Master's Thesis

Balancing Exercises for Seniors in VR with Interactive Elements

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Název diplomové práce:

Balanční cvičení pro seniory ve VR s interaktivními prvky

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Balancing exercises for seniors in VR with interactive elements

Pokyny pro vypracování:

1) Proveďte rešerši literatury zabývající se záznamem a analýzou pohybu ve virtuální realitě (např. kondiční cvičení, symetrie chůze, dosažitelnost objektů rukama).
2) Navrhněte rozšíření stávající aplikace pro balanční cvičení ve VR [1] o interaktivní (herní) prvky. Např. chytání pohybujících se objektů, uhýbání hlavou překážkám, odrážení objektů, odměny za úspěšné splnění. Vybrané interaktivní prvky po dohodě s vedoucím implementujte.
3) Navrhněte a implementujte postupy pro záznamy dat ze senzorů VR soupravy (IMU jednotky, pohyb kamery, pohyby ovladačů, zvažte i možnost externího trackingu). Dle rešerše 1) navrhněte metody jejich analýzy (statistiky, vizualizace).
4) Navrhněte a realizujte systém pro správu uživatelů a analýzu zaznamenaných dat v návaznosti na diplomovou práci [2].
5) Sesbírejte data s pacienty a zdravými uživateli. Navrhněte metody pro analýzu změny výkonu uživatele způsobenou pravidelným opakováním cvičení. Zhodnoťte přínos VR aplikace pro dané cvičení (např. porovnání statická vs pohyblivá scéna, bez zařízení pro cvičení (posturomed) vs s ním, s VR a bez VR).
6) Stávající aplikaci upravte dle potřeb (výkonostních, kvalitativních, atp.).
7) Finální aplikaci zveřejněte (např. webové stránky) včetně uživatelské dokumentace.

Seznam doporučené literatury:

1] Markéta Machová. Balanční cvičení pro seniory ve VR. BP FEL, ČVUT 2021.
2] Leoš Řeháček. Aplikace pro sběr a analýzu dat z VR tréninkových aplikací. Rozpracovaná DP FEL, ČVUT.
3] Jason Jerald. 2015. The VR Book: Human-Centered Design for Virtual Reality. Association for Computing Machinery and Morgan & Claypool, New York, NY, USA.
4] Steven M. LaValle - Virtual Reality, Cambridge University Press 2016

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III. PŘEVZETÍ ZADÁNÍ

Diplomantka bere na vědomí, že je povinna vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

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Datum převzetí zadání	Podpis studentky

Abstract

Falls, primarily affecting older adults, pose a significant problem due to their severe health and economic consequences, and potential fatalities. Regular proprioceptive training, such as balance exercises, can help prevent falls. This thesis presents a virtual reality (VR) application system designed to enhance balance training with the Posturomed balance platform. The goal is to improve this VR application by incorporating gamification elements for active training. The thesis provides necessary research on introducing active training to older adults and the design rationale for specific changes.

Another part of the thesis examines how to evaluate the impact of the VR-enhanced balance training. The VR application system is integrated with a patient management system and the evaluation of this specific VR-enhanced training with Posturomed is provided.

Abstrakt

Pády, které postihují především starší lidi, představují závažný problém vzhledem k závažným zdravotním a ekonomickým důsledkům a potenciálním úmrtím. Pravidelný proprioceptivní trénink, například cvičení rovnováhy, může pomoci pádům předcházet. Tato diplomová práce představuje aplikační systém virtuální reality (VR) určený ke zlepšení tréninku rovnováhy pomocí balanční platformy Posturomed. Cílem je vylepšit tuto VR aplikaci začleněním prvků gamifikace pro aktivní trénink. Práce poskytuje potřebný výzkum v oblasti zavádění aktivního tréninku pro starší lidi a zdůvodnění návrhu konkrétních změn. Další část práce se zabývá způsobem hodnocení dopadu tréninku rovnováhy s využitím VR. Systém aplikace VR je integrován se systémem pro správu pacientů taktéž je uvedeno hodnocení tohoto specifického tréninku s využitím VR s Posturomedem.

Klíčová slova: virtuální realita, VR, stabilita, kinetóza, balanční cvičení, Posturomed

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Introduction

The history of virtual reality dates back to 1968 when American computer scientist Ivan Sutherland and his student, Bob Sproull created the first virtual reality headset. The first references to virtual reality-like devices, however, can be traced back in the literature to the 1860s.

Virtual reality has therefore been with us for over fifty years, but for most of that time it has been a purely experimental technology that has not been widely used by the general public. Like most technologies, development was driven in the beginning mainly by the military industry. It was only when companies such as Atari and SEGA began to enter development that virtual reality began to reach the public. Although it was SEGA that promised to bring virtual reality to the general public, in the end their SEGA VR headset never made it to the public, mainly because people were afraid of the impact the device would have on their eyesight.

The turning point for virtual reality came in 2012 when Palmer Luckey stunned investors with his Oculus Rift prototype. Another breakthrough came two years later when Mark Zuckerberg, founder of social network Facebook bought Oculus VR for two billion dollars. Today, virtual reality is already becoming a common device that can be found in homes.[1]

The use of virtual reality was originally planned for military purposes or as a form of entertainment. Today, however, virtual reality is making its way into almost every industry. One of these industries is Medical technology.

Physical activity is proven to be beneficial for the human body and can prevent or reduce the effect of many diseases and improve overall fitness of the physically active person. Physiotherapy and exercise have also been shown to reduce the risk of falls and associated injuries.[29]

However, physiotherapists often encounter a lack of motivation and willingness to exercise and be active in their clients, especially in the elderly. Therefore, physiotherapists try to make their sessions more attractive by using different methods. Some use different technologies to do this, and virtual reality is one of the technologies that can greatly improve the motivation of exercisers and bring additional benefits (such as overall mood improvement or analytical data) for both the exerciser and the physiotherapist.

Chapter 1

Motivation

1.1 Falls

Falls represent one of the most significant health concerns among older adults. According to the World Health Organisation, an estimated 684 000 fall fatalities occur each year, making falls the second leading cause of unintentional injury deaths worldwide.[50]

Other consequences of falls include soft tissues injuries, fractures or head injuries.[7] These causes can lead to mobility limitations and the need for long-term care.[7]

Furthermore, an individual with history of falls can experience the fear of falling again, which further contributes to reduced physical abilities, decreased mobility and social isolation.[8] In consequence, falls may have an immense impact on the quality of life of older adults.

Age is a key risk factor for falls. The risk of having serious health consequences increases with age, making older adults the most prone to serious injuries or death arising from a fall. The reason behind the increased risk level include the decline in physical, sensory and cognitive abilities.[50]

Therefore, it is important to pursue measures of fall prevention.

The most common strategies for elderly people include home modifications for increased accessibility and safety, vitamin supplements, or active training namely targeting proprioceptive and balance exercises.[50]

1.2 Proprioceptive Training

Proprioception and balance are tightly coupled. Balance is the ability to maintain the body's center of mass within its base of support. Proprioception is the body's ability to determine body position in space and movement by detecting joint angles, muscle tension or providing sensory input.[60] In essence, proprioception provides the necessary information to maintain balance.

The alignment of the head with the spine is crucial for maintaining spinal stability and balance.[52] The spine is a complex structure depending on the coordination of its motion segments to support the head and trunk.[41]

Maintaining head angular stability is crucial for postural control during body movement. [31]
Proprioceptive training includes various exercises. The most common include:

- Balance exercising
- Foam pad exercises: performing movements and simple exercises on foam pads that represent an unstable surface

- Bosu ball exercises: performing movements and simple exercises on a half-sphere balance device
- Tai Chi: activities that include slow movements with focus on deep breathing[12]
- Yoga: activities that combine breathing techniques and movement with attention to maintaining postures[28]

1.2.1 Posturomed Training

The Posturomed device is a balance platform designed to provide control and adjustments for instability. An unstable platform situated on a frame oscillating horizontally requires individuals to continuously alter their posture to maintain stability. The device offers two modes of training - proactive training and reactive training.[5] Proactive training refers to training that results from impulses created by the individual who is exercising. Stronger body movement results in stronger oscillation of the platform, making the exercising individual suppress their own movements in order to stabilise the platform. Reactive training represents training when an individual's body has to respond to external and surprising stimuli. This way, the individual is required to stabilise their posture without relying on pre-planned movements.[27, 5].

Figure 1.1: The Posturomed balance platform [61]

The Posturomed balance training is conducted on a weekly basis in the Nová Slunečnice retirement home, under the supervision of a physiotherapist professional. The Posturomed balance training is performed using both proactive and reactive methods. In the proactive training, the individual stands on the Posturomed balance platform and stabilises their own movements. The reactive training involves the physiotherapist deflecting the balance platform or the individual to challenge their balance.

While the proactive stage remains the same in both traditional and VR-enhanced training, in the case of reactive training, the physiotherapist's role as an external source of deflection is substituted with stimuli originating from the VR experience.

These VR-induced stimuli result from the sense of motion caused by the slow-paced landscape. The apparent movement causes the individual's body to lean left or right when a turn is ahead in the VR experience. Similarly, uneven terrain and bumps cause individuals to compensate for vertical movement and unconsciously change their posture on the balance platform. In addition, the VR experience exposes the training individuals to irregular distractions. These stimuli divert the patient's attention and may also result in a change in their posture on the platform.

1.3 PhysioTrails

1.3.1 PhysioTrails VR

The PhysioTrails application was created as a part of the author's bachelor thesis. The aim was to augment existing proprioceptive training in the Nová Slunečnice retirement home. The purpose of the VR application is to aid a therapeutic process, during which an elderly patient performs proprioceptive exercises on the Posturomed balance platform with a physiotherapist as a supervisor. The application was developed for the Meta Quest VR headsets.

Using the VR application, the patient immerses themselves in a movement-visualising VR experience. During the experience, the patient is moved through an artificial environment and the apparent movement causes the patient's body to move on the balance platform, which results in the desired proprioceptive exercise.

Furthermore, the application makes the otherwise ordinary process more engaging for the patient. Instead of following explicit instructions from the physiotherapist on what body movements to perform, the patient performs those movements naturally in response to the pace and terrain changes in the virtual environment. The virtual environment includes vibrant colours and immersive sound effects to possibly create a stress-reducing experience.

Based on the experience of using the application in the retirement home, the patients respond positively to the VR experience. They show no signs of hesitation towards the new technology. In fact, they often describe that the virtual environment evokes memories from their younger age. They often engage in a conversation with the physiotherapist about what they see in the environment.

From the physiotherapist's perspective, patients are more confident while walking after incorporating the proprioceptive training. They are also more confident and stable during the training itself.

Previews of the existing scenes can be seen in the figures below.

Figure 1.2: Preview of the forest scene

Figure 1.3: Preview of the winter scene

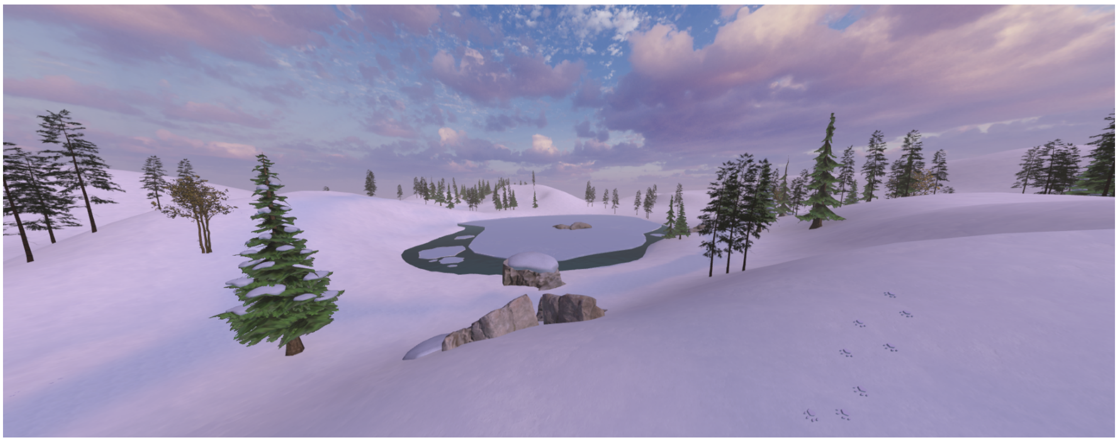


Figure 1.4: Preview of the rural scene

Hand tracking

The VR application utilises hand tracking to display a visual representation of one's hands but also as a mean of interaction. Hands position along with simple hand gestures are used to interact with UI and control the overall experience. This eliminates the need for using VR controllers, which can be problematic when the users are maintaining balance on the platform and perhaps need to hold onto the railings of the platform for support.

Motion Sickness

Motion sickness is a feeling of discomfort or sickness induced by motion, such as in a car, plane, or boat. It can also be induced by visual perception of motion, which includes VR usage.[47] Motion sickness arises when there is a mismatch between visual sensory input and the input of the vestibular system, which is responsible for assessing body movement. In VR, motion sickness occurs because the user perceives movement, while the vestibular system detects none.[42]

Symptoms include nausea, dizziness, headaches, and, in some cases, vomiting. Therefore, motion sickness can have a significant negative impact not only on the user experience, but also on the proprioceptive training.[42]

From the experience of the usage in the retirement home, motion sickness does not occur very often. It appears that users are less likely to experience it if they stand on the balance platform, and postural movements on the platform may influence the vestibular system that detects motion.

However, if motion sickness occurs, the VR session is stopped and the headset is removed from the patient. Reducing the speed can also help suppress the discomfort.

1.3.2 PhysioTrails Mobile

In addition to the VR application, a mobile application was created. The mobile application is used by the physiotherapist to control the virtual one during exercises.

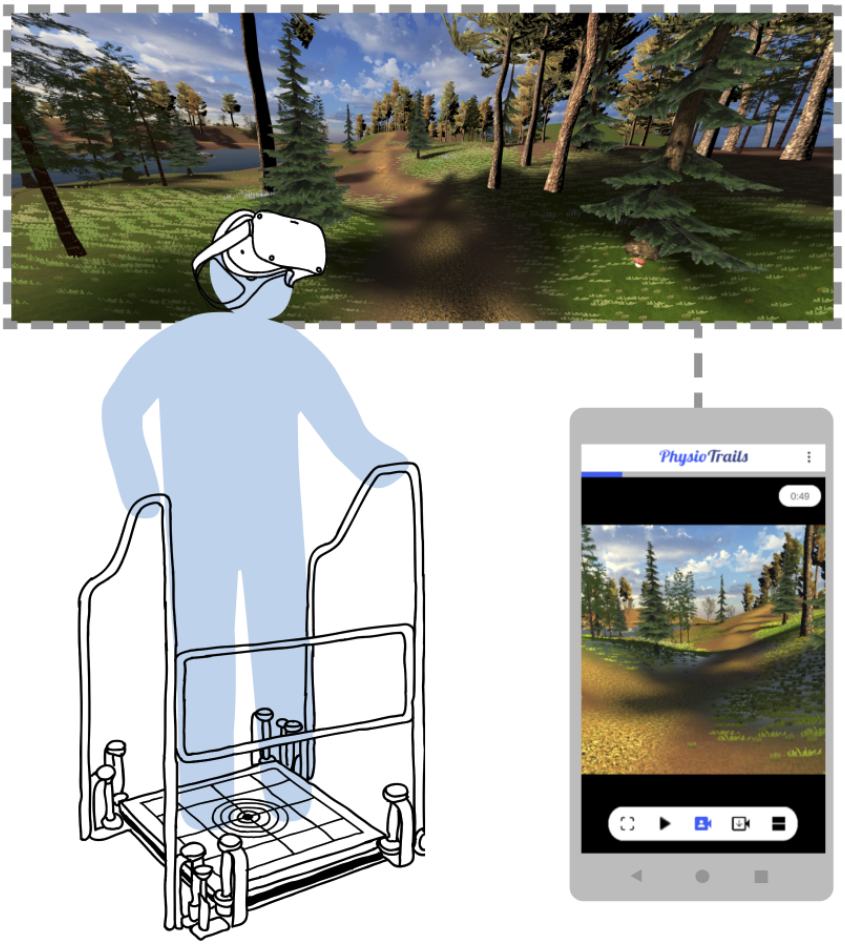
The mobile application allows the physiotherapist to start the VR movement once the patient is standing on the balance platform and has correctly put the VR headset on.

When the movement is started, the mobile application mirrors the view of the patient in VR, so the therapist can see what the patient sees. This allows the physiotherapist to prepare for upcoming changes in the movement so they can provide support in case the patient loses balance. The capability to see the patient's view also allows them to share the patient's journey and discuss it, which can make the exercise more thrilling.

The therapist can also pause the movement or stop the VR experience if needed.

They can also choose a specific environment to be run in the VR application. They base their selection on the needs and abilities of every patient. For further customisation of the experience, the physiotherapist can choose the speed of movement in the VR experience.

Figure 1.5: Schema of the PhysioTrails usage



Chapter 2

Interaction in VR

This thesis addresses the design of challenging mode interactions, making it crucial to discuss guidelines for such interactions in virtual reality. The issue of locomotion, which PhysioTrails VR also deals with, was covered in the author's bachelor's thesis. Additionally, this section discusses the challenges of gamification for the target group - elderly people.

2.1 Interaction Guidelines in VR

This section discusses the best practices for interaction design in VR. While these guidelines may overlap with conventional system guidelines, they reasons why certain interactions are better suited for VR.

It is particularly crucial to follow the guidelines for VR when designing a VR experience compared to other systems, since the user cannot simply look away from the system since they wear it on their head. Poorly designed VR can result in user frustration and even physical discomfort.[42]

2.1.1 Realistic Interactions

Jakob's law in UX design suggests that users will apply their knowledge and experience from similar systems they've used.[63] This implies that they expect the new system to behave similarly to others they are familiar with. By acknowledging this, designing a system conventionally and adhering to design guidelines for similar systems can result in intuitive interactions. Specific implementations of Jakob's law can include recognisable visual elements, maintaining consistency or intuitive interactions.[30]

Leveraging Jakob's law in VR design can be effective and beneficial. Since VR input systems offer a natural way to interact with the system, VR designers should ensure that the VR interactions comply with every day real interactions of the users.[42]

Paradoxically, the VR interactions do not need to be physically realistic. For example resizing objects using users' hands can still be a natural and intuitive interaction while not physically possible in the reality.[42]

One of the challenges related to realistic interactions in VR is the lack of haptic feedback the users get. While some of that can be compensated for with a special piece of hardware, such as haptic gloves,[56] interaction with virtual objects that in fact are not in the real world might always feel unnatural.[42] For example, conveying the weight of a carried virtual object to the user is difficult. The designer needs to compensate for the lack of haptic feedback with visual or audio cues,[56] such as slowing the movement of heavier objects or incorporating more resonant sounds for them.

2.1.2 Ergonomic Considerations

Physical comfort is another important aspect of designing VR interactions. Following ergonomic guidelines can significantly reduce discomfort and potential health issues. These issues may vary from minor discomfort to serious conditions like neck and shoulder strains, often due to extended VR equipment use without appropriate breaks or adjustments.[42]

Ergonomic guidelines recommend minimising large movements, avoiding the need for users to fully extend their arms, or frequently raise their arms above their shoulders.[42] Failure to incorporate these guidelines can lead to *gorilla arm*, a term used to describe arm fatigue from prolonged use of gestural interfaces.[42] The VR experience should also avoid requiring users to maintain hand poses for extended periods.[42]

2.1.3 VR Movement

Artificial movement in VR (movement of users' viewport without the user moving themselves in real world) leads to motion sickness.[42, 36, 46] Ideally, the user should not be moved at all in VR.[42, 36] Acceleration is in fact the leading cause of motion sickness, rather than the velocity of movement itself. For reduction of the occurrence of motion sickness, acceleration should be avoided, and the user should be snapped to constant velocity[42] or a compromise between extended acceleration of the movement and immediate snapping should be found, as snapping is unnatural.[36]

2.1.4 Gaze Cues

Providing the user with a feedback where their gaze is directed can be beneficial[36] for clarity purposes. The system can analyse where the user are looking and then modify its responses acordingly. This may have a positive effect for the immersiveness and the overall user experience.

Furthermore, a reticle can be placed at the user's gaze to serve as a visual marker without the need for analysis of their gaze, providing the user with an indication of their focal point. This can for instance aid the process of aiming when it comes to shooter games.[36] However, placing any larger elements permanently in the user's view in VR may overwhelm or even frustrate the user[42], or an option to turn off the reticles' visibility might be suitable.

2.1.5 Control of the viewport with Immediate Feedback

The system should allow the user complete control over the camera.[42, 36] This approach not only sustains the user's sense of immersion and control but also helps prevent motion sickness. Motion sickness can happen when the user's viewpoint shifts without their input.[42]

This is also linked to the the necessity of immediate feedback of the rendering system based on the user's control of the camera. When a user moves their head in VR, the system should react by appropriate movement of the user's viewport in the virtual world aiming for achieving the lowest latency possible. When current VR software development systems enable developers to use the VR headset's camera tracking features, saving them from having to implement such features themselves or deal with latency and rendering issues. However the developers should strive to optimise the VR experience in order to maintain the immediate feedback.

2.1.6 Compliance of Mapping

The system should allow for intuitive mappings between user's input and the system's feedback. For instance, moving a handle of a slider should correspond to the direction an element is moving.[42] The rate of moving does not have to be proportionate, for instance object can be scaled at a faster rate than what the user's input provide.[42] In VR, this can be beneficial for reducing the arm strain caused from extensive movement.

It can be useful to remember different cultural background of the users of the system. For example, users from Arabic cultures might be accustomed to opposite mappings to those of users from other parts of the world.[17, 45]

2.1.7 Hand Interactions

Hand tracking is a way of making VR more accessible to a wider user base. It caters to individuals who are unable or unwilling to navigate the complexities of interacting with controllers.[56] Interaction using hands is one of a few possible means of interaction with a system with close to no learning curve.[32]

Using hand tracking, the users can interact with objects naturally, in a way that mimics the real-world interactions[38, 49] the users are used to since young age. The virtual objects can be picked up, moved, dropped, thrown, or torn into pieces[56] in a very similar way as these interaction could be done in real life. The users can furthermore manipulate objects with a broad range of push, pinch, and grab interactions,[56] extending the interaction beyond real-life scenarios.

Gestures

Moreover, visual hand tracking capabilities enable different approaches on VR interactions in a form of hand gestures and poses. The advantages of using gestures is the absence of needing to incorporate abstract visual elements into an otherwise realistic virtual scene in order to trigger an event. Nevertheless, it presumes that there is a lower number of events that can be triggered, because of the capacity the user can and is comfortable to remember that number of gestures. Using gestures requires the users to recall what those specific gestures mean. However, some scenarios can enable the users to come out with the gestures naturally, such as a rock, paper and scissors game or a task of pointing at virtual objects in a scene. Nevertheless it is suggested to use the gestures sparingly.[56] The gestures work best when they trigger an action that is valuable and worth-learning to the users, such as triggering a system menu.[56] Moreover, using gestures can make more sense when they are used in systems that the users will be using for longer periods of time or repeatedly.[56]

Challenges

Drawbacks of using hand interactions include the system's lack of precision when it comes to hardware limitations. Using visual hand tracking systems that use cameras to identify the hands position and rotation in space and identifying gestures can lead to problems which occur when the lighting conditions are insufficient in the real life. Moreover, when the cameras do not have a clear view of the hands by either some objects occluding the hands or even the hands occluding one another by using a complex gesture, the tracking is also inaccurate.[56]

Some pieces of wearable hardware, such as trackable gloves or finger tracking rings can solve the mentioned tracking problems.[42, 22] However, the users are required to wear those intermediate devices, which can lead to reduced comfort, reduced immersiveness [62], performance or usability.[48]

2.2 General System Guidelines

2.2.1 Feedback and Responsiveness

The system should maintain constant communication with the users, providing them with timely and appropriate feedback regarding their interactions. This constant flow of information serves to keep users informed about the outcomes of their actions, and the status of ongoing processes. The feedback could be conveyed in various forms, including visual, auditory, or haptic cues.[42]

2.2.2 Recognition Rather Than Recall

The system should minimise the user's cognitive or memory load. This can be achieved by ensuring that objects, actions, and options within the user interface are clearly visible and easily accessible. The user should not have to remember information from one part of the system dialogue to another.[40]

The system should maintain consistency throughout its usage. Users should not have to hesitate whether different terminology, scenarios, or actions carry the same implications. [40] This consistency should extend across all aspects of the user interface, from the system interface elements to the functionality. It's important to comply with the established conventions of the platform being used.

2.2.3 Aesthetic and Minimalist Design

User interfaces should exclude irrelevant or rarely needed pieces of information. Adding extra piece of irrelevant information clutters the user interface and reduces the visibility of the relevant details.[40, 32]

2.2.4 Efficiency of Use

The system should accommodate both inexperienced and experienced users. This can be accomplished by enabling users to customise frequent actions and offering shortcuts to expedite interactions for expert users.[40]

The system should allows for errors from the user's side. The users should be allowed to have a straightforward way to go back from an unwanted action without needing to go through lenghty processes.[40]

2.2.5 Accessibility

Designs of a system should consider the varied abilities and limitations of the users to make the its usage universally accessible. This involves considering individuals with different physical capabilities, such as mobility issues or visual impairments, as well as those with diverse cognitive abilities.[40]

Virtual environments have the potential to be a more effective form of human-computer interaction. However, challenges exist in achieving precise interaction, and there is a need to develop natural forms of interaction for creating solutions to real-world problems.

Chapter 3

Gamification for Elderly People

When designing a system, it's crucial to identify the target user group, understand their characteristics, needs, and challenges. The system's behaviour should then be accommodated to meet these needs and address the identified challenges.

In popular belief, it's often assumed that modern pieces of technology are generally rejected by the older adults group. This suggests that system using such technology may never be fully adapted to meet the preferences of seniors. However, studies have demonstrated that seniors are indeed open to using modern technology.[58] This misconception may rise from the fact that seniors typically use systems not specifically designed for them.

The hesitation may result from the measure of ease of use of the input system. Direct input systems, such as tablets, might be more intuitive than indirect input devices like a mouse and keyboard. They could be more readily accepted as the touch gestures may feel more natural for the users.[58]

Virtual reality (VR), being increasingly utilised, provides interactions that closely mimic real-life experiences. This can potentially simplify the technology's use among the senior population[53, 37, 54]. VR systems have demonstrated good usability and acceptance among older people[55]. Furthermore, VR can provide stimulating experiences, relaxation, and evoke positive emotions, for elderly people.[37]

Despite another common perception that elders are often associated with a reluctance to play digital games, the use of digital games has proven to be beneficial in various aspects of elderly people's lives, including physical, cognitive, social and emotional.[23]

3.1 Characteristics of the Elderly User Group

The primary distinguishing factor of the elderly group is their age, which brings a multiple of unique characteristics that set this group apart. The characteristics are divided into physical, social and enjoynment categories.

3.1.1 Physical Aspects

Individuals of advanced age often encounter age-related changes that affect their daily life. Decreased mobility turns previously simple tasks such as walking into challenges, leading to dependence on other people, whether family members or retirement home staff.

Decline of physical condition not only restricts older people from moving around fully, but also greatly increases the risk of injury in conjunction with impaired balance. This issue is particularly significant with regard to the poorer recovery of the elderly.[12]

Impairment of movement and motor skills is not only related to physically demanding activities, but also to fine motor skills such as operating a telephone, sewing or opening a packaging.

Weakening of the senses and memory is another consequence of aging. Communication may be difficult due to vision and hearing loss, while memory and attention issues can cause forgetfulness or difficulty focusing. The effect of ageing cannot be reversed or eliminated completely, but its effects can be delayed or reduced. Technologies, especially new ones, such as VR, can be a useful complement to traditional methods of delaying ageing such as healthy living, exercise or medication.

3.1.2 Social Aspects

Greek philosopher Aristotle stated in his work, Politics, that "Man is by nature a social animal." The extent of this claim differs among individuals, meaning some people are more introverted, others are more extroverted. However, with few exceptions, it can be asserted that everyone requires some level of social interaction.

The elderly can be classified as the group that usually has the least social contact.[33] This can be explained by the fact that at a certain age people do not make as many new contacts, they may lose contacts with their peers, and it is often harder for elderly to participate in social gatherings as they may be less mobile or unable to use new telecommunication methods.

Due to these reasons, games containing social interaction are highly rated by older people.[57] Studies have shown that elders prefer social activities to individual ones.[57, 23]

Furthermore, elderly people's main motivation to play gamified applications is socialising. [23] Often, when older adults were asked about activities in their free time and the reasons why they do them, they frequently stated that the main motivation are their peers that also participate in those activities. The nature or type of the activity is of secondary importance.[57]

Research suggests that most older adults tend to avoid competition in games, favoring collaborative and caregiving experiences[23]. This avoidance can be attributed to a fear of failure or a preference for more leisure nature of activities. Thus, games designed for this user group should prioritise cooperation and teamwork over competition.

3.1.3 Enjoyment

Enjoyment is a key factor in motivation, but it varies significantly across different age groups.[43] However, age is not the sole influencer; other significant factors include gender and personality.[43]

Studies indicate that older people tend to prefer knowledge-based games such as puzzles, while fast-paced games like first-person shooters are not as popular in this age group.[26] This preference could be due to the general difficulty elders may experience with fine motor activities, leading them to prefer intellectual activities. Moreover, brain ageing, which involves a decline in brain tissue including areas responsible for dopamine production associated with motivation, could also contribute to this preference.[51]

Another aspect that needs to be taken into account is the lack of experience with digital games in most older people. For this reason, it is advisable to create simpler games without more complex mechanics and with faster delivery of rewards when tasks are completed.[26] This is further compounded by the lack of experience with technology, especially new technologies, such as VR.

Elderly users typically value past experiences and enjoy reminiscing.[39] A system or a game that can evoke these memories or include elements of nostalgia can be especially engaging for this age group.

3.2 Design Guidelines

This section provides the design guidelines for designing games or gamification elements to systems used by elderly target group.

3.2.1 User Research

Conducting early user research and exploratory user testing is an important step in understanding the needs of any target group. Applying this approach with the elders group, one of the less researched demographic, can ensure a better user experience.[57]

3.2.2 Accessibility and Simple Design

The user interfaces should be simple, assuring clarity. The interfaces should also be accommodated for limitations seniors may have, such as the provision of larger icons[35] or text-to-speech options for better accessibility.[58] Ease of use should be prioritised to make the gaming experience enjoyable and stress-free. Intuitive and easy-to-manage input devices, such as tablets should be used.[35, 58]

3.2.3 Feedback and Rewards

Immediate feedback and rewards should be provided to motivate continued play. The feedback should rather be positive, as it can significantly enhance the user's experience.[35, 58]

Whether to use badges and points should be carefully considered and supported by user research. They may be perceived as meaningless and could potentially pressure elderly users.[23]

3.2.4 Cognitive stimulation

Elements of cognitive stimulation are advised to be integrated into games to engage the minds of elderly players.[58]

3.2.5 Relevance and Familiarity

Games that are not only entertaining but also relevant to the interests of the elderly should be designed. Incorporating familiar themes to make the experience more engaging should be considered.[58] A variety of games could be offered to cater to different preferences.[58]

3.2.6 Adequate Level of Challenge

Rules and goals should be clearly established. The goals should not be overly challenging, there should be a balance maintained between challenge and enjoyment.[59, 35, 58] Casual games have been identified as possessing the necessary characteristics to provide an enjoyable user experience for the elderly.[59]

3.2.7 Social Interaction

Social interaction should be promoted by implementing multiplayer modes. This can establish a sense of community among the users.[35, 58]

Chapter 4

Measuring VR Movement

Patients that have been using PhysioTrails VR during the proprioceptive training, feel that the VR application has a beneficial effect, while physiotherapists have also observed an improvement in patients' performance during exercise and overall stability. However, to determine if these positive effects are due to the VR application and not by accident, proper testing should be conducted.

4.1 Evaluation of the impact of VR-enhanced balance training

The goal is to determine if the apparent movement in virtual reality causes patients to move on the platform. Seeing if the patients' head diverts from its initial position during the balance training should point at the fact that a patient is compensating for temporal instability on the balance platform.

Therefore, it is essential to systematically measure the patients' movement on the platform. This allows to evaluate how much the patients move overall and if it is on a significant level. The measurements can be taken during training with and without VR and compared later.

The movement measuring findings also enable to observe and track the long-term impact and effectiveness of the proprioceptive training by systematically analysing and seeing if individual patients move less on the balance platform.

4.2 Measuring VR Movement

The measurements can be performed with two different approaches, quantitative and qualitative measures. The section is further divided into quantitative and qualitative measures.

Quantitative measuring should provide more systematic methods suitable for evaluating larger quantities of training sessions, whereas the qualitative should provide a deeper analysis of individual training sessions.

4.3 Quantitative Measures

Possible ways of measuring participant's movement on the balance platform include the following methods.
VR Headset tracking

Utilise the built-in inertial measurement units (IMUs) of the VR headset to accurately record the position and rotation of the user's head. The position of head should be indicative of the participant's overall posture, since when the body is in stable upright posture, the head should be aligned with the spine in order to maintain stability. This approach, conveniently, does not require any additional piece of technology or hardware. On the other hand, in case of measuring the participants' training on the balance platform without VR, a different method needs to be used.

Balance platform IMUs

IMUs can be attached to the balance platform to detect accelerations and rotations. IMUs consist of accelerometers and gyroscopes[9], which can provide information about changes in tilt of the platform and therefore the changes in posture of the participant. In case of a horizontally oscillating balance platform, the changes in horizontal movement of a reference point should be measured instead.

Balance Platform Angle of Tilt

The tilt of the balance platform can be measured manually, using a video recording of the movement of the balance platform and the consecutive analysis. During the analysis of the video recording, a software protractor or automatic measuring tools can be used to establish the tilt of the balance platform. Similarily to the method of measuring the balance platform movement with IMUs attached to the platform, a horizontally oscillating platform requires defining a pivotal point to which the latter horizontal movement would be related. The relative distance of the pivotal point from itself in time can then be identified.

Pressure Sensors

Integrate pressure sensors into the balance platform to measure the distribution of forces exerted by the participant. These sensors can capture changes in weight distribution[11] as the participant responds to the VR motion.

Motion Capture

Attach motion capture markers on the participant's body. The system uses cameras to track the positions of the markers[10], enabling measurement of movements of the participant's limbs.

Electromyography

Utilise Electromyography (EMG) sensors to measure the electrical activity of muscles involved in maintaining balance.[6] The system enables to see the changes in muscle activity as the participant responds to the virtual movement.

4.3.1 Qualitative Measures

The qualitative measures should focus on aspects regarding the VR-enhanced balance training as a whole, such as the observable improvements in balance and stability or patient's subjective experience.

Observations Observing the balance training session, findings such as number of extensive body sways or number of falls could be tracked.

Balance Tests Participants' balance abilities and therefore improvements in stability

could assessed by conducting balance tests. Such tests could include for example the Single Leg Stance Test[4] or Tandem Gait Test[19].

Proprioceptive Tests Proprioceptive tests to evaluate proprioceptive performance, such

as joint position sense or postural sway measurements could be conducted to assess patients' proprioception and its development over time.

Subjective Findings Questionnaires or interviews could be used to collect self-reported

data from the patients regarding their perceived improvement in overall stability,

4.3.2 External Factors

External factors that might influence the participant's balance should be accounted for. A participant's fatigue, health conditions or medications are all factors that could hinder the findings of both the quantitative and qualitative methods used. This is especially important for longterm observation and evaluation.

4.4 Evaluation of the VR Movement

To be able to evaluate the participants' movement on the balance platform and whether VR contributes to the movement of the participants on the balance platform, the training data should be measured with and without the usage of VR during the training. Statistical tests should then be performed on the measured data to determine the significance of observed changes. It then can be establish whether the participants' movement on the balance platform during the VR experience are statistically different from the movement on the platform without VR.

4.4.1 Statistical Analysis

Statistical analysis is the process of collecting, analysing and presenting large volumes of data to identify trends, patterns, and insights.[13, 14] It should make the large volumes of data understandable to a general audience.[13] Statistical analysis usually comprises of the steps described below.

Error Checking

The measured data should be checked for any potential errors. This includes missing values, outliers, and inconsistencies. This initial step is important in ensuring the accuracy of the data.

Data Normalisation

Data should be normalised so that all the measurements are on the same scale and therefore comparable.

Hypothesis Definition

A research question should be defined first, and then a hypothesis about the data should be established based on that definition.

Variables Definition

Based on a specific research question, variables should be defined. These can be independent variables or dependent ones. Independent variables are the factors that are manipulated in an experiment.[24] In this case, the independent variable could be the use of VR during training sessions. Dependent variables are the outcomes or results that are measured in an experiment. In this context, the dependent variable could be the amount of movement of the participants on the balance platform.

Statistical Tests

A statistical test is a method for making quantitative decisions about a process, used to determine whether there is sufficient evidence to reject a hypothesis about the process. The appropriate statistical tests should be chosen based on the characteristics of the data, as well as the research question. The tests can help determine whether the observed changes in movement are statistically significant.

4.5 Visualisation

Visualisation techniques can complement with statistical analysis. They provide a way to uncover hidden patterns, anomalies, and relationships that might be otherwise obscured in tables of numbers. Additionally, visualisations can effectively communicate findings to diverse audiences, such as the physiotherapists.

The visualisation techniques are tightly related to the characteristics and amount of the visualised data. The characteristics of the data then results from the chosen method of measuring the participant's movement during the training on the balance platform.

Later during the design process of the updates of PhysioTrails VR, it was established that the movement data from the training shall be collected utilising the IMUs of the VR headset, as discussed in 4.3.

The measured data from the VR training is a three-dimensional data denoting the position of the participant's head in 3D space. For reaching the goal of determining the amount of movement of the head relatively to its starting position, charts allowing for such summary are preferred.

The later stages in design process and discussions with the physiotherapist pointed at the fact that one of the dimensions of the 3D data can be omitted.

There are numerous specific visualisation techniques. The suitable techniques might include scatter plots, enabling the depiction of the positional data in a form of point in 2D space. The position of the data point in the 2D space could correspond to the position of the participant's VR headset in front-to-back and left-to-right axes. The drawback of scatter plots include data points occlusion.[21] The heat maps, on the other hand, are robust to occlusion. Heat maps can depict the frequency of data points in defined ranges.[3] Other possible visualisation solutions might include line charts for visualisation of positional changes in time.

The determination of the used visualisation techniques for the evaluation was in the scope of the author of VR Dashboard, mentioned in 5.4.3

Chapter 5

Design

This chapter presents the design decisions related to the update of both PhysioTrails applications. It provides the reasoning behind those decisions considering the target user group and the design guidelines from the 2 to ensure a positive user experience. The design decisions were iteratively invented and checked with the physiotherapist from the Nová Slunečnice retirement home.

5.1 Target Group

There are two types of users of the system:

1. **Patient**: an elderly person performing the proprioceptive training using PhysioTrails VR

2. **Physiotherapist**: professional staff leading the proprioceptive training using PhysioTrails Mobile

The target group of the VR application are elderly people. The application is aimed to be used primarily at the retirement home, whose patients perform regular balance training with the Posturomed balance platform and PhysioTrails VR. The training sessions involve a small group between two to five patients and a physiotherapist as a coach leading the training. The patients perform various proprioceptive exercises one-by-one. While one patient is training, the other patients wait nearby. The patients usually chat during the training session with the physiotherapist and with each other. The currently performing balance training with VR are not entirely immersed in the virtual experience, maintaining some connection with the real world through their interactions with the physiotherapist and other patients.

The elders are of age roughly past the 70. Some degree of decline of mobility abilities is likely to have occurred with the patients, but they remain mobile - either by walking independently or using supportive devices such as a walking stick or a cart. The users are not expected to have a significant amount of technical knowledge and deep experience with advanced computer user interfaces. Some patients in the retirement home have some basic experience with using VR.

The design process should acclimate for users with reduced mobility or cognitive abilities and close to no technical skills. It should also count with the fact that the patients are balancing on the unstable platform while using the system. It is welcomed for the system to encourage social interaction between the patients in the training group.

The target group of the mobile application is a physiotherapist or generally professional staff leading the proprioceptive training. The physiotherapist is in charge of the training session, leading the group of patients to perform exercises. The physiotherapist guides each individual through a series of proprioceptive training exercises, which includes Posturomed balance training with PhysioTrails VR. During patient training on Posturomed, the physiotherapist uses a mobile application to oversee and manage the VR experience. They also provide occasional support to patients who may lose balance.

The design should consequently strive to make the interaction with the mobile application as straightforward as possible.

The physiotherapist is expected to have basic experience with using mobile applications. Also, the physiotherapist of the Nová Slunečnice retirement home is expected to have experience with using PhysioTrails Mobile. With that fact, onboarding or tutorial UI features may not be of significant importance. Instead, the emphasis should be placed on the efficiency of the interaction.

5.2 Active Mode

The current training method involved solely a movement-visualising experience where the user watches the changes in a virtual landscape. These changes seem to sufficiently cause the users to implicitly change their posture on the balance platform. However, a mode for active training was decided to be added.

The active mode is meant to require the patients to actively perform various body sways. This should theoretically cause the patients to move more on the balance platform and therefore pose a challenge for the patients to keep balance. The active mode also requires the patients to at least partially stop holding the railings of the balance platform. Moreover, it should make the patients react to unexpected situations, therefore train for the real-life unexpected events.

The active mode enhances the training with gamifying elements. These elements can pose an interesting upgrade for the training. It may help reduce the repetitiveness of the regular training and create an activity that the patients enjoys doing. The mode also provides a way of quantifying the performance of the patients. With computing a score with each activity, the score then can be easily compared to other scores of the past activities and a progress of the patient in time can be estimated.

5.2.1 Functional Requirements

The functional requirements of the active mode are the following.

1. Patients perform the active mode in the movement-visualising experience
2. The active mode requires the patients to actively do body sways
3. The active mode allows for symmetrical training of the body, e.g.: the active mode should allow for training both hands
4. The active mode should not be a required part of the training, so it should be possible to perform the balance training without the active mode
5. The active mode should present a quantification of the patient's performance in a form of a score number
6. The system should allow therapists to adjust the difficulty levels of the active mode
7. The active mode elements should be generated randomly

5.2.2 Qualitative Requirements

1. The active mode should consider the limited mobility abilities of the patients
2. The active mode should prioritise safety on the balance platform
3. Preferably, the active mode objects should be of a diegetic nature, meaning they appear as if they naturally belong to the environment[2]

5.2.3 Active Mode Challenges

This section outlines the specific challenges incorporated into the VR training. Each challenge is designed to engage different parts of the body and requires varying levels of activity. Each challenge also offers some extent of scalability of its difficulty, making it adjustable for different needs of the individual patients. The challenges are designed to propose ideal level between training effectiveness and safety. The body movements that the challenges require should be significant but not too excessive, so that it does pose the danger of falling on the balance platform. **Wire Loop**

The Wire Loop challenge is inspired by the classic game of the same name where the users are required to thread a hoop through a wire without touching the wire. Similarly, in the Wire Loop active mode challenge, a wire-like object appears in the virtual world, tracing along the trail the user travels in the VR experience. The user must hold a virtual hoop until they get to the scene destination without the hoop making contact with the wire object.

This exercise aims to train the patients' overall stability. Significant body sways might cause the patients to touch the wire with the hoop or to drop the hoop entirely. Therefore, the patients should strive to maintain a stable posture throughout the entire exercise.

The rationale behind designing this challenge with threading a hoop through a wire is mainly due to safety reasons. The hoop threaded through the wire should comfort the user that nothing is about to fall on the ground if they accidentally drop the object. Sudden falling of the object from their hands could cause the patient to startle and perhaps stagger on the balance platform.

Figure 5.1: The Wire Loop Interaction

If the user makes contact with the wire using the hoop, a sound alert is activated to notify them of the collision. In addition, the hoop undergoes a visual transformation, lighting up in an attention-grabbing colour. Once the user moves the hoop away from the wire, the warning colours stop illuminating, indicating a successful course correction. If the user loses grip on the hoop, the hoop is automatically snapped back to a position outside of the collision area. From there, the user is able to reach for the hoop again.

The score is calculated based on the duration the user holds the hoop and the number of collisions with the wire.

The difficulty of the Wire Loop challenge can be adjusted by altering the diameter of the hoop. Patients can train at three difficulty levels, with the highest level featuring the smallest diameter hoop. Moreover, adjusting the speed of the user's movement in the virtual scene can also alter the dificulty level of the challenge.

Object Finding

The Object Finding challenge tasks patients with finding specific items within a virtual scene and pointing at them once located. The challenge encourages arm movement, as far as the patient is comfortable, while also prompting the patient to actively explore the virtual scene. This could potentially enhance movement on the balance platform.

In addition to physical benefits, this challenge also aims to train the patient's cognitive abilities and perhaps incorporate an educational aspect to the active mode. Patients are required to recognise specific object types.

To interact with the virtual environment, patients perform a pointing gesture with their hands, triggering a laser pointer for more precise aiming and object selection. Once an object is chosen, it is highlighted with colours to indicate whether the selection was correct based on the given assignment.

Figure 5.2: The Object Finding Challenge

The hand gesture is used to initiate the selection process to prevent cluttering the user's viewport and accidental object selection when not actively performing the selection. The pointing gesture should mimic the way it's commonly used in real life to make it intuitive for users when pointing at objects. User testing should be conducted to determine the suitability of the gesture and assess the headset's hand tracking capabilities for accurate gesture recognition.

The objects that patients need to find are randomly generated within the virtual scenes. Every iteration of the challenge features a random subset of spawn points, which are each populated with a random object type.

Mushrooms posed the topic of previous training sessions. Patients discussed the types of mushrooms they recognized, whether they could identify those in the virtual scene, and if they were edible. As a result, mushrooms were included in the object finding challenge. The user decides if the task involves searching for edible, inedible, or poisonous mushrooms in the virtual scene.

To maintain the diegetic aspect, ensuring that the objects fit into the virtual winter scene, different types of objects were required for this challenge. It was suggested to use animal footprints in the snow. Users would be tasked with identifying whether the footprints belong to carnivorous, omnivorous, or herbivorous animals.

The difficulty of the Object Finding challenge can be adjusted based on the number of objects present in the scene. The challenge offers three levels of difficulty.

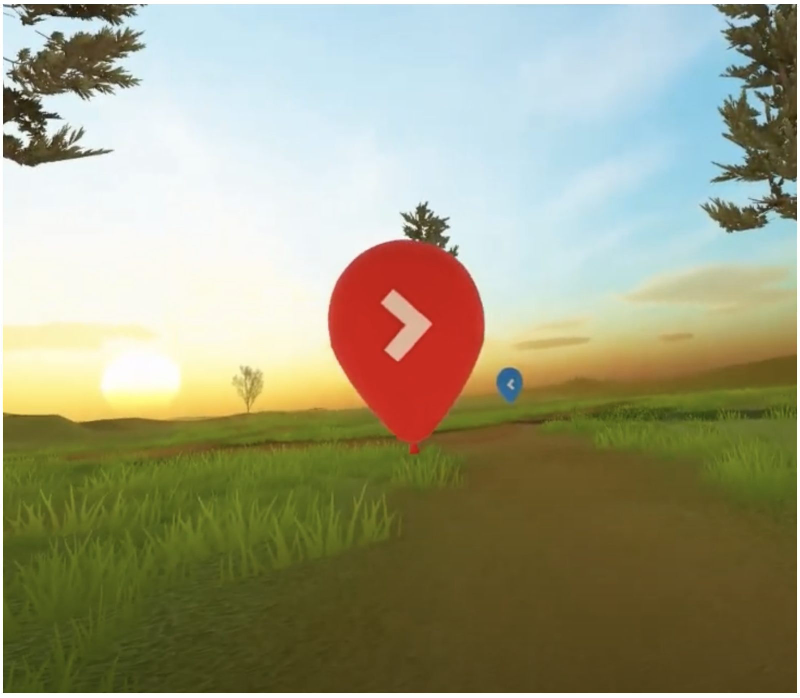
Avoiding Obstacles

The Avoiding Obstacles challenge involves patients avoiding obstacles within their path in the virtual scene. These obstacles are placed near the patient's headspace, allowing them to dodge them by simply leaning to the side instead of stepping aside on the balance platform.

There are two types of obstacles, each indicating the direction the patient should lean to avoid them. The intended avoidance direction is color-coded, and there are optional arrow symbols to clearly show the direction. This feature can be turned off to make the exercise more cognitively challenging.

Similarly to the Object Finding challenge, these obstacles appear at random points throughout the scene, and the avoidance direction at each spawn point is also random. Obstacles are spawned ahead of the user's arrival at the spawn location, ensuring the user has sufficient time to identify the obstacle and react accordingly.

Figure 5.3: The Avoid Obstacles Challenge



The obstacle objects were designed to appear harmless to prevent patients from feeling they might get hurt if they fail to dodge them. For this reason, models of plastic balloons were used as users can easily identify them as harmless. If a patient fails to dodge a balloon, it animates to simulate deflation.

This challenge offers three levels of difficulty, each determined by the number of obstacle spawn points in the virtual scene. The user's movement speed can also moderate the difficulty level.

5.3 UX Design

5.3.1 Score and Reward System

There was hesitation over whether to display the score number of their performance in the active mode to the patients. The score number could be too abstract for the elderly users not being used to score computing from computer games, as mentioned in 3.1.3 Furthermore, research from 3.1.2 also showed that elders are not very competitive among each other but rather see their personal progress. The design iterations with the physiotherapist however pointed at the fact that the patients are indeed competitive and that healthy competition could motivate the patients. It was decided that the application should make possible for the users to see their scores but the visual could also be turned off. The score number is however pushed to the patient management application.

5.4 User Progress Estimation

The PhysioTrails application has been in use at the Nová Slunečnice retirement home for over two years (as of the date 1.1.2024). Over this period, the physiotherapist has observed an improvement in the patients' stability, potentially due to regular proprioceptive training sessions with the PhysioTrails VR. The patients are generally more stable, and their comfort with moving at increased speed has grown. However, these observations are not concrete data that prove the efficacy of VR balance exercises as a method of proprioceptive training, nor that patient progress has increased. A method for data collection, storage, and analysis needs to be established.

5.4.1 Data Collection

The score number can be a suitable metric for quantifying the patients' performance from the training with the active mode. The score can be compared to scores from past trainings and therefore it is possible to establish the patient's progress over period of time. The score is however exclusive to the active mode and cannot be used for the training without the active mode.

Moreover, while the score rather provides information about the patient's performance in the scope of the game, it doesn't definitively reflect their stability on the balance platform.

Therefore, some method of measuring the patient's stability is required.

For PhysioTrails VR, it was decided to measure and utilise the position of the patient's headset on the balance platform. The position of head should be indicative of the participant's overall posture. If the head position stays relatively near the center point of the balance platform throughout the balance training, then the patient is presumably stable. Contrarily, significant headset movement towards the sides of the balance platform may indicate stability problems.

This approach utilises the built-in inertial measurement units of the VR headset and therefore does not require any additional piece of technology or hardware.

5.4.2 Data Analysis

The design and implementation of the data analysis was in the scope of student Leoš Řeháček's master's thesis.

To estimate a patient's progress, it's necessary to view and analyse the headset measurement data. From the analysis in Chapter 2 and consultations with the physiotherapist, it was decided to use a heat map chart for visualising the patient's head position. It provides an effective way of visualising data with a portion of data points concentrated in one area. It appears sufficient to use only the x (left-to-right) and z (front-to-back) coordinates of the 3D space, providing a top-down view of the patient's head.

A system is needed to store the data of multiple patients, allowing for viewing and comparison of measurement data over time to track progress. A suitable solution is an application that serves as a user management system for physiotherapists. This application should enable physiotherapists to manage patient profiles and training sessions. It should provide an overview of each patient's overall training progress, enabling the physiotherapist to evaluate their performance over time.

The consultation with the physiotherapist showed the following requirements:

1. The physiotherapist is able to create, view, update and delete patient profiles
2. The physiotherapist is able to visualise patient's training session data from PhysioTrails VR (VR training)
3. The physiotherapist is able to compare the VR training data with the data from the past training sessions of one patient
4. The physiotherapist is able to view metadata about a specific VR training session:
    (a) name of virtual scene used for the VR training

   (b) duration of the VR training session
   (c) patient who performed VR training
   (d) patient's score of active mode VR training
   (e) date of VR training

5. The physiotherapist is able to identify terrain features or events in the virtual scene that may affect patient's stability during the VR training

6. The physiotherapist is able to create, view, update and delete a custom note regarding a specific training session

7. The system should not store personal data of the patients that could directly identify the patients

5.4.3 VR Dashboard

VR Dashboard is a collection of a web application and supporting packages, created by a Czech Technical University student Leoš Řeháček. It is designed to accustom for the mentioned requirements while working together with the PhysioTrails applications. Its design process incorporated the author of this thesis and the physiotherapist in order to provide an effective mean of communication between the systems and contain the functionality needed by the end user.

Chapter 6

Implementation

This chapter outlines the steps taken to update the PhysioTrails applications. The objectives were to add a new challenging mode to encourage patients to be more active during balance training, and to implement tracking of the balance training sessions using VR Dashboard. This system, developed by CTU student Leoš Řeháček, manages patients and collects spatial data from VR experiences.

6.1 Technology Stack

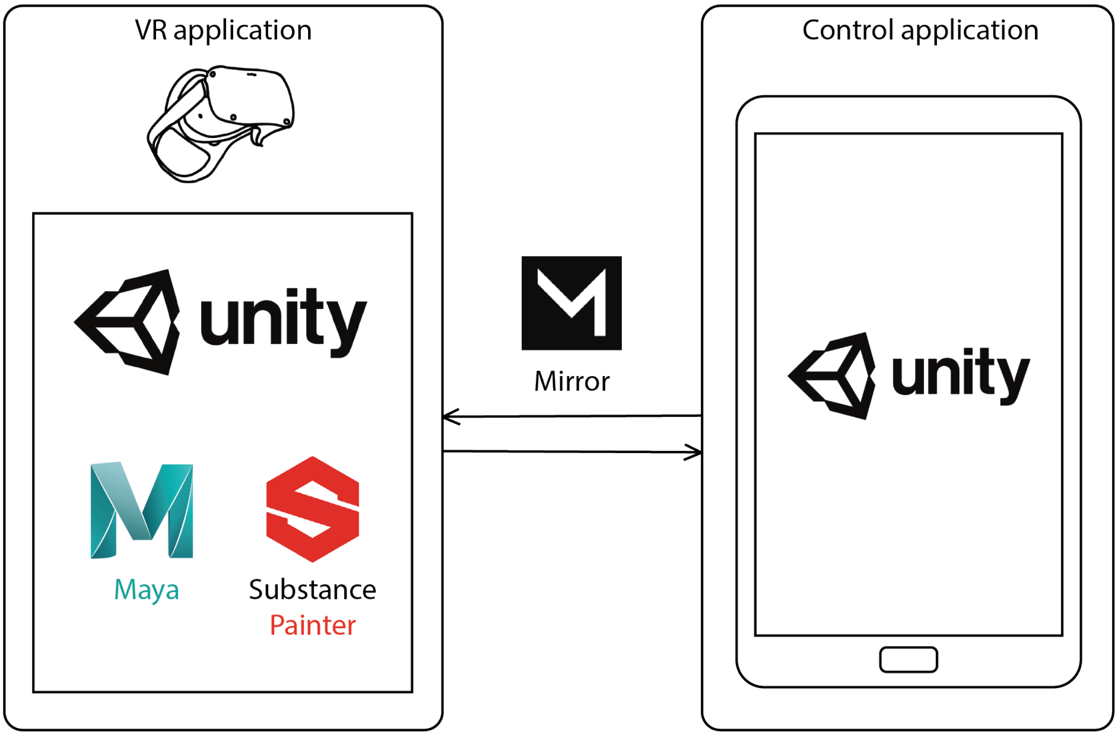
This section briefly presents the technology stack of both PhysioTrails applications. More detailed information about the technology used and the implementation process of the PhysioTrials applications can be read at the author's Bachelor's thesis.[46]

PhysioTrails VR was developed for the *Meta Quest* standalone VR headsets. PhysioTrails mobile was developed for mobile Android devices.

The applications were developed using the *Unity* engine, a platform for creating games, enabling their development for various platforms.[15] Both PhysioTrails VR and PhysioTrails mobile were created as a single Unity project, enabling an effective way of communication between the applications.

The communication between the applications, enabling the control of the VR experience from the mobile app and mirroring the view of the patient from the VR experience into the mobile application was achieved with a client-server communication over *Local Area Network*. Local Area Network (LAN) can be defined as a collection of interconnected devices located in a single location over a computer network.[20] For applications to communicate via LAN, the devices the applications run on must be connected to the same network, often established through Wi-Fi. The network communication was achieved with *Mirror*, a Unity framework for network communication and multiplayer systems.

Figure 6.1: System architecture and used technologies



6.2 Active Mode

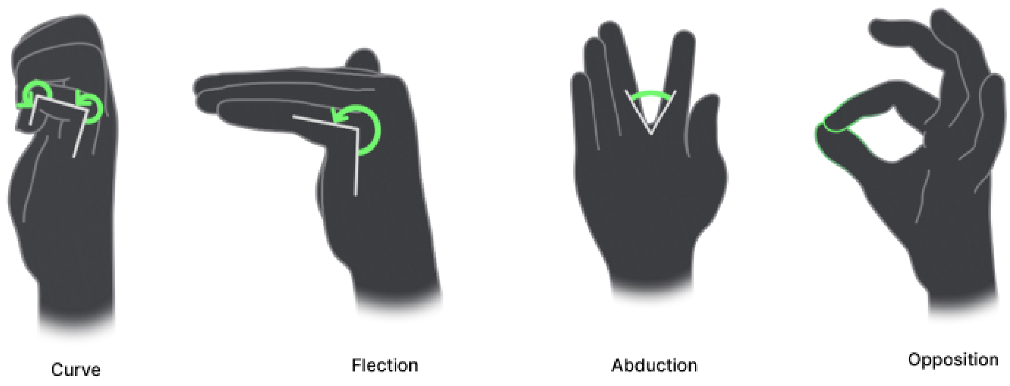
This section details the steps taken to incorporate the challenging mode into PhysioTrails VR. As the application was originally designed with hand tracking functionality, the recent updates have maintained this input option. The requirements for the challenging mode, defined in 5.2.1, were implemented, with the exception of the score number, which is implemented only partially, due to time constraints.

Hand Tracking

As the target devices of PhysioTrails VR are the *Meta Quest* platform (former Oculus), the *Oculus XR Plugin* for Unity was used for display and input support on the Meta devices. Furthermore, the *Interaction SDK*, a library for adding interactions for controllers and hands to VR experiences was used.

The Interaction SDK allows for defining custom hand gestures for the system to recognise. This is achieved by setting the recognisable transform denoting the orientation of the hand and then the configuration of each finger's features in terms of *Curl*, *Flexion*, *Abduction* and *Opposition*.

Figure 6.2: The figure depicts the gesture features of textitCurl, Flexion, Abduction and *Opposition*



PhysioTrails VR currently support three different gestures for its interactions:

1. **Pinch gesture:** for selecting UI elements and calibration of the VR cart to the Posturomed balance platform. Pinch gesture is detected when a user is snapping the index finger with the thumb
2. **Pointing gesture:** for pointing at mushrooms during the Object finding active mode challenge. Pointing gesture is detected when a user curves all the fingers, except for the index finger, which is extended.
3. **Stop gesture:** for escaping the VR training scene to the main lobby. The stop gesture is recognised when all fingers are fully extended with the palm of the hand facing forward.

These gestures aim to minimise the use of user interfaces, providing greater comfort for the elderly target group by eliminating the need to aim at interfaces and select with pinch.

Three gestures were considered sufficient for the VR interaction guidelines, as discussed in 2.1.7. However, hand tracking accuracy is still considered somewhat limited, particularly in poor lighting conditions or when the hands are occluded. The use of the pointing gesture in the Object finding challenge was found problematic, as noted during user testing.

Linking PhysioTrails VR and PhysioTrails Mobile

The active mode was linked to PhysioTrails Mobile via the Mirror framework. The information about selecting a specific challenge of active mode and its settings is passed in a form of Mirror's *SyncVar* and synced between the VR and mobile applications. This enables selecting the challenges for VR from the mobile application.

The complete synchronisation of the course of active mode challenges between VR application and mobile application however was not entirely achieved. Due to time constraints, the mirrored view of the VR user's viewport inside the mobile application currently does not display the hoop in the wire loop interaction, nor the user's hands picking mushrooms.

6.3 Linking VR Dashboard to PhysioTrails

The VR Dashboard provides a way of storing, analysing and presenting the data from patient's tracking session. *VRLogger*, a supportive Unity package for VR Dashboard created by the author of VR Dashboard, was integrated into PhysioTrails VR. VRLogger collects the data about position and rotation of the VR headset and hands in time during the balance training. The tracking is started once the patient is teleported into VR landscape scene and it ends once they leave the scene to the lobby.

Additional data regarding the landscape scene is gathered inside PhysioTrails, passed to the VRLogger and then synced to the VR Dashboard. This data is in the form of events depicting the presence of a bend, terrain bump, an encounter with animals or other important milestones of the landscape scene. These events are then visualised in the VR Dashboard charts, enabling to identify possible spikes of disrupted balance at these events.

In addition to the fixed landscape scene triggers, events concerning the interaction mode are also sent. These events pass information about a collision within the WireLoop interaction, picked mushroom or collisions with obstacles.

Chapter 7

Evaluation

This chapter describes the evaluation process of the PhysioTails applications along with the methods used to assess the gain of using the VR-enhanced balance training. It was decided to asses the advantage in two aspects: effectiveness and enjoyment.

7.1 Testing of Effectiveness of VR Training

The goal was to determine whether participants move more on the balance platform when they perceive apparent movement in VR. Testing was conducted in two groups: static and dynamic. Participants in the static group were asked to stand on the balance platform while using PhysioTrails VR with a static scene. Here, the participant remained stationary in the Forest scene within VR. For the dynamic group, the VR scene was set to move the participant virtually through the landscape, in the same way that is the usual balance training done. The Forest scene was also used for the dynamic group.

Both groups conducted three-minute tests in the scene, tracking the positional data of their VR headsets.

For collecting the data, the VR Dashboard was used. Positional data of the participant's head during the testing was then analysed.

Participants

The effectiveness of the VR-enhanced balance training was tested with only three participants. This is a major shortcoming, as the sample size is not large enough to draw significant conclusions.

Balance Platform

The effectiveness of the VR-enhanced balance training was tested using the Fitdisc balance platform.[18] It consists of a board situated on springs changing the tilt of the unstable surface. For consistency reasons, it would be better to use the Posturomed balance platform, as this is the platform used at the retirement home and the application was developed for Posturomed specifically.

Figure 7.1: The Fitdisc balance platform [18]

Overview of the Positional Data

Figure 7.2: The line graph depicting the course of the testing for the static group

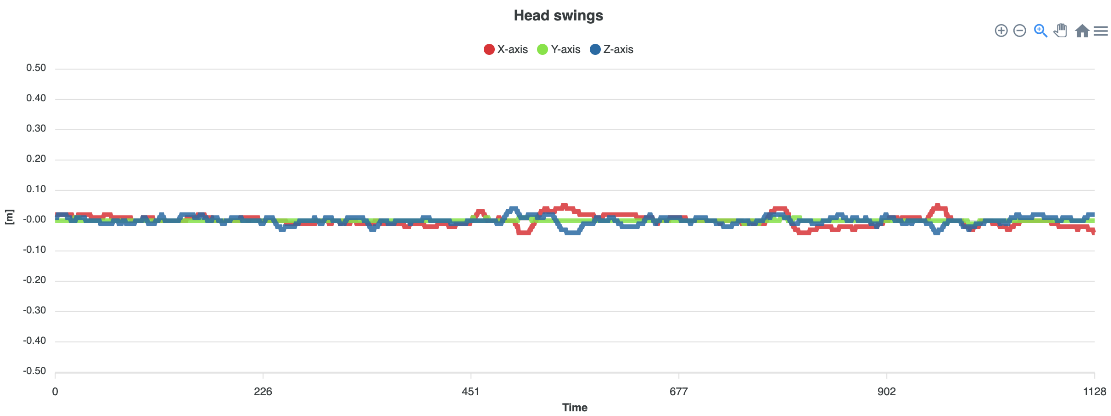
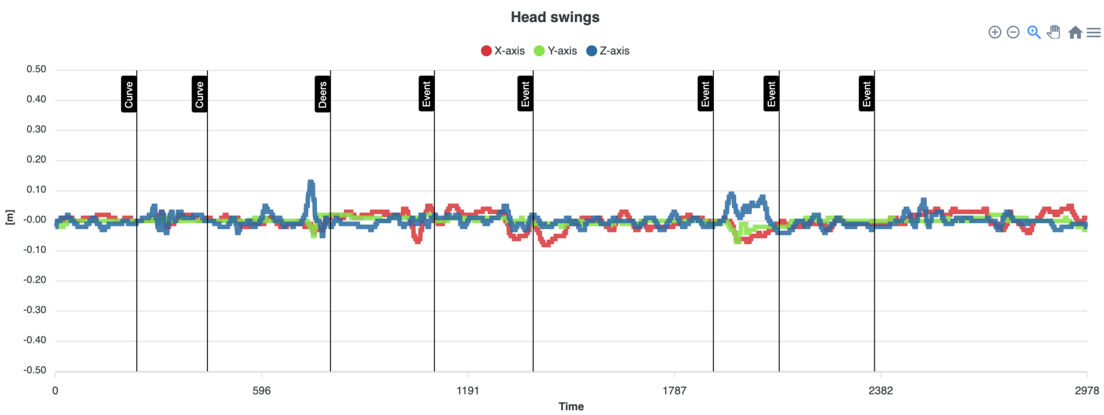


Figure 7.3: The line graph depicting the course of the testing for the dynamic group



Looking at the visualisations at 7.2 and 7.3 of the VR headset position from VR Dashboard, it can be observed that the dynamic group seems to have more variability in the head position on the front-to-back (Z) axis and left-to-right (X) axis in the form of spikes on the line graph.

Figure 7.4: The line graph depicting the course of the testing for the static group

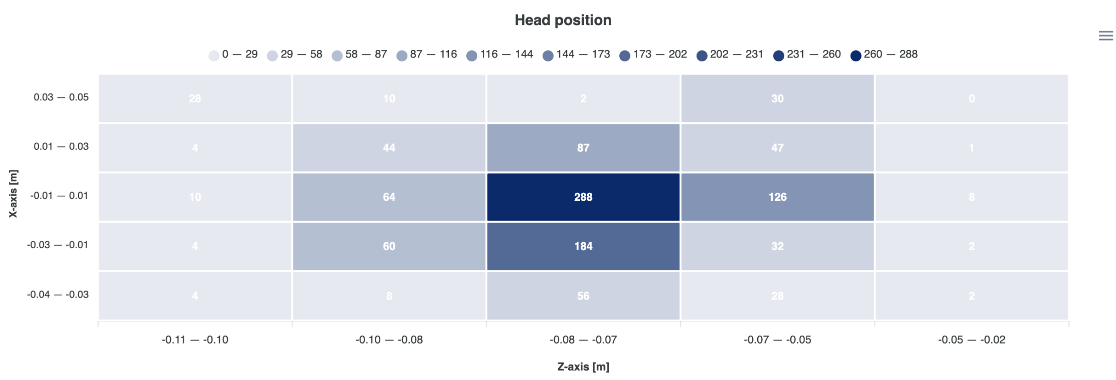
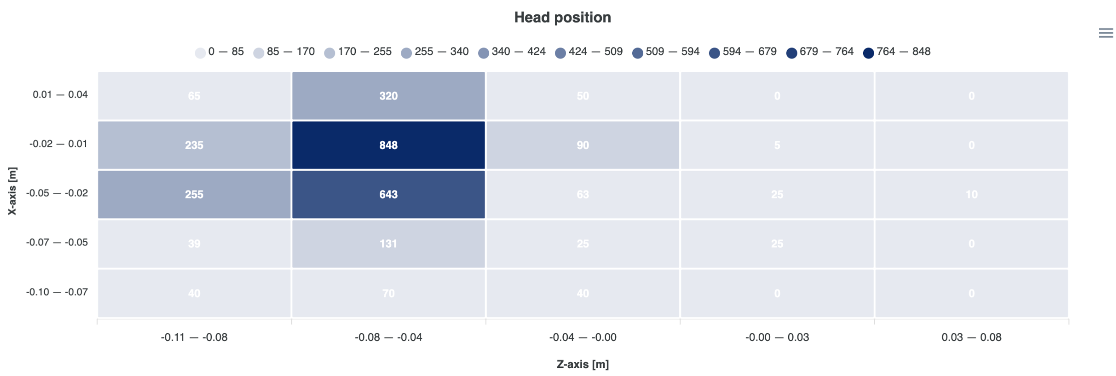


Figure 7.5: The line graph depicting the course of the testing for the dynamic group



Observing the heat map graph at 7.4 and 7.5, on the other hand, does not give promising differences at first glance.

7.2 Statistical Analysis

In order to determine which group moves more on the balance platform, the spread of the data positional data of the VR headset was decided to be calculated. The vertical axis of the positional data was omitted. This should determine how much the position varies in each group and compare those values. Eventually, the range, variance and standard deviations were established.

Range

Range denotes measure of the spread of a set of values. It is defined as the difference between the highest and lowest values in the data set.

Variance

Variance measures how far is each number in the set from the mean and thus from every other number in the set.[16]

- The variance of the dynamic group: *0.001387861*

- The variance of the static group: *0.001266786*

These values are quite close, suggesting that the spread of data around the mean is similar for both groups. However, the dynamic group shows a slightly higher variance.

Standard Deviation

Standard deviation is the square root of the variance. It is a measure of the amount of variation in a set of values. It is usually more commonly used than variance, as it is expressed in the same units as the data, making it more interpretable.[16]

- The standard deviation for the dynamic group: *0.03725401*

- The standard deviation for the static group: *0.03559193*

Similarly to variance, the standard deviations of both groups are similar, with the dynamic group having a slightly higher standard deviation. This aligns with the variance results and indicates that the dynamic group's data points are, on average, slightly more spread out from the mean than those in the static group.

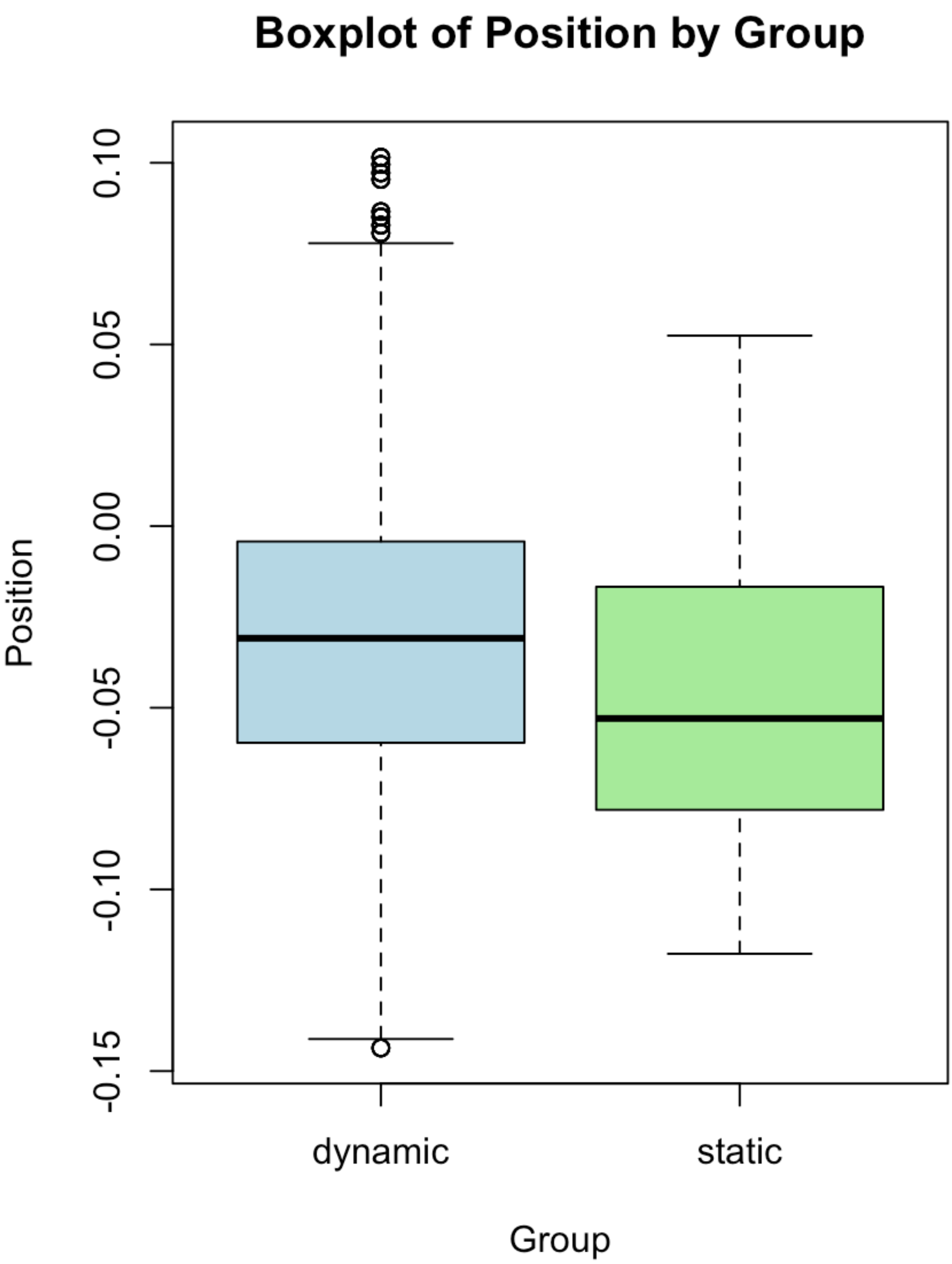
F-test

F-test for equality of variances is a statistical test used to compare the variances of two data sets to determine if they are significantly different. The null hypothesis is defined that the both variances are the same.[44]

The F-test resulted in an F value of *1.0956*, with a very low p-value (*7.248e-08*). This suggests that the variances of the two groups are significantly different, with the dynamic group having a slightly higher variance.

The boxplot depicts the distribution of the positional data for each group, highlighting the medians, quartiles, and outliers.

Figure 7.6: The boxplot depicting the distribution of data for both groups



7.3 Testing of Enjoyment of VR Training

The aspect of enjoyment is considered a valuable part of the benefits of the VR-enhanced training.

A notable aspect for most of the target group was their limited experience with computer games and likely no experience with VR. The majority of users reacted positively to the environment, particularly enjoying the immersion into positive surroundings. Participants specifically mentioned the sensation of being transported to a different world and exploring three unique environments as their favourite feature of PhysioTrails. Many users showed signs of nostalgia, recalling their own experiences in similar environments.

Nostalgia is associated with multiple benefits that improve a person's psychological state. Firstly, it reduces the amount of negative emotions, reduces stress that can cause back pain, headaches, digestive problems or problems with concentration. Also, nostalgia can cause individuals to regain certain values that they had at the time to which nostalgia refers.[25]

Dynamic scene elements in the form of animals were also positively evaluated as they increased the realism of the simulation for users. The animals, especially the deers, in the Forest scene evoked the most emotions among the participants. This fact can be explained by the fact that humans generally have a pleasant feeling when they see animals, especially those that are not threatening and are pleasing in appearance.[34] Despite this fact, more dangerous animals such as the wild boar caused mostly positive reactions.

7.3.1 User Testing

Prior to engaging in the testing of PhysioTrails VR, it was verified that none of the participants suffered from physical conditions which would place them at risk when participating in the testing. All the participants were made aware of the symptoms of motion sickness and informed they could pause or end the testing in case discomfort occurred. They all gave consent for analysing anonymously the tracked headset data from the VR experience and the findings from the user testing.

Findings

The user testing of both applications pointed at implementation flaws and deficiencies in used technology. However, none of them were severe enough to significantly affect usability of the applications. Majority of the shortcomings were related to the deficiency of the hand tracking capabilities. The VR application's gesture detection capabilities sometimes lacked the required precision. The railings of the Posturomed balance platform also occasionally obstructed the tracking of the hands and gesture detection. This required the participants to raise their arms above the waist for clear hand view and gesture recognition by the cameras. Although this specific shortcoming could be seen as a feature of the challenging mode, encouraging participants to be more active with their arm movements, inconsistencies in hand tracking hinders the user experience.

Some problems were related to the UI of the applications, making the participants question whether they had already performed certain actions or not. The physiotherapist also wanted more variation in the course of the wire in the Wire Loop challenge.

The design decisions for the applications were accepted to the full extent. The ideas of the challenging mode were appreciated. The used hand gestures were intuitive, easy to perform and memorable. The visual of the interactable objects added for the challenging mode was appreciated as both well integrated into the environment and distinct enough to be clearly interactable.

The end user of the mobile application is a physician who leads balance training. The app was tested with the physiotherapist from the Nová Slunečnice retirement home, who also consulted on the design process. The user testing scenario was conducted to mirror the process that the physiotherapist typically follows when conducting balance training with VR.

Conclusion

The author feels that the main goals of the thesis were fulfilled, but only to a limited extent. Due to time constraints, the implementation part of the thesis was not completed to its full potential, mainly in the development of the Active mode and its synchronisation with the mobile application. However, the author feels that the implemented parts could serve as a proof of concept with potential for further development and elaboration. The evaluation of the benefits of the VR-enhanced training was also deficient, due to the small sample size of participants. The testing results hinted that the perception of apparent movement in VR causes more movement of the patients on the balance platform. Still, the limited testing conditions also have to be taken into consideration. The application was integrated with the VR Dashboard patient management system, enabling the continuous collection of balance training-related data in a long-term perspective.

The author would like to continue the works on the PhysioTrails applications, as space for improvement can be seen, together with the willingness of the retirement home to keep improving the experience for their patients. The author considers the greatest achievement of the thesis to be the positive evaluations from both VR app users and the physiotherapist and that the application has found a real use in the Nová Slunečnice retirement home.

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Appendix A

User Manual

A.1 PhysioTrails VR

A.1.1 Installation

1. **Navigate to the GitHub Repository:** Open the PhysioTrails GitHub repository on this link: `https://github.com/marketamachova/PhysioTrails`
2. **Access the Releases Section:** In the repository, locate the Releases section near the top of the repository page.
3. **Find the Latest Release:** Look for the latest release in the list of releases. Download the release APK file for the PhysioTrails VR application.
4. Open SideQuest or other software for loading data into Oculus Quest devices.
5. Drag and drop *physioTrails-vr.apk* file from the Builds folder into the SideQuest application window and wait until the transfering process finishes.
6. Put on the Oculus Quest headset.
7. Enable hand tracking by navigating to *Settings/Devices/Hands and Controllers/Hand Tracking*.

A.1.2 Start the Application

1. **App Installation:** Follow the instructions outlined in the Installation Manual
2. **Connect the Quest Device to the Network:** Make sure your Quest device is connected to a stable Wi-Fi network. Access the device settings and connect to your preferred Wi-Fi network.
3. **Open Unknown Sources:** Enable the option to install applications from unknown sources on your Quest device. This option should be found in the device settings under Developer Options. Locate the VR application by navigating to the Application menu. Open the option *Unknown Sources*.
4. **Open PhysioTrails VR:** Launch the PhysioTrails application by selecting it from the list of installed applications.

A.1.3 Required Hardware

- Meta Quest device
- USB-C cable supporting data transfer

A.1.4 Required Software

- SideQuest - available for download at `https://sidequestvr.com/setup-howto` or other software for loading APK files into Oculus Quest devices

A.2 PhysioTrails Mobile

A.2.1 Installation

1. **Navigate to the GitHub Repository:** Open the PhysioTrails GitHub repository on this link: `https://github.com/marketamachova/PhysioTrail`
2. **Access the Releases Section:** In the repository, locate the Releases section near the top of the repository page.
3. **Find the Latest Release:** Look for the latest release in the list of releases. Download the release APK file for the PhysioTrails Mobile application.
4. **Install the Application:** Install the application through Android installation manager.

A.2.2 Start the Application

1. **App Installation:** Follow the instructions outlined in the Installation Manual
2. **Connect the Device to the Network:** Make sure your Android device is connected to a stable Wi-Fi network. Access the device settings and connect to your preferred Wi-Fi network.
3. **Open PhysioTrails Mobile:** Launch the PhysioTrails application by selecting it from the list of installed applications.

A.2.3 Required Hardware

- Android mobile device with Android OS 6 or above
- A cable for data transfer corresponding with the above Android device

A.2.4 Required Software

- Android File Transfer, or other software for loading APK files into Android mobile devices

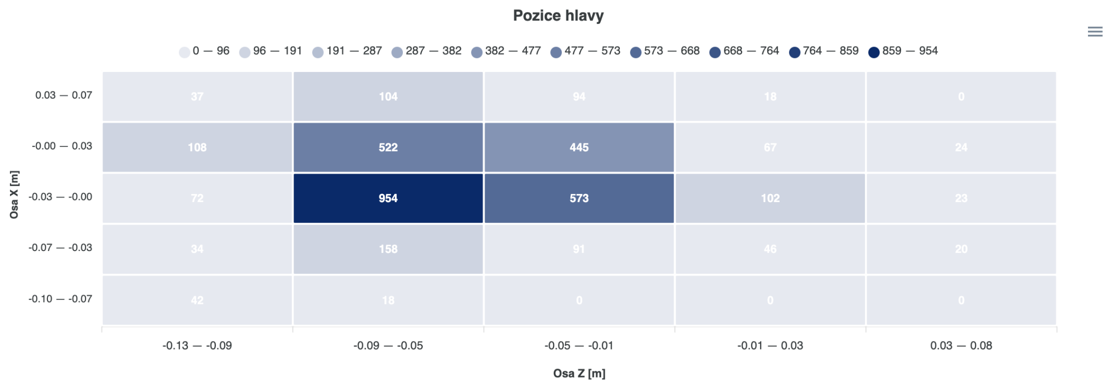
Appendix B

Testing of Effectiveness of VR Training Data

The following figures depict the graphs from the VR Dashboard generated during the testing of the static and dynamic group.

Figure B.1: The graphs depicting the course of the testing for the dynamic group (Participant 1)

Figure B.2: The graphs depicting the course of the testing for the dynamic group (Participant 2)



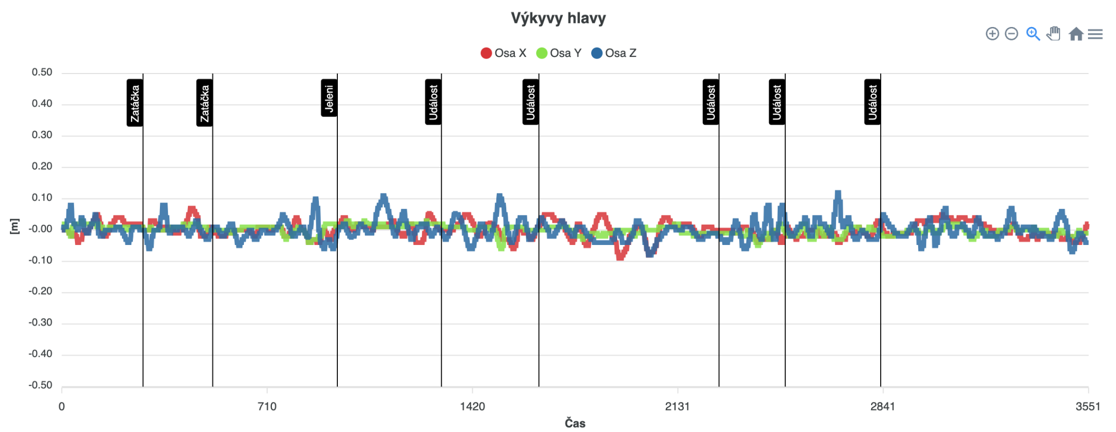
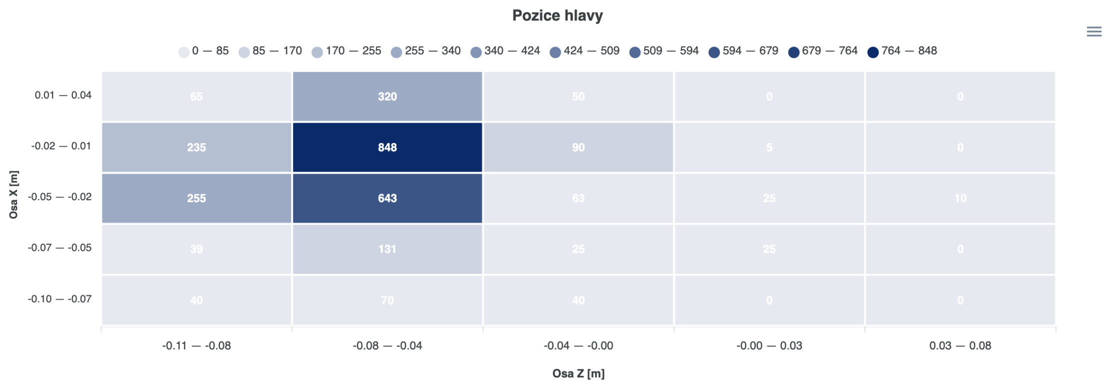


Figure B.3: The graphs depicting the course of the testing for the dynamic group (Participant 3)



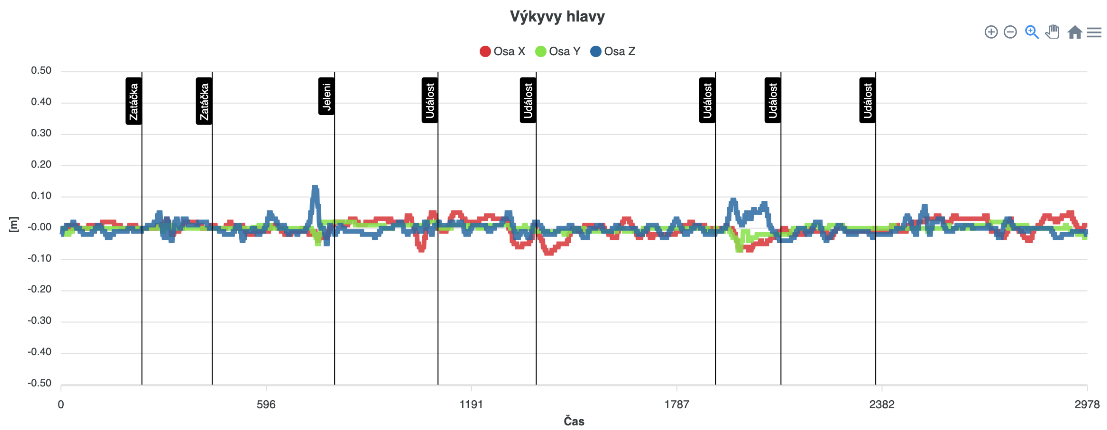
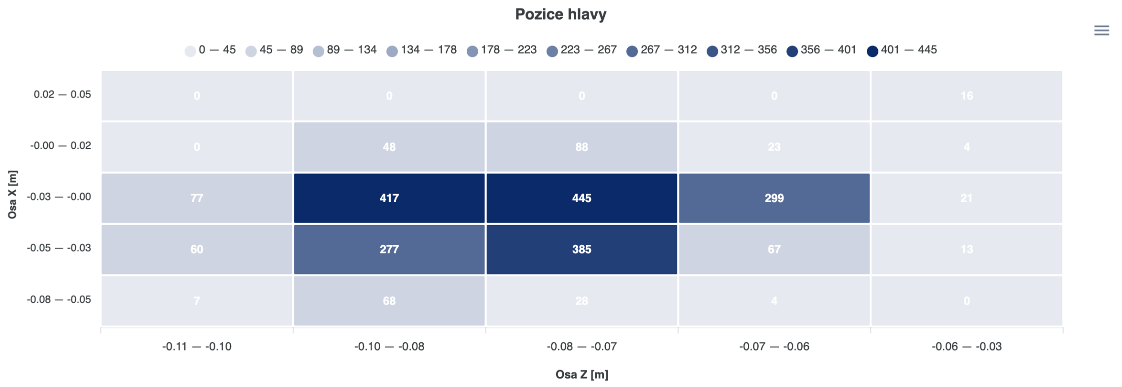


Figure B.4: The graphs depicting the course of the testing for the static group (Participant 1)



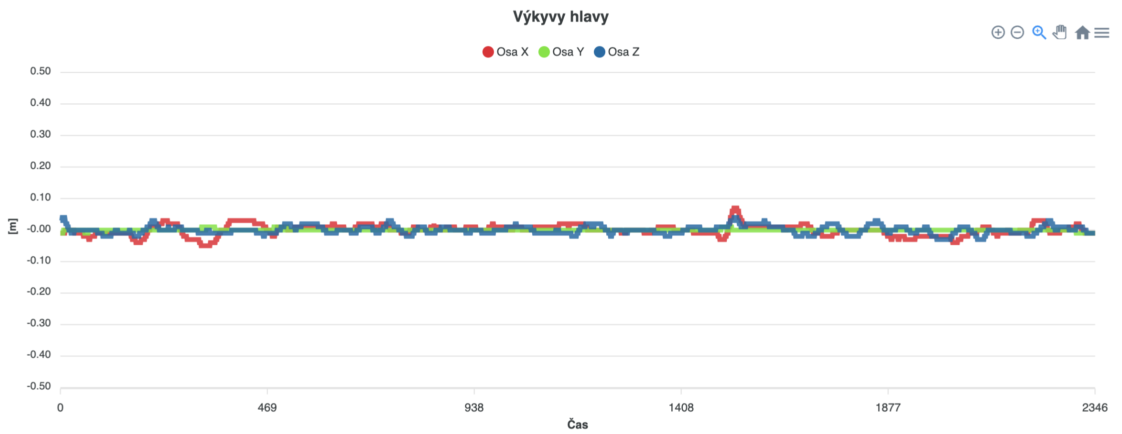
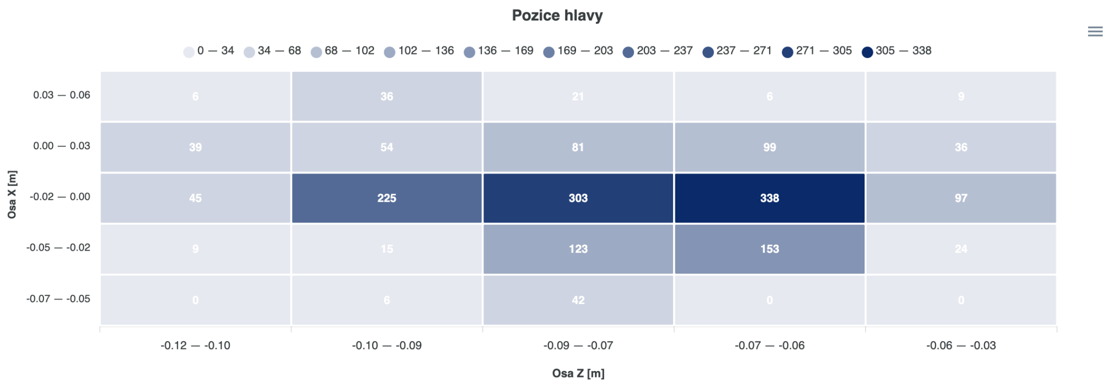


Figure B.5: The graphs depicting the course of the testing for the static group (Participant 2)



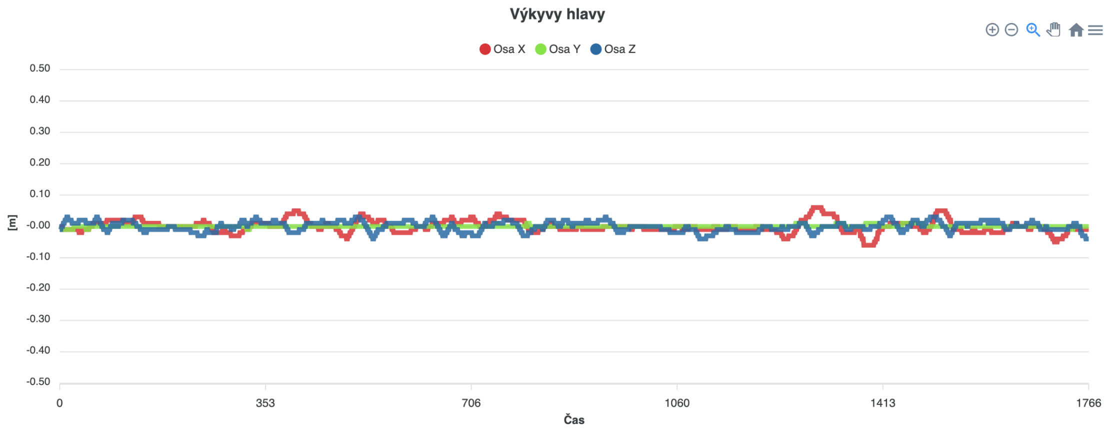


Figure B.6: The graphs depicting the course of the testing for the static group (Participant 3)