VR Games for Chronic Pain Management

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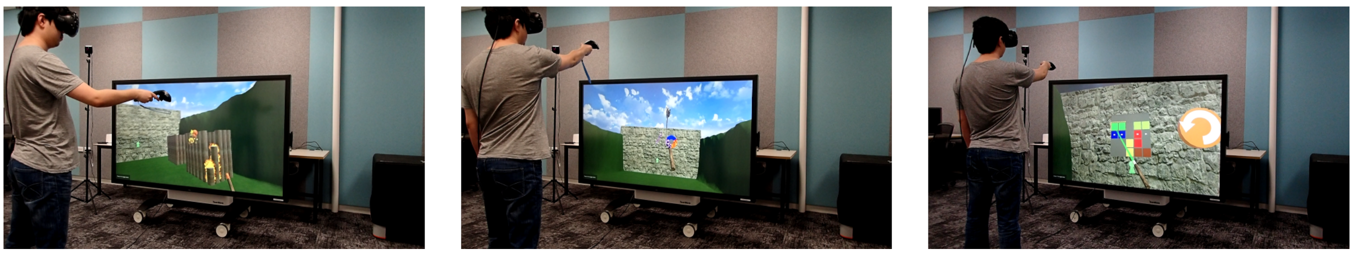

Figure 1: ChronicVR Game: a player throwing fireballs; a player readying a lightning arrow; and a player solving a puzzle.

ABSTRACT

Chronic pain is a continuous ailment lasting for long periods after the initial injury or disease has healed. Chronic pain is challenging to treat and affects the daily lives of patients. Distraction therapy is a proven method of relieving patients' discomfort by taking their attention away from the pain. Virtual reality (VR) is a platform for distraction therapy by immersing the user in a virtual world detached from reality. However, there is little research on how physical interactions in VR affect pain management. We present a study to evaluate the effectiveness of physically active, mentally active, and passive interventions in VR using games with chronic pain patients. Our results indicate that physical and mental activities in VR are equally effective at reducing pain. Furthermore, These actively engage patients, while the effects of observing relaxing content persist outside VR. These findings can help inform the design of future VR games targeted at chronic pain management.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

Chronic Pain Management, User Study, Virtual Reality

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1 INTRODUCTION

Pain is an unpleasant experience that indicates something is wrong with our body and is at risk of harm [40]. Pain is commonly divided into two categories: acute and chronic [57]. Acute pain is caused by disease, injury, or some other form of stimulation [57] and serves as a biological alert to prevent further damage [42]. *Chronic pain* is an ongoing disorder that lasts well after the initial injury has healed [47]. Chronic pain patients experience pain avoidance where they start thinking that performing specific tasks and activities will cause more pain, so they avoid doing them [44]. This avoidance reduces patients' lives as they withdraw from their day-to-day life and hobbies.

On the other hand, having patients perform physical activities, whether simple exercises or therapy, is an excellent way to help them explore their bodies and learn what they are capable of, as well as improving general health [1]. Drugs are the primary treatment mechanism for chronic pain, but they can have side effects over long-term use [21]. For example, opioids, a common painkiller, carry the risk of addiction, tolerance, dependency, and withdrawal [54].

An alternative approach for chronic pain management is non-pharmacological treatments such as distraction therapy which takes patients' attention away from pain and onto some other stimuli [38]. Humans have a limited cognitive capacity to focus on simultaneous stimuli, and distraction therapy seeks to help with something other than pain. Chronic pain can decrease productivity as patients cannot focus on the task at hand. Within distraction therapy, there are two subcategories: *active attention-diversion*, where patients perform a task, and *passive distraction*, where patients observe an engaging stimulus [12].

VR is a platform that stimulates users' visual, audio, and tactile senses. VR creates a virtual environment in which users can explore and interact with virtual objects [32]. Modern headsets can now track users' heads and hand positions allowing people to move physically in the real world and translate into the virtual world [3]. Physical engagement occupies users' sense of orientation, which can help disconnect people from the real world. Some people gave explored mobile devices to help motivate chronic pain patients to perform physical activities and provide feedback on performance with factors like posture and range of motion [52].

Adopting VR and engaging in all these senses, VR can become an effective platform for distraction therapy [36]. Introducing physical VR interactions can help divide the active attention-diversion category above into two subcategories: *physically active*, where patients move around and engage with the virtual world physically; and *mentally active*, where patients memorise and perform logical thinking. Physically active distractions cannot be practically used by acute pain patients while undergoing medical procedures because it would be too inconvenient for medical staff to have their patients move around while trying to perform the procedure on the patient. However, there is limited research on distraction therapy using VR for chronic pain relief [37, 41].

This paper presents a study to evaluate the effectiveness of physically active, mentally active, and passive interventions in VR using games with 14 chronic pain patients. We designed *ChronicVR* (Figure 1), a game for chronic pain interventions that included three levels emphasising the distraction categories: physical, mental, and passive. The results showed that physically and mentally active distraction tasks were equally effective when people were engaged in VR. However, pain reductions from passive distractions persisted beyond the VR session when using a relaxing activity.

2 RELATED WORK

VR for pain relief has been studied in a range of medical procedures, therapy sessions, induced/simulated pain, affliction, conclusively showing that VR was effective relief for acute pain [34, 35]. Some VR procedures include burn patients [6, 10, 22, 24, 25], labour [14], surgery [7], cancer [2], port access [17], and dentistry [23, 59].

Some research has conducted studies using VR as a distraction tool with chronic pain patients. [16, 20, 29, 30, 58]. These studies have shown that VR distraction therapy is effective for managing chronic pain. The VR sessions not only reduced pain but was a positive experience for patients. However, a common trend in these studies is that reductions in pain did not last beyond the VR session. One study did not report pain ratings after the session, only during [29]. None of the VR content used in these studies allowed patients to physically walk around to interact with the virtual environment. One study used a relaxing environment as a passive observation distraction which required no input, while the other studies used mouse/keyboard for interactions [58]. Other researchers have explored other modalities notably wearable devices (mobile phones strapped to the body) to provide audio feedback on the movements of people with chronic pain in the home [51–53].

Long-term use of VR may provide pain relief into the future. Some studies showed that repeated use of VR did not diminish the analgesic effects [16, 25, 26, 48, 56]. However, the study of the effects of long-term exposition to VR for pain relief is not yet addressed by previous work. Previous studies are not yet definitive and have some drawbacks for their use on pain relief including limited sample sizes of patients, short-term sessions, recording pain only once a VR session was finished and not when participants were actively using VR, nor using modern VR headsets.

VR can be used to train and teach patients to learn how to handle themselves in ways that existed beyond VR sessions. Gromala et al. conceived a method to direct and educate people with VR through a meditation process called Mindfulness-Based Stress Reduction (MBSR) [19]. The MBSR process requires people to focus on their internal state rather than their surroundings, and replaces the surroundings with a non-distracting VR environment to enter their meditative state.

Karuna Labs[1] focuses on treating chronic pain with VR. They achieve this by teaching patients about chronic pain, provide physical training based on patients' range of motion, games to help patients increase their range of motion, teaching patients to decrease anxiety by placing them in calm environments, and Virtual Embodiment Training. Virtual Embodiment Training shows a model of patient's body in VR, and by differing the model's movement from the patient's actual movement, it presents patients an image that those movements which were once pain, are non-threatening. AppliedVR[2] focuses on therapeutic VR for people with limited mobility which helps them to relax to aid pain and anxiety, providing relaxing videos, guided meditations, and games.

Dahlquist et al. [9] compared active distraction and passive observation for 40 children experiencing cold pressor pain. The active distraction group played a video game in VR with a joystick. The passive observation children watched, in VR, a pre-recorded footage of someone else playing the game. Some children were also not given any distractions and acted as the control group. It was found that while both active and passive forms were effective compared to no distraction, active distraction was significantly superior to passive observation.

3 CHRONICVR

The focus of our research is on distraction therapy for chronic pain patients that helps educate them by encouraging physical activity using engaging VR games and modern 6DOF headsets. We designed *ChronicVR* an interactive VR game to support managing chronic pain relief. A game is, by nature, designed to draw in the player and provides them with an engaging activity. Gameplay elements, such as having an objective to accomplish within a session, provides players with an incentive to do well within the game, further engaging their focus and attention. Within ChronicVR there are three distraction categories of gameplay: *physically active distraction*, *mentally active distraction*, and *passive observation.* ChronicVR is designed to isolate each category as much as possible so that the categories can be studied separately. Players assume the role of

[1]https://karunalabs.com/
[2]https://appliedvr.io/

a wizard using a magic wand (handheld controller) to cast different magic to interact with the virtual world, and solve puzzles to advance levels. See a video showcasing ChronicVR[3].

3.1 Design Requirements

The design of ChronicVR was created with consultation from Wellington Regional Hospital's Pain Management Service. The Pain Management Service advised on what chronic pain patients were capable of, what would be beneficial for the patients, what kinds of environment patients would enjoy, and access to patients.

Due to the pain in patients' bodies, there are limits on the amount or extent of physical interactions they can perform. For example, a patient with pain in their arm would not be able to perform broad, sweeping arm movements. However, some patients underestimate their limits, leading to pain avoidance. Pain avoidance is the situation where patients start to think that performing tasks that they are capable of would cause more pain, leading to them stopping perform these tasks [44]. This avoidance reduces their quality of life as they avoid many activities and lose sources of excitement. To regain the excitement patients should connect with their body in a better way rather than disconnecting from their body.

There is a belief that pain is merely a warning that something is wrong and needs to be repaired, chronic pain can not be easily eliminated, and aggressive attempts may cause more harm. Patients need to learn tools that help them live with and manage their pain, and education is seen as an essential part of pain management.

Our key design requirements for ChronicVR based on our consultations included the need to **Encourage movement (REQ1)**, allowing patients to explore their capabilities; **Bring Excitement (REQ2)** to patients, helping them understand that they can still enjoy activities; and **Teaching pain management (REQ3)** through techniques rather than relying on pharmacological painkillers.

3.2 Game Design

The game was designed using Unity3D for HTC Vive (3m x 3m setup) and has a magical theme, where players take on the role of a magician. A player is in a magician training facility, where they must complete a series of challenges to measure their magical skill. As the magical energy comes from nature, players are surrounded by green spaces under an open sky. A bright blue sky is used for the physical level, while a starry night sky is used for the mental level. Players exit into a beach with calming waves overlooking an expansive ocean at the end of the challenge. This setting conforms with the Pain Management Service's advice that the patients enjoy nature and the bush. Players interact with the world using one handheld controller (either left or right hand), and can navigate the environment using teleportation features.

The same background music ('Weightless" by Marconi Union) is used across all three levels. Weightless is claimed to be the most relaxing music in the world [50] and has been used as music therapy to reduce anxiety in patients [18]. Instructions were provided to players via a voice-over inside the game which was delivered at a slow pace to both allow players sufficient time to understand instructions and not to induce any sense of urgency. Voice-overs were used at the beginning of each level to introduce players to the level and to rate their pain level at the start and middle of a 10-minute session. Deep breathes help aid relaxation. Remembering to take deep breathes is part of the set of tools for chronic pain patients to self manage pain. A voice-over reminded players to breathe at regular intervals and to fill up their magic wand with magical energy, which happens at the beginning of the level in the introduction, and at the 3 and 7 minute marks.

Due to the target demographic it was assumed that some players will not have a full range of motion or ease of mobility in their limbs. As such, ChronicVR provides options for players so that they are not restricted to only one way of playing the game. The game can be played both standing and walking around, or sitting in a fixed position.

3.3 Physical Level

Physically active distraction content focuses on requiring the player to perform physical activities within VR. Excessive or large movements may cause increased pain for patients. ChronicVR is designed to reward players who perform the large movements, but still doable with small movements only. Larger or faster movements reward players with more distance in throwing objects which leads to faster completion times. Smaller movements mean players will take longer to complete each task, but not so long that they are stuck on the same task for the entire 10-minute session.

In the physical level, players progress by gaining access to a key somewhere in the level then moving the key into the vicinity of the keyhole on the gate (Figure 2). The key only needs to be within a certain distance of the keyhole and does not need to be inserted into the keyhole correctly. The key can be simply thrown at the keyhole to activate. The player achieves this using magic.

Players have access to three types of magic: *telekinesis*, *fireball*, and *lightning arrow*. These three types of magic are gradually introduced to the player in the earlier parts of the level. In later parts of the level, players must use a combination of magic to progress. Players can freely swap between the three types of magic using the controller's touchpad which is divided into three equal arcs, one for each magic. The centre of the circular touchpad is used for teleportation (Figure 3).

The telekinesis magic allows players to pick up objects from any distance (Figure 4). The telekinesis is the magic players use to pick up the key and put it in the keyhole. While the telekinesis magic is the currently active magic, a guidance pointer is projected from the tip of the wand. The pointer is blue, turning green when the player is aiming at something that can be picked up. The targeted object also glows with a yellow outline. The pointer turns yellow when the object is picked up. Players can aim at the object they wish to pick up with this pointer before activating the magic by pulling the trigger. The object remains in the player's "grasp" as long as the trigger is held down, dropping when the player releases the trigger. Upon release, the held object maintains the velocity it had immediately before release. Players are therefore able to throw objects around with this system by releasing the trigger while moving their hand. The concept is the same as throwing an object in the real world. Telekinesis magic, therefore, encourages players to move their arm and wrists. However, as the object is not held directly inside the player's palm but at some distance

[3]https://youtu.be/_MxnTbHb1lY

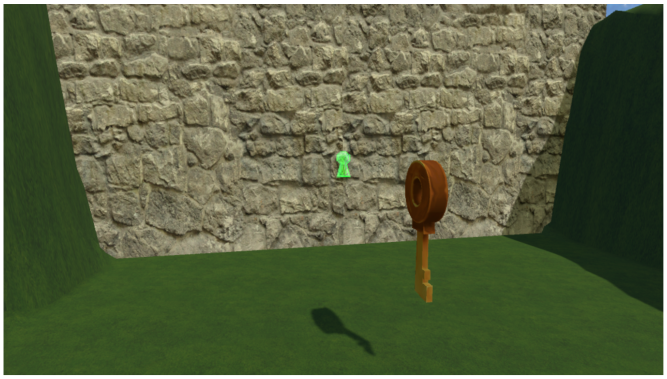

Figure 2: A key and the keyhole.

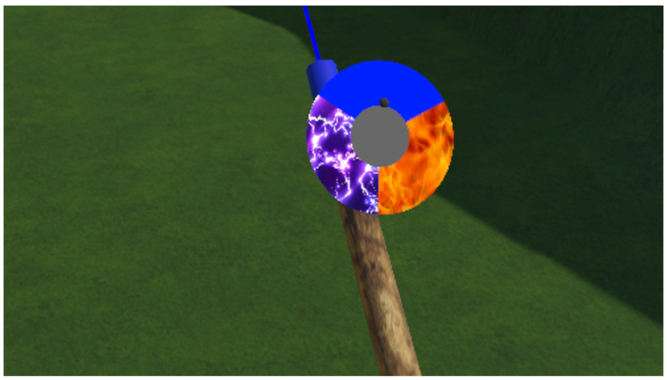

Figure 3: Circular Menu for selecting the three types of magic to be used divided by arcs.

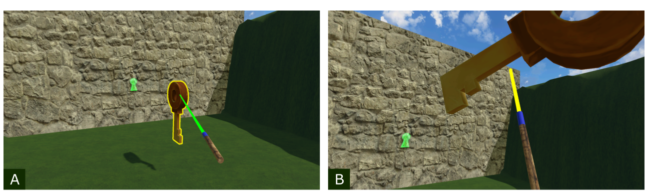

Figure 4: Telekinesis Magic : (A) Aiming at an object (B) Picking up and holding an object.

away with magic, the velocity of the object becomes higher than the velocity at which the player's hand is moving. This increase in velocity allows for players to throw objects in a considerable distance without requiring significant hand or arm movements.

The fireball magic allows players to create a fireball in their hand (Figure 5). Once created, the fireball behaves the same as an object held with telekinesis magic. The fireball is held in the player's hand as long as they are holding down the trigger. Releasing the trigger releases the fireball. When the fireball comes into contact with wooden logs, the logs burn away to reveal the key hidden behind it. In later parts of the level, the wooden logs grow back once burned, so the player must retrieve the key hidden behind the log within a certain amount of time before the log grows back. If players do not retrieve the key in time, they must burn the log again.

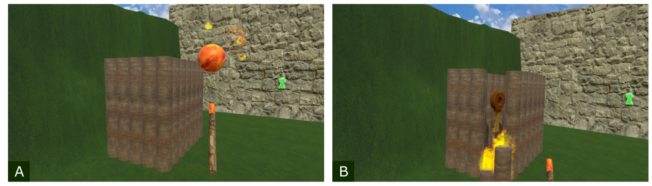

Figure 5: Fireball Magic : (A) Holding the fireball created with fireball magic (B) Wooden logs burning away after being hit with fireball magic, revealing the key hidden behind it.

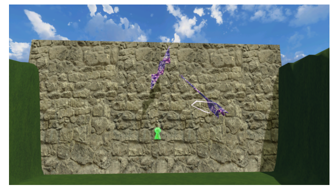

Figure 6: Lightning arrow magic. The target is above the keyhole and the arrow is to the right of the target.

The lightning arrow magic allows players to create and shoot an arrow (as in, bow and arrow) made of lightning (Figure 6). When players pull and hold the trigger, the tip of the arrow is set where the wand is. The feather end of the arrow following the player's hand while the player holds down the trigger. The arrow is then released in the direction it is facing once the trigger is released. The further back the player "draws" the arrow, the faster the arrow moves once released. Next, players use the lightning arrow to hit lightning targets in the level. All but one target is stationary. The moving target flies across the sky, and players must time the arrow correctly to hit it. Lightning targets open a particular door when hit. These could be the big gate to progress to the next level or a side door behind which the key is hidden. In the later parts of the level, the side doors close after a certain time, so the player must retrieve the key hidden behind the door within a certain amount of time before the door closes. If players do not retrieve the key in time, they must hit the lightning target again.

3.4 Mental Level

Mentally active distraction content focuses on requiring the player to think and memorise elements to solve puzzles. In the mental level, players progress by solving a series of puzzles. There are four types of puzzles: Concentration[4], Jigsaw, Flipping, and Rush Hour[5]. Concentration is a memory game, while the other three requires logical thinking. These four puzzles were selected as they had simple rules and goals, no complex strategy was required, were literacy agnostic, and were a representative sample of puzzle games.

The first puzzle, Concentration presents players with several cards, floating in the air (Figure 7). Players flip the cards around in twos and match the pairs. Once the player matches a pair, the pair disappears. Players can progress in the level once all the pairs are matched. To be effective at solving the puzzle, players must

[4]https://en.wikipedia.org/wiki/Concentration_(game)
[5]https://en.wikipedia.org/wiki/Rush_Hour_(puzzle)

Figure 7: Concentration puzzle: (A) Concentration puzzle with 6 pairs. The cards are turned to face the player. (B) Matching the pairs. (C) A partially solved puzzle with already matched pairs having disappeared

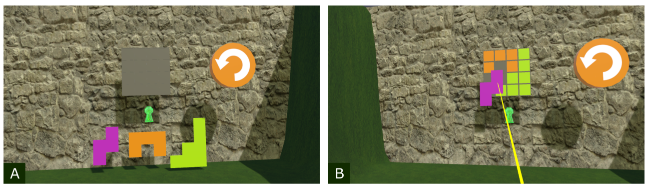

Figure 8: Jigsaw Puzzle: (A) A jigsaw puzzle in its initial state with a 4×4 grid and 3 pieces. The reset button can be seen on the right. (B) An almost solved puzzle. The player is 1 piece away from completing the puzzle.

remember the position of previously flipped cards so that they can match it when the corresponding pair appears. As players progress through the level, more and more pairs are added, increasing the difficulty of the puzzle. Players are not able to look behind the cards even if they move, as the cards automatically turn to face the player with what they should be seeing.

The second puzzle, Jigsaw, presents players with a rectangular grid puzzle board with Tetris-like[6] puzzle pieces (Figure 8). Players need to fit the puzzle pieces into the board such that all the pieces fit onto the board. The board will be filled up by the pieces. A reset button is next to the board should the player make a mistake in solving the puzzle. The reset button removes all the pieces from the board and places them back in their original position.

The third puzzle, Flipping, is based on the *Folding Blocks* game by *POPCORE*[7] which presents players with a rectangular grid puzzle board with some grids filled with pieces already displayed (Figure 9). The piece doubles and flips in the dragged direction when players drag on a piece. If the puzzle board has space in the flipped direction, the flipped piece doubles in size. If another piece obstructs the flipping, the flipped piece simply flips back as if nothing had happened. The goal is to cover the entire board with pieces.

The fourth puzzle, Rush Hour, presents players with a rectangular grid puzzle board occupied by $1 \times n$ or $n \times 1$ pieces (Figure 10). One piece is marked with arrows to indicate that piece as the key piece. Similar arrows are marked on a position on the board also to indicate the target position. The goal of the puzzle is to move the key piece to the target position. Pieces can only slide around the board along its long side, and can only move when there is no other piece blocking it. The difficulty of this game arises from the non-key pieces on the board. The non-key pieces must be moved out of the way to allow for the key piece to reach the target position.

[6]https://en.wikipedia.org/wiki/Tetris
[7]https://popcore.com/

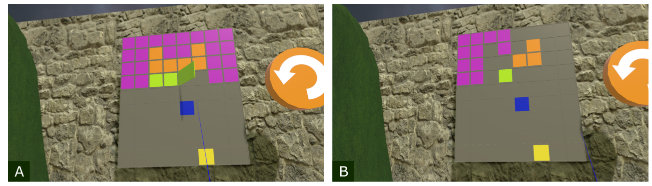

Figure 9: Flipping Puzzle: (A) A flip puzzle in its initial state with a 8×9 grid and 5 pieces. The reset button can be seen on the right. (B) A piece in the middle of a flip. The lime-green piece is flipping towards the right. The purple piece has flipped right, the orange piece has flipped left, and the lime-green piece has flipped left since the previous image.

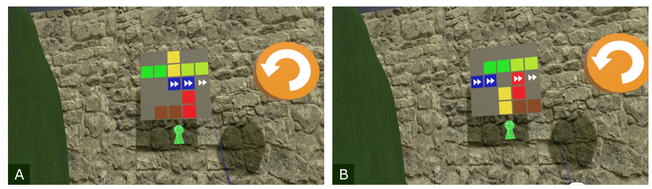

Figure 10: Rush Hour Puzzle: (A) initial state with a 5×5 grid and 6 pieces. The reset button can be seen on the right. The blue piece on the left is marked with the arrows indicating that it is the key piece. (B) A Rush Hour puzzle about to be solved. The blue key piece is one move away from the target position. The other pieces have been moved out of the way to allow for the blue piece to reach this position.

3.5 Passive Level

The passive observation level consisted of players watching relaxing 360-degree videos we recorded of natural scenery in VR. There were seven videos in total, evenly divided across 10 minutes, and are automatically played in the same sequence. Players are encouraged to look around and take in as much of the nature scenery as possible. Players are unable to interact with any of the VEs.

4 USER STUDY

To evaluate ChronicVR for the differences in pain relief between physically active distractions, mentally active distractions, and passive observations we conduced a user study. The study was approved by the Health and Disability Ethics Committee in the Ministry of Health. A pilot study was conducted with two healthy people to help inform the main study protocol.

4.1 Participants

14 chronic pain patients were recruited for the study from the Pain Management Service where the study took place (Table 1). The recruitment criteria was patients who did not require medical assistance (i.e. on a typical day), and having had a daily average pain intensity score of 4 or more on the 0-10 scale (§ 4.3) for the past three months or more. Seven participants were female, five were male, and two were non-binary. 12 participants were under 40 years old. 11 participants had daily pain rating average between 4 and 6, and the other three participants had average daily pain ratings of 7,

Table 1: Participant background information. Average daily pain is on a scale from 0 to 10 (§ 4.3). Pain regions are divided into the head (H), neck (N), torso (T), upper limbs or arms and hands (U), lower limbs or legs and feet (L).

PID	Gender	Age	Average Daily Pain	Pain Regions	Familiarity with VR
01	Female	30-39	5.5	HNT - L	A little
02	Male	30-39	5.5	HNTUL	A little
03	Female	20-29	5	- - TUL	A little
04	Female	40-49	5	- - T- -	A little
05	Male	40-49	6	- - T - L	Somewhat
06	Male	50+	5.5	- - T- -	Not at all
07	Male	50+	6	HNTUL	Somewhat
08	Female	20-29	4	- - TUL	Somewhat
09	Female	20-29	4	- - T - -	Not at all
10	Female	30-39	4	HNTUL	Not at all
11	Female	20-29	9	- NT - L	A little
12	Male	20-29	9.5	- NT - -	A little
13	Non-binary	20-29	7	- - TUL	A little
14	Non-binary	20-29	6	HNTUL	A little

Table 2: Participant self management techniques

Technique	Frequency
Medication/drugs	9
Listening to music/spoken media	5
Physical exercise	3
Watching visual media	3
Meditation/quietness	2
Rest/sleep	2
Talking/socializing	1
Reading	1
Heat	1
Eat healthy	1
Mobility tools (wheelchair)	1
Mental puzzles	1

9, and 9.5. Pain regions are divided into the head (H), neck (N), torso (T), upper limbs or arms and hands (U), lower limbs or legs and feet (L). Five participants had pain in the head, seven participants had pain in the neck, every participant had pain in the torso, seven participants had pain in the upper limbs, and 10 participants had pain in the lower limbs. Three participants were not at all familiar with VR, eight participants were a little familiar with VR, and three participants were somewhat familiar with VR. The frequency of participants' self-management techniques is shown in Table 2. The most used pain management technique by nine participants was the use of medication or drugs, followed by five participants listening to music or spoken media. All other techniques have three or fewer participants utilising it. No participant had used VR for pain management before and only one reported playing mental puzzles.

4.2 Procedure and Tasks

The procedure of the study involved an introduction, pre-study questionnaire, and training on ChronicVR. This was followed by four study tasks, and a post-study questionnaire. The entire study took up to 90 minutes, and participants were given a supermarket voucher as an honorarium for participation.

At the start an explanation was given on the basic overview of the study and what was required of the participants. Participants were asked to read an information sheet and sign a consent form. Participants completed a pre-study questionnaire which gathered participant's background information consisting of gender, age, ethnicity, average daily pain, where the pain is located, what they did to self manage the pain usually, and how familiar they were with VR. A training session with ChronicVR was then given before participants performed the study tasks. Before the first VR task, participants were given a tutorial on wearing the headset and were informed again that they were allowed to take off the headset at any time should they feel motion sickness [39]. Before the physically active and mentally active tasks, participants were given a tutorial on the controls and how to play the game. This tutorial was not necessary for the passive observation level as no input or interaction from the participant was required. The study tasks consisted of using ChronicVR and a non-VR activity. There were four tasks in total: physically active distraction, mentally active distraction, passive observation, and non-VR distraction. The first three tasks were completed in ChronicVR, and the non-VR distraction was an activity that the participant likes to do regularly, such as reading or listening to music. The four tasks were completed by a within-subjects randomised crossover study [5]. Each task lasted 10 minutes, and a 5-minute cooldown period was given between each task, allowing participants to rest their eyes as well as recover from any VR sickness side-effects such as discomfort or nausea [8, 39].

4.3 Data Collection and Analysis

We collected both objective and subjective data to measure users' experience and the effects of ChronicVR on chronic pain treatment. We collected subjective data through questionnaires, that included a pre-study (§4.1) and post-study questionnaire which is a common method for collecting qualitative data in user studies [43]. During the study, participants were asked to subjectively rate their pain verbally at the beginning, middle, and end of each of the four tasks, resulting in 12 pain ratings per participant. The mid-session pain rating was asked at the 5-minute mark. A post-study questionnaire was conducted that collected the thoughts of the participants about the VR game and overall experience. The four questions asked about 1) general enjoyment (*Did you enjoy the VR experience?*), 2) VR for pain relief (*Would you use VR for pain relief in your daily life?*), 3) VR recommendations (*Would you recommend others to use it?*), 4) open questions for any other feedback, and a follow up interview.

For assessing the pain level of the participants, we chose to use Permanente's[8] "0-10 scale of pain severity". This scale takes into account that pain is a subjective measure for each person and representing pain with a number can be misleading [11]. For this reason, the scale includes a description for each pain level, to better describe the level of pain the participants were experiencing. The descriptions that were given concerns the impact of the pain on the day-to-day lives of the participant and were given in a more objectively measurable way. This description provides a better reference point for participants which also helps them decide on the rating.

[8] https://healthy.kaiserpermanente.org/

Table 3: Descriptive Pain Scale. The description associated with each pain rating.

0	No Pain - I have no pain.
1	Minimal - My pain is hardly noticeable.
2	Mild - I have a low level of pain. I am aware of my pain only when I pay attention to it.
3	Uncomfortable - My pain bothers me but I can ignore it most of the time.
4	Moderate - I am constantly aware of my pain but I can continue most activities.
5	Distracting - I think about my pain most of the time. I cannot do some of the activities I need to do each day because of the pain.
6	Distressing - I think about my pain all of the time. I give up many activities because of my pain.
7	Unmanageable - I am in pain all the time. It keeps me from doing most activities.
8	Intense - My pain is so severe that it is hard to think of anything else. Talking and listening is difficult.
9	Severe - My pain is all that I can think about. I can barely talk or move because of the pain.
10	Unable to Move - I am in bed and can't move due to my pain. I need someone to take me to the emergency room to get help for my pain.

Table 3 shows the descriptions used to measure participants pain level. The participant pain ratings were preprocessed in preparation for statistical analysis. The three pain ratings for each task (start, middle, and end) were subtracted from each other to give three new numbers: Middle-Start, End-Start, End-Middle. These values show the changes in pain while performing the task. A positive number indicates a drop in pain, which is the desired result. The decreases were tested for normality with a Shapiro-Wilk test [46]. As the decreases were not normally distributed, we used a Friedman test to determine if decreases in pain between the four tasks were significantly different [15] using a Wilcoxon Signed ranks tests post-hoc test with a Holm-Bonferroni correction [27] to test each pair of conditions. A linear mixed-effects model was also created to examine if different aspects of participants (e.g. gender, age) had significant influences on pain ratings.

5 RESULTS

This section presents the results of the pain ratings presented by the participants at the start, middle, and end of each task for the four tasks investigated: physical, mental, passive observation, and non-VR.

Table 4 shows the mean and standard deviation of pain ratings for each task, measured at the start, middle, and end of the task. Figure 11 presents the Pain Rating column of Table 4 graphically, with the first, second, and third data points representing the average pain rating at the start, middle, and end of each task respectively. Error bars show one standard deviation above and below the mean. Although the pain was rated on a 0-10 scale, the y-axis has been adjusted to a more suitable range to display this data better.

The data was processed, and the decrease in pain ratings was calculated for each task. The three calculations were Middle-Start, End-Start, and End-Middle. A larger value is better as it indicates a larger decrease in pain. These results are the focus of the statistical analysis later in this section. The values are provided in the last two columns of Table 4. Figure 12 presents this data graphically.

Table 4: Mean and standard deviation of pain ratings at the start, middle, and end each task. For the physical, mental, and passive observation tasks, participants played through the respective level in ChronicVR. For the non-VR task, participants engaged in an ordinary activity that they liked such as reading or listening to music (§ 4.1).

Task	Time	Mean (SD) Pain Rating	Mean (SD) Decrease Start	Mean (SD) Decrease Mid
Physical	Start	4.250 (0.872)		
	Mid	3.500 (1.271)	0.750 (0.915)	
	End	3.714 (1.528)	0.536 (1.184)	-0.214 (1.139)
Mental	Start	3.857 (1.393)		
	Mid	3.214 (1.369)	0.643 (0.663)	
	End	3.250 (1.590)	0.607 (1.243)	-0.036 (0.909)
Passive	Start	4.321 (1.203)		
	Mid	3.929 (1.269)	0.393 (0.944)	
	End	3.821 (1.381)	0.500 (1.109)	0.107 (0.626)
NonVR	Start	3.679 (1.137)		
	Mid	3.714 (0.848)	-0.036 (0.634)	
	End	3.893 (1.147)	-0.214 (0.995)	-0.179 (0.504)

Participants reported a decrease in pain ratings in the physical, mental, and passive observation tasks in the middle of the task. The mean pain rating dropped by 0.750, 0.643, and 0.393, respectively. At the end of the physical and mental tasks, the mean pain rating went back up by 0.214 for the physical and 0.036 for mental task. However, in the passive observation task, the mean pain rating decreased even further by 0.107. In the non-VR task, mean pain ratings increased both in the middle of the task and at the end.

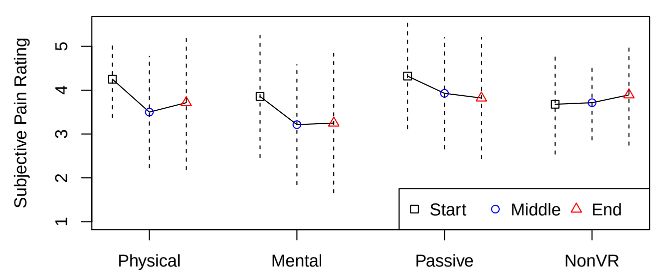

Figure 11: Mean ± 1 standard deviation of pain ratings at the start, middle, and end each task.

For the three VR tasks (physical, mental, and passive), reported pain rating was lower at both the middle and end of the task when compared to the start. Whereas for non-VR tasks, pain ratings went up at each step. This result was affected by less than half of the participants, as 10 participants saw no change in pain ratings between the start and middle of the non-VR task, 7 of whom saw no change between the start and end either. This result is illustrated in Figure 13, where the median (and for two of them, interquartile range) was 0 for all three time-point comparisons. The reasons for

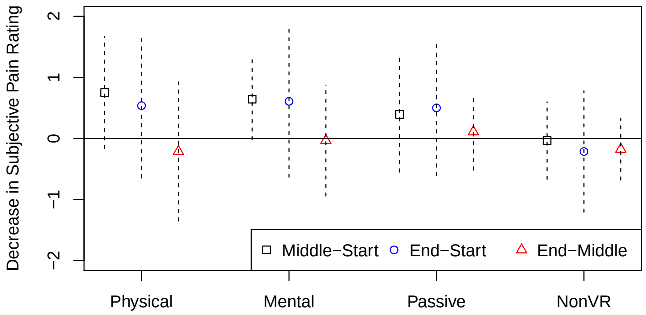

Figure 12: Mean ± 1 standard deviation of the decreases in pain ratings between start and middle, start and end, and middle and end. A higher value indicates a higher decrease in pain ratings.

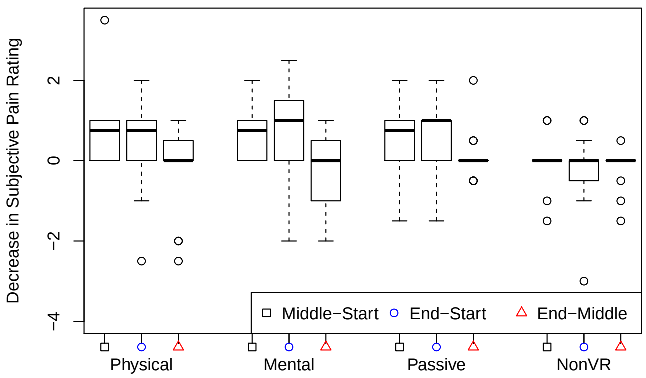

Figure 13: Decreases in pain ratings between start and middle, start and end, and middle and end, showing the median, quartiles, and outliers. A higher value indicates a higher decrease in pain ratings.

the increase in pain varied between participants. In some cases, participants were sitting and did not move for a long period of time. For one participant, it was due to the effects of medication, which was applied in an appointment before participating in the study, wearing off.

For physical tasks, mean pain ratings increased between the middle and end of the task. This result was also due to three outliers, as shown in Figure 13. One participant's pain ratings increased by 2.5, while two others increased by 2. Seven participants did not notice any change in pain ratings between the middle and end of physical tasks, and four noticed a decrease in pain. We noticed that the increase in pain ratings reported by the participants were caused by the difficulty in completing later levels of the game. Performing repeated motions for ten continuous minutes also caused pain for some participants. Participants reported different forms of pain between them. These included pain on the arms related to using the controllers for long periods of time, and pain on the legs caused by standing for long periods of time (10 minutes or more). In the physical and non-VR tasks, pain ratings increased between the middle and end of the task. Average pain increased by 0.214 in the physical task and 0.179 in the non-VR task. Pain also went up between the middle and end of the mental task, but not by as much as physical. The pain increased by 0.036 between the middle and end of the mental task. Only in the passive observation task pain continued to decrease between the middle and end of the task, dropping by 0.107 on average.

As the results are not normally distributed, a Friedman test was used to determine if decreases in pain between the four tasks were significantly different. All three of Middle-Start ($p = 0.103$), End-Start ($p = 0.0838$), and End-Middle ($p = 0.769$) were found to be not significantly different between tasks. These results were validated by a Wilcoxon signed-ranks test with p-values adjusted using the Holm–Bonferroni method. Although on average tasks in VR reduced more pain than non-VR, due to the spread and range of the results, there were no statistically significant differences between the four tasks.

A linear mixed-effects model was created using R version 3.5.2 [45] and the *lme4_1.1-21* package [4]. Gender, age, the order of the task, participants' average daily pain, and their familiarity with VR were set as the fixed effects. Participants were set as a random effect. This model was used to examine if different aspects of participants had significant influences on pain ratings.

The *car_3.0-7* package [13] was used to perform an analysis of deviance using Type II Wald chi-square tests to determine which fixed factors had a significant influence on pain ratings. None of the factors had significant influence on the pain ratings. Age ($\chi^2_1 = 0.663, p = 0.415$), gender ($\chi^2_2 = 1.464, p = 0.481$), session ($\chi^2_1 = 2.683, p = 0.101$), average daily pain ($\chi^2_1 = 0.071, p = 0.789$), familiarity with VR ($\chi^2_1 = 0.519, p = 0.471$), head pain ($\chi^2_1 = 0.647, p = 0.421$), neck pain ($\chi^2_1 = 0.572, p = 0.449$), upper limb pain ($\chi^2_1 = 2.616, p = 0.106$), lower limb pain ($\chi^2_1 = 2.068, p = 0.150$) were found to have no significant impact on pain ratings. Torso pain was not included in the model as every participant was reported to have torso pain, so there are was nothing to compare against.

6 DISCUSSION

The findings for physical and mental levels are consistent with previous studies in which pain decreased during VR sessions, but the pain returned after the session. However, for the passive observation level, the pain decreased between the start and middle and decreased even further between the middle and end. The decrease could be due to the relaxing nature of the task continuing after the task was completed. Both physical and mental are active distractions. Once the task was completed, the distraction finished. Active attention-diversion VR content is most effective while the patient is actively using VR and engaging with the content. Once the patient has taken off the headset, their pain reverts to previous values. However, with a relaxing activity like the passive observation level, the relaxation experienced by the patient continues after the VR session has ended. The gap between the end of the task and when the pain is rated as minimal. Preference between active attention-diversion and passive observation was also divided, some preferred to be engaged while others relaxed and watched videos.

Physically active and mentally active distraction yielded remarkably similar results in the 10-minute session. Had the session have gone on for longer, say, 20 minutes, some participants may have experienced increased pain and stress as they tire. Some participants did begin to tire towards the end of the 10-minute session. Over longer sessions (e.g. 20-30 mins), mentally active might prove more effective than physically active as mentally active requires less stamina. However, it is hard to determine what the effects of long-term use on pain would be. Should a patient play physically active distraction content for 10 minutes every day, they can potentially become more comfortable with their body as they explore their full range of motions, and result in lower pain ratings even outside of VR. This longitudinal exposure is worth exploring further.

The results between the four tasks were not significantly different when analysed with a Friedman test, as all participants reported a positive experience with VR. While VR was a novel experience for some, previous research has shown that repeated VR exposure does not diminish our results [16, 25, 26, 48, 56]. ChronicVR divided up physically engaging content, mentally engaging content, and passive observation content into their distinct level to evaluate each individually. The three types of content should be used together cohesively to increase the engagement of the game. If a well-designed game has a player performing a physical task one moment and solving a mental puzzle the next, and having a relaxing break with passive observation content from time to time, it will draw in players' focus and attention, making them continuously wonder what would be next. Although the VR tasks did not significantly decrease participants' pain ratings, a better designed and engaging game could improve the VR effectiveness for pain relief.

Music was played during the passive observation task, the same music as the physical and mental levels. Two participants reported that they would prefer to have the natural sound of the video or a guided meditation. Natural sound playing as part of the video environment would strengthen immersion and provide a stronger sense of presence [49]. It was established that a stronger sense of presence led to stronger pain relief. Playing guided meditation audio would lead to increased relaxation in the patient. Patients would also be able to use the opportunity to learn meditation techniques that they can apply outside of VR. Teaching patients self-management techniques inside VR also ties back to our design principles (REQ3).

The weight of the headset was a concern for four participants. Having such a weight sit on their head had increased pain for two participants, discomfort for one, while for one participant, the content was engaging enough that they forgot about the weight. There is a balance between high-tech headsets for more immersion and lightweight headsets to reduce pressure on the head and neck. However, this is maybe a diminishing problem as the headset hardware improves and becomes smaller and lighter. VR headset makers are aware of the strain headsets put on the head and neck and are actively working to reduce the weight of headsets [33]. No participant reported any motion or VR sickness [55]. This is most likely due to participant sampling, as with a sample size of fourteen, instances of motion sickness can be expected. The short 10 minutes session times, combined with frequent 5-minute rest, could also be a contributing factor. However, we never asked participants to complete a survey on VR sickness such as SSQ [31].

While participants had fun playing the game, many were unaccustomed to the VR controller. This unfamiliarity with the controllers was a source of frustration for most participants at the beginning as they learned how to operate the controls. Although the controls were explained to them, and time was given for them to practise using the controller, those inexperienced with video games often pressed buttons different to their intentions. For most participants, the struggle with controls would last until around the 5-minute mark, but for a small number of participants, they were unable to become fully accustomed to the controls. These participants struggled to complete levels in the game and did not get through many levels in the 10-minute session. On the opposite end, participants with more familiarity with video games were able to quickly pick-up the controls and complete levels at a much faster pace, completing up to the ending levels or even every level in the 10-minute session. There were no observed correlations between pain levels of participants who had more difficulty with the controllers than those who did not. Although ChronicVR was designed to introduce players to the game mechanics gradually, a more effective tutorial system could help with learnability.

Limitations. A sampling bias potentially arose from participant willingness. 10 participants were under the age of 40, which is not reflective of the population observed during recruitment. The population observed at hospitals skews towards older generations [28]. This bias arose from the younger generations more willingness to engage with novel technologies and elderly (aged 70+) generation's stigma that video games had issues. The sample size of 14 makes accurate statistical analysis difficult. Every participant had a noticeable impact on the numbers. Both quantitative and qualitative data were self-reported by the participants. Self-reported data opens up the possibility of bias. Introducing an objective measure would strengthen the validity of the data. Participants only played one VR game in one sitting. The longitudinal effects of physically engaging content were not studied, but left for future work. The game did not allow for movement personalization so players could compare themselves and their min and max movement range, something to consider for future versions. Participants activities before participating in the user study were not controlled. Their activities could lead to fluctuations in pain ratings. Many participants participated after their appointment with the Pain Management Service. One participant received pain medication during this appointment, and the medication began to wear off during the study, leading to increases in pain ratings. Other participants may have been tired from their prior appointment or the effort to attend the study.

7 CONCLUSION

In this paper, we presented a user study to evaluate the effectiveness of physically active distractions, mentally active distractions, and passive observations have on pain relief using ChronicVR with 14 chronic pain patients. The results showed that the decreases in perceived pain were higher for active attention diversion content, but the decreases were not significant. Active attention-diversion was most effective while patients were actively engaged with the content, and the pain ratings reverted once they had taken off the headset and disengaged from the content. The results are consistent with other findings. However, decreases in pain in passive observation content persisted after the VR session had ended. Pain ratings when using passive observation content decreased further after the session was over, possibly due to continued relaxation from the content. Between physically active and mentally active distraction, the results were similar for the 10-minute sessions in the user study. However, longer session times may see pain ratings in physically active content increase as patients become tired. Longitudinal exposure to physically active content should be explored in future work. Future designs of VR games and other content targeting chronic pain management should not discount any of physical, mental, or passive content, but instead, work to bring them all together into a cohesive and thoroughly engaging experience where patients can forget about their pain.

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