot of bass) and those that were most popular according to the Music Care company's registry. We tried to respect the patients' musical preferences by eliminating musical styles they disliked. The results show that few spa-goers disliked the music offered, and even those who did found the technique beneficial for pain management and relaxation.

In the 2011 study at the Allevard thermal baths (10), the effectiveness of listening to music on pain was already noted in fibromyalgia patients: the pain score on the Visual Analogue Scale (VAS) decreased from 5.5 to 3.4 (a 38% reduction) after the first session. Here, the pain score decreased from 3.8 to 1.4 (a 63% reduction) after the first session. The same effects on anxiety were observed, with a significant decrease, as in our study. There appears to be a cumulative effect of the sessions on pain: a 42% reduction in pain by the 5th session in the Allevard study and a 90% reduction by the 3rd session of crenomusic-care. Finally, the intensity of the pain decreases steadily before the sessions, with a cumulative effect: the more music listening sessions one has, the more the pain diminishes. A comparison of the two studies (30 spa-goers in the Allevard study and 20 in the Crénomusic-Care study) seems to indicate consistent but more powerful results with underwater listening compared to conventional listening in the air, within the same spa treatment environment.

The limitations of this study are the absence of a control group, the small number of participants, and the limited number of variables studied. A combination of pain-relieving techniques is involved, making it difficult to measure the contribution of each to the relief. It would have been interesting to be able to evaluate the effects of the treatment long afterward, given that this is a chronic condition. We were able to gather some feedback from participants who had completed the experience remotely, which is reported in Appendix 4.

Finally, regarding the underwater diffusion of music listening in healthcare settings, it would be interesting to analyze the different components of such listening: both conscious tympanic and retro-tympanic listening, but also a quasi-unconscious somatic listening (through activation of cutaneous mechanoreceptors) that may have an impact on the modulation of pain sensation.

# CONCLUSION

This is the first pilot study to describe a combination of several non-pharmacological treatments used for chronic pain. We combined two validated techniques: crenotherapy and music therapy. Underwater listening, the innovative tool added here for the first time, warrants further investigation for its relaxing and soothing properties. This combination will very likely contribute to reducing chronic pain as part of a holistic approach. The encouraging results and the technical feasibility within a dedicated ecosystem warrant confirmation through a controlled, randomized study with a larger number of participants. A medium- to long-term evaluation will also be necessary.

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