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An immersive virtual reality exergame as a patient education approach in fibromyalgia: Pilot study

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Abstract

Background: Immersive Virtual Reality (VR) has been applied in pain management for various conditions, but its use in fibromyalgia (FM) remains underexplored. While physical activity plays a role in treating FM, patients' low tolerance often limits its effectiveness. After reviewing the literature on VR and games for FM, we designed a novel VR exergame to assist FM patients in performing physical activity, and evaluate its feasibility.

Materials and Methods: This pilot study involved three female subjects with FM and four healthy female volunteers. The main outcomes included qualitative assessments of exertion, pain levels, psychological states experienced during the VR session, but also device comfort.

Results: Improvements in perceived exertion and pain intensity were observed during the VR exergame session in comparison to pre-exergame levels, along with a reduction in depression, stress and anxiety levels while using the VR immersive system. Most participants experienced also increase of relaxation and positive emotions during the exergame. Only one participant was not able to complete all levels of the exergame due to musculoskeletal pain exacerbation; nevertheless, this patient reported an improvement in motivation and enjoyment during the gameplay. Many participants expressed a greater motivation to perform the exercises in the VR environment compared to traditional training methods.

Conclusion: The proposed VR exergame is a feasible system that might reduce depression, stress and anxiety, while boosting motivation and relaxation in both healthy and FM subjects. A calibration protocol is required to tailor the system to each user's pain levels and physical abilities.

Keywords

virtual reality, patient education, exergame, fibromyalgia, educational game, musculoskeletal pain

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Introduction

Fibromyalgia (FM) is a chronic musculoskeletal disease of unknown aetiology, characterized by widespread nociplastic pain, and tender points in muscles and soft tissues.[1] Diagnosing FM can be challenging due to its numerous symptoms and comorbidities, including sleep disturbances, fatigue, muscle rigidity, and cognitive issues like anxiety and depression. Affecting an estimated 2% to 8% of the population, this syndrome significantly reduces quality of life and presents a substantial socio-economic burden through decreased productivity and increased healthcare use.[2] Considerable efforts have thus been made to establish a comprehensive diagnostic and therapeutic approach that addresses all aspects of FM, with a particular focus on pain reduction.[3]

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As pain involves both sensory and emotional components, pharmacological treatments should be complemented by non-pharmacological strategies such as physical activity, cognitive-behavioural therapy, and relaxation techniques.[1,4–6] The attentional modulation approach has been shown to reduce pain and influence patients' perceptions, thoughts, and emotions. Techniques such as cognitive distraction, mindfulness, and guided meditation, where a voiceover aids relaxation, are frequently employed.[7,8] In recent years, traditional interventions have been integrated with emerging technologies, including both immersive and non-immersive virtual reality (VR) systems. Previous studies that explored the potential of video games have shown the positive effect of distraction on the perception of pain; furthermore, past research on VR analgesia has shown how VR can modulate the processing of nociceptive stimulation, offering effective pain management by increasing pain threshold and tolerance both in FM patients and pain-free individuals.[8,9] Exergames are video games that require physical exercise to progress, offering low-impact, controlled movements that can effectively distract players from pain.[10] A VR exergame can combine the characteristics of physical training with the benefits of VR and make players perform specific movements recommended in motor rehabilitation.[10] Recent studies have explored immersive and non-immersive systems in contexts such as motor training,[6,11–18] relaxation,[8] cognitive-behavioural therapy support,[1,5] pain awareness[19] and spatial memory research.[4]

This paper proposes a new immersive VR exergame as a tool to educate FM patients in daily motor training. The main objectives are: enabling users to learn and perform the suggested motor activities correctly; exploiting storytelling and missions in the game to increase motivation; promoting relaxation thanks to a virtual natural environment; and enabling home use by using a portable, self-contained, and low-cost VR headset.

The article is organized as follows. First, we survey previous video games and VR systems developed in the context of FM treatment. Then, the Method section describes the proposed immersive VR exergame design for patient education and the design of the pilot test to assess acceptability of the system. The Results and Discussion sections present and discuss the outcomes of the study. The last section concludes the paper, outlining limitations and future research.

Related work

Different previous studies have explored the acceptability of non-immersive video games for FM patients, assessing their effectiveness in improving quality of life, mood, or even physical abilities. In this context, the use of immersive VR with a Head-Mounted Display (HMD) remains limited. In some cases, the games incorporated complementary interventions, such as biofeedback, guided meditation or mindfulness, and showed good potential in reducing acute pain.[1,5,7,8,19] Table 1 categorizes video games and immersive VR systems used with FM patients, and Table 2 summarizes the results of related studies.

Exergames for physical and muscular strengthening

As previous studies have shown, exercise training through exergames can boost energy, improve quality of life and cognitive function, and reduce anxiety, depression, and pain.[8,16] The standard physical training protocol for FM includes exercises focused on flexibility, strength maintenance, endurance and aerobic conditioning.[8] Motion-controlled video games require autonomous movement of different parts of the body, increasing user's muscle tone, and compliance and reducing movement-related fear caused by continuous pain.[22] Video games and exergames used for training include two immersive VR exergames to improve balance and mobility,[15] one non-immersive exergame specifically designed for FM, with expert-led videos to guide physical conditioning[11–14] and several commercial motion-controlled video game consoles that offer exercises to improve mobility and resistance.[6,16–18] The studies involving these systems demonstrated the capability of exergames to contribute to treatment both in reducing depression[16] and in reducing pain-related emotions.[18] The results obtained in Gulsen et al.[15] showed that immersive VR systems are promising as an adjunctive therapy for FM patients, in combination with other exercises, with improvements regarding kinesiophobia, pain, level of physical activity and the mental component of quality of life.

Video games for visual-spatial memory

Cánovas et al.[4] used two non-immersive virtual maze environments to examine learning and spatial memory in patients with FM. The environments were navigated in first-person view and contained landmarks to facilitate spatial learning, while auditory feedback was provided.[4] The study identified spatial navigation as a specific cognitive process that appears to be disrupted by FM because patients with FM made more errors than the control group, even though the study demonstrates a reduction in the number of errors and a decrease in searching time with more trials.[4]

Video games for relaxation and pain management

Six different studies highlighted how video games and immersive VR are well accepted as a complementary treatment by patients with FM; they also showed an increase in relaxation,[5,21] an improvement in perceived quality of life,[1,20] a reduction in anxiety,[8,19] and a reduction in pain-related sleep interference.[21] Two non-immersive systems used Cognitive Behavioural Therapy (CBT) techniques

Table 1. Categorization of systems used with FM patients.

Reference	Goal	Device	System	Objective	Adaptability to the patient
Gulsen et al. (2020)[15]	Exercise training	Immersive: Oculus Rift HMD, Microsoft Kinect for body movements detection and personal computer	Football Game	Improve balance and mobility	The therapist decides speed and direction of the virtual ball according to the patient's potential (over time, the level of difficulty can be increased)
Gulsen et al. (2020)[15]	Exercise training	Immersive: Oculus Rift HMD, Microsoft Kinect for body movements detection and personal computer	Guillotine Game	Improve balance and mobility	The therapist randomly adjusts the coming order of guillotines and logs according to the patient's potential (over time, the level of difficulty can be increased)
Collado-Mateo et al. (2017)[11], Collado-Mateo et al. (2017)[12], Martin-Martinez et al. (2019)[13] and Villafaina et al. (2020)[14]	Exercise training	Non-immersive: Microsoft Kinect, for body movements tracking, connected to a personal computer	VirtualEx-FM	Improve physical conditioning and the ability to perform daily activities, as well as increase motivation and engagement	The speed of movements, involved body part, and step cadence or amplitude can be controlled manually by the sport technician
Polat et al. (2021)[6], Carvalho et al. (2020)[16], Carvalho et al. (2021)[17] and Mortensen et al. (2015)[18]	Exercise training	Non-immersive: TV set connected with Motion-controlled video game consoles (use of Microsoft Xbox Kinect with Xbox Sports)	Wii Fit Plus, PlayStation3 Move, Microsoft Xbox Sports	Improve mobility and resistance	No
Canovas et al. (2009)[4]	Practice spatial memory	Non-immersive: Portable computer with Logitech joystick	Morris Water Maze	Assess spatial learning and visuospatial memory capabilities	No
Canovas et al. (2009)[4]	Practice spatial memory	Non-immersive: Portable computer with Logitech joystick	Boxes Room	Assess spatial learning and visuospatial memory capabilities	No
Herrero et al. (2014)[1], Botella et al. (2013)[5] and Garcia-Palacios et al. (2015)[20]	Pain management and relaxation	Non-immersive: Two personal computers, a 3 × 4 meter screen made of reflective material, two	EMMA's World	Relaxation: participants have to follow system instructions for slow breathing. Mindfulness: refocusing attention on the present moment, observing	Mood induction procedure: the therapist can include different elements in the scenarios such as sounds, images, videos, changes in weather or in time

(continued)

Table 1. Continued.

Reference	Goal	Device	System	Objective	Adaptability to the patient
		projectors and a surround audio		different elements in the scenarios to pay attention to stimuli that are not related to pain	
Venuturupalli et al. (2019)[8]	Pain management and relaxation	Immersive: Samsung GearVR goggles with a Samsung Galaxy S7 mobile phone	EaseVRx	Relax to decrease pain and anxiety following a voiceover providing instructions on correct breathing (if using biofeedback environment) or guiding meditation (if using guided meditation environment)	The breathing instruction environment includes adaptive biofeedback
Vilalta-Abella et al. (2017)[19]	Pain management and relaxation	Non-immersive: Portable computer (laptop)	VirtualPain	Reduce perceived pain intensity and associated symptoms through visual and auditory manipulation of a personalized 3D avatar based on pain assessment	No
Darnall et al. (2020)[21]	Pain management and relaxation	Immersive: Oculus Go VR headset	Pain Care with AppliedVR software	Enhance pain management and relaxation though diaphragmatic exercises (using biofeedback environment)	The breathing instruction environment includes adaptive feedback

FM: fibromyalgia.

Table 2. Studies about the use of video games or VR systems with FM patients.

Reference	Tasks	Control Group (CG) tasks	Duration	Outcomes	Main findings
Polat et al. (2021)[6]	Aerobic exercise program (20 minutes) followed by 15 minutes of Beach Volley using Microsoft Xbox Kinect	Aerobic exercise program (20 minutes), followed by 15 minutes of balance, flexibility exercises and muscle strengthening	4 weeks exercise program plus 4-week follow-up period of home exercise program	Pain intensity, general health status, mood, somatic and cognitive symptoms, functional capacity, health-related quality of life	All outcome scores were higher than the baseline in both groups (at the end of the exercise program and the follow-up), but the median satisfaction score was higher in the Xbox Kinect group
Carvalho et al. (2020)[16]	Exergame program (1 hour) featuring six subgames of Wii Fit Plus	Chain muscle stretching for an hour	7 weeks	Physical performance and exercise capacity, FM impact and pain threshold	Both groups showed an improvement in pain levels, but the Wii group showed an enhancement in several areas of the body and in physical performance. The Wii group showed a higher fatigue reduction
Carvalho et al. (2021)[17]	Exergame program (1 hour) featuring six subgames of Wii Fit Plus	Chain muscle stretching for an hour	7 weeks	Muscular tension and balance	Both groups showed a decrease in tender point count but only the Wii group improved in dorsiflexion and in muscle strength in lower limb
Mortensen et al. (2015)[18]	15 consecutive sessions (five with Wii, five with Microsoft Xbox Kinect and five with PS3 Move)	No CG	7 weeks	Pain, fatigue, performance of activities of daily living and playfulness during the experience	All participants were distracted from the pain sensations while playing and many of them reported having a stronger body. There were no improvements in pain. Due to the lack of energy, most reported difficulties in their everyday lives
Collado-Mateo et al. (2017)[11]	Training program based on the	Continued their daily routine	8 weeks	Health-related quality of life, perceived health	Improvement in mobility, pain perceived, anxiety

(continued)

Table 2. Continued.

Reference	Tasks	Control Group (CG) tasks	Duration	Outcomes	Main findings
	VirtualEx-FM exergame			status and effects on FM	and depression level, as well as in feeling good, in the exercise group
Collado-Mateo et al. (2017)[12]	Training program based on the exergame the VirtualEx-FM	Continued their daily life routine	8 weeks	Mobility skills, balance and fear of falling	Measures related to fear of falling increased in the CG while decreased in the exercise training
Martin-Martinez et al. (2019)[13]	Training program based on the exergame VirtualEx-FM	Continued their daily routine	24 weeks	Strength in upper limbs, mobility skills and flexibility in the limbs	The CG worsened while the exercise group improved their performance
Villafaina et al. (2020)[14]	Training program based on the exergame VirtualEx-FM	Continued their daily routine	24 weeks	Heart rate variability	The exercise group showed an improvement in automatic modulation compared with the CG, addressing abnormalities associated with fibromyalgia
Gulsen et al. (2020)[15]	Exercise training for an hour (aerobic training and Pilates) followed by a 20 minutes of immersive VR training (Football and Guillotine game)	Exercise training for an hour: aerobic training and Pilates	8 weeks	Pain experienced in last week, level of physical activity, impact of FM, kinesiophobia, health-related quality of life, perceived impact of fatigue in last month, vestibular and vision sensations on balance, effects of somatosensory, functional exercise capacity	After the intervention, both groups showed improved values, but the VR group exhibited significantly greater improvements in pain, fatigue severity, physical activity levels, kinesiophobia and mental quality of life
Canovas et al. (2009)[4]	Playing multiple times the Morris Water Maze and Boxes Room video games	People without FM doing the same activity of the FM group	A single session	Neuropsychological measures and comparison across groups	FM group made more errors than CG in both games, but all the participants made fewer errors with more trials. FM patients with longer chronicity showed lower visuospatial memory

(continued)

Table 2. Continued.

Reference	Tasks	Control Group (CG) tasks	Duration	Outcomes	Main findings
Botella et al. (2013)[5]	Group Cognitive Behavioural Therapy (CBT) program supported by EMMA's World	No CG	7 weeks + 6-month follow-up	FM impact's assessment, behavioural and somatic symptoms of depression, chronic pain coping strategies and general satisfaction	Slight reduction in FM impact, as well as in the depression assessment. The levels of satisfaction were high. Regarding the use of coping strategies, there was an increase in seeking social support
Herrero et al. (2014)[1]	Session group of 20 minutes in front of the screen with EMMA's World	No CG	5 sessions of CBT	Assessment of general mood state, pain and fatigue intensity, motivation and sense of self-efficacy. Evaluation of the intensity of different emotions	Self-efficacy and motivation increased, as well as joy and calmness, while sadness and anxiety decreased. Even though most felt better, some felt worse or much worse
Garcia-Palacios et al. (2015)[20]	Session group of 20 minutes in front of the screen with EMMA's World	Treatment as usual	6 sessions of CBT	Assessment of FM impact, depression and pain intensity, chronic pain coping strategies, perceived quality of life, as well as acceptability and satisfaction	Compared with the CG, the EMMA's World group showed an increase in the perceived quality of life with also positive effects in reducing FM impact
Venuturupalli et al. (2019)[8]	30-minute VR session: biofeedback (BFD) followed by guided meditation (GM)	30-minute VR session: GM followed by BFD	A single session	Pain, emotional distress, anxiety and anger, general impressions about the virtual experience	Greatest reduction of anxiety level after the VR GM intervention rather than BFD use. Both VR environments decreased pain in patients. Most participants enjoyed both VR experiences
Vilalta-Abella et al. (2017)[19]	20 minutes of VirtualPain software after 40 minutes of CBT	No CG	4 weeks + 1-year follow-up	Measurements of anxiety experiences with pain, expectations of pain and pain intensity, as well as assessment of catastrophic thoughts related to pain	Pain anxiety and catastrophic thoughts were reduced at post-treatment and after the 12-month follow-up all the

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Table 2. Continued.

Reference	Tasks	Control Group (CG) tasks	Duration	Outcomes	Main findings
					outcomes improved. Self-efficacy increased
Darnall et al. (2020)[21]	Engaging with a self-administered VR programme (15–30 minutes per session) that includes skills-based content rooted in pain CBT along with relaxation training (diaphragmatic breathing) and mindfulness exercises	Audio-only treatment with similar therapeutic techniques (relaxation training and mindfulness) but without immersive VR elements	3 weeks	Measurements of pain intensity, pain catastrophizing, pain self-efficacy, pain-related interference (how pain interfered with daily activities, mood, sleep and stress) and satisfaction with treatment	High engagement and satisfaction combined with low levels of adverse effects support the feasibility and acceptability of at-home skills-based VR for chronic pain. A significant reduction in pain intensity, pain-related stress, activity, mood and sleep interference was found

BFD: biofeedback; CBT: cognitive behavioural therapy; CG: control group; FM: fibromyalgia; GM: guided meditation; VR: virtual reality.

for the treatment of FM with the aim of offering coping strategies to improve quality of life, achieve relaxation and improve mood.[1,5,19,20] Engaging Media for Mental Health Applications (EMMA's) World was originally used for mood induction and emotion activation and processing: users see different natural scenarios where instructions are intended to reduce anxiety, focusing their attention on elements such as sound and images.[1,5,20] All the studies that exploit this system[1,5,20] revealed its positive effect in reducing FM impact on patients' lives, making participants more involved during CBT; additionally, the system helps to recall virtual scenario images for practising relaxation and mindfulness at home.[1,5] The VirtualPain system was used to reduce pain intensity and associated symptomatology in FM patients. The patient specified the features of the pain experienced by selecting colours and sounds, but the system reported the level of pain experienced using the Visual Analogue Scale (VAS): by modifying the virtual representation of the pain, the patient could modify the perception of its intensity.[19]

Darnall et al.,[21] through the AppliedVR system, investigated the viability of a self-administered VR program integrating content and skills informed by evidence-based behavioural treatment for chronic pain. Subsequently, the efficacy of the VR program was assessed in terms of improvements in pain intensity, pain-related interference with activity, stress, mood, and sleep, as well as its impact on pain-related cognition and self-efficacy, compared to an audio-only treatment. Patients underwent treatment involving a program that combined skills rooted in pain CBT training, relaxation exercises, and mindfulness. The study demonstrated high engagement, feasibility, and acceptability of the at-home VR intervention, coupled with a reduction in chronic pain outcomes over the 21 days of VR compared to the audio-only version.[21]

The EaseVRx system contains two environments, one for the guided meditation and the other for biofeedback, a self-regulation technique by means of which patients can learn how to control no conscious body processes, such as heart rate, muscle tension and breathing.[8] Finally, most of the systems used for FM[1,5,6,8,16–18,20] exploit virtual natural environments to stimulate relaxation and encourage anxiety reduction.

Materials and method

The exergame proposed in this paper was designed and developed in the HCI Lab of the University of Udine. The pilot test was conducted in a gym and was aimed to qualitatively assess user acceptability and experience with the proposed VR exergame, focusing on exercise comprehension and the game's strengths and limitations. Additionally, we collected individual measures relevant to FM management. In total, the project spanned seven months.

The proposed exergame

This section introduces our exergame, designed to help FM patients learn motor activities that enhance muscle strength and joint flexibility. The exergame guides patients in executing movements correctly within an immersive virtual environment, supporting accurate practice and physical improvement. Two kinesiologists collaborated in selecting exercises for the exergame and setting guidelines for correct execution. To our knowledge, no prior immersive system has been designed to integrate both physical exercise and relaxation education tailored specifically for FM patients. As highlighted in the Related Work section, prior systems generally lacked a focus on the educational component. Most relied on off-the-shelf video games that were not specifically designed for the needs of FM patients, and only VirtualEx-FM[11–14] was an original system developed for this purpose. However, VirtualEx-FM is a non-immersive training, while our exergame is designed to exploit immersive experience.

The design of the system is based on four main decisions.

First, we selected a virtual forest as the setting, enhanced with 3D natural sounds (e.g., wind and bird songs). This choice is supported by previous studies suggesting forest therapy as an effective non-pharmacological treatment for reducing depression and anxiety.[23] Moreover, the selection of a virtual natural environment is typical of many systems developed for FM,[1,5,6,8,16–18,20] as it facilitates relaxation among users.

Second, we integrated narrative elements to create an engaging exergaming experience, where motor exercises are embedded in activities designed to advance the storyline. Rewards were included for both individual activities as well as for extended use of the system. Additionally, a voice-over provides encouragement regardless of activity execution, aiming to motivate users and to enhance their self-efficacy.

Third, we paid particular attention to the choice of device, opting for a consumer headset (Oculus/Meta Quest HMD) to develop an exergame that users can potentially use independently in a domestic setting. We chose this device for its lightweight, wireless design, eliminating the need for additional external devices, further increasing the potential for home use. Moreover, the HMD is equipped with in-built cameras that we exploited to track the execution of the exercise. In this way, users of the exergame do not need to hold controllers in their hands, as required by other systems. This allows a more natural execution of the exercises, and also the possibility to use small weights to strengthen muscles during activities. To ensure patients' safety, and considering that the HMD cameras do not allow to track user's legs, the selected exercises focused on joint mobility of the upper limbs[24] and included three specific movements: forearm flexion and extension, horizontal shoulder circumduction and horizontal arm abduction. Previous studies have demonstrated the effectiveness of dynamic and active stretching aimed at strengthening muscle and improving joint mobility in FM patients[16,24]; however, experts recommend a level of physical exertion that allows to perform motor activity without excessive pain, along with a gradual progression that provides physiological adaptation, especially for users who may experience physical inactivity due to their symptoms.[25] To enhance adaptability, together with the kinesiologists, we defined three levels of difficulty that can be selected for each session (as shown in Figure 1), allowing the training intensity to be tailored to the user's perceived potential. Before the start of the exergame activities, users are prompted to choose their preferred level of difficulty (simple, moderate or intense) as shown in Figure 1. To ensure a wide range of movement and improve muscle and joints flexibility, the system detects hand position and movement through the in-built cameras of the headset, calculating the total displacement of the limb in the space while performing the different exercises. The number of

a) b)

Figure 1. Adapting the difficulty of the experience: (a) Users can select the starting level (easy, moderate or intense) in the central hub; (b) the system proposes a recovery time of 30 seconds when the participant keeps his/her hands below a certain threshold for a given time.

Figure 2. Visual and auditory feedback: (a) Negative feedback example: incorrect speed and execution of the abduction exercise makes the manipulated object glow red, accompanied by an unpleasant sound. (b) Positive feedback example: the bush grows greener when the circumduction exercise movement is performed correctly. The changes occur during arm movement.

Figure 3. The user collects energy as light points by correctly performing each task during his/her journey in the forest. The energy is released and channelled into the old tree, with visible positive effects on its health.

repetitions is determined by the total displacement of the limb rather than by the difficulty level, as relying solely on difficulty could result in small movements and an inadequate total volume, below recommended levels. Consequently, increasing or decreasing the level of difficulty may result in a corresponding increase or decrease in the number of repetitions of the exercises. Each exercise is designed to be completed in two minutes on each side, according to the physical capabilities of each user and the level selected. Furthermore, to allow for recovery time during training, we introduced specific pauses.

Finally, the system monitors the correctness of performance and provides auditory and visual feedback to educate patients about their motor activity (Figure 2 provides two examples). Specifically, movements should not be performed too fast, and, during the horizontal arm abduction exercise, the palm must be correctly rotated to ensure muscular strengthening.

To ensure that the exergame supports correct and safe performance, its development followed an iterative approach in which new versions were repeatedly tested by the kinesiologists.

The final game environment is organized in two main areas: a central hub where the user is introduced to the story and can select the level of difficulty, as shown in Figure 1, and an enchanted forest where activities take place. Within the forest, an old magic tree spreads lifeblood throughout its surroundings, sustained by a crystal cluster embedded in its roots. However, a terrible storm has weakened it. The user must complete challenges in order to acquire 'light points' which are accumulated inside a crystal that follows the user throughout the adventure. This crystal allows the user to transfer energy to the old magic tree, as shown in Figure 3. As a final reward, at the end of each session, which comprises all three exercises, the user sees the magic tree regaining its vigour proportionally to the energy transferred.

Within the virtual world, a magic screen (see Figure 2) reproduces real-life videos of each exercise performed by an expert trainer, accompanied by a voice-over to clearly instruct the user about the physical exercises.

A video demonstration of the game is available in the additional materials of this paper.

Participants

Participants were volunteers recruited at the University of Udine and at the rehabilitation section of a fitness centre.

Table 3. Table of participants with demographic information (age, gender, level of education and FM), the chosen difficulty level inside the VR training (easy, medium or hard) and RPE results for each exercise using the Borg CR scale (R) (CR10).

Participant	P1	P2	P3	P4	P5	P6	P7
Age	14	20	21	62	65	66	69
Gender	Female	Female	Female	Female	Female	Female	Female
Level of education	Middle school diploma	High school diploma	High school diploma	High school diploma	High school diploma	High school diploma	Middle school diploma
FM	Yes	No	No	Yes	No	Yes	No
Disease Duration	4 months	-	-	5 years	-	7 years	-
Game level	Easy	Easy	Hard	Medium	Medium	Medium	Medium
RPE circumduction	9	2	0	0	4	2	0
RPE flexion	9	1	0	0	1	2	0
RPE abduction	10	3	1	0	4	2	0

FM: fibromyalgia; RPE: rate of perceived exertion; VR: virtual reality.

Table 4. Variation of VAS scores across eight parameters (pain level, fatigue, muscle strength, tiredness, stiffness, anxiety, stress and depression). Values represent the difference between pre-assessment level and highest level perceived during the VR experience. Each parameter's variation is shown for all participants.

Participant	P1	P2	P3	P4	P5	P6	P7
Pain	+2.75	−0.04	0	+0.29	-1.40	−1.45	0
Fatigue	+0.60	+0.17	+0.05	−1.56	-3.00	-2.20	−0.02
Strength	−0.72	-3.70	0	−0.28	+0.08	+5.43	-1.30
Stiffness	+1.28	−0.68	+0.05	+1.41	−3.11	-0.10	−1.96
Tiredness	+0.68	−0.78	−1.75	−1.47	+0.20	−3.16	−2.25
Anxiety	−0.25	−2.87	−0.28	0	+2.54	−6.29	0
Stress	+7.37	−1.62	−0.61	-4.90	+0.22	−2.83	0
Depression	0	−0.26	−0.24	0	−0.06	-7.60	0

VAS: Visual Analogue Scale; VR: virtual reality.

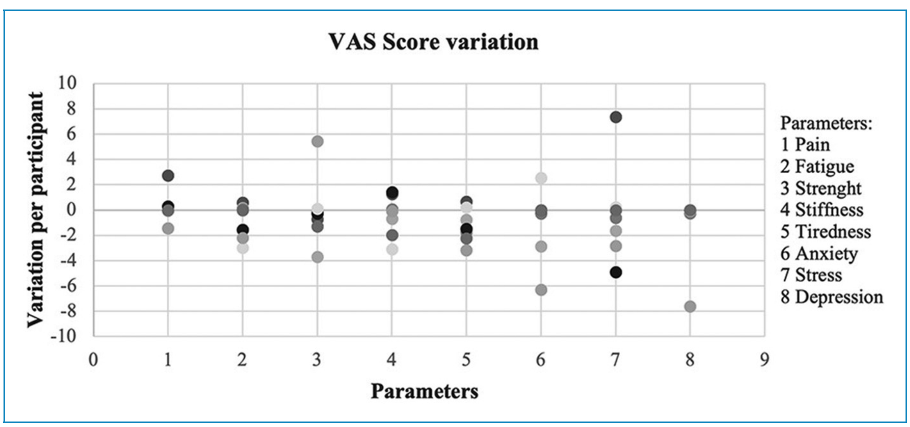

Figure 4. Visual representation of the data in Table 4 showing the variation in VAS scores across eight parameters for each participant. The horizontal axis of the graph displays each parameter's results for individual participants as separate points. The vertical axis indicates the positive or negative change in VAS scores, comparing pre-assessment results with the maximum values recorded during the experience. VAS: Visual Analogue Scale.

The pilot test involved seven female participants aged between 14 and 69. Among them, three were diagnosed with FM according to the 2016 Modified Diagnostic Criteria of the American College of Rheumatology (ACR),[26] while four were healthy volunteers similar for gender, age and Body Mass Index (BMI). Eligibility criteria excluded individuals with major psychiatric disorders affecting reality perception (e.g., schizophrenia, bipolar disorder), conditions limiting joint mobility or physical endurance (e.g., orthopaedic, cardiac, rheumatic, neurological, or respiratory issues), and conditions posing risks for VR exposure (e.g., epilepsy). These criteria were established to exclude participants unsuited for the proposed exergame.

Measures

The demographic characteristics of participants were collected anonymously before the experience.

The protocol included eight FM-related measures: pain level, fatigue, physical strength, muscle stiffness, tiredness, anxiety, stress, depression, each rated on 10 cm Visual Analogue Scale (VAS). Participants marked the eight VAS to reflect what they were experiencing at that moment, before wearing the HMD. When the immersive experience ended, they were asked to do the same, considering the maximum value experienced during the exercise. VAS is a validated tool for assessing subjective experiences, particularly for measuring pain,[27] anxiety and stress.[28]

To measure the perceived intensity and effort of each exercise we used the Borg CR scale (R) (CR10) (© Gunnar Borg, 1982, 1998, 2004),[29,30] where 0 corresponds to no perceived exertion and 10 is the maximal perceived exertion. This perceived exertion evaluation scale is widely validated and has been used extensively in exercise science to assess perceived exertion. The license to use the scale for measuring the Rate of Perceived Exertion (RPE) was obtained from BorgPerception AB (www.borgperception.se).

The final semi-structured qualitative interview was organized into two modules (as shown in Online Supplemental Material 1): the first explored the immersive VR experience, including strengths and weaknesses and focusing on possible effects on pain and mood, while the second explored participant's opinion of the proposed VR training, as well as comments on device comfort and experience.

Procedure

The pilot test involved individual sessions with each participant. Formal ethical approval was provided by local Institutional Review Board (IRB: 325/2024; Tit III cl 13 fasc.209/2024). Participants provided written informed consent. For the minor participant, a parent provided consent and attended the session. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki. After completing initial questionnaires, participants tried the VR experience, which lasted about 10 min, using an Oculus/Meta Quest 2 HMD. At the end, VAS and RPE scores were recorded, followed by a qualitative interview.

Results

All participants completed the exercises, except for the recently diagnosed, 14-year-old FM participant who found the abduction exercise too difficult. Most participants used the system without issues, and feasibility was further supported by the low exertion levels reported on the Borg CR scale (R) (CR10) (see Table 3).

Table 4 and its visual representation in Figure 4 report the variation between the values obtained from the VAS questionnaires before the VR experience (pre) and the highest level perceived during the VR experience (max). Participants completed self-evaluations twice: before the VR experience, indicating the highest level for each measure at that moment, and after, noting the highest levels perceived during the exergame. Of the participants, three out of seven reported a slight reduction in pain from baseline to peak levels, two showed stable values, and the remaining two reported an increase, one mild and the other more pronounced. Regarding fatigue and stiffness, a reduction was observed in four out of seven participants, while a minor increase was recorded in the remaining three. Muscle strength was the only characteristic that showed a decline in most participants: two out of seven reported an improvement, four out of seven showed a subjective reduction, and one experienced no change from pre to max. For emotional state, five of seven participants reported improvements in tiredness and stress, with only two showing mild worsening. Anxiety and depression levels improved in four participants. Anxiety remained stable in two participants, with only minimal worsening in one participant; depression remained stable in three participants, with no recorded worsening.

Qualitative analysis

Semi-structured interviews were transcribed verbatim and analysed following Braun and Clarke's method[31]: we performed a thematic analysis on the transcripts, identifying prominent themes. In the following interview extracts, the portions in square brackets are words or phrases added to clarify the sentence. The themes that emerged from the interviews are:

1. Relaxation: participants reported how the exergame promotes a greater relaxation compared with traditional training. Four participants stated that the virtual natural environment helped them to relax: the contributing elements include the virtual forest, sounds and colours. About the exergame, the 66-year-old FM user said: '[the exergame] provides greater serenity [than traditional training] because you are more isolated [compared a gym class]. It relaxes you, if it does not include heavy exercises'.
2. Motivation in performing motor activities: participants highlighted the motivational component in performing motor activities. Three participants stated that the game component helped them to finish each activity, motivating them to achieve the goal of the activity, while two participants considered the exercises too simple for them, even compared to traditional training. The 14-year-old FM participant reported that she was able to perform a greater number of repetitions per exercise compared to the weekly gym sessions, which is why the level of pain increased. She said she generally did not enjoy traditional motor activity, but she felt more involved in the exergame than traditional training, and consequently less distracted during the workout. Likewise, the 21-year-old user without FM stated: 'When I go to the gym, I think that if I do one more repetition I am going to struggle, instead [using this system] I perform a movement without thinking about the effort I am making, so perhaps it leads me to move more'.
3. Increased self-efficacy: visual feedback of each exercise helps reinforce the abilities of participants. Three participants experienced greater self-efficacy because of the

tasks. For example, the 21-year-old healthy user stated: ‘I felt a sense of achievement to see the exercise completed […] and the visual feedback of the increased energy in the crystal’.

4. Positive moods: the exergame promotes calmness, contentment, serenity in most of participants. Six participants reported happiness and serenity, five of them also felt satisfied and pleased. For example, the 66-year-old healthy participant said: ‘[I felt] satisfied [because] I succeeded. Pleased because I breathed life back into the tree’.
5. Fun and enjoyment: the game component of the experience is perceived as fun. For example, the 14-year-old FM participant said that the game and fun component engaged her despite experiencing pain and that she felt involved inside the game: ‘You are feeling pain, but you are also having fun’. The two 20-year-old participant without FM stated that ‘it feels like you are not struggling but playing’. Additionally, the 66-year-old FM user said: ‘I feel like a child again […] It was nice to live in that world’.
6. Pain: the exergame impact on pain perception varies depending on the initial pain level before using the game. The participant with higher initial pain levels perceived more pain during the exergame, while those with lower initial pain levels experienced a reduction in pain. Indeed, only the 14-year-old FM participant reported negative sensations like fatigue and catastrophism. Before using the VR system, she reported pain: she could not stand for long, so she asked to play the exergame while sitting. She reported constant pain during her everyday life: ‘I do not like doing motor activity [in general] […] I always feel pain’. Regarding the immersive VR training, she stated: ‘I felt more pain because I did more repetitions [than usual]’. Moreover, in response to the question ‘How capable did you feel in performing the activities?’ the user answered, ‘Very poorly. [I succeeded] with great, great sacrifice and effort’. For these reasons she felt much more pain and was disappointed.

Tables S1 and S2 in the Online Supplemental Material (Qualitative Analysis) list the main responses obtained from the semi-structured qualitative interview on immersive experience and VR training.

Discussion

Consistent with previous studies,[1,5,8] our qualitative analysis supports that the immersive VR experience can help distract from pain, while virtual natural environments can enhance relaxation. The immersive nature of VR allowed two participants to report better concentration and relaxation compared to traditional gym training. Our results align with previous findings[18] on exergames’ ability to entertain and distract users from pain and worries. Six participants reported positive emotions, and three emphasized the game’s capacity for distraction. The game’s rewards also motivated participants, particularly those without FM, enhancing their sense of self-efficacy and satisfaction in contributing to the virtual forest improvement.

The participant who did not complete all three exercises reported that the game dynamics and the isolation from the real environment led her to increase the number of repetitions of the exercises compared with her usual training, despite the higher pain level. She also mentioned that, based on her personal interest, dance exercises would probably have encouraged her more. Interestingly, the youngest participant had a negative experience, while older users reported mostly positive feelings. This suggests that age is not necessarily a limiting factor for this approach and highlights FM’s complexity, requiring multifaceted treatment strategies. A range of interventions should therefore be available to address this form of chronic pain. It is interesting to note that a clinical cluster of FM (identified through an unsupervised machine learning approach) has been recently described by Hugle et al.[32] to be more prone to respond to VR interventions, thus highlighting the opportunity of a tailored treatment strategy also in FM.[32]

The exercise instructions were clear to all participants, aided by videos of a live instructor within the virtual environment. Two participants, one with FM, reported less muscle pain during the VR experience and found the exercises easier than some they performed regularly in the gym. For this reason, they said they would not consider using the exergame again because it was too easy for them, and one of them considered the training less stimulating because of the absence of direct contact with the instructor. The other five participants stated that they would instead use the exergame again, as an adjunct to traditional gym training or independently at home, to relax through exercise. Finally, the exergame appeared to be generally well accepted both for motor activities and for relaxation. In terms of overall experience, all users reported a high level of enjoyment of the immersive exergame and a sense of satisfaction and accomplishment. Three users without FM reported that they were happy to have contributed to creating a more beautiful and stronger forest, indicating a sense of involvement within the immersive experience. In addition, two participants reported a shorter perceived experience, a phenomenon known as time compression.[33] The findings demonstrated the overall feasibility of the proposed exergame for both healthy individuals and FM participants. Notably, users reported improvements in depression, stress and anxiety levels during the use of the immersive exergame, which were lower than their pre-immersive VR experience values. This highlights the potential of the intervention to provide immediate psychological benefits even during the activity.

According to the most recent European recommendations for the management of FM, exercise is strongly recommended as a non-pharmacological treatment capable of improving pain and physical function.[3] However, patients with FM often exhibit a greater tendency toward sedentary behaviour compared to healthy individuals, which is related to fear of movement due to potential pain exacerbation, fatigue and associated depressive states.[34–36] Our exploratory study suggests that immersive exergames could help address these limitations by making physical activity more engaging, providing a distraction from chronic pain and promoting relaxation, self-efficacy, and motivation. The potential to use a low-cost, self-contained headset at home to independently perform immersive exergame interventions, combined with the opportunity to offer a wide variety of exercises across adjustable difficulty levels in customizable, engaging virtual environments, may improve treatment adherence and sustain patient motivation over the long term. Indeed, longitudinal efficacy studies in FM patients with longer durations, as well as clinical trials comparing exergames with traditional physical exercise, are necessary to confirm the possible benefits suggested by our exploratory pilot study.

To improve efficacy and motivation through our approach, future research and development should include a calibration protocol to adapt the difficulty of each exercise to individual pain levels and physical capabilities. At the beginning of the experience an initial tutorial to familiarize users with basic game movements could also be included, in order to perform key and standardized movements (e.g., arm raises) to assess patient's limits and motor capabilities, along with a posture check to ensure comfort and stability during the experience (e.g., standing or seated position). Based on the data collected, the difficulty of each exercise could be customized to the user's potential and current capabilities, allowing for both the intensification and simplification of training as needed. This initial calibration could be important, because users with FM may experience varied and inconsistent joint and muscle pain across different sessions. Moreover, an extension of the system with lower limb sensors, as current consumer headsets unfortunately do not track legs, would support full body dynamic training for users with greater physical strength and less joint pain. Finally, the integration with other non-pharmacological interventions, which can be delivered by smartphone apps, should be considered.[37]

Some limitations of this study need to be mentioned. First, the pilot study involved a small sample size of heterogeneous participants that does not allow for a quantitative statistical analysis of within- or between-groups comparisons. The small sample size and participant heterogeneity also make it difficult to generalize our qualitative findings to a larger clinical population. The participant group consisted exclusively of females, so future studies should aim for a larger sample that better reflects the gender distribution, various FM diagnoses, and age ranges. Second, we did not consider a control group that performed the same exercise without using VR. Moreover, our data come from a single VR session, without a long-term evaluation. Third, although the VAS is validated for measuring pain and various emotional states, the self-formulated order of assessment (level of pain, fatigue, physical strength, muscle stiffness, tiredness, anxiety, stress and depression) may limit the findings. Finally, this pilot study primarily aimed at exploring whether VR exergaming could be used as a patient education tool for FM, rather than to demonstrate its efficacy.

However, this study also introduces, for the first time, an immersive exergame as a potential non-pharmacological, multimodal treatment for FM, addressing some limitations of conventional physical therapy. Additionally, the ability of the immersive exergame to promote relaxation, positive mood, enjoyment and engagement may provide psychological benefits for FM patients. Notably, there were reductions in depression, stress and anxiety for most participants during the immersive experience, suggesting potential for early relief, at least in a subset of patients.

Conclusions

This study proposed a new immersive VR system for independent home use, designed to engage and educate FM patients in recommended physical activities. To our knowledge, this is the first immersive VR exergame for FM patients that uses in-game narrative to enhance user experience. Our preliminary findings are promising, supporting the feasibility, motivational potential, and benefits of an integrated immersive VR exergame system for both healthy individuals and FM patients. If these promising results are confirmed, a refined system that automatically adjusts activities to individual patients could be tested in clinical trials. Such a system could become part of multidisciplinary rehabilitation or physiotherapy programs for FM patients. Future studies with larger samples and longer follow-up will be essential to confirm these findings and explore the potential of immersive VR exergames in FM treatment protocols.

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