LumaPath: An Immersive Virtual Reality Game for Encouraging Physical Activity for Senior Arthritis Patients

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Abstract. Arthritis occurs typically in the senior populations which involves stiff and painful joints. The prevalence of arthritis in the U.S. is 20% and in Canada is 15.8% for 4.3 million, and it decreases the patients' joint movement and physical activity to a severe degree. Even worse, more than half of the patients do not receive any treatment at all. Studies have shown that physical exercise or movement of the affected joint can noticeably improve long-term pain relief. In general, studies have shown that arthritis patients' movement of the affected joint implies physical activity. However, very few commercial games or research prototypes have been specially designed for arthritis population for promoting activities and their Range of Motion (RoM). Therefore, we created an immersive VR game named *LumaPath*. Meanwhile, we conducted a pilot study with five senior arthritis patients to evaluate their experience and assess *LumaPath*, and twenty-three healthy participants among which there are three senior participants. Overall, the study results showed that *LumaPath* had great potential as a gamified tool to motivate senior adults to stay physically active. Furthermore, we discovered that patients' limited physical movement and RoM, and the age were significant factors affecting their gaming experience, interactions and how to execute certain physical movements.

Keywords: Virtual reality · Arthritis patients · Range of Motion · Physical activity · Game design · Senior adults

1 Introduction

Arthritis is a term often used to describe a disorder that involves stiff and painful joints and decreases the Range of Motion (RoM) of the joints. There are many kinds of arthritis and the two most common forms are osteoarthritis arthritis (OA) and rheumatoid arthritis (RA). Osteoarthritis (OA) usually happens in the senior population, and can affect fingers, knees, and hips. Rheumatoid arthritis (RA) is an autoimmune disorder in about 0.24% of the population and often affects the hands and feet [1, 2]. In the U.S., 20% of senior adults have some kind of doctor-diagnosed arthritis [3]. In Canada, over 4.6 million Canadian adults (one in six Canadians aged 15 years and older) report having arthritis, and most of those patients (67%) are over 55 years old. In China, more than one billion people are arthritis patients and less than half get treatment [4]. Arthritis becomes a severe health condition that affects the senior population's Quality of Life (QoL).

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In general, studies have shown that physical exercise or movement of the affected joint can noticeably improve long-term pain relief [5]. Furthermore, performing exercises of the arthritic joint are encouraged to maintain the health of the particular joint, the overall body of the person, and delay the need for surgical intervention in advanced cases [5]. Regular and moderate activity is one of the best ways to ease the pain, increase mobility, and overcome the limitations of arthritis [4, 5]. That said, it is possible to damage affected joints by overuse. Taking exercise of the arthritic joint is encouraged to maintain the health of the particular joint and the overall body of the arthritic person. However, their hurt arthritic joints and painful experience become obstacles for them to maintain a healthy physical activity level, let alone to keep a sustainable exercise. Many approaches are recommended to elderly patients for promoting their physical activity, such as general physical exercise, Yoga, Pilates, tai-chi, therapeutic rehab with physiotherapists, playing sports or digital games, etc.

Immersive VR is a computer technology and 3-dimensional (3D) environment of high immersion and interactivity, presence, and sense of body ownership. VR is a quickly emerging technology that has been shown to help motivate physical activity, especially forms of rehabilitation or chronic disease and pain management. Through the VR environment, a user can live, act or interact in a virtual world which simulates the reality. Interaction with the environment and presentation of the world is achieved using assistive devices of a Head-Mounted Display (HMD), biosensors, controllers and other devices. From previous studies that had done with pain patients for pain management and rehab exercise purposes, VR approach showed a significantly higher level of impact at patients' pain levels compared to both of the traditional management approach and game approach [6, 7].

Moreover, scientific experiments found that the sensorimotor experiences and tasks created in VR games enhanced participants' sense of agency and task performances compared to doing the same tasks with PC display control group. Therefore, VR leads to great promise in creating systematic human testing and treatment environments compared to traditional management, where virtual representations of real environments can be precisely controlled and guided according to therapy needs. Furthermore, game mechanics have been demonstrated to generate greater motivation for adults when using VR environment. For instance, the ease of use and external motivations created by its game design made Wii Sports quite popular with older adults. Retirement community members in Lincolnshire, England, for example, with an average age of 77, were actively using Wii Sports not only to have fun, but to be physically active while socially engaged with their peers [8].

Therefore, the goals of this research were to investigate elderly arthritis patients' experience and feedback on *LumaPath*, especially how they felt about the difficulty of the game interactions and the ease of control. Furthermore, we would like to study how effective *LumaPath* is for promoting arthritis patients' physical activity and RoM in VR and explore what are the potential factors that can affect one's movement. Here, we designed and created an immersive VR game named *LumaPath* to promote arthritis patients' physical activity and RoM. Meanwhile, we conducted a pilot study with 5 senior arthritis patients to evaluate their experience and assess *LumaPath*, and 23 healthy participants among which there were three senior participants (here, senior participants meant adults who are older than 50 years old). Overall, the study results

showed that *LumaPath* had great potential as a gamified tool to motivate senior adults to stay physically active. During the design and testing processes, the limitations of senior adults emerged as a significant factor since it can fundamentally affect the way these senior patients interact with the VR environment. In this paper, we introduce the background of this research, the VR game tasks, study methodologies and results, as well as our discussions.

2 Related Work

Keeping the body physically and mentally active is important for a healthier Quality of Life (QoL). As a person ages, this may become more challenging, let alone for arthritis patients. For instance, changes in motor, cognitive and psychological skills will affect a person's perception and visual abilities, which are the common aspects of the aging process [3, 10]. Moreover, activities that need physical dexterity – like quickly pressing buttons on a controller or reacting to fast visual cues – might become more difficult to perform by the senior populations [17]. Memory, especially short-term memory, and attention are also profoundly affected. Aging changes not only affect how an individual uses VR controllers, but also affects how they learn the conventions inside a game. Such limitations must be considered when designing virtual environments, since they can completely change how this demographic will interact with the digital systems compared to a younger or healthier population. Therefore, in this section, we review literature which discusses how the senior population or patient groups would interact with Virtual Environments (VE) or play games and how it can benefit the elderly group of people or how the games motivate them to have more physical activities, so their findings could shed lights on our research.

2.1 Games, Virtual Environments and the Senior Population

Many studies have shown the positive effects of interacting with VE or playing games for older adults' health, not only physically, but also mentally. As mentioned in a study [9], the repetitiveness of games that has players quickly reacting to visual and auditory cues for long periods of time while mastering a particular skill in the virtual environment can, for example, improve the motor coordination of older adults. These VEs can be fun and provide mental stimuli for older adults, heightening their self-esteem through game rewards, providing constant positive feedback and a sense of mastery. Researchers [6] found that participants who played Super Tetris 5 h a week for 5 weeks demonstrated a significant improvement in study tasks' reaction. Furthermore, the participants also reported higher self-esteem and emotional well-being ratings. Benefits such as these can happen even in situations where players have moderate physical and mental limitations.

To counter the aging-related speech processing ability decline, Miller et al. developed *HiFi* [12] – a game to boost the functions of the aging brain. In their study, they recruited ninety-five healthy participants whose average age was 80 were split into the gaming group, the PC lecture group, and the control group. In the game group, participants played the game for an hour each day for 8 weeks, while the second group

spent the same time watching lectures on their computers. The third group didn't change their routines. The group that played games increased their scores on a standardized test of memory and attention by an average of 50% more points compared to the other two groups. According to the researchers, this improvement could be compared to the performance of people who are 10 years younger than them.

Some studies have also shown that VE or VR can be more entertaining than the traditional therapy approach. For instance, in a feasibility study [14], the researchers aimed at testing a low-cost system using Kinect for rehabilitation of the stroke survivors who had an impaired upper limb. The authors developed the game in conjunction with a physical therapist team. In this case study, a forty-six years old stroke survivor played the game for ten days, in which she was required to move her impaired arm by sliding it on top of a transparent screen. In the post-test survey, the participant acknowledges interest in using a similar system at home every day.

Muñoz et al. developed a *Microsoft Kinect* game prototype called *Exerpong* for senior adults, which requires the player to use a paddle to hit the ball using their body. They implemented real-time adaptations to the game task according to the player's HR level [9], so that the game difficulty and exertion level are changed accordingly. Results showed that the seniors increased 40% the time they spent in the recommended levels of exertion compared with conventional training. However, this was a full body movement and it was not customized for arthritis patients.

2.2 Gaming for More Physical Activity

Wii Sports is a Nintendo game that was released in 2006 [20]. Players use motion controllers to interact with a collection of games based on 5 different sports: tennis, bowling, golf, boxing and baseball. The ease of use and the external motivations provided by the game rewards made Wii Sports quite popular among older adult players. For instance, as mentioned in IJsselsteijn's research [9], the retirement community members in Lincolnshire, England, whose average age were 77, were actively using Wii Sports not only to have fun, but also to engage in the physical activities and social interactions with their peers.

In 2007, Nintendo released the next iteration of "games to play by moving" with the Wii Fit [19]. Wii Fit's game experience was very different compared to Wii Sports, because it included the new Wii Balance Board besides the controllers. This new input method allowed the players to use their weight to balance, and their feet positions to control the game world. Exercise using the Wii Fit was proved to be feasible, safe and efficacious according to a few studies. In a study with 36 women aged 56 and above [15], Wii Fit was tested in the experimental group as an alternative to traditional balance exercises to decrease the risk and fear of fall. Participants in the experimental group ended up requiring less supervision from their therapists or assistants initially and later were also able to perform their exercises more independently compared with the control group. The positive result happened possibly because the game system could provide real-time feedback regarding the players' performance. In another study conducted by a therapist [4], they recruited 32 participants aged between 65 and 80 using Wii Fit three times a week for eight weeks. Results showed that the participants' balance ability improved considerably compared to the control group which did not

have exercise at all for eight weeks. In Tsuda's research [16] with 16 hospitalized senior patients (aged 60 years and above) who had hematologic malignancies, the participants were asked to exercise for 20 min a day from the start of their chemotherapy until hospital discharge using the Wii Fit, five times a week. The adherence rate was 66.5% and most of them reported enjoy playing the game.

Nintendo Wii's Big Brain Academy had also been investigated by a group of researchers [1]. They recruited 78 adults between 50 and 71 years old, and asked them to complete 20 sessions of one-hour training game over one month. In the following month, the participants completed the same amount of time playing the game, but this time they were asked to read articles on 4 different topics. Cognitive and perceptual speed were tested before and after each month of training, along with a knowledge test. Results showed a clear increase in performance with the group who had Wii games, but less improvement on the knowledge tests, and practice-related improvements. Participants said they enjoyed the game activities more than the reading sessions, and 40% of the participants reported a potential interest in continuing to play after the study was over.

In a recent study, the researchers evaluated the actual and perceived exertion of various commercial games through measuring the ten participants' Max HR, Self-reported Borg score, enjoyment and time spent in each game [10]. The VR games included *Fruit Ninja*, *Holopoint*, *Hot Squat*, and *Portal Stories*. Results found that different games brought participants various levels of actual and perceived exertion. For instance, *Hot Squat* had a heavy perceived exertion and *Holopoint* had a moderate level of exertion, while *Fruit Ninja* had a light exercise level and *Portal Stories* brought the lowest exertion. Furthermore, no correlation was found between participants' enjoyment level of the games and their exertion levels. The authors draw the conclusion that these VR games could provide exertion. But the result suggested that an engaging game can have a lower level of perceived exertion compared to the actual exertion. This result indicates that VR games have the potential to motivate players' physical activity.

However, none of the games tested in Yoo et al.'s research designed specifically for increasing arthritis patients' exertion. Neither did these game considered the concerns of how the senior population would interact with the game control or inputs. Therefore, we designed an immersive VR game combining specific motor tasks for senior upper limb arthritis patients and evaluated its effectiveness and patients' feedback.

3 Methodology

3.1 Study Goals

The goals of this study were threefold. Firstly, we'd like to understand if the VR game and two movement interventions/tasks designed in *LumaPath* would affect participants' physical activities and exertion. Secondly, we'd like to understand what are the player's thoughts and experience on this VR game from various aspects, and how they would interact with the VE. Lastly, how arthritis patients and healthy subjects would perform differently and what might be the possible differences between young participants versus seniors.

3.2 Procedures

Participants. The inclusion criteria are either (1) healthy adults who are older than 19 years old for the control group; or (2) arthritis patients who have arthritis and are older than 19 years old for the experimental group. Twenty-eight people participated in this study (Female = 15, Male = 13, M = 37.63, SD = 18.89), and their age ranging from 20 to 79. Eight of the twenty-eight were senior adults (>50 years old), and five were arthritis participants out of these senior adults with limitations in physical movement (3 females, mean = 61.5, SD = 11.01). The participants were recruited via the convenient sampling approach.

The Game. *Lumapath* is a VR system that uses HTC VIVE VR Head-Mounted Display (HMD) [11], a stereoscopic VR headset that comes with handheld controllers, to track the user's position in space, including their arm and hand gestures. The HMD is 1080 × 1200 pixels per eye (2160 × 1200 pixels combined), 90 Hz refresh rate and 110 degrees field of view, and its weight is 470 grams. The system is designed to create a safe virtual environment for users to be immersed in and work on their RoM. "Safe" is defined here as a VE that takes the target player's physical limitations in consideration to create an experience that will not motivate players to perform possible dangerous physical movements. *Lumapath* was created to motivate people with arthritis to physically move as much as possible and focused on providing the player with motion gestures which allow the upper limb joints movement (wrists, elbows, and shoulders) to have a larger RoM. In *Lumapath*, the player can drive a ship and can travel to different planets in search of rare plants and life forms using the motion controllers. Figure 1 shows the screen grab of the Cactus Planet and the look inside the player's ship, and Fig. 2 was a picture of one participant playing the game.

Fig. 1. Screenshots of *LumaPath* game scene: the cactus world (left) and the living room inside the ship (right)

In *LumaPath*, two different types of motion tasks were included as the interventions for promoting the patients' activities, as demonstrated in Fig. 3. The left one is originated from Tai-chi, to draw lines with different shapes, which requires the participants to use both controllers to match the VR task, move at a slow speed according to the performances. While the second task (the right image in Fig. 3) is "connecting the dots" in 3D space as inspired by Yoga and Pilates movement – reaching and holding

positions. The images in Fig. 4 illustrates the controllers' visual look in *LumaPath*, and how the players can teleport from one location to another using the controller in VR beside physical movement.

Fig. 2. The study setup, one patient with the HTC VIVE HMD and the handheld motion controllers.

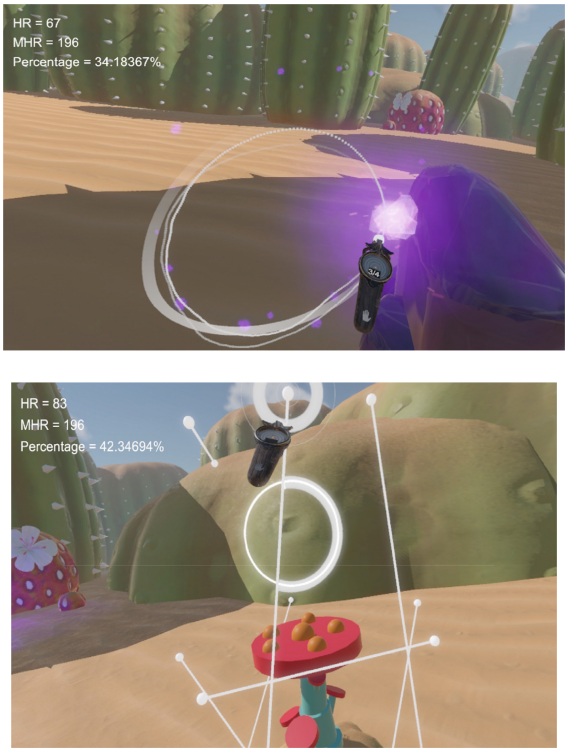

Fig. 3. The two intervention tasks in *LumaPath*: (left) following the tracks and drawing circles or irregular shapes (i.e. taichi gesture); (right) connecting different pairs of dots into lines (i.e. stretching gesture).

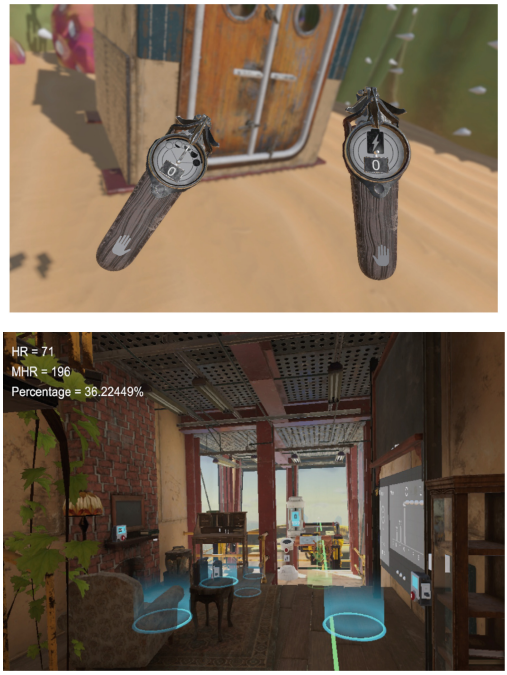

Fig. 4. Left, the two controllers used in *LumaPath* to perform physical activities (game actions) in VR; Right, participants use teleporting to move among all teleport spots to move in a larger range (they normally walk to reach objects in shorter distances).

Procedures. This was a mixed-method study design with both quantitative measurement and a qualitative semi-structured interview which was audiotaped after obtaining consent from the participant. First, the participants were given 20 min to free-explore in this game after a 10-min tutorial, during which period their real-time Heart Rate Variation (HRV) data were collected. After the test, the participants were asked to fill in the Rating of Perceived Exertion (RPE) Scale questionnaire. At the end of the study, the participants had a short semi-structured interview with the researchers about their thoughts, experience and feelings in playing *LumaPath*. The entire study takes 40–50 min for each participant.

3.3 Instrument

HTC VIVE VR headset was used to provide the immersive experience and motion tracking, and Scosche's Rhythm + Heart Rate Monitor Armband [12] that participants wore on their forearm during the VR study.

3.4 Measurement

The measurements include capturing real-time Heart Rate (HR) and Heart Rate Variability (HRV) data. As shown in Table 1, participants' perceived physical exertion was

documented using The Borg Rating of Perceived Exertion (RPE) questionnaire [13] and we adopted Yoo et al.'s [10] mapping to compare HR to Borg Score in the result session. The RPE is a subjective way of measuring one's physical activity intensity level. The results from the RPE questionnaire were compared to the Heart Rate data collected afterward. In addition, a semi-structured interview was conducted with each participant after the intervention regarding their gaming experience, ease of control, the interactions with the game, and their feelings about their activity level. During the interview, participants took notes of the conversation and the transcribed the interviews after the study. The researchers coded the interview transcription according to the question categories (game exploration and aesthetics, instructions, motion sickness of VR environment, input and interactions, and the session length - 'dosage') and then summarized the results to different themes.

Table 1. Mapping of intensity: borg rating of perceived exertion scale and its mapping to as %-age of max HR.

Intensity	Max HR %	Borg score
No exertion	20–39	6–7
Very light	40–59	8–10
Light	60–69	11–12
Moderate	70–79	13–14
Heavy	80–89	15–16
Very heavy	90–99	17–18
Maximal	100	19–20

4 Result and Discussion

4.1 Physical Activity and Exertion

Four out of the healthy subjects' HR data was lost because of the hardware malfunction. For the HR and HRV data, we found there was an increase in HRV as participant's age increases. Patients reported perceived physical exertion rated by from the Borg Rating of Perceived Exertion Scale is lower than their real exertion collected from the wearable HR watch (M = 82.25, SD = 7.05). This indicated that our VR game was able to immerse and distract the patients from the amount of physical activity without noticing that they were already in an aerobic state. Overall, all participants had their average HR of above or close to their 50% HR thresholds value (threshold values are the maximum HR they experienced). Ten of the twenty-four participants had an average HR above their 50% threshold of max HR. This means that on average they were in a light aerobic state while playing *Lumapath*. Six participants had their HR go above their 60% threshold at least once during the game. One participant had their HR go above their 70% threshold once during gameplay. It's also important to note that all senior participants above 40 years of age had their average HR above or very close to their 50% threshold (also shown in Fig. 5).

As for the RPE data, nine participants had a perceived exertion lower than their actual average HR. Four participants had a perceived exertion of only 1 or 2 BPM higher than their average HR. The other eleven participants had a perceived exertion of 5 or more BPM compared to their average HR. If comparing the perceived exertion to the lowest and highest HR (Fig. 5 Blue area) of participants, only 6 participants had a perceived HR above that area. Ten participants were above their 50% of max HR threshold. They reported that *Lumapath* was able to immerse players enough so that they were distracted from the amount of physical activity they were performing. No patterns were found regarding participants' gender, experience with digital games or physical exercises.

4.2 Qualitative Interview Analysis

From the qualitative interview, in general, we found out patients liked the immersion side of our VR game and the overall gameplay design. The interview results were coded by the researchers and then categorized into below themes:

Game Exploration and Aesthetics. Overall, the environments were interesting and participants wanted to look around and see new things. Participants reported that they "loved" exploring the environments and were visibly enthusiastic. Exploring the environment was the most mentioned aspect of the experience that participants said they liked most. Based on participants' reports, aesthetic immersion was important to complement gameplay mechanism, and to give it more meaning and context. As mentioned by the participants, "… I really liked the environments. I wish I could have walked a bit further cause at some point there was a wall." (09) "… the space is quite hard to see in real life, the desert and the cactus." (13).

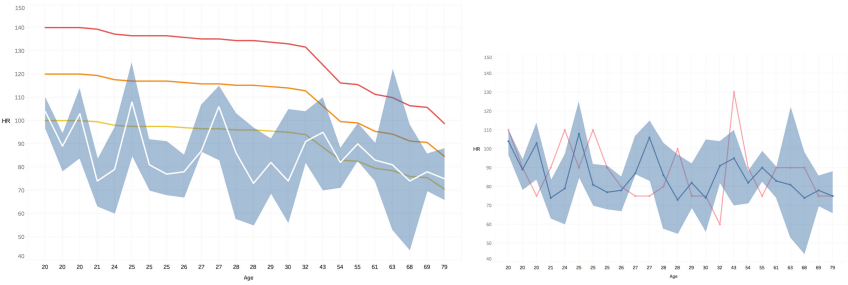

Fig. 5. Left: participant's HR vs. max HR thresholds (50% yellow line, 60% orange line and 70% red line. Right: perceived exertion (pink line) vs. average HR (blue line) vs. lowest and highest HR (blue area) of 24 participants. (Color figure online)

Exploration also appeared to be a crucial aspect that kept some of the participants from feeling embarrassed or apologetic when they didn't know how something worked since they felt they were discovering interactions just like they were discovering new areas while they played. "I have control issues so not having any direction of what the

task was or not knowing what I was supposed to be doing, but, like, I didn't mind like, trying to figure it out so much, just exploring the environment, yeah." (14).

One of the main "aha" moments of the experience was when participants were in the cacti planet and then they saw the ship for the first time. Players would instantly start either mentioning how cool it was or questioning themselves if that was the ship they came from. It motivated most of the participants to teleport closer, or to explore more of the environment. For instance, "I liked how you are in the ship and it is up in the air and then you teleport down and you can see the whole thing." (06) "I like the exploring part, just like looking around, like looking up and seeing the ship, 'ok I guess this is my ship'. I liked that a lot." (09) "… the environments were really cool. I think my favorite part was I like looking at all the environment like, 360 looking around. And then I didn't even notice the ship was up in the air at one point and that was really cool too." (12).

Discomfort or Motion Sickness. No one reported motion sickness during the study, even participants who initially reported that they might be sensitive to the issue. From the participants' replies, having static, clear geometric shapes around the player helped them feel grounded. They have also suggested that the environment animations should be kept to a minimum amount since it can trick the brain into thinking the body is moving, even though the player might be physically still. Furthermore, having enough contrast in color values and hue provided the players with a clear visual reference of the space around them. Any avatar related movement that happens in the VE should be controlled or at least expected by the player.

However, over half of the participants did mention that the HMD was heavy and it was a possible cause for not seeing themselves playing the game for a longer period of time. Below are some participants' quotes. "Only towards the end. It was not motion sickness, but my head felt a little heavy, I felt something in the back of the head, I was getting a little tired. (01) "… no, I only feel the headset is, the headset is heavy and my eyes are, not the eye, the forehead is not comfortable because I make it tight, so after I take it out I have to massage it." (04) "… no, and I do have a very sensitive stomach but I don't think I ever felt that." (21).

Instructions. Almost all participants would like more instructions to be introduced in the VR game world, especially the seniors. The older participants would prefer being guided for longer, so they felt more familiar with the game before having to figure stuff out on their own, and they would frequently report feeling lost and ashamed of not knowing what to do next. "… I think you noticed I was just like switching places, and then I was like, what to do, what is happening, lack of instructions." (08) "… the tutorials are fine, but when I start to walk on my, own I don't know where I'm going to." (11) "… there were only a few things that were harder to understand like what to do in some areas, where to go when there were so many options like in the house." (15) "… It took a little while to discover that there were little hints to do things. I probably never got the feel of which buttons did what, although I expect that eventually that would have occurred to me." (21) It also seemed that some participants didn't mind feeling lost because of the sense of exploration that the environment created. Discovering how the game worked seemed to players like it was part of their exploration.

Input Simplicity. A lot of participants mentioned they would prefer if the inputs required to interact with the game world were simpler somehow. Memorizing the actions to the buttons sometimes was a problem for the older participants and patients comparing to non-patients.

Moreover, the tactile feedback of the controllers also helped players with immersion and functioned as cues for some of the interactions. For example, P5 said that "… it's really cool… I'm holding something that I can create, like Iron Man like I don't know, virtual stuff… that was really cool." P11 mentioned that "… I think I really like the vibration because it feels like touching something, holding something… the only thing I feel is real because it's in my hand."

The "Dosage": Session Length. Overall, the participants stayed in the virtual environment for approximately 20 min. In the end, many would mention that the HMD was heavy, but wouldn't mention standing for the last 20 min as a problem. Based on the perceived exertion, participants felt it was, on average, light activity. This shows that the game managed to keep participants immersed enough to not notice the fatigue of standing and moving their arms around for at least 20 min. Participant 14 had a sore hand before the gameplay session started, but still managed to play the game for 31 min without mentioning her hand once. Like P14 reported, "… my hand was hurting a bit at the beginning but the experience did not make it worse. It didn't make it worse, it's just tingling, so I don't know if it's from vibrating… it's not unpleasant I can feel I did something. The responsiveness and the light touch on the controllers wasn't a challenge for me."

In general, most of the participants enjoyed playing the game. The mechanics seemed to be rewarding, also challenging enough to make players feel a sense of achievement and progress. Using the participants' feedback as references, "… I liked realizing I learned something. It was an accomplishment." (07) "In the past, I actually only experienced very simple things like when you are under the sea or flying in the sky. You can change your direction and see different things. But this time I actually can control more. It's cool to change the mode and do something I want to, and when I succeed, I feel a sense of achievement." (11) We have voiced participants' interests in seeing more of the game world and experience more tasks, which would result in longer play time. This is particularly important since the physical benefits or behavior changes of interacting with the game could only be seen in more frequent and long-term use.

5 Conclusion

VR shows great promise in creating testing and treatment environments where virtual representations can be precisely controlled and guided according to therapy needs. Therefore, the goal of this pilot study was to explore how arthritis pain patients and normal senior adults might like or dislike our VR environment and how effective it was at promoting physical activity. The HRV and RPE results confirmed that the initial difficulty presented by the tasks was enough to get senior adults into an aerobic state. One of the main objectives of *LumaPath* was to motivate the participants to work on

their joint RoM movement. Based on the way participants interact with the game, it was clear that they were not only stretching their upper body, but also working on their balance to compensate for the upper body movements. No participant reported any problems during their gameplay session, and none were observed. Even when they mentioned some kind of physical limitation, the system never put them in actual danger of hurting themselves. Therefore, the objective of creating a safe VE appears to have succeeded in this test so far. However, the main question is if the system would be able to adjust its difficulty to increase the average HR of not only senior adults, but also of younger arthritis patients' activity level.

To conclude, participants not only enjoyed the VR experience and being immersed in *Lumapath*'s game world, no matter of their age, but most of them were also in an aerobic state according to their HRV data. This supports the idea that designing a VR system that motivates physical movement and increases players QoL is possible, particularly when care is taken to address all possible needs of the target player group. However, it's important to consider some of the possible limitations of this study. On average, participants played *Lumapath* for 20–30 min, including the tutorial. This can be a problem since participants need to learn many new things to better interact and explore this game, such as how to use the hardware to interact with more objects, and several other different rules and mechanics – all before even starting to freely experience the game. Because of the time limitation and the participants spent a majority of the testing time in the tutorial, the experience of the participants in the first 10 min could greatly vary, compared to the experience they could have in the last 10 min of the gameplay session. Therefore, in the future, a longitudinal test would be important to measure the efficiency of all the implemented mechanics. Patients should ideally interact with the game in their own home, so that the game's ability to keep players interested could be really tested over time. We understand that there is room for the game to be improved from participants' semi-structured interviews, so constant iterations are needed and the design process would be beneficial in the longitudinal study too.

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References

1. March, L., et al.: Burden of disability due to musculoskeletal (MSK) disorders. Best Pract. Res. Clin. Rheumatol. **28**(3), 353–366 (2014)
2. Nancy Garrick, D.D.: Arthritis and rheumatic diseases. National Institute of Arthritis and Musculoskeletal and Skin Diseases 20 April 2017. https://www.niams.nih.gov/health-topics/arthritis-and-rheumatic-diseases. Accessed 15 Jan 2019
3. Arthritis-Related Statistics: Data and Statistics: Arthritis: CDC. https://www.cdc.gov/arthritis/data_statistics/arthritis-related-stats.htm. Accessed 15 Jan 2019
4. Bhatia, D., Bejarano, T., Novo, M.: Current interventions in the management of knee osteoarthritis. J. Pharm. Bioallied Sci. **5**(1), 30–38 (2013)

5. Fransen, M., Crosbie, J., Edmonds, J.: Physical therapy is effective for patients with osteoarthritis of the knee: a randomized controlled clinical trial. J. Rheumatol. **28**(1), 156–164 (2001)
6. Gromala, D., Tong, X., Choo, A., Karamnejad, M., Shaw, C.D.: The virtual meditative walk: virtual reality therapy for chronic pain management. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, New York, NY, USA, pp. 521–524 (2015)
7. Gromala, D., Tong, X., Shaw, C., Amin, A., Ulas, S., Ramsay, G.: Mobius Floe: an immersive virtual reality game for pain distraction. Electron. Imaging **2016**(4), 1–5 (2016)
8. Ijsselsteijn, W., Nap, H.H., de Kort, Y., Poels, K.: Digital game design for elderly users. In: Proceedings of the 2007 Conference on Future Play, New York, NY, USA, pp. 17–22 (2007)
9. Muñoz, J.E., Cameirão, M., Bermúdez i Badia, S., Gouveia, E.R.: Closing the loop in exergaming - health benefits of biocybernetic adaptation in senior adults. In: Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play, New York, NY, USA, pp. 329–339 (2018)
10. Yoo, S., Ackad, C., Heywood, T., Kay, J.: Evaluating the actual and perceived exertion provided by virtual reality games. In: Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems, New York, NY, USA, pp. 3050–3057 (2017)
11. VIVE™: Discover Virtual Reality Beyond Imagination. https://www.vive.com/us/. Accessed 15 Jan 2019
12. Heart Rate Monitor Armband: Rhythm+ ™. https://www.scosche.com/rhythm-plus-heart-rate-monitor-armband. Accessed 15 Jan 2019
13. Williams, N.: The Borg Rating of Perceived Exertion (RPE) scale. Occup. Med. **67**(5), 404–405 (2017)