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24 participants from the university and one expert took part in the evaluation. All participants participated in four conditions to measure how CD gain and body representation affect range of motion, and embodiment.
The expert found the concept interesting in several forms of clinical use, though the experiment found no increase in range of motion of spinal rotation but did in hip rotation. It was seen that the visual-proprioceptive incongruency associated with scaling was not present when body representation was added alongside the scaling.
In the future it would be interesting to explore this aspect further, and also see how this can affect chronic low back pain patients.

Measuring the Effect of Control-Display Gain and Virtual Body Representation in Range of Motion Exercises

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ABSTRACT

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24 participants from the university and one expert took part in the evaluation. All participants participated in four conditions to measure how CD gain and body representation affect range of motion, and embodiment.

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KEYWORDS

rehabilitation, chronic low back pain, fear-avoidance, virtual reality, control-display gain, body representation

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1 INTRODUCTION

Low back pain is a commonly occurring symptom affecting people of all ages and social backgrounds. In recent decades it has become the leading cause of disability worldwide [7]. Chronic low back pain (CLBP) is characterised by having the pain experience last from several weeks up to years, and results in decreased quality of life and decreased physical activity in those who are affected [19]. Patients with CLBP are prone to developing fear-induced movement avoidance, or kinesiophobia, for fear of pain or (re)injury [21].

Emerging evidence suggests that virtual reality (VR) is a feasible treatment option for chronic pain and kinesiophobia in several ways [20]. VR enables us to modify variables that would be impossible to do outside a virtual environment. One example is changing Control-Display (CD) gains to provide modified visual feedback to the users. A gain of 1.5 would mean a head rotation of 30° would be displayed as a rotation of 45° to the user. Research shows that presence is highly dependent on body representation, which might help distract from the visual-proprioceptive incongruency and pain. On the contrary, it might bring attention to the incongruency as the sense of embodiment is heightened. To the best of our knowledge, the effect that these two concepts have on CLBP and each other, have not been thoroughly tested.

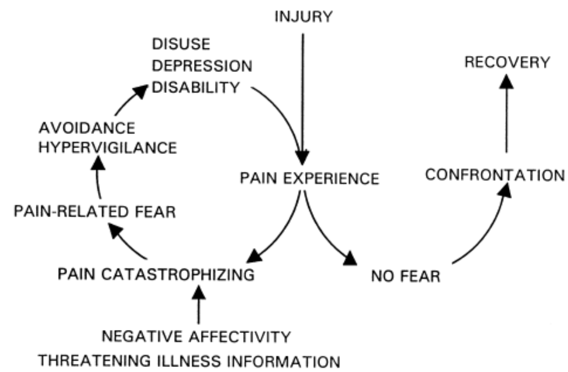

Figure 1: Fear-avoidance model

To test it, a 2x2 matrix repeated measures experiment has been designed. A virtual environment has been created to encourage spinal rotation, and the rotation in degrees of several tracker points is being measured. Additionally, body perception is measured.

Results showed that there was no significant difference over time in hip-to-back rotation, which might have been caused by increased rotation of the hip. It was seen, however, that the visual-proprioceptive incongruency related to altered CD gain was diminished when adding virtual body representation, which in theory could increase the just-noticeable difference in scaling found in state of the art papers.

2 RELATED WORKS

2.1 Virtual reality-rehabilitation

Fear-avoidance beliefs have been shown to be a factor in the development of chronicity. When people have a pain experience, they generally deal with it in two ways; avoidance of movement due to fear of said movement or confrontation of pain [6]. Avoidance can lead to worsening of the condition and physical health of the patient, therefore, confronting the pain is important for recovering. The full fear-avoidance model can be seen on figure 1. Therapy techniques commonly used in CLBP rehabilitation indicate that CLBP can be self-managed [22] and can be decreased if anxiety is decreased. These results have been mirrored in rehabilitation using VR.

Hoffman et al. [1] and Yelvar et al. [25] measured pain intensity in rehabilitation patients (n = 12, n = 44, respectively) using several

100mm visual analogue scales (VASs; a continuous line between two end points), while also measuring the physical capabilities of these patients between conventional and VR-therapy. The physical capabilities were measured with different therapeutic exercises such as measuring the full movement potential of their injured extremity in range of motion (ROM) exercises or Time-Up and Go test (TUG; time from seated position to walking three meters and back to seated position) and 6-Minute Walk Test (6MWT; distance walked over six minutes). Yelvar et al. also measured fear-avoidance using the TAMPA Kinesiophobia Scale (TKS). The results showed that pain intensity decreased from a mean of 48.17 (min: 36.33, max: 60) to a mean of 19.94 (min: 14.67, max: 25.2), while Yelvar et al. also reported a decrease from 43.72 to 29.56 on the TKS (the cut-off point normally being 37 [23]). 10 out of 12 patients exceeded or matched their control ROM in VR, while TUG was improved from 7.72 seconds to 5.25 and the 6MWT improved from 414.31 meters to 504.9 meters.

The pattern shown by Hoffman et al. and Yelvar et al. indicates that the functional capabilites of CLBP patients are limited by their fear (in line with the theory of fear-avoidance) and that this fear can be alleviated using VR-therapy, making it a useful tool for rehabilitation. The research by Hoffman et al. indicates that higher presence supports this effect, and this presence can be manipulated by increasing the level of immersion through interactivity, narrative [10], and having a virtual body [18]. Crombez et al. [5] shows that CLBP patients tend to not generalise the effect of exposure to other contexts than the exposure was performed, adverse to a major goal of rehabilitation [20], so virtual environments can be created to support this generalisation.

2.2 Gamifying therapy

One draw of including virtual reality in therapy is the aspect of gamification. Using a game makes it possible to create an immersive experience that can potentially lower pain experience by having the brain focus on different aspects of the game, and in theory the resulting increase in cognitive load will mean the participant will not focus on the pain as much. This means that their attention is being used for the game rather than for processing pain. Most importantly, gamification can lead to greater patient satisfaction and good user experience, which in turn can increase patient adherence to treatment. This is important, as this would mean that therapy could be moved to the patients' home, becoming self-administered and cost- and time-effective [2, 13].

One study, conducted with 99 CLBP patients, all of whom were military personnel, used an interactive VR gaming intervention to check how participants reacted to such a system. Findings included above moderate treatment acceptability, and overall positive interest in the intervention. 75% of participants agreed that it would be an improvement to the intervention if it had a military setting [15]. Another paper corroborates this, as it seems important to place the users in an environment that matches their day-to-day activities [20]. The paper argues that even though placing a participant outside of their normal environment may provide enough distraction, they will not associate movements and activities in other conditions to those that they carry out daily [5].

2.3 Modulation of movement in rehabilitation

Other research has taken another direction in VR-rehabilitation, and looked on how VR directly can affect the movement of the user. As indicated in subsection 2.1, the functional capabilities of the user could be held back psychologically, and not by physical abilities; therefore, changing the control-display (CD) gain, could increase their movements. CD gain in VR is the ratio between a user's movements and their visual feedback, meaning that a CD gain <1 will show lesser movement in VR than the physical movement. This concept is illustrated in figure 2.

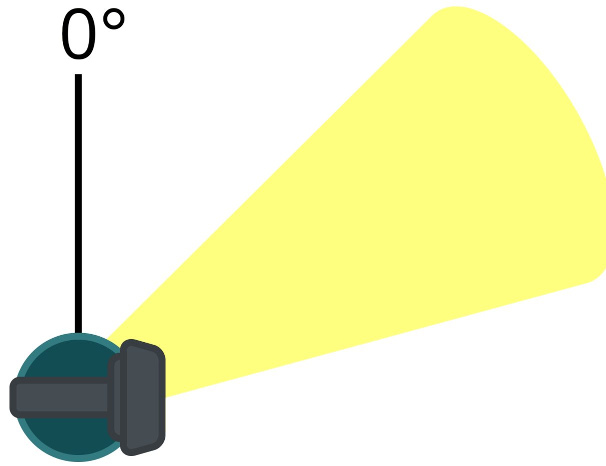

Figure 2: The yellow cone illustrates the visual feedback from the head-mounted display, and shows the visual feedback altered with CD gain of 0.66.

Results from a repeated-measures experiment by Harvie et al. [8] showed that a neck rotation in VR (only tracking head-motion, with no mention of the amount of body representation) with a CD gain of 0.8 made pain occur at a 6% greater rotation than the baseline, indicating that this hypothesis is correct. Similarly, Bolte et al. increased the proportion of back rotation to full body rotation by 4.1% for CLBP patients by penalising the hip and neck rotations with a gain of 0.5, meaning that greater back rotation was necessary to reach pre-defined angles (between 0°and 90°). They did not provide any representation of the body in VR. They also found that CLBP patients reported a significantly lower presence than the healthy participants (r = 0.36).

Several papers measured the just-noticeable difference (JND) of CD gain of a movement, to encourage patients to perform therapeutic exercises without fear-avoidance beliefs interfering. Harvie et al. additionally found the just-noticeable difference (JND) of a CD gain of a movement of neck pain patients (n = 24) to be 0.73. This was found using the forced-choice paradigm, though it differed from other experiments in the same domain, as they offered three alternatives and asked whether the virtual movement was faster, slower, or equal to the physical movement, and had no concrete detection threshold.

Roosink et al. [16] (who had done previous testing on healthy participants [17]) and Chen et al. [4] measured the JND in scaling flexion (of back) and rotation (of neck) movements respectively in VR of symptomatic participants (n = 15 and 9, respectively) and asymptomatic participants (n = 15 and 10, respectively) using two-alternative forced-choice, asking either if a virtual movement was greater or smaller than a physical movement, or if there was a difference between two consecutive movements with a detection threshold of 0.25 probability of detection. While Chen et al. measured CD gains between 0.7 and 1.5 in 0.1 increments, Roosink et al. used five CD gains equally spaced between two extremes (0.667 and 1.5) and a CD gain of 1. Both papers measured the degrees of movement in some form of therapeutic exercise; either an exercise with pre-defined angle-goals or in a ROM exercise. Both papers tracked the movements of the entire body, though only Roosink et al. used a virtual (complete) body. In addition, Roosink et al. measured immersion using a questionnaire. The results show that the JND CD gain of a movement for symptomatic patients is between 0.93 and 0.95, quite a bit different than the findings of Harvie et al. which might be explained by the difference in methods.

When modulating the visual feedback from a head-mounted display (HMD), an incongruency between motor feedback and visual feedback is created, which affects the embodiment. According to Kilten et al. [11] this sense of embodiment is supported by three central components: *sense of self-location* is the feeling of being located in one's own body; *sense of agency* is the feeling of having complete motor control of said body; *sense of body ownership* is the feeling of owning a perceived body. Westhoven et al. [24] measured the effect of CD gains of 0.9 and 1.1 on presence using the Igroup Presence Questionnaire (IPQ) for healthy participants, and concluded that presence is not affected. This is reflected by Roosink et al. who concluded that the immersion was generally great (+5 out of 7).

Since visual feedback is altered, it is important to consider that it might induce simulator sickness or otherwise affect presence in VR. Multiple studies confirm that movement scaling does not affect presence or induce more simulator sickness than unscaled VR [3, 9, 14, 24]. However, in order to be sure that this implementation and system falls in line with the literature, simulator sickness will be measured. Kim et al. designed a questionnaire specifically to be used with virtual reality, as some items on the Simulator Sickness Questionnaire are not relevant for VR. The resulting index was the Virtual Reality Sickness Questionnaire, designed for use for future VR projects. [12] As opposed to SSQ's three components, VRSQ is only composed of two: the oculomotor and and disorientation components, leaving out the nausea component as it did not contribute to motion sickness as much as the other components. In VRSQ, participants rate their symptoms on a 4-option Likert-scale, like in SSQ. The VRSQ measures the following 9 symptoms in participants: general discomfort, fatigue, eye strain, difficulty focusing, headache, fullness of the head, blurred vision, dizziness with the eyes closed and vertigo.

3 PRELIMINARY STUDY

To understand how to implement a solution to address this issue, an expert was consulted before designing the prototype. The expert consulted was a Master student in Clinical Science and Technology with a degree and work experience in physical therapy. An interview was conducted to understand what exercise to implement and how to do so.

It was determined to focus on a single, general movement, without any resistance or weight added to it, as weight would require therapist supervision.

4 METHODS

In order to measure the effect of scaling and virtual body representation on range of motion, a virtual reality system has been implemented. The prototype consists of a gamified range of motion (ROM) exercise that requires participants to perform spinal rotation movements to progress through the different conditions. The participants will be situated in a living room, where they will be sorting four fruits on a circular table. The setting of a living room was chosen in order to situate participants in an environment that resembles everyday surroundings. The setting can be seen on figure 3. The participants will be asked to pick up a fruit from the bowl in front of them and rotate as far to their left or right (depending on the fruit picked up) as possible and drop it. They will have to sort all four fruits (2 oranges and 2 apples) from the bowl. This activity will be performed six times per condition. Point values will be assigned to the participants' movements. The points will be based on the participants' hip and back rotation.

Figure 3: The living room setting used for this experiment.

The results of the participants' movements will be visualised by a small peg at the location the fruit was dropped on the table. There will be maximum of one peg present on each side of the table which will be replaced by new ones at the location of subsequent fruit drops. Moreover, the difference between the angle of the hip and back will be shown to them via an arc above the table. A green arc will follow the movement of the player, with its beginning at the angle of the hip and the end at the angle of the back showing their current rotation. Once a fruit is dropped, the green arc is saved as a blue arc remaining where the green arc was. A blue arc may be saved on each side to show previous rotations.

Figure 4: The placement of the trackers during the experiment.

Trackers will be placed on the participants in order to track movement data to later use for analysis. As the spinal rotation is the movement in focus, two trackers will be placed along the spine; one on the hip and one between the shoulder blades. Additionally, the rotation of the head-mounted display will also be measured. The precise tracker placements can be seen on figure 4.

As a baseline, the CD gain is 1 and there will be no body representation (referenced as BR on table 1), but these variables will be changed to see their effect on the independent variables. For this experiment, these conditions result in the 2x2 matrix seen on table 1.

CD Gain = 1	**CD Gain = 1 → 0.85 -0.03 increments**	
Baseline	Only scaling	**No BR**
Only BR	Scaling and BR	**BR**

Table 1: A matrix representing the conditions.

After each set of four fruits, the scaling will be increased by -0.03% until reaching a CD gain of 0.85. This CD gain is slightly higher than the just-noticeable differences normally identified in the state of the art, but through pilot testing it was determined that the total CD gain would be increased to see whether the scaling would be noticed, and whether noticing the scaling would interfere with the range of motion.

(a) The setup with body representation.

(b) The setup without body representation.

Figure 5: The two different settings for body representation.

Body representation might serve as a way to relate the movements more to one's own body, which in theory could go one of two ways: it could mean that the participants will not notice the visual-proprioceptive incongruency; or it could mean that the incongruency becomes more noticeable. The two settings for the body representation can be seen on figure 5. With body representation enabled, the user will have hands that react to button presses, stationary legs, and a torso that follows the motion of the trackers, as seen on figure 5a. Without body representation there will be no torso or legs, and the hand placement will only be represented by red dots, as seen on figure 5b.

All participants will go through four conditions in a within-subjects experimental design to see the effect of every combination of independent variables on the dependent variable. The alternative hypotheses are therefore:

> *"Decreasing control-display gain will have an effect on the amount of degrees of movement."*

and

> *"Adding a virtual reality body representation will have an effect on the amount of degrees of movement."*

Participants. The main, statistical experiment will be conducted with 24 healthy participants recruited from a university setting with many students, familiar with virtual reality systems, to see whether the system augments movement before using CLBP patients. In addition to this, the expert from the preliminary study will also be trying the system.

Measures. The Virtual Realty Sickness Questionnaire (VRSQ) will be used to measure whether the system induces any form of motion sickness. Participants will fill it out once pre-test, and once when they have tested with all four conditions on a 4-point Likert scale. During the test, after each of the first three conditions, a facilitator will ask whether the participant experiences the symptoms listed on VRSQ, and binary data will be logged. This is done in order to get an indication of where a possible increase in motion sickness might come from.

During each condition, the system will track the rotational movements of the participants in several different ways: the rotation of the head, back and hips; the difference between the head and the back, and back and hip rotations; the direction of the rotation; the participants' perceived rotation; the angle of rotation they experience in virtual reality; the amount of scaling currently applied. The main measurement will be the difference in rotation between the hip and the back.

Following the completion of the post-test VRSQ, participants will be asked to answer questions about the system, pertaining to body perception and aspects of gamification. The questions about body perception require participants to rank the conditions based on three factors: Which felt most natural, which represented their motion the best, and which represented their body the best. For the gamification aspects, participants will have to evaluate the usefulness of the score, the arc indicating the subjects' rotation and the score on a 1-10 scale. The goal of these questions is to find out whether any specific element of the system (outside of scaling), such as body representation, had an effect on the participants' range of motion.

No concrete measurements will be done during the expert visit, but the expert will try the system in-depth, which will be followed by an interview exploring their view on the prototype.

Procedure. The procedure for the statistical experiment will consist of many quantitative measurements throughout, and can be seen on figure 6. The participants will go through all four of the conditions before answering the post-test VRSQ. The participants will be told to stand in a specific position and not move their feet when performing the movement. They will also be told to use their left hand to move fruit to the left, and right hand to move fruit to the right. The participants for the main experiment will perform four (4) motions six (6) times per condition resulting in 96 total motions.

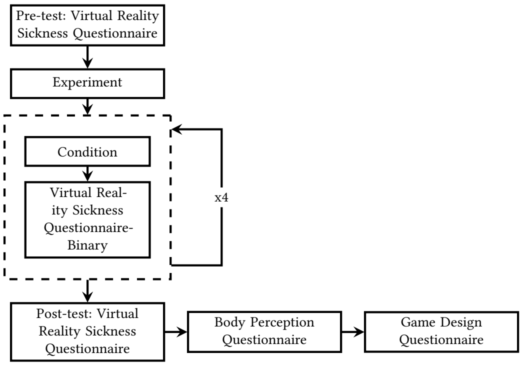

Figure 6: Procedure for the statistical experiment.

The expert will not go through the test procedure, but will have the system explained to her, as to evaluate the different aspects implemented.

5 RESULTS

After the expert had been introduced to the system, and explicitly shown how rotation can be manipulated in VR (by telling her to rotate 90° in virtual reality and removing the head-mounted display) she was very enthusiastic about the possibilities of the system in a rehabilitation setting, but that a more precise and interactive avatar might be helpful.

The main data collected was the rotations of the hip-tracker, back-tracker, and the head-mounted display. The main rotation for this project is the difference between the hip-tracker and the back-tracker, as this measurement gives an indication of the amount of spinal rotation the participants performed. To analyse the data collected, some assumptions had to be understood. The data collected is within-subject, so all participants performed all conditions. Second, the data was tested for normality with the Shapiro-Wilks test. It was seen that the "baseline" condition (W = 0.97, p = 0.0021), "only-scaling" condition (W = 0.97, p = 0.0037), and "both" condtion (W = 0.98, p = 0.038) were non-parametric, while the "only-avatar" condition (W = 0.98, p = 0.1224) shows indication of being parametric. Each condition consists of multiple sets of four motions that were done over time. The first set in all conditions will be referred to as *Ctr* in the analyses, while the subsequent sets will be referred to as *Trt1*, *Trt2*, etc. For the conditions that do not include any scaling ("baseline" and "only-avatar") each treatment only refers to the order the sets were performed in, while for the conditions involving scaling ("only-scaling" and "both") they refer to the amount of scaling applied (respectively 0%, -0.03%, -0.06%, -0.09%, -0.12%, -0.15%). When the data is parametric, ANOVA will be used to analyse the differences between the means of the different treatments, while Friedman's ANOVA was used for the non-parametric data.

The outliers were identified before doing any statistical analysis of the variance. This was done by plotting all the treatments in all the conditions into individual boxplots, revealing the outliers, and then removing them from the datasets.

For the "baseline" condition there was a 1.63 degrees increase from the Ctr to the Trt5 (respectively the means were 31.83°, 32.16°, 32.82°, 33.58°, 32.36°, 33.46°). The "only-avatar" condition had an increase of 0.39 degrees (respectively 31.70°, 30.76°, 30.73°, 32.25°, 32.32°, 32.08°). The "only-scaling" condition had an increase of 1.96 degrees (respectively 31.72°, 31.81°, 32.97°, 32.55°, 32.81°, 33.68°). The "both" condition had an increase of 0.75 degrees (respectively 32.48°, 31.90°, 32.13°, 32.77°, 33.70°, 33.22°). To understand whether there is any significant difference between the various treatments for the individual treatments, the ANOVA was used.

The "only-scaling" and "only-avatar" conditions reported that there was no significant difference between the treatments (respectively, p-values of 0.1434 and 0.985 were reported), so no further data processing was conducted on this data. The "baseline" and the "both" condition reported p-values of 0.0021 and 0.038 respectively, indicating that a significant difference between treatments could have been detected. Using Friedman's ANOVA to do multiple comparisons between groups showed this to not be the case for the "both" condition, but the "baseline" condition reported a significant difference between the Ctr and Trt3.

Additionally, this same procedure was done on the raw hip-rotation data. The hip-rotation data was prepared in the exact same way as the hip-back data, with Ctr and Trt1 to Trt5 corresponding to the same measurements. The Shapiro-Wilks test showed that the "baseline" condition (W = 0.982, p = 0.1091), the "only-avatar" condition (W = 0.99, p = 0.349), and the "only-scaling" condition (W = 0.99, p = 0.577) were all parametric, while the "both" condition (W = 0.97, p = 0.009293) was non-parametric.

The ANOVA hypothesis tests showed no significant differences between means of treatment within the "baseline" condition and "only-avatar" condition (the tests reported p-values of 0.927 and 0.997 respectively), but indicated possible differences in the "only-scaling" and "both" condition (reporting p-values of 0.02448 and 0.01888). Further tests showed that the significant differences occurred between the Ctr and Trt5 in the "both" condition (an increase of 6.72°or 12.99%), and between Ctr and Trt4 and Ctr and Trt5 (an increase of 5.65°and 5.10°, corresponding to 11.03% and 10.08%, respectively) in the "only-scaling" condition.

Before testing, the participants' VRSQ scores were between 0 and 30.83 (M = 8.99, SD = 9.29), and stayed within the same range after testing (M = 11.84, SD = 9.53). The test participants found the indicator arc useful (M = 7.5, SD = 2.28), and rated the score shown below the arc similarly (M = 7.17, SD = 2.40). The test participants felt neutral towards the total score shown in the virtual environment (M = 5.12, SD = 2.85).

One of the rankings from the body perception questionnaire was excluded, as the participant filled out that part of the questionnaire wrong. For the remaining 23 answers, in all three factors the "only-scaling" condition was ranked the worst (third and fourth by 19, 16 and 18 people in the three factors).

The "baseline" condition is spread evenly in ranking among the factors, with a slight preference over the "both" condition in the factor asking which movement felt the most neutral. The "only-avatar" and "both" conditions were ranked first in both the movement and body representation factors, with a combined 16 and 17 people ranking it first.

6 DISCUSSION

Based on the results from the ANOVA, it can be concluded that, for this prototype, negative scaling does not significantly increase the amount of spinal rotation between the hip and the back. Additionally, the data also indicates that adding an avatar had no significant effect on the amount of spinal rotation measured in degrees. Therefore, the null hypotheses cannot be rejected in both cases.

Based on the results from the ANOVA hypothesis tests, it can be concluded that, for this specific prototype, merely adding body representation or merely adding scaling has no significant effect on the degrees of rotational spine movement between the hip and the back for healthy participants. Initially, the Friedman's ANOVA reported a significant difference between means in the "baseline" condition, which should not occur, since nothing was changed between treatments. After comparing the treatments in the "baseline" condition, it was seen that no treatments differed significantly from each other. It was seen that the "only-scaling" condition showed a higher difference than the "only-avatar" condition, but not high enough to be deemed significant. The "both" condition also showed a significant difference between treatments and this difference was located to be between the Ctr and Trt3 (which corresponds to a scaling of -0.09%). Again, in theory, this is a good result, as long as it is followed by significant differences in Trt4 and Trt5 (corresponding to scalings of -0.12% and -0.15%), which was not the case. This observation, and the observation that none of the treatments around it had a significant difference, makes this instance of significance seem like an outlier or a random occurrence.

This might be explained by the movement instructions not being adequately given during the explanation of the procedure to the participants. For the measurements to be made correctly and successfully, the movement required quite a few things to be done properly. They were told not to move their feet, both because the feet were not tracked, as they had no part in the movement being tested, but also because moving them could interfere with the spinal rotation, as part of the movement would be supported by the feet instead of the spine. The participants were also told that the goal was for them to keep their hips still, while mostly rotating in their shoulders. If they rotated in their hips, while also rotating their spine, the two trackers along the spine, would not display any difference between them, and the system would log their degrees of motion as $\sim 0°$. The raw hip-rotation data was originally captured to calculate the difference between the hip and back trackers, but when applying statistical analysis on this data it is possible to see whether scaling or virtual body representation had an effect on these rotations, and therefore on the hip-back rotation.

The results showed no significant differences in the "baseline" condition and the "only-avatar" condition, but did show significant differences in the conditions with scaling present ("only-scaling" and "both" condition). The differences were found to be between the Ctr and Trt5 (-0.15% or a CD gain of 0.85) in the "both" condition, and between the Ctr and Trt4 and Trt5 (-0.12% and -0.15% or a CD gain of 0.88 and 0.85). These results indicate two things: that adding high rotational scaling to visual feedback in VR can increase hip-rotation of healthy participants, and that rotation of the hips might have prevented a significant difference in the hip-to-back rotation.

Another interesting result was from the body perception questionnaires, which showed that the conditions the participants found best represented their movements and felt most natural were the "only-avatar" condition and the "both"-condition. This is interesting, as it indicates that having body representation does increase the amount of embodiment, and also that it distracts from visual-proprioceptive incongruency. This makes it an interesting aspect in a rehabilitation context, as previous solutions have often looked into applying the just-noticeable difference in scaling to encourage movement without the patients noticing, and adding some body representation might be able to increase the just-noticeable difference, and therefore increase the amount the movements could be scaled.

6.1 Validity and reliability

A couple of observations in the data collected through the experiment indicates that the validity of the experiment might have been faulty. First, the observation that there was a possibility of a significant difference in the "baseline" condition, where no changes were made, might indicate that some confound variables had an effect on the amount of rotational movement. It might be an indication that, even though the order of conditions were completely randomised, some form of warm-up or training effect might have occurred. Second, is the observation that degrees of motion did not increase in the "only-scaling" condition as was indicated in the state of the art. Because of this, it can be argued that the internal validity is low for this project.

These errors might have occurred because of a few different things. The presence of gamification elements encouraging people to move more, might have diluted the theorised effects of the scaling and body representation, as they were encouraged to improve after every round. This means that the cause of any potential increased range of motion cannot be confidently identified.

Because of the randomised order of the conditions and the opportunistic sampling of test participants from the university, the experiment is deemed to be reliable.

6.2 Future works

In the future, it could be beneficial to perform the procedure from this paper again, but making the experimentation more narrow and precise, to remove as many confound variables as possible. This could be done by removing any gamification elements that encourage maximum range of movement.

Throughout the semester, the idea of including symptomatic chronic low back pain (CLBP) patients was expressed multiple times, but never came to fruition. As the limitation of range of motion in healthy people is only limited by physical capabilities, and therefore might not be affected by changing the CD gain of the visual feedback, it would be interesting to see if the psychological limitation of CLBP patients is affected by the system. For this, it would also be necessary to perform the body perception experiment with more valid questionnaires. In the case of using CLBP participants, it would also be interesting to look into how pain intensity and pain expectancy is effected in addition to movement.

It would also be interesting to add more tracking points on the users' bodies, to determine where movements occur. This would make it easier to determine if the absence of an effect on spinal rotation might be coming from hip-movement, feet-movement, or something else. Adding more tracker points would also reinforce the body representation as there would be more interaction and similarity between virtual reality and real-life movements.

It would also be beneficial to look into other ways of altering the CD gain. At the moment, the gain is created by rotating the room in the opposite direction of the head-mounted display, which means that every object in the room is repositioned, making the physics calculations slow. By moving a secondary camera according to the gain, and then rendering this camera to the head-mounted display would eliminate these calculations.

7 CONCLUSION

The purpose of this study was to investigate the effect of altered visual feedback using control-display gain, and virtual body representation on range of motion exercises. Additionally, it was investigated whether these two had an effect on each other when in relation to range of motion exercises, added to the same system.

Chronic low back pain and fear-avoidance was researched to understand how these concepts could have a positive effect for the user.

A system was created to test a 2x2 matrix of conditions to carry out this goal. The participants were told to sort fruit to either side of themselves to encourage spinal rotation. The CD gain was altered in increments of -0.03 until reaching 0.85. Additionally, some conditions had virtual body representation with a torso following real life rotations, hands interacting with the fruit, and stationary legs. When body representation was not present, the body and legs were removed and the hands were replaced by red dots.

The results from the ANOVA analyses showed that when any significant difference in the hip-back rotation happened over time it was random, and this may be because the participants instead rotated their hip more than anticipated. Based on this data it was determined that the null hypotheses could not be rejected.

It was seen however, that when virtual body representation was present, the negative effects of scaling on movement and body representation was eliminated. Potentially, this means that adding some level of virtual body representation could increase the just-noticeable difference investigated by other state of the art papers.

In the future, it would be interesting to see if altered CD gain and body representation would have an effect on the psychological limitations of CLBP participants, as they have more potential to improve than asymptomatic participants.

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REFERENCES

[1] [n. d.]. Use of Virtual Reality for Adjunctive Treatment of Adult Burn Pain During Physical Therapy: A Controlled Study. 16 ([n. d.]).

[2] Mobolaji Ayoade and Lynne Baillie. 2014. A Novel Knee Rehabilitation System for the Home. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2521–2530. https://doi.org/10.1145/2556288.2557353

[3] B Bolte, M de Lussanet, and M Lappe. 2014. Virtual reality system for the enhancement of mobility in patients with chronic back pain. *Virtual Reality* (2014), 9.

[4] K. B. Chen, M. E. Sesto, K. Ponto, J. Leonard, A. Mason, G. Vanderheiden, J. Williams, and R. G. Radwin. 2017. Use of Virtual Reality Feedback for Patients with Chronic Neck Pain and Kinesiophobia. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 25, 8 (2017), 1240–1248. https://doi.org/10.1109/TNSRE.2016.2621886

[5] Geert Crombez, Chris Eccleston, Johan W. S. Vlaeyen, Debora Vansteenwegen, Roeland Lysens, and Paul Eelen. 2002. Exposure to physical movement in low back pain patients: Restricted effects of generalization. 21 (2002), 573. https://doi.org/10.1037/0278-6133.21.6.573

[6] Julie M. Fritz, Steven Z. George, and Anthony Delitto. 2001. The role of fear-avoidance beliefs in acute low back pain: relationships with current and future disability and work status. *Pain* 94, 1 (Oct. 2001), 7–15. https://doi.org/10.1016/S0304-3959(01)00333-5

[7] Jan Hartvigsen, Mark J Hancock, Alice Kongsted, Quinette Louw, Manuela L Ferreira, Stephane Genevay, Damian Hoy, Jaro Karppinen, Glenn Pransky, Joachim Sieper, Rob J Smeets, Martin Underwood, Rachelle Buchbinder, Jan Hartvigsen, Dan Cherkin, Nadine E Foster, Chris G Maher, Martin Underwood, Maurits van Tulder, Johannes R Anema, Roger Chou, Stephen P Cohen, Luciola Menezes Costa, Peter Croft, Manuela Ferreira, Paulo H Ferreira, Julie M Fritz, Stephane Genevay, Douglas P Gross, Mark J Hancock, Damian Hoy, Jaro Karppinen, Bart W Koes, Alice Kongsted, Quinette Louw, Birgitta Oberg, Wilco C Peul, Glenn Pransky, Mark Schoene, Joachim Sieper, Rob J Smeets, Judith A Turner, and Anthony Woolf. 2018. What low back pain is and why we need to pay attention. *The Lancet* 391, 10137 (June 2018), 2356–2367. https://doi.org/10.1016/S0140-6736(18)30480-X

[8] Daniel S. Harvie, Markus Broecker, Ross T. Smith, Ann Meulders, Victoria J. Madden, and G. Lorimer Moseley. 2015. Bogus Visual Feedback Alters Onset of Movement-Evoked Pain in People With Neck Pain. *Psychological Science* 26, 4 (April 2015), 385–392. https://doi.org/10.1177/0956797614563339

[9] Caroline Jay and Roger Hubbold. 2003. Amplifying Head Movements with Head-mounted Displays. *Presence: Teleoper. Virtual Environ.* 12, 3 (June 2003), 268–276. https://doi.org/10.1162/105474603765879521

[10] Jason Jerald. 2016. *The VR book: human-centered design for virtual reality* (first edition ed.). Number 8 in ACM books. Morgan & Claypool, San Rafael. OCLC: 945367096.

[11] Konstantina Kilten, Raphaela Groten, and Mel Slater. 2012. The Sense of Embodiment in Virtual Reality. *Presence: Teleoperators & Virtual Environments* 21, 4 (2012), 373–387. http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=83480165&site=ehost-live

[12] Hyun K. Kim, Jaehyun Park, Yeongcheol Choi, and Mungyeong Choe. 2018. Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment. *Applied Ergonomics* 69 (May 2018), 66–73. https://doi.org/10.1016/j.apergo.2017.12.016

[13] Emily F. Law, Lynnda M. Dahlquist, Soumitri Sil, Karen E. Weiss, Linda Jones Herbert, Karen Wohlheiter, and Susan Berrin Horn. 2011. Videogame Distraction using Virtual Reality Technology for Children Experiencing Cold Pressor Pain: The Role of Cognitive Processing. *Journal of Pediatric Psychology* 36, 1 (2011), 84–94. https://doi.org/10.1093/jpepsy/jsq063

[14] Luan Le Ngoc and Roy S. Kalawsky. 2013. *Evaluating usability of amplified head rotations on base-to-final turn for flight simulation training devices.* https://doi.org/10.1109/VR.2013.6549359

[15] T. Penn, W. Browning, C. France, G. Hardee, M. Zielke, and Z. Trost. 2017. Attitudes toward a virtual reality physical activity intervention among veterans with chronic low back pain. *The Journal of Pain* 18, 4, Supplement (April 2017), S1. https://doi.org/10.1016/j.jpain.2017.02.004

[16] Meyke Roosink, Bradford J. McFadyen, Luc J. Hebert, Philip L. Jackson, Laurent J. Bouyer, and Catherine Mercier. 2015. Assessing the Perception of Trunk Movements in Military Personnel with Chronic Non-Specific Low Back Pain Using a Virtual Mirror. *PLOS ONE* 10, 3 (March 2015), e0120251. https://doi.org/10.1371/journal.pone.0120251

[17] Meyke Roosink, Nicolas Robitaille, Bradford J. McFadyen, Luc J. Hebert, Philip L. Jackson, Laurent J. Bouyer, and Catherine Mercier. 2015. Real-time modulation of visual feedback on human full-body movements in a virtual mirror: development and proof-of-concept. *Journal of NeuroEngineering and Rehabilitation* 12, 1 (Jan. 2015), 2. https://doi.org/10.1186/1743-0003-12-2

[18] Mel Slater, Bernhard Spanlang, and David Corominas. 2010. Simulating virtual environments within virtual environments as the basis for a psychophysics of presence. *ACM Transactions on Graphics* 29, 4 (July 2010), 1. https://doi.org/10.1145/1778765.1778829

[19] James S. Thomas, Christopher R. France, Megan E. Applegate, Samuel T. Leitkam, and Stevan Walkowski. 2016. Feasibility and Safety of a Virtual Reality Dodgeball Intervention for Chronic Low Back Pain: A Randomized Clinical Trial. *The Journal of Pain* 17, 12 (2016), 1302–1317. https://doi.org/10.1016/j.jpain.2016.08.011

[20] Zina Trost, Marjorie Zielke, Adam Guck, Liza Nowlin, Djanhangir Zakhidov, Christopher R France, and Francis Keefe. 2015. The promise and challenge of virtual gaming technologies for chronic pain: the case of graded exposure for low back pain. *Pain Management* 5, 3 (May 2015), 197–206. https://doi.org/10.2217/pmt.15.6

[21] J.W.S. Vlaeyen and G. Crombez. 1999. Fear of movement/(re)injury, avoidance and pain disability in chronic low back pain patients. *Manual Therapy* 4, 4 (Nov. 1999), 187–195. https://doi.org/10.1054/math.1999.0199

[22] Johan W. S Vlaeyen, Jeroen de Jong, Mario Geilen, Peter H. T. G Heuts, and Gerard van Breukelen. 2001. Graded exposure in vivo in the treatment of pain-related fear: a replicated single-case experimental design in four patients with chronic low back pain. *Behaviour Research and Therapy* 39, 2 (2001), 151–166. https://doi.org/10.1016/S0005-7967(99)00174-6

[23] Johan W. S. Vlaeyen, Ank M. J. Kole-Snijders, Ruben G. B. Boeren, and H. van Eek. 1995. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. *Pain* 62, 3 (Sept. 1995), 363–372. https://doi.org/10.1016/0304-3959(94)00279-N

[24] Martin Westhoven, Dennis Paul, and Thomas Alexander. 2016. Head Turn Scaling Below the Threshold of Perception in Immersive Virtual Environments. In *Proceedings of the 22Nd ACM Conference on Virtual Reality Software and Technology (VRST '16)*. ACM, New York, NY, USA, 77–86. https://doi.org/10.1145/2993369.2993385

[25] Gul Deniz Yilmaz Yelvar, Yasemin Cirak, Murat Dalkilinc, Yasemin Parlak Demir, Zeynep Guner, and Aysenur Boydak. 2017. Is physiotherapy integrated virtual walking effective on pain, function, and kinesiophobia in patients with non-specific low-back pain? Randomised controlled trial. *European Spine Journal* 26, 2 (Feb. 2017), 538–545. https://doi.org/10.1007/s00586-016-4892-7