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VR Landscapes for Therapy of Gait Insecurity

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Abstract: Therapy of gait insecurity is usually a lengthy and laborious process, which requires a high level of motivation and willpower on the part of the patients. The aim is to return the patients to a level of confidence for everyday life by providing therapy sessions that promote dual-task performance and support patient motivation. This can be fostered by integrating everyday situations into physiotherapies. In the presented study, a prototype involving virtual reality (VR) technologies was designed for gait insecurity therapy. It has been shown that this approach has the potential to be used in the healing process. An immersive 3D point cloud-based application was developed and tested in a between-design study with gait insecure patients during daily half hour therapy sessions over a period of two weeks. Patients saw the VR environment in a head-mounted display. By walking in the physical space, they moved through the virtual scene following the topography to cross streets, climb stairs or ramps. The results revealed a noticeable difference between the VR therapy patients and the standard therapy patients with the VR therapy patients having greater improvement of gait speed, as well as general mobility status. Further, a higher motivation was shown by patients using the VR application. The prototype should be further enhanced and its effectiveness should be analyzed more rigorously. The effects of a wider range of day-to-day situations as well as of restorative environments should be further investigated.

Keywords: Virtual Reality, 3D point clouds, Unity, patients with gait instability, VR therapy

1 Introduction

For the therapy of gait insecurity, task-oriented exercises related to activities of daily living should be trained, such as getting up from sitting, performing stepping patterns, or walking with a defined gait speed (BRACH and VAN SWEARINGEN 2013). One problem with the current therapy, however, is the lengthy and laborious process of strengthening the security (BOONE et al. 2017). In addition, performing different cognitive and motor tasks simultaneously is difficult for gait-insecure patients. Hence, dual-task gait performance must be promoted through combined physical and cognitive training (LIAO et al. 2019). For this, considerable motivation and willpower of the patients are necessary.

BOONE et al. (2017) suggest that incorporating virtual reality (VR) videogames would lead to higher motivation and level of enjoyment and, therefore, would help to enhance gait speed and kinematics. In contrast to Mixed or Augmented Reality, where the user would actually see and experience the real-world surroundings and the virtual objects at the same time (LEE et al. 2014), VR can be employed for customized trainings in virtual real-world environments in a controlled and safe setting (PARALKAR et al. 2020). However, BOONE et al. (2017) only tested their system on participants without disabilities. LIAO et al. (2019) have demonstrated in their study, an improvement of the cognitive dual-task gait performance was only revealed by patients therapized by VR-based physical and cognitive training. Patients visiting a combined traditional physical and cognitive training did not show such improvement. In contrast, advancement of single-task and motor dual-task gait performance was observed in both

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groups. The potential influence of enhanced motivation on the success of gait therapy as well on dual-task performance remains to be investigated.

Today, the semi-immersive VR therapy with a second person view is implemented most frequently because of compared to immersive VR therapy its easier implementation, lower cost and complexity (MONTALBÁN & ARROGANTE 2020). Yet, using immersive simulations of actual environments in VR training reduces the translation effort of training tasks to patients' daily activities (KIZONY et al. 2003, HOWARD 2017, PARALKAR et al. 2020, FANDIM et al. 2021). Hence, a further question is, whether computer-generated immersive VR landscape environment situations close to everyday life could increase motivation for and effectiveness of the VR training.

Technically, with game engines audio-visual VR simulations can be created with high level of detail and realism, and employing them via Head-Mounted Displays (HMDs) can foster immersion into the environment (WISSEN HAYEK et al. 2016, ECHEVARRIA SANCHEZ et al. 2017). Moreover, based on 3D point clouds from terrestrial laser scanning, such simulations can accurately reconstruct a real environment including aesthetic qualities (URECH et al. 2020). However, enabling natural walking in virtual environments without having large physical space is still a technical challenging task (NILSSON et al. 2018).

We developed a prototype for VR gait therapy by simulating a real environment in the game engine Unity utilizing 3D point clouds from terrestrial laser scanning, animation of car objects, and environmental auralization. The objective was to investigate (1) how good the perceived quality of the 3D point cloud-based audio-visual landscape simulation is for therapeutic use with gait-insecure patients, and (2) whether a noticeable difference in rehabilitation is achieved by therapy with the VR application compared to conventional therapy only.

In this paper, we present the used methodologies for producing the VR application for therapies with geriatric patients to improve their gait performance. During a within-subject study, physiotherapists provided feedback, which helped to enhance the design of the VR application concerning the requirements of the VR therapy. In a between-group study, we then compared the improvements of gait performance during two weeks by a group only visiting the traditional gait therapy and another group visiting additionally ten sequences of VR therapy. We present and discuss the results concerning the improvements of the gait speed, the general mobility status, as well as the personal perception of the patients' motivation for joining the therapy. Further, we reflect on the benefits and shortcomings of the VR therapy prototype and provide an outlook on what aspects of the application would need to be improved, respectively which changes in the structure of the study should be considered to better measure its effects.

2 Method

The overall workflow of the procedure of creating the VR application as well as carrying out the studies is presented in Fig. 1. First, the selected actual environmental area was recorded with Terrestrial Laser Scanning (TLS). This data was then post-processed to correct errors in the 3D point clouds. Afterwards, the data was integrated into the game engine *Unity 2019.4.19f* (www.unity3d.com), to create an environment where the user can walk through the 3D point cloud of the real environment. Then, object animation and auralization was added to the setting. A first user study with physiotherapists was carried out to receive feedback on the VR application and its usability for gait therapies. The second user study was then conducted with geriatric patients with gait instability. Finally, the data was analyzed and discussed. In the following, the steps are presented in more detail.

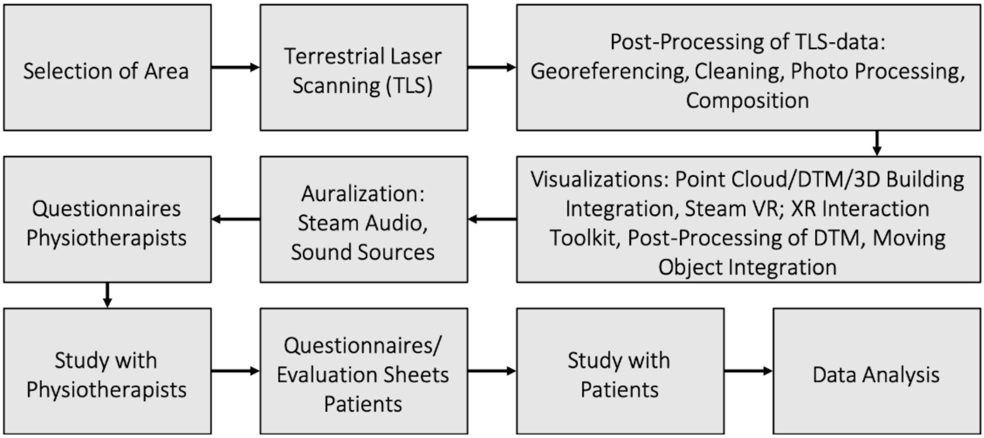

Fig. 1: Flowchart of the overall approach

2.1 Setup of the Virtual Reality

Selection of the Environment

Since the purpose of the application is to provide therapy units close to everyday life, the visualized situation should be familiar to the patients. Hence, the roundabout at the "Obertor" was chosen, a place near the patients' hospital in Schaffhausen (CH). It is a well-known place with the statue of Johann Conrad Fischer, who was a Swiss metallurgist and the first mayor of Schaffhausen. Moreover, the area was selected because it is well contained, which provides the perception of an outside room that visually seems to be completely represented. Additionally, for dual-task training, moving cars can be added that match the location. Whereas the contained space had advantageous for recording sufficient data with few terrestrial laser scans, the dense traffic at the roundabout impeded processing of the scans and complicated auralization, as addressed in the following.

3D Point Cloud-based Audio-Visual Simulation

To create a 3D visualization of the environment around the Obertor in Schaffhausen with high level of detail and realism, a 3D point cloud-based visualization approach was chosen. Therefore, the area was scanned with the terrestrial laser scanner RIEGL VZ-1000 (www.riegl.com). Twelve different viewpoints were chosen to record the whole environment with 3D point clouds. On top of the scanner, a calibrated Nikon D700 camera was mounted for taking pictures to use for coloring the point clouds. The post-processing of the laser scans was made with *RiSCAN Pro 64 bit v2.7* (www.riegl.com). For the georeferencing of the twelve scans the method of *Backsighting Orientation* was used, whereby the relative orientation as well as the relative position of the scans are automatically estimated. Then, error points in the point cloud, which were produced through reflections (windows, etc.) or moving objects (passengers, cars, etc.) had to be eliminated manually to get a clean scene of the environment. In addition, the photos made during the scanning were edited in *Adobe Photoshop 2020* (www.adobe.com). Since in the field we took always in minimum two times the same image from one spot and orientation. Therefore, a layer mask could be used to reduce interfering objects like cars or passengers. Smaller errors were eliminated with the clone source panel. After finishing the editing of the photos, the scans were colored with the command "color from images" using the Mounting Matrix (COP) in *RiSCAN Pro*. In *Cloud Compare v2.9.1 [64-bit]* (www.cloudcompare.org) the twelve scans were combined to one single point cloud. Additionally, the point cloud density was decreased to reduce the amount of data (134'425'487 points; 4.25 GB).

A 3D project in *Unity* was set up, where the generated point cloud was imported using the plug-in *PointCloudTools v2.4* (www.assetstore.unity.com). This plug-in converts the point cloud into a mesh. The official digital terrain model (DTM) from Switzerland (swissSURFACE3D; position accuracy: ±20cm; height accuracy: ±10cm) was used to generate a terrain with the *Unity Terrain Tools.* For enabling physical movement in the virtual world, we used the plugin *Steam VR 4* (www.assetstore.unity.com) and the interaction system *XR Interaction Toolkit* (www.docs.unity3d.com). *Steam VR* calculates the position of the virtual character in the VR space based on the real movements of the VR headset. It additionally allows changing the size of the virtual space to change the real walking distances. On the other hand, *XR Interaction Toolkit* was employed to enable walking and following the virtual terrain. The main *GameObject [XR Rig]* was used to build a virtual character and to add different scripts. The most important script is called *Movement Provider* (https://www.youtube.com/watch?v=4WiMogkep1U) which permits the calculation between the physical position of the VR headset and the provided screen view. Due to this script, the *GameObject [XR Rig]* is yielding the gravity on the virtual terrain.

To provide the scene with more realism, moving objects (here cars) were integrated. These objects can be used for different tasks in gait therapy (e. g., cross the street after the red car has passed; follow the direction of the blue car, etc.). 3D models of cars were converted to point clouds in *Cloud Compare v2.9.1 [64-bit]* to achieve similar appearances as the remaining VR environment. Afterwards, the 3D point cloud car objects were imported into *Unity* the same way as the other 3D point clouds were. For defining the route of the car objects, we used gizmos, which are provided by *Unity* for visual debugging and set up in the Scene view. Two scripts define the animation: An *Editor Path* script connects the gizmos to easily create the route. And a script called *Move On Path* allows the cars to drive on predefined routes. With the latter script, distances and rotation to the next gizmos are calculated and followed. The speed for driving and rotating can be defined individually per car. For better use in therapies, this script was extended to *On Click Move On Path,* so that a click on the controller starts the moving action of the cars. This is achieved through if-loops that control if the trigger-button of the controller has already been pressed or not.

In addition, sound was integrated into the simulation to foster a realistic environmental perception. Therefore, audio clips of sound around the Obertor were recorded. However, due to the intense traffic, the recordings had to be processed and mixed with other recordings to provide congruent sounds. Clips with as little as possible noise from cars were used as a basic atmosphere. Recordings of construction sites, wind, and cars were used to add further location specific sounds. The sound of the moving cars has been mixed based on sounds of abrasion of the tires on the road, the engine noise, and other vehicle-specific noises recorded elsewhere. For integrating the sounds into the Unity scene, *Steam Audio* (www.valvesoftware.github.io) was used. This plug-in provides a full audio solution that can interact with the user and the environment, realized with the head-related transfer function (HRTF), and calculates the sound propagation based on the shape and texture of the 3D objects of the buildings and of the terrain.

A build of the final Unity Scene was made resulting in an application running on every platform of PC, Mac & Linux, as well on the VR headset (*HTC Vive Pro Eye*, www.vive.com) we implemented in the user studies.

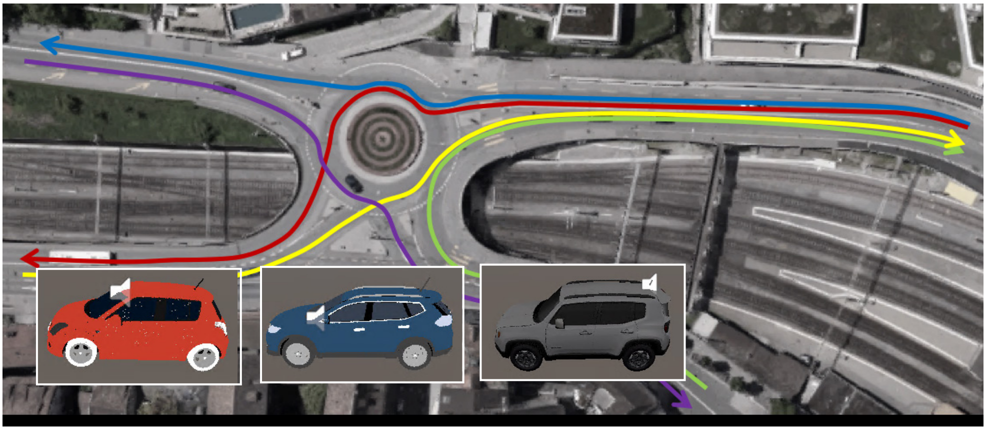

Fig. 2: 3D models of car objects used and the routes created for their animation

2.2 Suitability Testing of the Initial Prototype with Therapists

To answer the research question (1) a study with therapists was made. In this study, the goal was to receive feedback on the prototype and generate information about the quality of the 3D point cloud-based audio-visual landscape simulation. Therapists tested different scenarios prepared for the VR therapy (crossing streets, walking up stairs or a ramp) and presented with the virtual reality headset *HTC Vive Pro Eye*. The VR headset was connected by a wireless adapter to get rid of the cable connecting the headset to the computer. Questions about the appearance of the scene, quality of colors, perceived safety while wearing the VR headset, any observations made and some free feedbacks were asked.

The therapists judged the overall view of the scene to be close to reality. Therefore, also their experiences of the VR environment felt very real. Some unease appeared because of image flickering. The moving cars were assessed as too abstract, and the sound was not perceived as realistic. However, the therapists stated, that the cars supported a more realistic impression of the situation. The auralization was said to foster immersion into the VR environment. The movement options in the VR environment were clear. The therapists expressed some wishes, like a larger virtual room to walk longer distances, having other moving objects like birds or cats, and cleaning further errors in the point clouds (e. g., white areas around trees).

2.3 Enhancement of the Prototype

The results obtained from the study with the therapists were used to enhance the prototype, which mainly included solving troubles with the image flickering and distracting transparency. For a more stable image, the GameObjects from Steam VR and XR Interaction Toolkit needed to be combined. Both packages had their own camera, whereby these interfered with each other, and caused heavy jittering. By combining both packages and switching off one camera, the jittering could be removed. To prevent seeing through the surface, grey cubes were placed directly behind the 3D point clouds. In addition, adjustments of the auralization were made, especially the sounds of the cars were improved.

Fig. 3: Screenshots of the different scenes prepared for the VR therapy

2.4 Implementing the Prototype with Gait-insecure Patients

Six gait-insecure patients (3 women and 3 men, 81 years old on average) were split into two groups: a control group and an intervention group. They suffered from various conditions that lead to gait instability, such as multifunctional gait disorder with recurrent falls, debilitation due to pneumonia with fall, or cardiac problems leading to falling. The study was conducted over two weeks. The control group was joining the normal therapies, which included 30 minutes of individual training and 45 minutes of group training (strength and endurance training) per day. The intervention group joined the same therapies but had an additional 30 minutes training with the VR application every day using the wireless *HTC Vive Pro Eye*.

There were four different scenarios for VR therapies: just sitting and acclimatization to the VR impressions (1), walking over a street (without and with moving cars) (2), walking up a ramp (3), and climbing stairs (4). For the ramp and the stairs corresponding physical objects were placed in the room to match the virtual environment (Fig. 4).

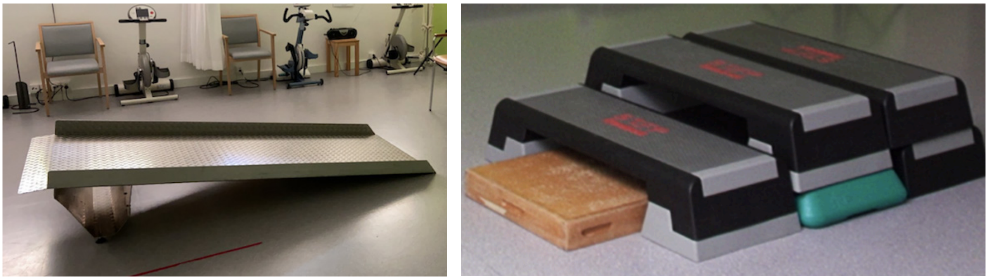

Fig. 4: Setup for the VR training with the physical ramp (left) and stairs (right)

To measure the progress of healing three different tests were used:

- *De Morton Mobility Index (DEMMI)-score.* Assessment for proving the mobility status in 15 different items. The higher the score, the better the mobility of the geriatric patient is (BRAUN and GRÜNEBERG 2013).
- *Three-Minute Walking Distance (3MWD).* Recorded walking distance completed by the patient during three minutes. Also used to calculate the average walking speed.
- *Functional Independence Measure (FIM) (walk, stairs, memory).* Test to assess everyday independence using various items covering locomotion and memory (LÜTHI 2006).

3 Results

3.1 Effects of the VR Therapy on Gait-Insecure Patients

The two groups of gait-insecure patients performed several medical tests to see their enhancements over two weeks. In both groups, the DEMMI-score was improved almost around the same percentage. The 3MWD was improved by the intervention group from 45% to 115%, whereby the control group achieved deteriorations from -35% to improvements to 52%. In the different scenarios of the FIM mostly all patients could achieve some improvements. The improvement of walking was higher in the control group, but for climbing stairs, the improvement was higher in the intervention group. A little better improvement could be shown in the intervention group concerning memory.

The motivation to enhance gait security through therapies from the patients of the intervention group was higher than the motivation of the control group. The patients liked the additional therapy. In contrast, patients in the control group did not wish to attend any further therapy sessions. Further observations of positive changes could be made by the attending therapist, e. g. patients lifting their feet higher when walking, positive influence on the feelings, or that the therapy time was perceived to be significantly shorter as it actually was. No signs of dizziness or discomfort, so-called motion sickness, due to the VR headset were shown by the patients. In most cases, the VR headset was never taken off during the half-hour therapy.

3.2 Suggestions for the Improvement of the Prototype

In the discussions with the therapist, who conducted the VR therapy with the patients, suggestions for further improvement of the prototype were mentioned. These were, e. g., integrating the feet of patients into the virtual world to give them higher security in walking stairs and ramps. Another enhancement would be allowing unconstrained walking through the virtual world without having a large physical space (NILSSON et al. 2018). Therefore, a type of teleportation for moving over larger distances than three to four meters in the virtual world could be integrated. Further, presenting a variety of scenes could help to achieve higher motivation to join the therapy over a longer period of time. Additionally, further exercises close to everyday life should be implemented.

4 Discussion and Conclusion

The goal was to generate and test a prototype for VR therapy of gait insecurity. We developed such a prototype by simulating the real environment in the *Unity* game engine utilizing 3D point clouds from terrestrial laser scanning, animation of car objects, and environmental auralization. The prototype was presented with a wireless virtual reality headset allowing the patients to physically walk around, and the simulation was used in combination with physical elements to foster the patients' immersion into the virtual environment and their training effects. In this initial study, the 3D point cloud-based audio-visual landscape simulations already showed to have potential value for therapeutic use with gait-insecure patients. Overall, it would make sense to further develop the prototype. To this end, first, a concept for enhancement should be developed in collaboration with a group of therapists. Furthermore, the effectiveness of the VR therapy should be investigated in a more robust study with a higher number of gait-insecure patients and more medical expertise to evaluate the results.

The use of immersive apps of real environments such as the one developed, where the user is integrated into the VR environment, has hardly been used in gait therapies to date. KERN et al. (2019) showed that the well-being of the patients is higher when using immersive applications, as less effort and frustration were observed in the VR therapies than in conventional therapies. These findings could also be demonstrated in our study as the patients' motivation increased by the VR therapy.

Utilizing 3D point clouds for the VR environment allows manipulating the model and designing new shapes (URECH et al. 2020). In this way, not only new training situations for gait therapy can be created. But also designs could be tested concerning their accessibility for people with gait problems in order to avoid difficult situations in the urban environment.

Ultimately, the influence of restorative values of an environment (TABRIZIAN et al. 2020) should be investigated in VR therapies. As COLLADO et al. (2016) have demonstrated, restorative environments can foster people's health and well-being. This could be an additional advantage in the gait therapy to achieve progress more quickly due to a better general condition and increased motivation of the patients.

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