Evaluating Kinect Technology in Balance Rehabilitation: A Pilot Study

Master Thesis

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Abstract:

This pilot study explores the feasibility and effectiveness of using Kinect technology for balance rehabilitation exercises at home. The study addresses issues with traditional at home exercises, such as patients not adhering due to boredom, by incorporating Microsoft Kinecs motion sensor technology and Unity's interactive game engine. The system captures and analyzes user movements, providing immediate auditory and visual feedback to enhance patient motivation and adherence. It furthermore addresses interests from physiotherapist about digitised patient monitoring. Quantitative and qualitative data from five elderly participants undergoing balance rehabilitation were collected through exploratory testing, including performance metrics and user experience questionnaires and interviews. Results indicate that the Kinect based system can potentially improve patient engagement and exercise compliance, while offering insights for physiotherapists to monitor and evaluate patient progress remotely. However, suggestions for clearer instructions, enhanced auditory feedback, and system accuracy were identified as areas for future improvement. The study concludes that Kinect technology has much potential to transform balance rehabilitation by making exercises more engaging and effectively monitored, thereby improving patient outcomes.

Contents

1 Introduction

Balance exercises are beneficial not only to people living with various conditions impairing their balance such as stroke[5] or Multiple Sclerosis[8], but also helps with fall risk for elderly people[9].

However, patients prescribed with at home balance exercises for their rehabilitation, sometimes forgets or chooses not to do them, as they are not interested in doing them because they find doing the exercises to be both boring and tedious[5]. With the development of newer more ubiquitous portable computer technologies, new more interactive and fun alternatives approaches can be developed[5][8].

The utilization of at-home exercises prescribed by physiotherapists plays a vital role in the rehabilitation processes, particularly for patients suffering from injuries that impair their balance as well as the elderly population who are prone to balance-related issues. Adherence to these prescribed exercises contributes to the effectiveness of their rehabilitation However, patients prescribed with at home balance exercises for their rehabilitation, sometimes forgets or chooses not to do them, as they are not interested in doing them because they find doing the exercises to be both boring and tedious[5].

efforts. However, a substantial fraction of patients remains disengaged from their at-home physiotherapy exercises, citing them boring and tedious[5]. Research indicates that approximately one-third of these patients neglect their exercises, primarily due to perceptions of monotony and a lack of immediate feedback on their performance accuracy (Smith et al., 2020). This lack of engagement not only hampers patient recovery but also prevents physiotherapists from monitoring and evaluating the correctness of exercise execution in real-time, posing a significant barrier to effective treatment.

To address these challenges, innovative solutions that incorporate technology to increase engagement and provide real-time feedback are crucial. This report explores the feasibility and efficacy of using Microsoft Kinect, a motion sensing input device, in conjunction with Unity, a powerful cross-platform game engine, to capture and analyze user movements during physiotherapy exercises. The integration of these technologies aims to transform mundane rehabilitation exercises into an engaging and interactive experience while providing physiotherapists with valuable data on the patient's adherence and exercise quality.

Microsoft Kinect offers a non-invasive, cost-effective solution for capturing detailed body movements without the need for physical contact. Its depth sensors and camera enable the accurate tracking of 3D body joint movements, making it a suitable tool for monitoring exercise performance in a home setting. Unity, on the other hand, allows for the creation of customized interactive environments. By leveraging Unity's capabilities, it is possible to design intuitive and stimulating exercise programs that can motivate patients to consistently engage in their prescribed routines.

This report will detail the development of a prototype system that integrates Kinect's motion-sensing technology with Unity's interactive software framework. It will examine the system's potential to enhance patient engagement through gamification elements and the effectiveness of its real-time feedback mechanism in improving exercise compliance and execution. Furthermore, the study will discuss the technical challenges encountered during the integration process, the limitations of the current system, and potential future improvements. The overall goal is to foster higher levels of exercise adherence, enhance the quality of rehabilitation, and thus, improve overall patient outcomes.

2 background

Knowledge about some of the psychological and physical aspects that challenge balance of people are required. This chapter will delve into these aspects and explore various digital experiences that exists as well as other types of treatments currently available.

At home exercises are effective but research suggest that while at home exercises are effective many people do not adhere to them [5].

2.1 What is balance?

Balance is a complex physiological function that involves the maintenance of the body's center of mass over its base of support. It is a key component of everyday movements and activities, from standing and walking to more dynamic motions.

The ability to balance is governed by the coordination of several body systems: the vestibular system, the visual system, and the proprioceptive system[8].

Vestibular System: Located in the inner ear, this system detects changes in head movements and helps to regulate the body's sense of equilibrium and spatial orientation. It informs the brain about motions, head positions, and spatial navigation. Visual System: The eyes play a crucial role in balance by providing visual feedback about the body's position in relation to its surroundings. This input helps to correct and stabilize body movements. Proprioceptive System: This involves sensors in the muscles and joints that provide information about the position of body parts. It allows the body to make automatic adjustments to maintain posture and balance[8].

2.2 Balance decline

As individuals age, the risk of losing balance increases significantly, often leading to falls and related injuries. This susceptibility is mainly due to decline in physical strength, flexibility, and sensory perception, as well as medical conditions that exacerbate balance issues. Neurological disorders, such as multiple sclerosis and stroke, directly affect the nervous system, disrupting communication between the brain and the body, which impairs balance and coordination[8][6].

Additionally, the vestibular system, crucial for maintaining balance, can deteriorate with age, leading to conditions like vertigo and dizziness. Neurodegenerative diseases such as Alzheimer's further compromise balance by affecting spatial navigation and motor coordination[8][11].

2.3 Physiotherapy and balance exercises

Current physiotherapy practices for improving balance involve a combination of clinic-based and at-home exercises designed to address the specific needs of individuals experiencing balance impairments. In a typical therapeutic setting, physiotherapists assess the patients balance using various tests and tools to tailor a set of exercises that target the improvement of coordination, strength, and proprioception[8].

Additionally, the use of equipment such as balance boards and resistance bands can further challenge the patient's balance under controlled conditions. These exercises are often simple to execute but require regular practice to yield significant benefits. The goal is to facilitate safe, independent mobility in daily activities, thereby improving the quality of life for individuals with balance deficiencies[11][8].

2.4 Kinect and other depth sensors

The Azure Kinect DK is a cheap piece of hardware which features an array of sensors designed for versatile applications. It integrates a 1-Megapixel Time-of-Flight (ToF) depth camera, which supports multiple operating modes for various resolution and field of view settings. Additionally, it has a 12MP RGB camera with rolling shutter capable of capturing color images in several formats and frame rates. The device is also equipped with an Inertial Measurement Unit (IMU) for motion sensing and a seven-microphone array for capturing sound with high fidelity. Using it's bodytracking capabilities it is possible to get positional information about the following joints[1][1]

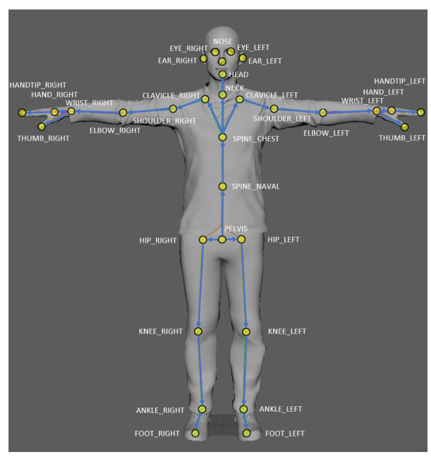

Figure 1: Kinects 32 Joints and their location

2.5 Body movement descriptors

Low-level motion descriptors provide foundational metrics derived directly from the raw mo-

[1] https://learn.microsoft.com/en-us/azure/kinect-dk/body-joints

tion data captured during movement analysis. These descriptors are crucial in quantifying specific kinematic and dynamic properties of human motion, as well as geometric characteristics of body postures[10]. The utility of low-level descriptors lies in their ability to offer detailed, quantitative insights into the movement without the need for higher-level interpretative layers. Here, we explore two primary categories of low-level descriptors as outlined in the source material[10]:

Kinematic/Dynamic Descriptors: These descriptors quantify the physical aspects of motion, focusing on the movement trajectories over time: Velocity and Speed: These descriptors measure the rate of change of position for a joint, providing insights into the movement's pace and intensity. The speed (scalar value) is derived from the vectorial velocity, emphasizing the magnitude of movement irrespective of direction. Acceleration: This metric quantifies the rate of change of velocity, offering a deeper understanding of how motion dynamics evolve from one moment to the next. Jerk: Representing the rate of change of acceleration, jerk is instrumental in assessing the smoothness or abruptness of movements, which can be particularly relevant for quantifying smoothness in movements[3]. Displacement: Measures the change in position of a joint relative to a fixed point, highlighting the range and extent of movement. Rotation: Captures the angular movement between joints, which is critical for analyzing the orientation and alignment changes throughout a motion sequence. Center of Mass (CoM): Computes the weighted average position of body joints, reflecting the body's overall stability and balance during movement[10].

2.6 Exergames and gamification

Exergames and gamification refer to the integration of gaming elements into exercise activities to enhance engagement and motivation in physical therapy and fitness routines. Exergames, or exercise games, employ technology that requires physical activity as a core component of gameplay, effectively merging physical exercise with the interactive features of video games[9]. Gamification involves applying game-like elements such as scoring, competition, and rules of play to non-game contexts, including rehabilitation exercises. These strategies aim to increase user participation and adherence by making the exercise process more enjoyable and psychologically rewarding. Through gamification, routine rehabilitation exercises are transformed into dynamic and compelling challenges, thus potentially increasing patient commitment and enhancing recovery outcomes[5][6] .

2.7 Good movement and smoothness

Good movement in the context of physical therapy and rehabilitation is often characterized by its smoothness, which indicates the quality of motor control and efficiency. According to Balasubramanian et al., smooth movements are "perceived to be smooth, when it happens in a continual fashion without any interruptions" and are typical of healthy motor behavior. Such movements are believed to be the result of effort minimization, a crucial aspect of motor learning and recovery post-stroke[2][5].

Smoothness in movement is especially critical in neurorehabilitation, where it is used as a marker for motor recovery[7][12]. Effective rehabilitation aims to reduce movement intermittency, which can be visibly noted as deviations or jerkiness in the trajectory of limb movements. Therefore, assessing and enhancing movement smoothness can significantly impact the quality of motor rehabilitation, offering a measurable parameter that correlates with improvements in patient mobility and function[5][4].

2.8 State of the art

There have been made multiple attempts to digitise and make the at home rehabilitation exercises more enticing and interesting. In the following section I will outline some of the most relevant attempt made for this.

One paper tried skiing game controlled by the players center of mass. They specifically try to estimate an intensity level players should do balance exercises with. Some people may need more or less intensity, and this skiing game was made for users to this indication of how their own needed intensity[6].

Icura is a digital platform[2] designed to enhance home-based training and rehabilitation for individuals recovering from illness or injury. It

[2]https://www.icura.dk/

utilises an app and sensors to facilitate and monitor exercises, making physical therapy accessible regardless of a users location or IT skills. This approach not only motivates consistent exercise through direct feedback but also supports physiotherapists in monitoring progress remotely, thereby reducing the need for physical visits. Icura has demonstrated benefits in improving user motivation, exercise frequency, and overall health outcomes.

2.9 Research question

"Based on the research mentioned above, the following points serve as design considerations and guidelines. "

- Remote Monitoring: Include functionalities that allow therapists to monitor patients progress remotely.
- Facilitate real time feedback to enhance user experience
- Accessibility: Design interfaces that are simple and intuitive.

Thus, we arrive at the following Research question:

How do patients perceive the user experience of a Kinect-based depth sensor system for at-home balance exercises? Supporting Sub-Questions: What improvements do they suggest to enhance its effectiveness? How do the feedback provided by the system influence patient motivation? How can the system help provide insight about patients progress to clinicians for a more effective evaluation?

3 Design and Implementation

In this chapter the design aspects of the application, and how users should be able to interact with it is laid out. As the demographic of users primarily includes elderly individuals and those with neurological conditions, the design focuses on accessibility, engagement, and effectiveness.

3.1 Info for the physiotherapist

It should give meaningful insight to the physiotherapist about the patient using the system. Through the meetings with Kasper, specific metrics was requested about the user:

- Time and date of the exercise session
- Amount of repetitions made
- Weighted Center Of mass estimate
- How far patients arms can reach
- Potentially a way to rate the quality of movement by looking at smoothness metrics such a LDLJ and SPARC
- A nice way to give feedback to the patient if they do something wrong.

From the velocity data can the acceleration and jerk metrics also be derived, and the smoothness metrics can be calculated. Additionally, administrative information will be also be added, such as the time and date for the completed sessions of the users.

3.2 Info for the user

The application should provide useful information that users don't already know. It is also important that the screen does not take too much attention from the patient this specific exercise required the user eyes should follow their hands. Therefore, audio feedback to the user about correct movement, and warning sounds will be implemented. Furthermore, in order for the users to understand how the exercise should be done, it should at all times be possible to see a short video of how the exercise is done. This will be displayed by a user gesture, like raising their right hand.

The system should also get the information necessary to calculated the smoothness metrics discussed in section REF to get a better understanding of the quality of the users movements.

3.3 Motion tracking

Through the SDK of the Microsoft Azure Kinect, users joints are located when inside the range of the depth camera regardless of their height. For the incorporation of the first exercise, it is important that users arms are tracked, and as per the conversation with the physiotherapist checks the nose also moves as the body does. Below an illustration is shown for the flow of the system:

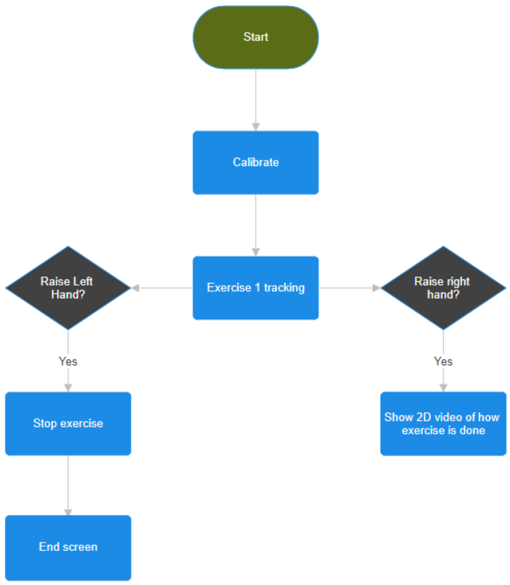

Figure 2: Design architecture

The system consists of one computer, one screen, and the Azure Kinect depth sensor. In the first stage, users start the system, and calibrate to ensure patients with all body proportions can use the system effectively. Once calibrated, users can freely exercise. Raising their right hand above their head should start a 2d video of a person doing the exercise correctly as to illustrate and remind the user of how the exercise is performed correctly. When the user no longer wishes to continue to exercise they can raise their left hand to end the exercise.

3.4 Gamification aspects

As mentioned in section 2.6 an added aspect to the system is adding gaming elements to the rehabilitation, to further increase motivation. By incorporating elements such as point scoring, or timing, patients can experience a more interactive and rewarding exercise routine. This can also provide instant feedback and a sense of accomplishment, further motivating patients to complete their exercises regularly. It was therefore chosen to create a simple green natural forest like environment with a mountainous horizon to exude a soothing and healing aesthetic. However for parts of the exercise it is important for patients to move their head, and have their eyes follow their hands. For that reason the environment on the screen should be simple to ensure it is not a distraction for the user. To provide feedback when the user is not looking at the screen, auditory feedback should be utilised, as well as making the system more engaging.

3.5 Auditory feedback

Sound feedback should be heard, letting the user know that they have completed the calibration, that they finished a repetition correctly. Below is a list describing what audiotory feedback can be included:

- Countdown to calibration is completed
- The calibration is complete
- A successful repetition
- A warning sound when the user keeps their head too still.
- A sound indicating the end of the exercise

As this is used for rehabilitation it is vital that audio feedback be encouraging and not harsh sounding.

3.6 Iterative design and implementation

The Design and implementation of the system have been through multiple iteration with feedback from the fysiotherapist either in person or through mail.

4 Implementation

The following section details the implementation process of the Kinect-based depth sensor system, outlining the technical setup, integration with Unity, and the development of the balance exercise system.

4.1 Azure Kinect and bodytracking

The Azure Kinect Body Tracking SDK and its accompanying example Unity package from Microsoft provide the tools for implementing body tracking capabilities in Unity. The SDK uses Microsoft's own machine learning algorithms to track skeletal movements and provide data on joint positions and orientations. The example Unity package, available on GitHub[3], offers a nice starting point for integrating these body tracking features into Unity projects. It includes sample scripts and scenes that shows how to capture and visualize the body tracking data from the kinect, enabling quick access to the joint data.

4.2 Detecting movements

Using the C# wrapper, users' joints are represented as 3D vectors that can be accessed continuously. By examining how these joints move relative to each other, the system can determine users movements and postures. To ensure that the arms are moving correctly, the movements of the right and left hands are tracked in relation to the pelvis. Similarly, by comparing the horizontal (x-axis) position of the user's nose to the neck's x-axis position, the system can detect whether the user is turning their head.

This way, by identifying and monitoring the relevant joints, various exercises can be tracked to ensure users are performing them correctly.

4.3 System interaction

In order to start the calibration process, and during exercising to either see the guiding video or end the exericise, user can raise their hand above their head. First both hands for calibration, then either right or left hand to indicate video guide or ending the exercise.

4.4 Calibration

Not everyone will have the same body proportions, so before beginning any exercise it is necessary to create a definition of users proportions for the exercise tracking. The bodytracking SDK already holds information about the joint location regardless of height, length of their arms, and calculating the lengths of their arms are therefore simple.

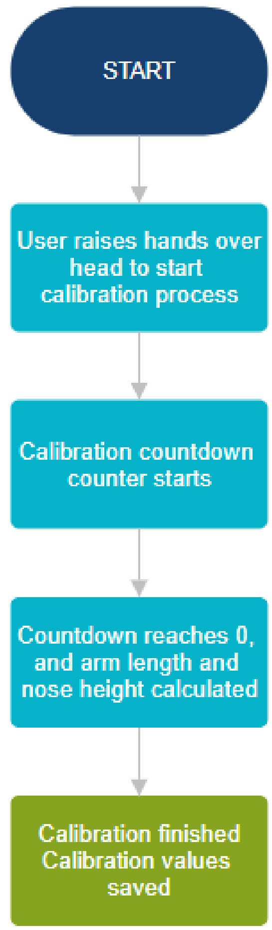

Figure 3: Calibration process

After the countdown ends of the calibration, the lengths of the users arms, the users height will be calculated to be used in the movement tracking.

[3] https://github.com/microsoft/Azure-Kinect-Samples/tree/master/body-tracking-samples/sample_unity_bodytracking

4.5 Exercise tracking and logging

To ensure that users are moving their arms correctly, a reaching threshold was made, and only when users extends their hand past this threshold and then retracts it, their hand is counted as correct. If, at the same time head movement have been detected, a repetition is counted. When a repetition is counted, the system logs the current metrics and information about the user for later data processing.

4.6 Auditory feedback

Auditory feedback was achieved using Unitys own audio engine, using simple nice pleasant sounds for the indications mentioned in design section 3.5. One warning sound was recorded and played when the user was moving their hands correctly, but included to little head movement. The warning gently reminding the user to remember to move their head also.

4.7 Environment

To create a nice and aesthetic atmosphere, a small green natural environment was made, as seen on the image below. It has green areas, some trees, and mountains in the background, made using the Polygon Nature Unity package[4]

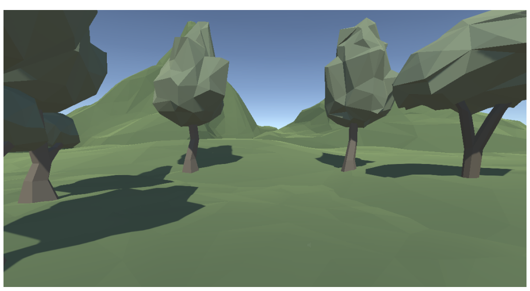

Figure 4: 3D environment

4.8 Center Of Mass

To understand information about the user, the center of mass is calculated. The 3D coordinates of joints such as the head, shoulders, etc. with the weight as described in section 2.5. Each joint is assigned a weight, reflecting its relative mass in the body. The center of mass is then calculated by taking the weighted sum of these joint positions and dividing it by the total weight sum using two lists.

4.9 Leaning.

By using the Center of mass, it is possible to calculate a leaning metric by finding the difference between the Pelvis joint location and the center of mass location in 3D.

4.10 hand reaches

One of the requested features from the fysiotherapist was being able to see how far patients were reaching. Reaching defined by the difference in length between the pelvis and the right and left hand.

4.11 Data handling

In order to save information for the fysiotherapist, two data structs were made. One data structs holds information about the user for each repetition, and the other data struct holds information about the user for every frame.

Whenever a repetition was successful, data was added to a list of this struct. When the user then indicated to end the exercise, the data is printed to a csv file to use for analysis.

4.12 Exercise end

Once the user no longer wishes to continue exercising, ending the exercise by raising their left hand will play a sound to indicate finished exercise, and then calculate a simple score based on their session duration and their max hand reaches.

[4]https://assetstore.unity.com/packages/3d/vegetation/trees/polygon-nature-low-poly-3d-art-by-synty-120152

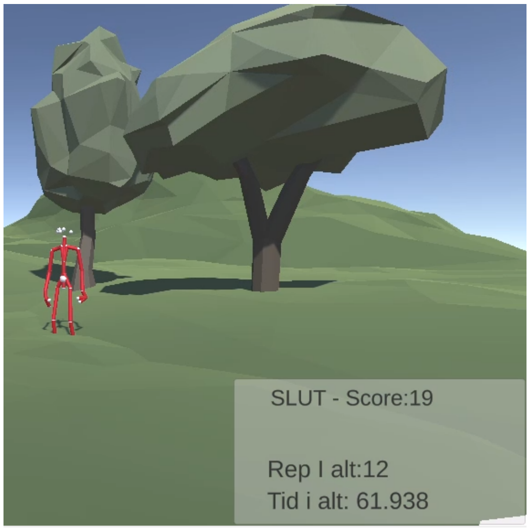

Figure 5: End message

4.12.1 Printing data as csv

In order to process the data, methods was created to print the data stored in the data structs to a csv file, for both the per repetition data and per frame data after exercise session has been ended.

4.13 Smoothness metrics

During exercising speed, acceleration and jerk data is calculated between each frames and stored in every frame for the per frame data, and an average value stored in the per repetition data. The LDLJ mentioned in section 2.7 is also calculated each frame here.

5 Methods

The following chapter details the methodologies used to answer the final problem statement from the previous chapter. It will outline the process of gathering qualitative and quantitative data to assess the interaction quality and user experience from a user perspective.

5.1 Mixed methods

Mixed methods research combines both quantitative and qualitative approaches to collect, analyze, and integrate data. This methodology leverages the strengths of both quantitative and qualitative data to provide a better and more comprehensive understanding of research problems. Quantitative methods involve the collection and analysis of numerical data, allowing for statistical testing and the identification of patterns and relationships. Qualitative methods then involve non-numerical data such as interviews, focus groups, and observations, providing in depth insights into participants perspectives and experiences. This approach also allows for the triangulation of data to ensure a more nuanced analysis.

5.2 Short version of User Experience Questionnaire

The User Experience Questionnaire - Short Version (UEQ-S) is a short questionnaire designed to quickly assess user experience across two primary dimensions: pragmatic quality and hedonic qualities[13]. It is a condensed version of the full User Experience Questionnaire (UEQ), reducing the original 26 items to 8 items while maintaining its reliability and validity.

The UEQ-S evaluates these two aspects:

- **Pragmatic Quality:** Measures the products usability and functional aspects, including efficiency, clarity, and supportiveness.
- **Hedonic Quality:** Measures the products appeal, capturing users feelings, their engagement, excitement, and feeling of novelty.

The questionnaire is designed to be quick to complete, taking approximately 1-2 minutes, which is ideal for the target audience not to feel overwhelmed.

5.3 Physiotherapist meeting

To gain further insight into the prioritisation of which functionalities should be included for the system, several meetings were held with a Physiotherapist. The iterative design phase was kicked off after the first meeting with the physiotherapist at Gentofte Hospital. During this meeting, the physiotherapist detailed the most common balance exercises he prescribes patients, and common pitfalls when doing them. He lays out a want for a digitised system that will not only help aid patients when they are doing exercises at home, but also give him insightful information about how the patient is doing. He lists various metrics that he is interested in when patient go through their at home rehabilitation, since he has no knowledge about whether they do them or if they do them incorrectly. Specifically he was interested in how center of mass changes when a patient is exercising, and how far patient can reach with the exercise. He played an important role in the development of the system as further meetings and consultations were held with other iterations of the system, and his consultations and suggested research helped guide development process of the system. Meetings would usually take place at his office in Gentofte Hospital where progress were discussed. Durings these meetings it was patients ages were also mentioned and the need for the system to be intuitive and simple to use were noted.

5.3.1 Reaching exercise

It was chosen to focus on the first exercise to ensure correct tracking and good data collection, and because the first exercise seemed the most complex. The first exercise was described like Standing with the back to a wall with their feet standing still, reaching far to touch the wall with the finger on the opposite side, illustrated on the image below[14]

Figure 6: First exercise from hospital

The main purpose of the exercise is to train the patient to "almost" fall to challenge the patients balance. This is the reasons for the importance of centre of mass and hand reach were important metrics for physiotherapists to measure.

From these conversations, it was clear that the system should enable physiotherapists to more effectively evaluate and monitor patients progress, while also guiding and motivating the patients.

5.4 Target group

Through the physiotherapist, a small group of five patients currently undergoing balance rehabilitation said yes to participate with testing. They were available for testing during their physical group session at the hospital. In total two test session with the patients were held. White initially meant for patient with damage to the vestibular senses, the home rehabilitation system could also be beneficial for many older adults, and people suffering from other balance impairments.

5.5 Testing procedure

In order to gain the most insight from the patients, a short exploratory test was performed. At one of the offices in the hospital the system was set up. In the setup, a computer screen and the kinect was placed on an office table. The kinect was placed 1.8 meters from where the patient would be standing. For safety precautions patient needed to be standing in a corner with a stool in front of them to ensure the did not fall.

Each of the patients in the group was then send in to try the system out one after the other.

5.5.1 First test session

Upon arrival at the office, participants received a brief introduction to the system and answered a few preliminary questions. They then had the opportunity to use the system for as long as they wished, or up to approximately three minutes, after which they were instructed to stop. Their performance during this period was observed.

After finishing trying out the system, they were then presented with the short version of the User Experience Questionnaire (UEQ-s[13]) about the system as a whole as well as the sound feedback. The questionnaire ended with a few open ended questions for further comments.

5.5.2 Second test session

Through feedback from the first session it was decided not to include any more questionnaires, but have a quick mini interview after each each patient was done testing. The mini interview included four questions relating to the hedonic and pragmatic qualities that the UEQ-s also explored. After every patient was done testing, four patient were available for a mini focus to further share their thoughts.

5.5.3 Mini focus group

A mini focus group is a qualitative research method involving a small group of participants, usually around 5 people, who are brought together to discuss specific topics. The discussion is normally moderated by a facilitator guiding the conversation, ensuring all participants have the opportunity to share their experiences and their thoughts about it. Because of the small size of the group, more in-depth discussions and a more intimate setting is allowed, which can lead to deeper insights and a better understanding of participants thoughts, perceptions, and behaviors. The mini focus group conversation was around 24 minutes in total, and strived to make the conversation with the patients more comfortable, to ensure the patients answer questions as honestly and authentically as possible.

6 Results

The results section presents the findings from both the qualitative feedback and quantitative performance data collected during the exploratory testing of the system. In total, five participants (n=5) partook in the study, with ages ranging from 77 to 82 (μ = 80,8). Of the five participants, four had little or more previous experience with this exercise.

6.1 Quantitative Data

Each participant has two data sets, one with info for each repetition, and one for each frame. All metrics for both datasets can be seen in the appendix figure 15. A comparison between all five participants right hand average speed can be seen below:

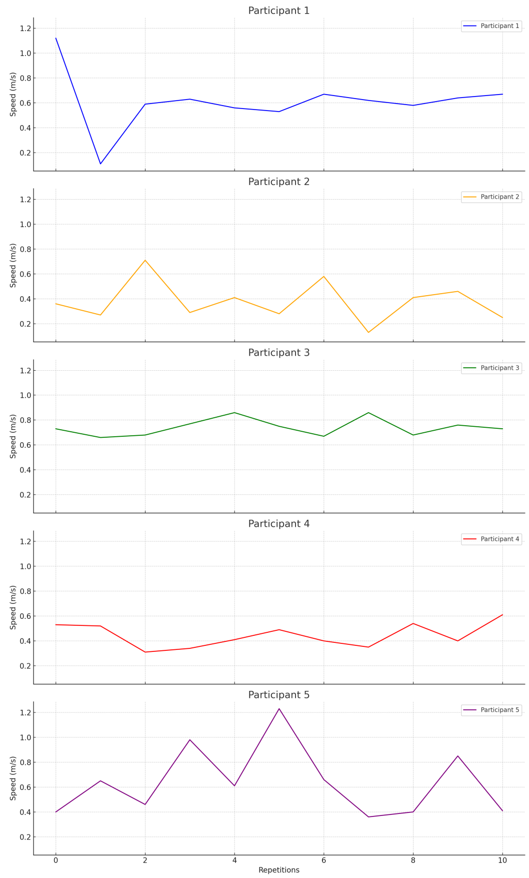

Figure 7: Average speed of right hand across all Participants

To assess a single participant, both hand average speed per repetition can be seen below:

Figure 8: Speed

With the data it is possible to compare participants between sessions. Here is a comparison of the right hand reaches for participants first and second session:

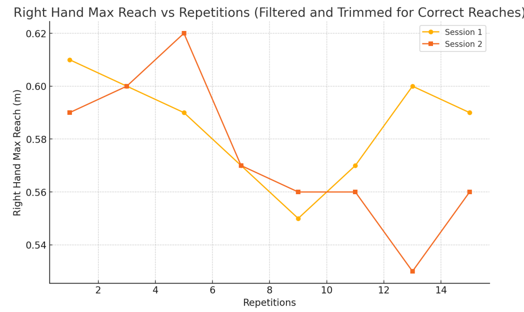

Figure 9: Participant max right hand reach Session 1 and 2 comparison

Movement can further be analysed using the LDLJ smoothness metric described in section 2.7 over several repetitions seen here for one participant:

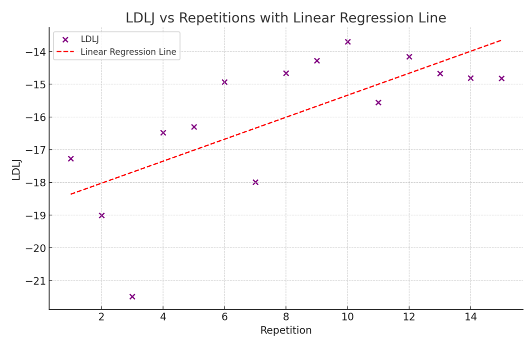

Figure 10: Log Dimensionless jerk through repetitions

Another interesting metric was pelvis tilt, seen increase over repetition for the one of the participants:

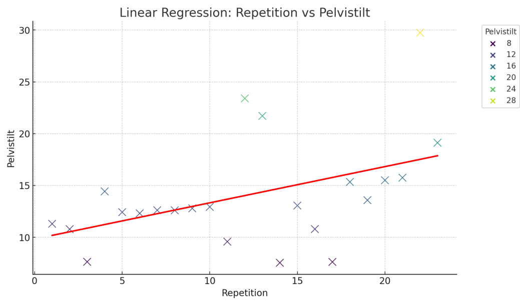

Figure 11: Pelvistilt

Further indication of leaning is through the centre of mass distance metric, describing the distance between the pelvis and the center of mass. The following graph shows Centre of mass distance to pelvis over repetitions for another patient:

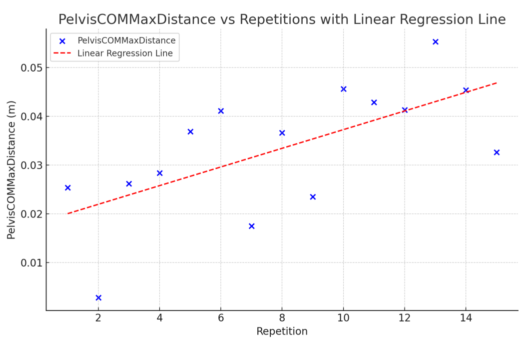

Figure 12: Change of Center of Mass

The more the user challenges their centre of mass, the larger distance from the pelvis, indicating leaning. This suggests the user perhaps got more comfortable with the exercises over time.

To The COM excursion mentioned in the analysis section 2.8:

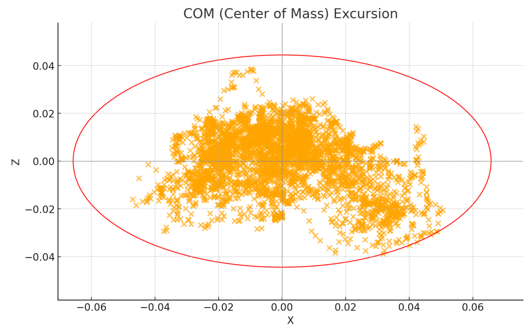

Figure 13: Change of Center of Mass

6.2 Qualitative Data

In this section the qualitative data and thematic analysis will be presented, starting with the results of the UEQ-s where test participants pragmatic and hedonic scores can be seen:

Aspect	Overall System	Sound Feedback
Pragmatic	0.90	0.70
Hedonic	1.05	-0.20

Table 1: UEQ-s Scores for the Overall System and Sound Feedback

The results from the UEQ-S indicate that the system performs good in both dimensions of user experience. The Pragmatic Quality score of 0.9 suggests that the system is usable, while the Hedonic Quality score of 1.13 indicates a stronger positive engagement from users. The sound however while usable had a negative impact on users.

6.2.1 Mini interviews answers

The thematic analysis revealed four main themes: Ease of Use, Helpfulness and Feedback, Improvement Suggestions, and Interaction and Engagement.

Theme 1: Ease of Use Participants generally found the Kinect-based system user-friendly. The intuitive design allowed them to follow the exercises with little difficulty. Participant 1: "It was quite easy to use following the guidelines." Participant 2: "Very easy." **Theme 2:** Helpfulness and Feedback The feedback provided by the system, specifically the auditory cues, did a great job in guiding participants and confirming correct performance. This feedback played an important role in maintaining their motivation during the exercises, and was often mentioned as something positive.

Participant 5: "It makes a sound so you can see that you did it right." Participant 4: ""It says 'booh' when I do it right."

Theme 3: Suggested Improvement Suggestions Participants suggested several was of improving the system to better its effectiveness, like incorporating clearer and louder auditory instructions and refining the accuracy of the avatar's movements.

Participant 2: "There should be a speaker added." Participant 3: "It should tell me what to do." **Theme 4:** Interaction and Engagement The interactive elements, such as the avatar mimicking participants' movements, were well-received. However, there were concerns about system accuracy and positioning, which could affect the overall user experience.

Participant 2: "The little red man does the same as me." Participant 3: "That I wasn't standing in the middle."

6.2.2 Mini focus group

Themes found through the analysis of the mini focus group. **1. User Experience and Interface Design** Participants had varied reactions to the user experience and interface design of the Kinect-based depth sensor system. While some found the system engaging and interesting, others pointed out several areas needing improvement, though most noted it potential use if developed further. Positive Aspects: I think it's exciting; I'm not used to computers, so it's not something I would use at home." (Participant C) Negative Aspects: "It's also a research study, and it seems incomplete at the moment." (Participant D) "I think the head was too small... You might have been able to see it, so it was OK for you. But I couldn't see it." (Participant C)

2. Accessibility and Clarity of Instructions Participants found the instructions needed improvement, and both negative and positve feelings about the natural environment. They suggested several improvements. *More Detailed and Clear Instructions:* "More instructions are needed. More instructions, and that's what we talked about. It should be audio, like a voice saying something." (Participant E) "And then you see if it's OK. It's something about instructions and feedback on such a program, so I think it's fine for home training." (Participant E)

Enhanced Visual Feedback: "He could be much bigger, and the trees could be removed." (Participant C) "There should be some form of display showing what to do, and it should be more realistic." (Participant E)

3. Motivation Factors Personalized feedback and clear cues were essential for maintaining motivation.

Personalized Feedback: "I also think it lacks the whole aspect of motivation, which you don't have at home when you take out a piece of paper. But when we come here, we are motivated and want to participate." (Participant D) "you have to make such a schedule. You can wish it is a man or a woman" (participant D)

Visual and Audible Confirmation: "The best technical part was that it acknowledged when you did the exercise correctly by saying 'booh' or 'beep beep'." (Participant D)

4. System's Potential for Clinician Insight Participants saw the system's potential to provide valuable insights for clinicians. However, some also noted that they did not like that clinicians could see their data

Progress Tracking: "The physiotherapist can adjust your program based on whether you do it three times or thirteen." (Participant B) "I don't think it's very pleasant" and "You should be able to turn that off" (participant E).

physiotherapist monitoring their progress, also noting that the system would be useful for people that dont see a physiotherapist. Improvements like clearer instructions, larger visual feedback, and personalized audio guidance, along with the system's ability to monitor and report progress, may significantly better its effectiveness.

7 Discussion

As seen in result section 6.1, it is possible for physiotherapists to gain more insight into the movement patterns and improvements of patients doing the reaching exercise using this system. The movement metrics will be available after each session, and could paint a picture about a patients development over time. However some observations were made during testing. Originally, keeping track of the patient feet during testing not possible due to the stool that was placed in front of the depth sensor, placed there for safety of the patient. Originally it was planned to keep track of the patients feet to ensure they were still, as that was an important factor to perform this exercise correctly according to the physiotherapist.

Several graphs suggest that patients become more accustomed to and proficient at the exercise with increased repetitions. This is supported by multiple weak correlations, such as the correlation between LDLJ per repetition and smoother movements observed after several repetitions. Similarly, the metrics for pelvis tilt and leaning indicate that patients are becoming more comfortable and increasingly challenging their center of mass over time.

Through the data, it will be easier to find relationships between metrics, which could make it easier for the physiotherapist to prescribe the best balance exercise for the patient, and track their progress more effectively.

The qualitative data collected from the User Experience Questionnaire Short version (UEQ-s) and mini-interviews provide valuable insights into the users' perceptions of the Kinect-based system. The UEQ-s scores revealed that participants had moderately positive perceptions of both the pragmatic and hedonic qualities of the system, with mean scores of 0.9 and 1.05 respectively, and an overall UX score of 0.98. These scores suggest that while users generally found the system to be functional and enjoyable, but there is room for improvement in both areas. The scores for the sound feedback also revealed that participants had a moderately positive perception of the pragmatic qualities with score of 0.7. However, the hedonic qualities received a negative mean score of -0.2, suggesting that users did not find the audio feedback particularly enjoyable or engaging. It is important to note that during testing observations were made about the patient view on these questions. As the mean age of the patients is 80, many felt confused and angry about the UEQ-s and most patient commented multiple times their dislike of these questions, also noted in the focus group "I don't think those questions make any sense to me to answer them (Participant E)". This could also reflect on the hedonic and pragmatic score in table 1, as the last questions to be answered on the questionnaire is about the auditory feedback. Open ended questions in the questionnaire yielded no more interesting answer than "fine" or "okay", another reason for a changed format for the second test session.

The smaller interviews with patients immediately after testing highlighted the ease of use as being crucial for ensuring that patients can independently perform their exercises at home. Additionally, the auditory feedback was mentioned as particularly helpful in guiding participants and confirming correct performance. Participants appreciated this feature, stating, "Get a bit of sound so you can see that you have done it right". However, there were several suggestions for improvement, including the need for clearer and louder auditory instructions and enhanced accuracy of the avatar's movements.

This further aligns with the mini focus group, where participants were intrigued about the system and saw the potential of it, though noting the need for further development and improvement. Specifically they wanted louder more clear instructions, possibly by a voice telling them what action they should perform. Overall participant were positive about a future version of the system and noted that they would rather use that if possible. Interestingly, participant noted to have the option for physiotherapists to monitor patients turned off, both because she did not feel comfortable with the monitoring, but also since she felt like the system could be beneficial for other people not seeing a physiotherapist. The addition of using the system for multiple exercises were mentioned, and specifically the option to individualise the system was highlighted.

7.1 Limitations

There are several aspects that limits the project.

This limited sample restricts the findings and the ability to draw robust conclusions. Additionally, the studys short duration may not capture long term adherence and effectiveness of the system, and no real difference would be seen between the two test sessions three days apart. Despite these limitations, the ecological validity of the study is enhanced by testing the system on actual patients in a real setting. Another limitation also discussed with the physiotherapist is the variability of the exercise. Patients should as freely as possible reach their hand in whichever direction they choose. But to detect movement restriction need to be set. However, especially interaction with the system restricted this aspects. It was observed during testing that a patient extended their hand upwards, thereby triggering either the 2d guide video or ending the exercise. People interpret things differently, and had I another team member, calculating intercoder reliability could ensure better reliable analysis results of the qualitative data.

After testing was already completed, a translated version of the UEQ-s was found by the authors of the original UEQ-s paper[5].

7.2 Future works

In later iterations, more types of exercises should be added. Expanding he system to include various balance exercises can help cater to a broader range of rehabilitation needs. Additionally, improving the accuracy and responsiveness of the stick figures movements will better the users ability to mimic the correct postures and actions, addressing the concerns about system accuracy and positioning raised by the patients.

In future iterations, greater emphasis should be placed on enhancing the accessibility of the onscreen written text and auditory feedback. Making the instruction even more clear, and consider adding a supportive voice that was guiding the user in what to do in the exercise. Placement and size can also be considered, especially in an individualised context.

8 Conclusion

This study investigated the user experience of a Kinect-based depth sensor system for at home balance exercises, focusing on patient perceptions, feedback's influence on motivation, and the system's potential to provide clinical insights described by the research question defined in section 2.9.

Patient Perception

Patients generally perceived the system as easy and intuitive. The qualitative feedback indicated that the system was easy to use, which is crucial for ensuring that elderly users can independently perform their exercises at home. The visual and auditory feedback provided by the system played an important role in guiding users and confirming correct performance, contributing positively to the overall user experience.

Influence of Feedback on Motivation

The systems real time auditory feedback was effective in maintaining patient motivation. Participants appreciated the immediate auditory cues, which confirmed correct exercise performance. This immediate feedback was crucial in making the exercises more engaging and enjoyable, addressing the common issue of exercise monotony and enhancing adherence to the prescribed routines. Although seen as helpful, it was also seen as simple an lacking, with wishes for more and better instructions.

Clinical Insights

The system demonstrated potential in providing insights for clinicians. The movement data captured during exercises allowed for the calculation of various metrics such as hand reach, movement smoothness, and center of mass changes. These metrics can offer clinicians a view of patient progress, potentially enabling more effective evaluation and adjustment of rehabilitation programs. The ability to remotely monitor patient progress also addresses a barrier to effective at-home rehabilitation, ensuring that patients perform their exercises correctly and consistently.

Suggestions for Improvement

Participants suggested several improvements to enhance the system's effectiveness. Key suggestions included:

Clearer and louder auditory instructions to improve guidance during exercises. Enhanced accuracy and responsiveness of the avatar's movements to better mimic the correct postures and actions. Larger and more accessible visual feedback to ensure that users can easily follow the exercise routines. Personalized audio guidance to cater to individual needs and preferences.

Further testing with a larger and more diverse group of participants is necessary to refine the system and validate it's effectiveness. Long-term studies are recommended to assess the sustainability of patient engagement and adherence over many sessions, and the systems effectiveness in various rehabilitation contexts. Additionally, integrating other types of exercises and more advanced and clearer feedback mechanisms could enhance the system usability and user satisfaction.

In summary, the Kinect-based depth sensor system shows potential in enhancing the user ex-

[5]https://www.ueq-online.org/Material/UEQS_Items.pdf

perience of at-home balance exercises through its user friendly design, feedback mechanisms, and potential to provide clinical insights. Patients testing the system generally agreed on it's potential but also stated it's need for further development and improvements. By incorporating the suggested improvements, the system may further increase patient motivation, adherence, and the overall effectiveness of at-home rehabilitation programs, ultimately leading to better patient outcomes.

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A Appendix A

A.1 UEQ-s

Test participants were asked to rate the following statement from 1 to 7 according to how much they agreed or disagreed:

A.2 Interview questions

The following questions were asked patients immediately after testing, based on the hedonic and pragmatic qualities of user experience:

- Hvad fandt du interessant?
- Hvad der noget særligt du lagde mærke til?
- Hvor nemt synes du system var?
- Synes du systmet var hjæklpsomt?
- Hvad kunne gøre den mere hjælpsom?

For the mini focus group the following questions were asked:

- Hvad synes i om systemet?
- Hvad var det første i tænkte da vi startede?
- Hvor nemt synes du system var?
- Synes du systmet var hjæklpsomt?
- Hvad kunne gøre den mere hjælpsom?

For the focus group, the prepared questions were used:

- Generelt om dette her system, den her oplevelse kan i beskrive - Hvad synes i om det?
- Hvad synes i så om den lyden var den OK eller skulle det have været anderledes?
- Hvilke positive eller negative ting i synes i i har oplevet ved dette system?
- Var der nogle af øvelserne eller nogle af bevægelserne, som var svære eller ubehagelige, synes I?
- Hvad synes i om det grønne miljø?

- Hvis i havde Sådan et system derhjemme, ville i så bruge det?
- Har nogle spørgsmål til mig, nogle sidste kommentarer eller Der er noget jeg ikke synes i fik sagt?

A.3 Short version of User Experience Questionnaire

Participants were asked how much they disagree or agree the statement about the system (from 1 to 7).

obstructive	o o o o o o o	supportive	1
complicated	o o o o o o o	easy	2
inefficient	o o o o o o o	efficient	3
clear	o o o o o o o	confusing	4
boring	o o o o o o o	exiting	5
not interesting	o o o o o o o	interesting	6
conventional	o o o o o o o	inventive	7
usual	o o o o o o o	leading edge	8

Figure 14: Short version of the User Experience Questionnaire

Below is the translated version I translated:

- Hæmmende eller støttende
- Kedelig eller spændende
- Klar eller forvirrende
- Ineffektiv eller effektiv
- Kompliceret eller nemt
- Sædvanlig eller banebrydende
- Uinteressant eller interessant
- Konventionel eller opfindsom

B Translations

Here are the danish quotes from the qualitative amanlysis in order:

B.1 Mini interviews

Participant 1: "Det var ganske nemt at bruge efter retningslinjer."

Participant 2: "Meget nemt."

Participant 5: "får lidt lyd så man Kan se at man har gjort det rigtig."

Participant 4: "det siger jo bøh når jeg gør det det rigtige."

Participant 2: "der være en højtaler på."

Participant 3: "den skulle sige til mig, hvad jeg skulle gøre."

Participant 2: "den lille røde mand gør det samme som mig."

Participant 3: "At jeg ikke stod i midten."

B.2 Focus group

"Jeg synes det er spændende, jeg er jo ikke vant til computer så men det var ikke noget jeg ville bruge derhjemme." (Participant C)

"Den er jo også på forskningsstudie på den virker ufuldkommen på nuværende tidspunkt." (Participant D)

"Jeg synes hovedet var for lille... Det kunne godt være du kunne se det, så er det jo OK. Men jeg kunne ikke se det." (Participant C)

"Der skal mere instruktion til. Mere instruktion, og det var det det vi talte lidt om. Det skulle være altså lyd, Altså en stemme der sagde noget." (Participant E)

"Og så ser man om det er ok Det er noget instruktionen og Sådan noget feedback på Sådan et program, så synes jeg Det er fint til hjemmetræning." (Participant E)

"Han måtte godt være meget større og så kunne træerne være væk." (Participant C)

"Der skal være en eller anden form for visning af hvad Det er man skal gøre, og Det er jo selvfølgelig godt være noget mere naturtro." (Participant E)

"Jeg mener også det mangler det hele afdelingen om. Motivation, den man ikke har derhjemme, når man tager stykke papir frem, men når man kommer herind, så er vi jo motiveret vi vil ikke lave andet deltage så." (Participant D)

"Det var vel nok det bedste tekniske i den, at den kvitterede for at den gjorde øvelsen rigtig vigtigt at sige bøh eller bib bib." (Participant D)
"Fysioterapeuten kan indrette dit program efter om du gør det måske 3 gange eller 13." (Participant B)

"synes jeg ikke er særlig rart" and "Det skal man kunne slå fra" about the (participant E)

B.2.1 From discussion

de der spørgsmål synes jeg ikke for mig giver det ikke nogen mening at besvare dem(Participant E)

"får lidt lyd så man Kan se at man har gjort det rigtig"

C Metrics

Below is a list of all the metrics for both per frame data and per repetition data.

C.0.1 Per frame Data

- Date
- Time
- Repetition
- Pelvistilt
- PelvisCOMDistance
- MaxRightHandToFoot
- MaxLeftHandToFoot
- RightHandMaxReach
- LeftHandMaxReach
- RightHandAvgSpeed
- LeftHandAvgSpeed
- RightHandAvgAcc
- LeftHandAvgAcc
- RightHandAvgJerk
- LeftHandAvgJerk
- LDLJ
- Duration

C.1 Per frame data

- Frame
- Repetition
- Pelvistilt
- PelvisrotationX
- PelvisrotationY
- PelvisrotationZ
- rightHandToFOot
- leftHandToFoot
- leftreach
- rightreach
- COMX
- COMY
- COMZ
- PelvisCOMDistance
- LeaningX
- LeaningZ
- LefthandPosX
- LefthandPosY
- LefthandPosZ
- NosePosX
- NosePosY
- NosePosZ
- PelvisPosX
- PelvisPosY
- PelvisPosZ
- RighthandPosX
- RighthandPosY
- RighthandPosZ
- LefthandSpeed
- LefthandAcc

C.1 Per frame data

- Lefthandjerk
- RighthandSpeed
- RighthandAcc
- RighthandJerk

Date	Time	Repetition	Pelvistilt	PelvisCOMMaxDistance	MaxRightHandToFoot	MaxLeftHandToFoot	RightHandMaxReach	LeftHandMaxReach	RightHandAvgSpeed	LeftHandAvgSpeed	rightHandAvgAcc	leftHandAvgAcc	rightHandAvgJerk	leftHandAvgJerk	LDLJ	Duration
2024-05-13	11:34:16	1	8.87	0.01	1.32	1.28	0.36	0.4	0.53	0.48	19.73	18.05	1083.02	1014.68	-16.0	12.65
2024-05-13	11:34:25	2	10.17	0.01	1.34	1.28	0.41	0.41	0.52	0.2	17.11	10.78	884.26	588.35	-18.64	21.81
2024-05-13	11:34:30	3	11.85	0.01	1.37	1.28	0.41	0.39	0.31	0.38	15.28	10.11	780.8	532.4	-16.09	26.31
2024-05-13	11:34:34	4	7.99	0.01	1.37	1.28	0.33	0.42	0.34	0.41	14.09	9.74	708.75	504.01	-15.04	30.34
2024-05-13	11:34:38	5	13.34	0.0	1.37	1.28	0.42	0.3	0.41	0.29	13.19	9.1	659.04	466.37	-14.79	35.03
2024-05-13	11:34:43	6	8.44	0.0	1.37	1.28	0.36	0.43	0.49	0.33	13.28	8.65	661.52	440.71	-15.74	39.23
2024-05-13	11:34:51	7	11.07	0.01	1.37	1.29	0.4	0.42	0.4	0.37	12.53	8.03	616.2	400.78	-17.97	47.79
2024-05-13	11:35:00	8	9.57	0.0	1.37	1.34	0.36	0.42	0.35	0.26	11.61	7.31	566.69	360.42	-18.04	57.14
2024-05-13	11:35:05	9	13.31	0.0	1.41	1.34	0.42	0.28	0.54	0.25	11.43	7.0	553.53	343.5	-15.78	62.14
2024-05-13	11:35:09	10	11.07	0.0	1.41	1.36	0.35	0.43	0.4	0.42	11.31	6.94	547.84	339.16	-14.43	65.8
2024-05-13	11:35:18	11	12.02	0.01	1.41	1.36	0.51	0.42	0.61	0.32	11.4	6.66	549.6	322.03	-17.0	74.26
2024-05-13	11:35:28	12	9.73	0.01	1.41	1.36	0.4	0.4	0.31	0.33	10.82	6.46	520.76	308.79	-18.2	84.48
2024-05-13	11:35:32	13	16.5	0.01	1.45	1.36	0.45	0.24	0.33	0.14	10.6	6.29	509.38	300.39	-14.73	88.28
2024-05-13	11:35:36	14	11.67	0.0	1.45	1.36	0.36	0.42	0.47	0.41	10.64	6.26	506.92	298.42	-15.51	92.97
2024-05-13	11:35:40	15	3.41	0.01	1.45	1.36	0.4	0.25	0.49	0.21	10.52	6.15	500.19	292.61	-14.53	96.84
2024-05-13	11:35:45	16	4.06	0.0	1.45	1.36	0.23	0.41	0.3	0.55	10.36	6.17	490.0	291.87	-15.19	101.43
2024-05-13	11:35:53	17	4.3	0.01	1.45	1.36	0.39	0.42	0.47	0.36	10.28	6.17	484.21	289.22	-17.69	109.26
2024-05-13	11:36:01	18	5.86	0.01	1.45	1.36	0.37	0.42	0.46	0.27	10.23	6.06	480.39	283.29	-17.1	117.85
2024-05-13	11:36:09	19	6.28	0.01	1.45	1.36	0.4	0.41	0.45	0.42	10.12	6.06	473.38	282.59	-17.37	126.21
2024-05-13	11:36:17	20	7.4	0.01	1.45	1.37	0.38	0.43	0.55	0.37	10.16	6.05	471.76	280.8	-16.74	133.97
2024-05-13	11:36:29	21	14.04	0.01	1.45	1.37	0.4	0.39	0.48	0.29	10.11	5.9	467.97	273.35	-19.2	145.39
2024-05-13	11:36:32	22	6.79	0.01	1.45	1.37	0.37	0.43	0.5	0.58	10.25	5.89	475.51	272.34	-14.71	149.02
2024-05-13	11:36:40	23	6.55	0.01	1.45	1.37	0.39	0.43	0.58	0.38	10.5	5.91	486.52	271.81	-17.92	156.28
2024-05-13	11:36:43	24	2.89	0.01	1.45	1.37	0.4	0.22	0.79	0.2	10.63	5.86	491.47	269.45	-14.8	159.84
2024-05-13	11:36:46	25	6.11	0.01	1.45	1.37	0.27	0.44	0.29	0.57	10.54	5.9	487.37	270.41	-14.23	163.14

Figure 15: Per repetition data

D Extra graphs

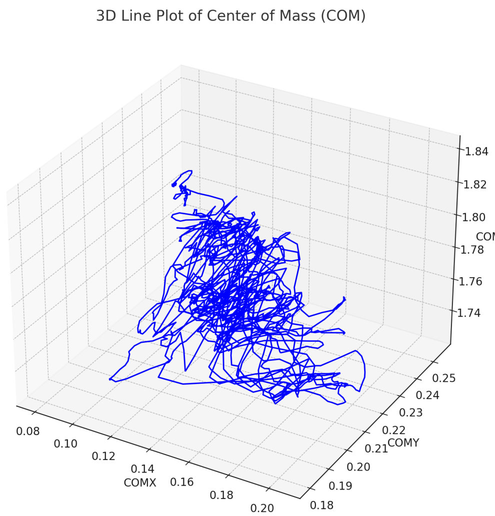

Figure 16: 3D Center of Mass

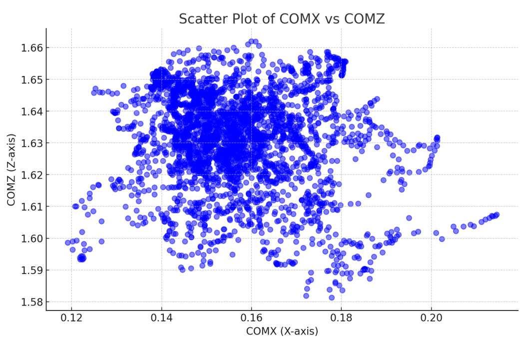

Figure 17: XZ Center of Mass

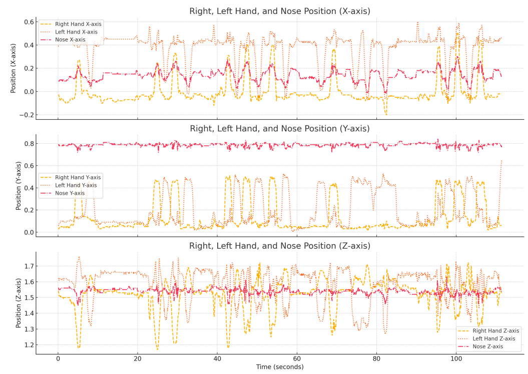

Figure 18: Joint position data

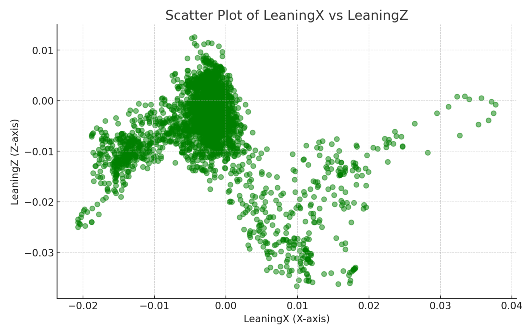

Figure 19: LeaningX vs LeaningZ

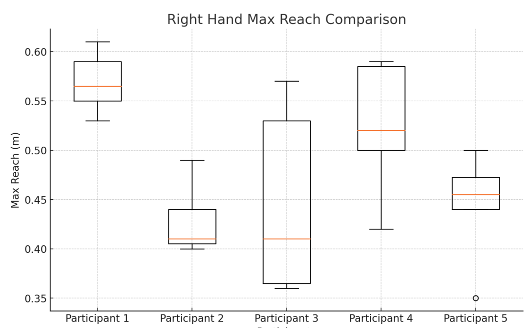

Figure 20: Boxplot comparison of hand reaches