CaregiVR: A Virtual Reality System that Provides Concurrent and Terminal Feedback for the Self-Directed Training of Ergonomic Patient Transfers

Master Thesis

by

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Konstanz, 2021

Abstract

Caregivers often care for patients with functional disabilities. While assisting with a patient's daily activities, caregivers are often required to transfer the patient. However, conducting manual patient transfers poses a risk to the physical health of the caregiver. Although the Kinaesthetics care conception can help address this issue, existing mechanisms for self-directed training are limited. This thesis presents a virtual reality system, in the following called *CaregiVR*, that can support self-directed training of ergonomic patient transfers by providing concurrent and terminal feedback. CaregiVR is a combination of two components: A feedback system for detecting risky behavior related to ergonomics and a patient transfer task in virtual reality. This thesis focuses on the effect of various types of feedback on self-directed training of ergonomic patient transfers. Theories related to feedback, Kinaesthetics, and information visualization inform the design requirements of CaregiVR. Relevant works from training in nursing-care and feedback systems in motor learning provide a foundation for the design process. A novel sketching template was a part of the design thinking process that facilitates easy conceptualization in the early stages of the design lifecycle. CaregiVR was implemented as a prototype of the design concept. The thesis proposes a study design for conducting a qualitative user study. This study design was iterated after a pilot test. Moreover, this work also discusses various techniques to analyze data collected by the proposed study design. Finally, we look into the benefits and shortcomings of CaregiVR and discuss how future researches could extend this work in various directions.

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1. Introduction

Since childhood, we all evolve physically while learning different motor skills. It is a crucial part of our growth and understanding of our bodily movements. Training in particular motor skills even in later life stages is essential for medical professions such as nursing care. As caregivers in nursing care deal with patient transfers daily, practical training to develop relevant motor skills is crucial. The training helps the caregivers to perform the patient transfers ergonomically. This knowledge reduces the risks of mishandling the dependent patients and, in turn, physically straining their own(caregiver's) bodies. One of the key aspects of such practical training sessions is providing useful feedback during and after their training activity. Currently, a professional known as a Kinaethetics expert monitors and provides feedback during these training sessions. However, in Germany, the integration of methodologies for ergonomic patient transfers training based on Kinaesthetics' concept(henceforth referred to as Kinaesthetics) only consists of a rudimentary course over three nonconsecutive days. Hence, internalization and application of the concept in real-world practice often fail. Safe patient handling techniques learned and understood in theory do not make their way into the job's practical application.

Recently, mixed-reality technologies have progressed to an extent where we can use them for various training purposes. Virtual reality(VR) has been widely used for motor learning due to its advantages, such as simulation of different situations[1], cost-effectiveness[2], hands-free interactions[3], and more field-of-view than the current Augmented Reality(AR) headsets. These progressions in technologies have allowed us to develop virtual reality systems for the training of ergonomic patient transfers. However, the areas of delivering relevant feedback according to the users' ergonomics remain unexplored.

The upcoming section 1.1 addresses the current issues in practical training in nursing care as a motivation for this work. Next, the goal of this work is highlighted and expands upon the kind of feedback system that is the focus of this work. Furthermore, in section 1.3, the structure of this thesis is addressed.

1.1. Motivation

The elderly population (people aged > 65 years) in European countries is rising rapidly. Germany is among the top three countries with the highest elderly population of 21.45%. The increase in the elderly population has, in turn, led to an increase in the number of nursing-care personnel in Germany [Figure 1.1]. One substantial part of nursing care is patient transfers, which comes under mobility care. Although transferring is an integral part of taking care of the elderly, it is also a significant cause of risk in nurses. The physical risks majorly include lower back pain(LBP) due to musculoskeletal strain and other physical detrimental effects such as Musculoskeletal Disorders [4, 5, 6]. Musculoskeletal Disorders or MSDs are injuries and disorders that affect the human body's movement or musculoskeletal system (i.e., muscles, tendons, ligaments, nerves, discs, blood vessels, Etc.).

To reduce the nurses' physical deterioration during patient-transfer, courses based on kinaesthetics care conception are taught in medical schools. However, figure 1.2 highlights the limitations of the current educational system for the nurses. The red mark highlights the pain-points in the system. In the existing curriculum, nursing-care students mostly only take part in one basic kinaesthetics practical training course over three nonconsecutive days in a formation of three years. This shows that opportunities to gain practical knowledge are quite limited. Since, from this course, typically no further support for learning kinaesthetics transfers is provided by these educational institutions [7]. The knowledge transfer in the field from experienced nurses is also limited by the factor that the curriculum changes over time. The investigation conducted by Dürr et al. (2019) clearly states that nurses report further need for self-directed practical training. As per the implications, this need is characterized by support for interactive learning by instruction, feedback, and reflection mechanisms [7].

Staff in care homes and home care services[1]

Specification	Unit	2009	2011	2013	2015	2017	2019
In care homes	number	621,392	661,179	685,447	730,145	764,648	796,489
including							
full-time staff	number	207,126	212,416	203,715	209,881	220,958	231,847
In home care services[2]	number	268,891	290,714	320,077	355,613	390,322	421,550
including							
full-time staff	number	71,964	79,755	85,866	96,701	109,657	117,124

1: As at 15 December.

Figure 1.1.: The increasing number of nursing care staff in home care services [8]

Previous researches have effectively demonstrated that interactive technologies like smart mirrors [9], virtual reality [10] and vibrotactile feedback mechanisms [11] can be used for training of movements. Although these implementations are limited by training movement, including a single-entity(oneself), the learnings are carefully translated for a system with two entities. There exists a virtual patient transfer system developed by Daniel Schweitzer as a part of his master project. The system, as mentioned above, tries to mimic the process of a real-patient transfer setting in a virtual reality environment. This system suffices some part of the self-directed learning by enabling the learner to experience the patient transfer in a virtual reality environment. However, other factors like - feedback related to posture based on kinaesthetics concepts, revisiting, and reflecting on errors made during the training are not addressed inherently by the virtual patient transfer system. Hence, there is a possibility to extend the system based on the factors mentioned earlier. The next section discusses this work's primary goal of facilitating ergonomic virtual patient transfer training by integrating feedback methodologies. It also lays the foundational scope of this thesis work.

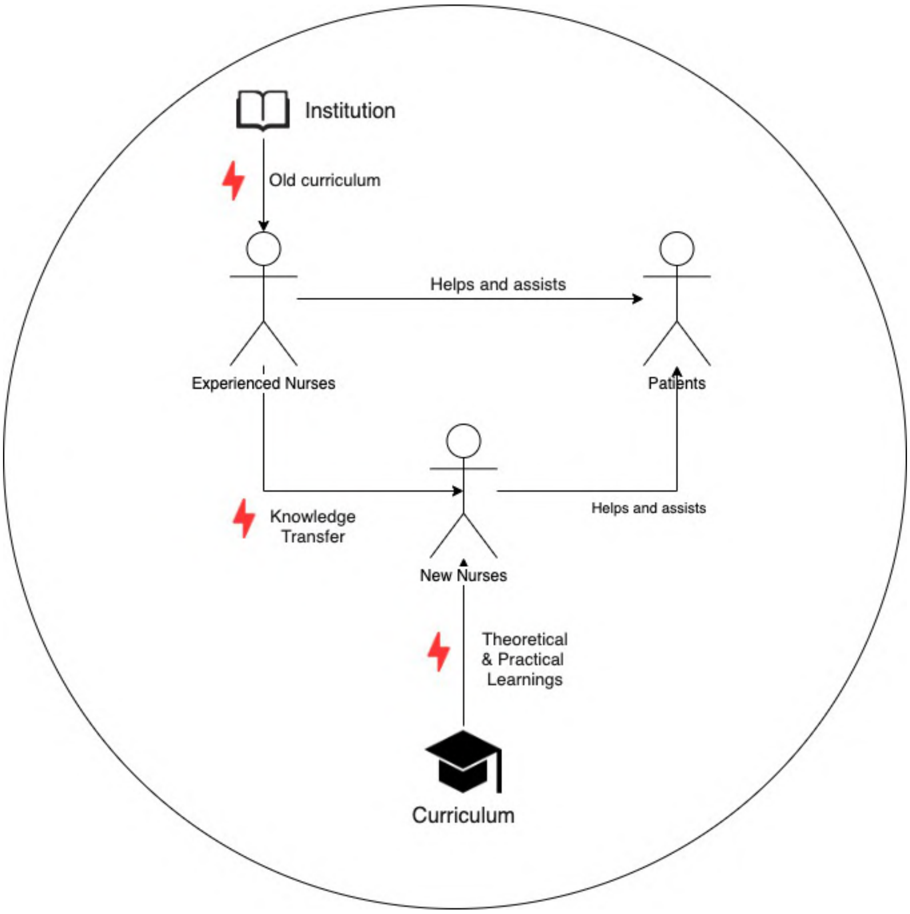

Figure 1.2.: Limitations of the current system

1.2. Goal

This thesis intends to investigate how various types of feedback can be delivered to the user to help them perform self-directed patient transfers in virtual reality ergonomically. Hence, the overall goal of this thesis can be encapsulated as follows:

> To determine the effect(s) of providing concurrent and terminal feedback during self-directed learning of patient transfers in virtual reality.

The aforementioned goal can only be realized by merging the feedback system and a relevant patient transfer task in virtual reality. It is clear that the feedback can only be provided to the user in a context related to a task. The system developed as a part of master's research is hereby referred to as *CaregiVR* [Figure 1.3]. To define this work's contributions clearly, the part highlighted in blue was developed as a part of this research. The patient transfer task (initially developed by Daniel Schweitzer) is integrated to generate a coherent system for conducting a research study.

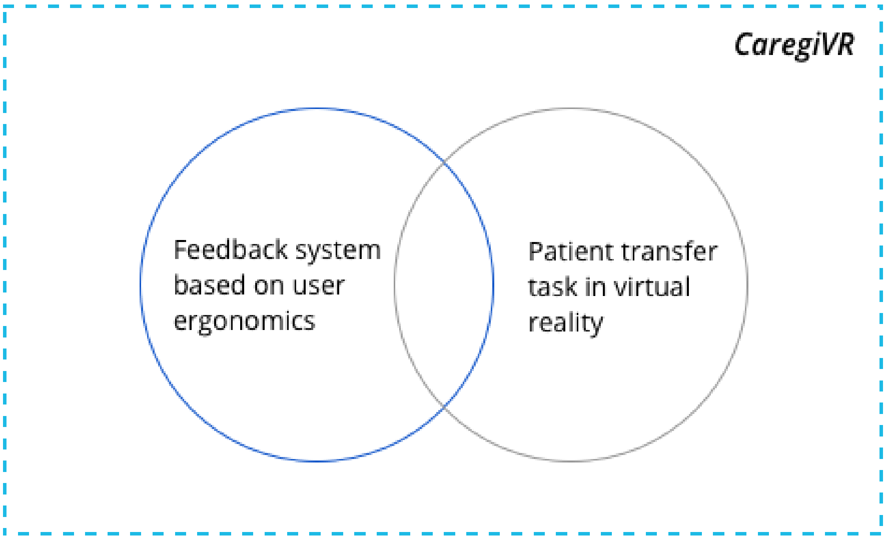

Figure 1.3.: Defining scope by segregating parts of the CaregiVR system

Previous researches in nursing care have developed an understanding of how MSDs impact health-care workers, specifically geriatric nurses. They also suggest that proper training, including reinforcement of lifting techniques and body mechanics, is the most important factor in reducing injuries [12]. To bring the real-world procedure close to the recommended procedure, frequent and timely feedback to the nurses is critical [13, 14]. As a part of the seminar research, various benefits of the feedback modalities depending on the learner's learning stage are discussed. Similarly, other research in virtual movement training has highlighted how different types of feedback can be beneficial [15]. Consequently, *CaregiVR* takes advantage of findings in previous research and applies them to provide relevant feedback to the user during their training. As of current knowledge, *CaregiVR* is the first virtual reality system that provides instructions and feedback for self-directed training of patient transfers ergonomically.

1.3. Outline

This thesis is structured into six parts ranging from the first phase of requirement analysis to the last phase of system evaluation. The initial chapter already covered the motivation for this work along with the goal and contribution of this research. The upcoming chapter 2 covers different theories to better understand this work's content and provide an overview of the rationale behind certain decisions. In chapter 3, the related works are discussed, which helped to defined the goal and scope of the *CaregiVR* system. Chapter 4 expands upon the conceptualization process based on the previously generated requirements. The initial concepts and their final iterations are described as a part of this chapter. Moving further, chapter 5 realizes the interaction concepts finalized previously. It also dives into the primary hardware requirement and analysis performed before developing the feedback system. Study design and details regarding implications of pilot study findings are part of chapter 6. Finally, chapter 7 discusses the future implication of this research and the work is concluded in chapter 8.

2. Theoretical background

Before proceeding with literature research by analyzing related works, it is essential to understand the theoretical background in the context of the system. At first, CaregiVR is a virtual reality training system, and it is essential to skim through some virtual reality basics. Section 2.1 explores the basics necessary from a perspective of training in VR. Next, the working context of the CaregiVR system is for the training of nurses. Thus section 2.2 provides a short introduction to Kinaesthetics. In the succeeding section 2.3, we delve into two consequential types of feedback that are the focus of this thesis. Finally, CaregiVR will provide this feedback to the user(nurses) using different visual and auditory modalities. One of the critical modalities is vision; it can quickly increase the user's cognitive load. Hence, in section 2.4, we look into the literature related to information visualization that helped us inform design decisions during the conceptualization phase.

2.1. Virtual reality for training

The primary purpose of virtual reality(VR) is to place a person in a stimulated environment that resembles a real-world. The person in this synthetic environment has a sense of self-location within it and can explore the environment around him/her by interacting with it. Immersive VR training systems are already being used for movement training purposes ([16], [9], [10], Etc.). The core components of VR that makes it immersive are [17]:

- Head-mounted display(HMD) - A tracked HMD lets you see the new visuals of the virtual world. One can see and interact with the world primarily from an egocentric perspective.
- Tracking - An unobtrusive tracking mechanism is essential to register one's movements and manipulate contextual information based on the tracking data.
- Gesture and force feedback - Gloves to interact with the virtual objects and haptics to provide a sense of touch together add to the compelling VR experience. Tactile reinforcement of the presence of an object considerably improves the virtual experience for training.
- Stereo sound - A sense of presence and immersion develops when stereo sound helps localize an object.

- Voice synthesis and recognition - Voice input and command recognition, however unexplored in earlier systems, can lead to a high degree of freedom. Adding voice as an interaction modality allows one to interact efficiently when the visual channel suffers from an overload of information.

The five components stated above are considered while designing the concepts and prototype of CaregiVR. CaregiVR system balances these components appropriately to help deliver an immersive and engaging patient transfer training experience.

2.2. Kinaesthetics

> "Kinaesthetics is the study of movement and perception, which in turn originates from motion - it is the teaching of the sensation of movement." - translated from German ([18])

Developed during the 80s by F. W. Hatch and L. S. Maietta [19], Kinaesthetics aims to improve the caregiver's fundamental understanding of interaction and human movement. One of the main areas of application is the domain of healthcare. The focus of Kinaesthetics training lies in the movement support of a care-dependent person in daily activities. By raising awareness of one's movement and the counterpart's movement, one learns to adapt the support in a health-promoting way. Basic Kinaesthetics training is a part of the nursing institution's curriculum in Germany, where the students are taught these concepts in a workshop spanning over three non-consecutive days. The Kinaesthetics experts during this workshop deliver feedback to the students in regards to the quality of their movements.

A central element of Kinaesthetics training is the Kinaesthetics concept system, a teaching tool used to observe and describe human movement activities from different perspectives. It consists of six concepts (also known as dimensions): interaction, functional anatomy, human movement, human functions, effort, and the environment as described in Figure 2.1. The techniques taught at the nursing institutions as a part of the curriculum act as a link between ergonomic patient transfers and these six dimensions of Kinaesthetics. The techniques are not meant to be followed as a set of instructions but are to be understood overall for the purpose of practical application.

Concept	Content
Interaction	The concept interaction addresses the following topics: senses (sense of sight, hearing, smell, taste and touch), movement element (time, effort and space) and forms of interaction (simultaneous-mutual, stepwise and unilateral interaction). The quality of interaction via personal contact and motion is central for the learning processes of the care-dependent person.
Functional anatomy	The human body consists of stable body parts (e.g. head, chest, pelvis) and space in between / joints (e.g. neck, waist, axilla) which have different functions and characteristics. Another aspect of this concept is orientation, meaning the ability to orient in the room and within one's own body. The interaction of these aspects allows to move the body with less effort and greatest possible control.
Human movement	The concept of human movement is not only concerned with movement from A to B, but also with posture and coordination necessary to organize the body's weight against gravity. One way to categorize human movement is to divide movement patterns into parallel (two-dimensional) and spiral (three-dimensional) movement.
Effort	A certain effort is needed to carry out movement. Two factors describing the characteristics of effort are pulling and pushing. When pulling, we use muscle strength to pull a part of the body to another part of the body. With pushing, we use muscle strength to push a part of the body to another part of the body. Extremities play an active role in pulling and pushing.
Human functions	Different functions of movement are classified into two categories: simple functions and complex functions. Simple functions are positions, e.g. lying, sitting. Complex functions are divided into movement without change of place (e.g. eating, elimination) and movement with change of place (e.g. walking, running). Simple functions are the foundation for complex functions.
Environment	Adjusting the physical environment by using the right equipment in the right place at the right time increases better interaction, facilitates locomotion and reduces physical strain.

Figure 2.1.: The six dimensions of every Kinaesthetic-based interaction by A. Fringer [20]

2.3. Types of feedback

Feedback can be defined as an information received in response to a task performed. When it comes to interactions mainly in the field of HCI, we can classify feedback based on its relational trigger.

> Inherent feedback "is information provided as a natural consequence of making an action". In contrast, augmented feedback is external feedback artificially presented to the user based on "information from the measured performance outcome." [21]

As a part of previous researches, it is generally accepted that augmented feedback, provided by a human expert or a technical display, effectively enhances motor learning [22]. Hence for the purpose of this thesis work, we will focus on augmented feedback and its types.

> Augmented feedback, also known as extrinsic feedback, is defined as information that cannot be elaborated without an external source; thus, it is provided by a trainer or a display. [21] [23]

Augmented feedback can also be a function in relation to time. Such strategies of providing feedback can be categorised according to when the feedback was provided with respect to the motor task.

1. **Concurrent feedback:** Also known as real-time feedback, is provided during the execution of the motor task or when the movement is being performed.

2. **Terminal feedback:** Is provided after the completion/execution of motor task. This is beneficial for reflection.

Motor learning aims to enhance complex movements (re-)learning by optimizing instructions and feedbacks. To train a specific motor movement, instructors use specific modalities to tailor the learning of the motor task. For instance, instead of showing the learner corrections, they move the learner through the motor task's set-by-step movements. Analogous to this approach, in virtual reality, we can provide augmented feedback while addressing different modalities. How these different feedback modalities can be addressed are: vision (screens, head-mounted displays), hearing (speakers, headphones), haptics (robots, vibrotactile actuators), or a combination of them [22]. It is difficult to determine to what extent each modality enhances motor learning. However, a direct correlation has been made by Sigrist et al. 2013 when it comes to motor task complexity and feedback modality. Figure 2.2 illustrates the effectiveness of using different combinations of feedback modalities according to the functional task complexity. We consider these learnings from previous researches for designing the feedback module of the patient transfer task of CaregiVR.

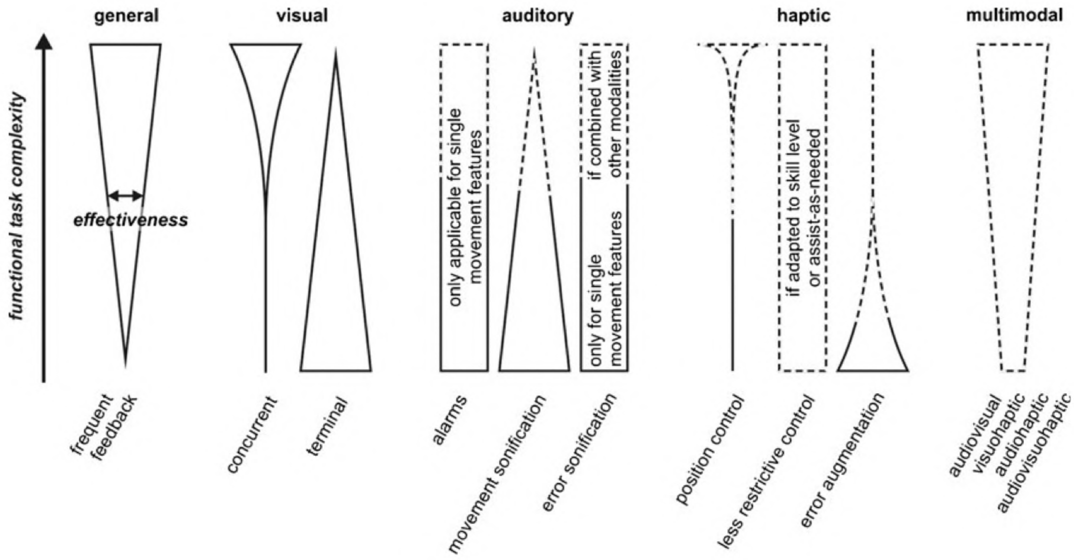

Figure 2.2.: The figure shows the experimentally confirmed (solid) and hypothesised (dashed) effectiveness of a feedback strategy to enhance motor learning depending on functional task complexity. The broader the shape, the more effective the strategy is [22]

2.4. Visualization - Some general guidelines

As we have briefly discussed feedback modalities, it is necessary to point out that some of these feedback modalities can easily be over-used and cause cognitive overload to the user. One such feedback modality is the visual channel. As CaregiVR is a virtual reality system, most of the virtual environment is perceived by our users visually. Visual highlights also provide support for the patient transfer task. Due to this concern, it is necessary to introduce some theories related to contextual interfaces and information visualization.

Literature related to contextual interfaces and data visualization provides an understanding of relevant concepts. Previous research on contextual interfaces has established that users need to interact with more information and with more interface components that can be conveniently displayed at one time on a single screen [24]. The works talk about four approaches categorized based on interface mechanisms used to separate and blend views. These approaches are:

- Overview+Detail - uses a spatial separation between focused and contextual views
- Zooming - uses a temporal separation
- Focus+Context - displaying the focus within the context
- Cue-based - selectively highlight or suppress items

These approaches can help us to provide necessary information to the learner based on their actions and surrounding situations.

Another work of interest that later improves the conceptualization phase is from the field of information visualization. Work written by Tamara Munzner [25] as a part of designing visualizations provides key insights into core principles of how information visualizations could be designed. The chapter 5 of the book talks about two fundamental kinds of sensory modalities, namely, the **identity** and the **magnitude** channels [Figure 2.3]. We perceive information about *what* something is or *where* it is by means of the identity channels. In contrast, the magnitude channel tells us *how-much* of something there is. Further, the chapter presents an interesting medium to present two different types of data - table data-set and network. Although these two types might sound irrelevant from the naming convention, they implicitly define the data we need to present to the user of CaregiVR. Table data-set contains data that can be categorized. We have already mentioned that we will be using an implementation of terminal feedback. Hence the information represented after the task is performed must be categorized appropriately and visually linked. This type of representation is analogical to a network data-set. According to the literature, these data-types can be well depicted using *Marks* - for table data-set and *link-nodes* - for representing a network data-set.

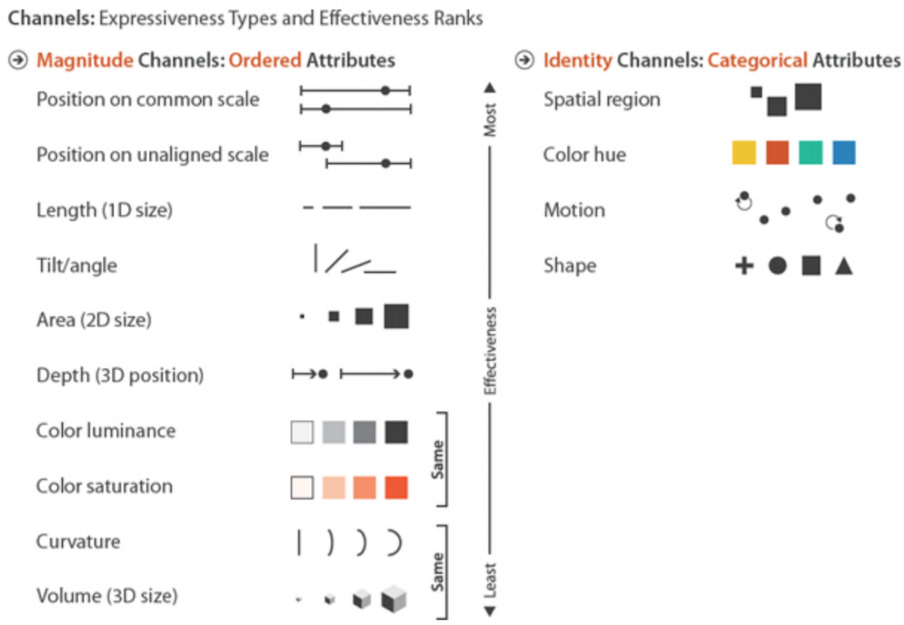

Figure 2.3.: Expressiveness and effectiveness rankings of visual channels [25]

Furthermore, it is said that the most common beginner's mistake in visualisations is violating the expressiveness and effectiveness principles [25]. We take these understandings from the literature research and later apply them in the chapter 4 of concept design.

3. Related work analysis

After gaining an adequate understanding of the relevant theories to this work, we now focus on the initial requirement analysis part and what is later used in designing the CaregiVR system. Though direct user interviews were not conducted, relevant pieces of information from previous works in the nursing and movement training domain were shortlisted and analyzed to derive system requirements.

Section 3.1 provides an overview of the related works from two perspectives. Firstly, systems that support learning in nursing and secondly system that support movement training. The overview of these systems would allow us to determine the requirements of CaregiVR, a system focussed on providing feedback to movement training in nursing care. Section 3.2 utilizes these requirements as a blueprint to conduct an in-depth analysis of previous works in movement training and what learnings and essential aspects can be carried forward in CaregiVR's system concept design.

3.1. Overview of related works

When it comes to ergonomic patient transfers training, there are very few systems that employ mixed reality display technologies. However, there have been various researchers who explored mixed reality possibilities in other parts of nursing care like intravenous catheter training system[26], simulator for learning nasogastric tube placement[27], and medication administration[28]. Although this limits the learnings available, it also paves a way to clarify what this thesis contributes. We will briefly discuss digital systems in nursing care, which would help us better understand the requirements.

3.1.1. Systems related to training in nursing care

System by Huang et al. [29] is one of the closest work in related to self-directed training of patient transfers. It employs a robot patient that can replicate the patients who are suffering from mobility problems. The system allows a trainee to have voice interaction with the robot patient. This kind of input modality is interesting when it comes to training a complex task like patient-transfer. However, this system is limited by providing feedback only related to voice interactions and mobility of patient's joints. To take our analysis further, an interesting system that provides feedback for the ergonomic patient-transfer training is introduced by Huang et al. [30] in 2014. This system trains nursing students, and it tracks the user during the training session. The system uses RGB-D sensors to determine the errors in the posture of the trainee. Though the system requires another user to act as a patient for training, the user tracking and feedback mechanism is interesting from the system development point of view. The feedback is terminal in nature and is provided by a desktop computer interface that presents users with a checklist and videos. The results of the experiment conducted by the authors showed a more significant improvement in the participants who used this system. Another system by Kopetz et al. [31] explores the possibility of providing instructions using smart glasses during patient-transfer training. The system evaluates a realistic use-case setting with 29 nursing students as participants. Result analysis by the authors showed that smart glasses could potentially support skills training in nursing care. Both of the works mentioned above [30] [31] focus on transferring a patient from a bed into a wheelchair. Though these systems provide insights into providing different types of feedback, namely terminal and concurrent, we need to explore some works that would give us information about what metrics are to be considered for feedback related to a user's ergonomics.

One of the critical studies conducted by Muckell et al. (2017) directs us towards reducing the injuries in Direct Care Workers(DCWs) employed by nursing and residential care facilities. In their work, the authors conducted an exploratory study using the body tracking system. They used 3D video feed and wearable sensors to track the direct care workers' bodies to detect risky patient transfer behavior. This study highlights four key risk-metrics, common in different lifting and carrying techniques [Figure 3.1]. These risk-metrics consider important factors to stress the disc, vertebra, muscles, and ligaments of the low back. To summarize, these risk-metrics eventually focus on the MSDs mentioned as part of the goal and motivation of CaregiVR. We will consider these risk-metrics later as an essential part of our prototype. These risk-metrics are as below:

1. Detecting Wide Support Base
2. Detecting Squat
3. Detecting Good Posture (Upright Stance)
4. Detecting Good Posture (Avoid Spine Twist)

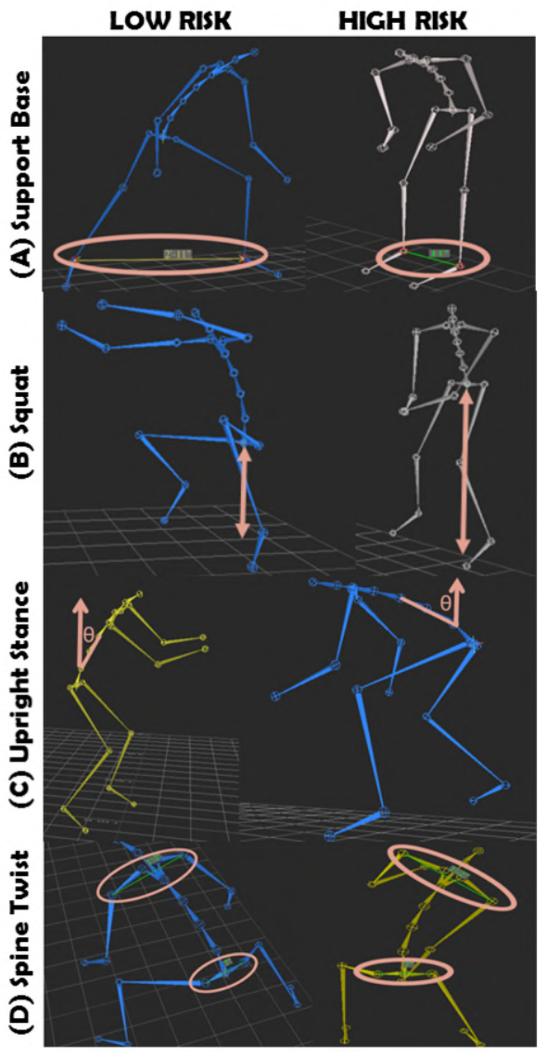

Figure 3.1.: Low vs. high risk motions for each metric [32]

Furthermore, there are two digital systems named NurseCare [33] which is smartphone-based, and KiTT [34] which is tablet-based which directly explores the training of ergonomic patient transfers using technology. Both systems by Dürr et al. also employ feedback mechanisms on the concurrent and terminal level. NurseCare system facilitates both kinds of feedback for the user. The terminal feedback provided is in a long-term format where nursing students can reflect on their errors. While the KiTT system provides

support during the training session, the feedback provided
as a part of this system is mostly terminal using an RGB video recording. The feedback aspects of both of these digital systems are interesting as they employ different methods for the trainee to reflect on their learnings.

Overall, all the systems reviewed related to nursing care training either require a second human entity or lack in-situ feedback related to ergonomics. This strengthens the contribution of this work which addresses three key points - (i) Self-directed training, (ii) Patient transfers, (iii) Concurrent and terminal feedback related to trainee's ergonomics.

3.1.2. Systems that support movement learning

In past two decades, there has been a significant research done in the area of movement learning using technology. However, most of these systems support learning of movements involving a single entity. For example, learning of full-body arbitrary movements [9], learning of simple arm movements [16], support learning of physiotherapy exercises [35].

Systems like Stylo & Handifact [36] and Naviarm [37] utilize haptics for real-time feedback to the users. The haptics also act as an unobtrusive medium for delivering feedback specially for complex tasks.

In addition to these, there are also works that allows learning of complex movements like salsa dance in virtual reality [38]. Furthermore, system by Takala et al. [39] allow for training of martial arts. Both of these system include a second virtual entity in VR which allows them to train by themselves. These works are highly relevant from feedback perspective as they extend the feedback mechanisms beyond conventional ways by employing VR.

3.1.3. Key factors to analyze the training systems

A quick overview of related systems can provide us with factors that we analyze in current systems, which will help us as takeaways for CaregiVR. On over-viewing the previous works in respective domains, we have narrowed down key factors for an envisioned system like CaregiVR. Further, we look into what these factors are and what do they mean in this work's context.

1. **Supported perspectives**

   They types of viewing perspectives supported by the system for delivering feedback

2. **Extent of tracking**

   To what extent is the body of the user being tracked

3. **Types of feedback**

The types of augmented feedback are covered by the training system

4. **Feedback modalities**

   The types of feedback modalities utilized to inform the user of an error

3.2. In-depth analysis of related works

We will now take the aforementioned key factors and analyze some relevant movement training systems in-depth. We will look into how various factors are realized using certain technologies. We will also discuss the advantages and disadvantages of certain implementations. Later, we will conclude this chapter by summarizing our findings for our concept designing phase.

3.2.1. YouMove

YouMove is a system for learning full-body movements [9]. This signifies that the whole body of the user is tracked during the training process. The system comprises a half-silvered mirror in which the user can see his/her reflection. The mirror is superimposed with graphical overlays to provide instructions and guidance to the users. The superimposed virtual skeleton on the user's reflection makes the user imagine the movements from a third-person perspective.

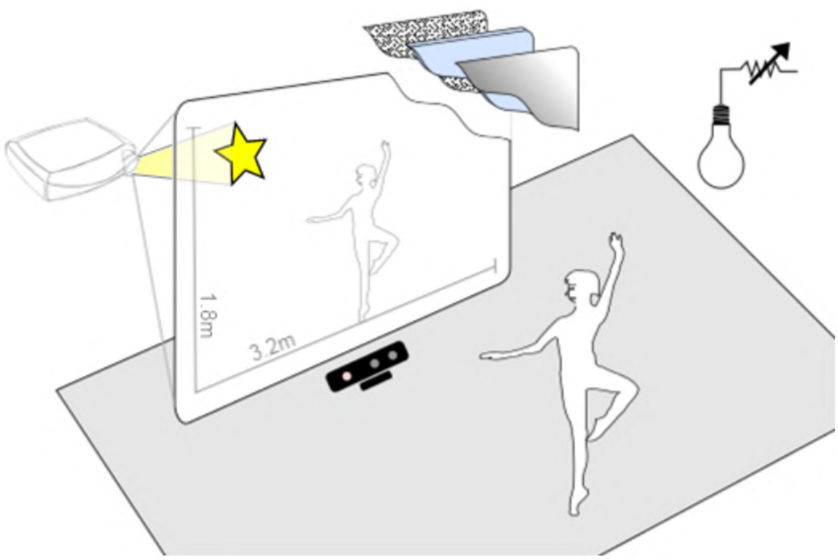

Figure 3.2.: Overview of YouMove System [9]

The instructions provided to the user are in terms of audio cues and adaptive movement graphic overlays. This is one of the only systems which dynamically adapts the speed of guidance overlays according to the user. YouMove notably focuses on user-driven learning by allowing the user to select their level of expertise. It also supports both concurrent and terminal feedbacks. Figure 3.3 shows the anomaly in posture conveyed to the user by highlighting the knee-joint in red.

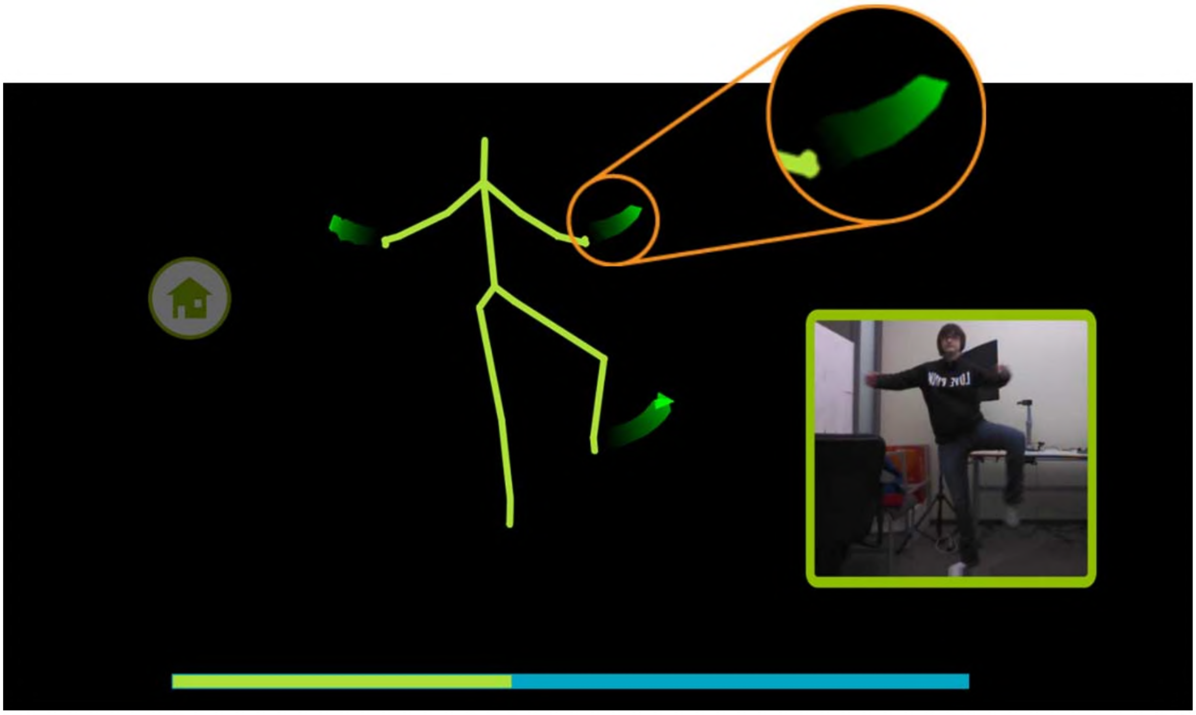

Figure 3.3.: Concurrent feedback in YouMove System [9]

While the terminal feedback is provided as a summary at the end [Figure 3.3]. During this feedback summary, the user is provided with keyframes and can watch each moment's aggregated errors. While the feedback is displayed, the user can still see their reflection. This still helps the user to understand a particular frame posture by again performing it without any system assistance. The learner can also see their video compared to an expert's video while performing the same movement. The video helps to reflect on learner's errors.

The system uses the Root Mean Square Error (RMSE) as a measure of learning, which is limiting in terms of providing accurate errors. But this method works similar to threshold detection mentioned by Muckell et al. [32]. Some of these systems' features can prove beneficial while designing the interaction concept of CaregiVR.

3.2.2. Physio@Home

Physio@Home guides people through pre-recorded physiotherapy exercises using real-time visual guides and multi-camera views [35]. This work domain closely relates to what should potentially be addressed by our system for learning patient transfers. Physiotherapy exercises also require a level of

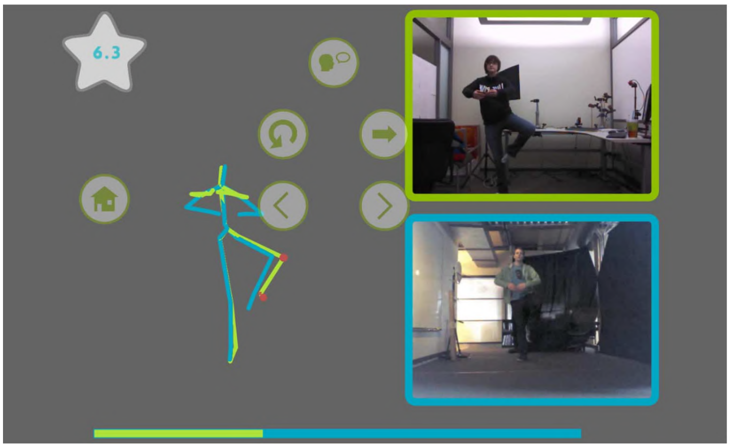

Figure 3.4.: Terminal feedback in YouMove System. Errors in joint position are indicated by red circles [9]

correctness to avoid any injuries. Usually, the patients are also assisted/trained by an expert - physiotherapist. However, after some time, the patient has to perform these exercises by themselves. The system is limited to tracking upper body movements only. But, it supports multiple camera views for the user - top view and front view of the user's arm movement. This multi-view approach helps in depth-perception when the movement is perpendicular to the camera. The visualizations shown in both the view are generated correctly because of an integrated tracking mechanism. Physio@Home addresses the guidance and feedback requirements quite extensively. The system uses something defined by them as a Wedge visualization for displaying the exercise's movement characteristics. This visualization acts as both guidance and real-time feedback for the learner. The wedge visualization is composed of a movement arc, a directional arrow, the nearest arm, and a top-down angle [Figure 3.5]. This implementation of real-time visual guidance and feedback can prove beneficial for our scenarios of learning patient transfers.

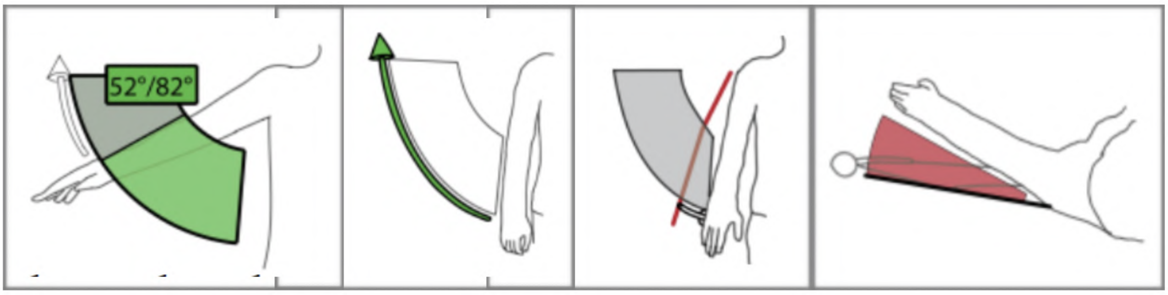

Figure 3.5.: Wedge visualization in Physio@Home [35]

As terminal feedback, the system allows the learner to playback their recording and shows error metrics. The error metric provided after the exercise is generated by comparing the learner's movement with the pre-recorded movement.

3.2.3. EXILE: Experience based Interactive Learning Environment

The motivation behind developing Exile was the hyper-aged society of Japan. This system was built for promoting the health of the elderly people not necessarily dependent on the nurses [40]. However, this system's important factor is the complexity of the movement and focus on the safety of one performing it. Though the EXILE system's overall goal differs from ours, the intricacies of system implementation overlap with the goals of CaregiVR. The system uses tracking for the whole scope of the body. The user feedback provided is based on overlapping the skeleton of the instructor on the learner. Visual concurrent feedback is provided by thresholding. If the movement's angle exceeds a specific limit, the system warns the learner of the imperfection in their movement. This particular part of implementation can be used as a basis for full-body tracking in our envisioned system. It would be beneficial for nurses training for patient transfer movements, as MSDs such as lower back pains occur due to incorrect postures.

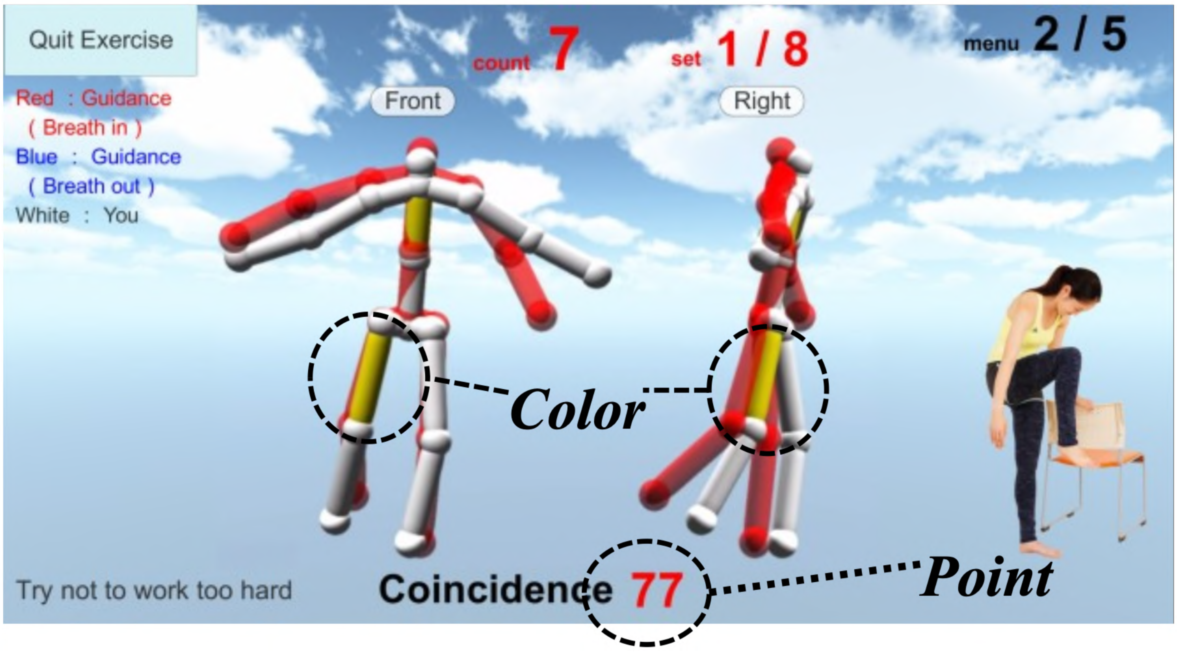

Figure 3.6.: EXILE system highlights [40]

3.2.4. Onebody: Remote Posture Guidance System

Onebody is a virtual reality system for remote posture guidance using a first-person perspective [41]. The system utilizes the Microsoft Kinect sensor for skeletal tracking of an instructor and a student who are not collocated. By overlaying the virtual avatars of the instructor and the student [Figure 3.7], the system creates a visualisation of first-person perspective to deliver movement instructions. The system generates an error value when a particular movement is completed and then compares it to the instructor's pre-recorded movement. The system shows upper limb visualization from the trainer's perspective. However, the learner can also observe the whole body movement mirrored in front of them during the whole process. This also helps the learner understand movement dynamics from alternative angles, a crucial implementation takeaway for our work.

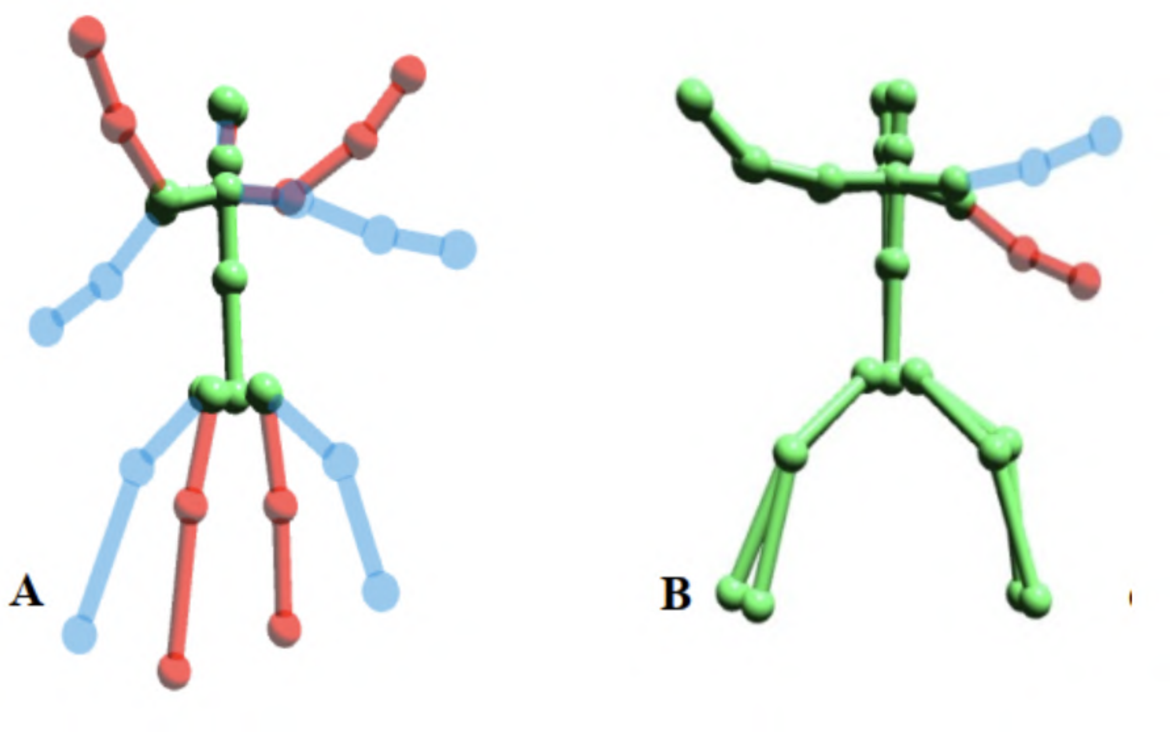

Figure 3.7.: Overlapping avatars [41]

3.2.5. Superimposing 3D Virtual Self + Expert Modeling for Motor Learning

Le Naour et al. [42] developed this virtual reality system to help with the learning of throwing movement in American football. The system has full body tracking of the learner. It highly focuses on utilizing augmented feedback in virtual reality to improve trainee performance. The authors comprehensively discuss the application of two types of augmented feedback - concurrent and terminal. The study conducted by the authors focussed on identifying the advantages of using VR-based feedback for motor learning. [Figure 3.8] shows the system setup for training of ball throwing movements.

This system utilized motion capture system to determine the motor execution improvements in addition to the generic accuracy measure. These kind of measures would be beneficial for CaregiVR because of the underlying philosophy of Kinaesthetics concept system. The concepts of Kinaesthetics ask the learner to develop an overall understanding of the bodily motor movements in relation to that of the dependent patient rather than following a set of instructions [2.2]. Furthermore, the motion capture mechanism allows the system to reconstruct the whole body movements of the learner. These movements can be played back to the learner as terminal feedback. This feature is specially interesting as it leverages the VR capabilities and goes beyond simply showing a video recording.

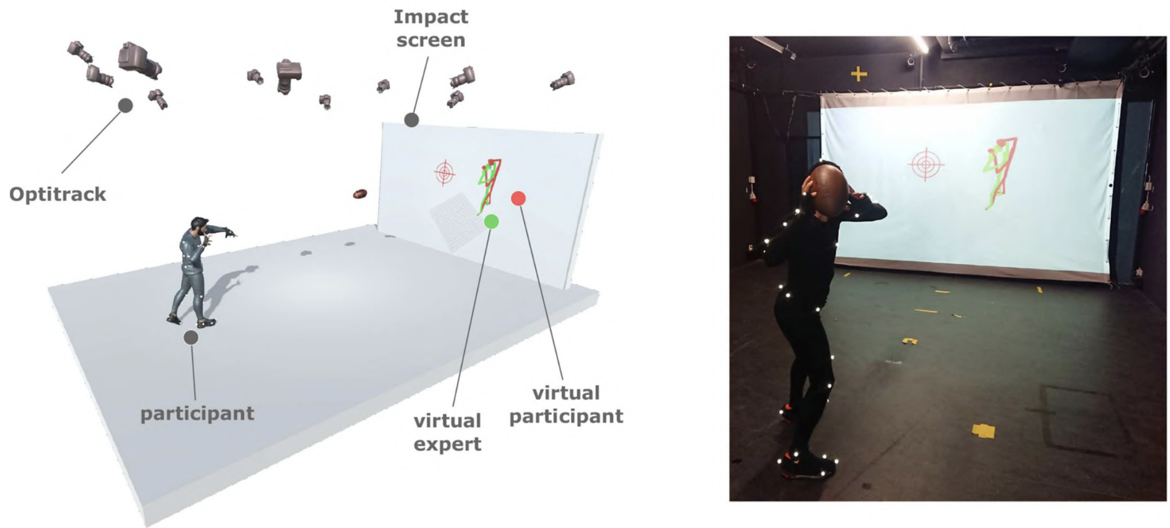

Figure 3.8.: System overview of Superimposing 3D Virtual Self + Expert Modeling for Motor Learning [42]

3.3. Conclusion

The detailed analysis of relevant works are summarized in table 3.1 according to the four key factors that we initially discussed as a part of this chapter. We will carry these findings forward to our next chapter and will look into how they influenced certain design decisions during the conceptualization phase. Though these related work analysis are not a direct indication of what and how the CaregiVR system should be developed, they provide a foundation to this thesis work to extend upon.

Name of system	Supported perspectives	Extent of tracking	Types of feedback	Feedback modalities
YouMove	Third person	Full body	Concurrent and terminal	Audio-visuo
Physio@Home	Third person	Upper body	Concurrent and terminal	Visual
EXILE	Third person	Full body	Concurrent and terminal	Visual
Onebody	First-person	Full body	Terminal	Visual
3D self + expert	First and third person	Full body	Concurrent and terminal	Audio-visuo

Table 3.1.: Comparison of existing technologies from implementation perspective.

4. Concept design

After analyzing various related works based on key factors, we now take those factors as essentials for our system design. In other words, the four key factors mentioned earlier could be considered as the initial requirements for the CaregiVR system. Firstly, in section 4.1, we discuss the design thinking process that we follow and some suitable methods for each of those stages. This initial step would allow us to define a basic structure of a user's system journey. Later in section 4.2, we employ design exploration methodologies to extend the user journey's basics into detailed concepts.

4.1. Design thinking

As a part of their book, Hartson and Pyla [43] defines a process called the UX design lifecycle. This lifecycle divides the process of user experience design into four stages, as shown in figure 4.1. This chapter focuses on designing concepts; hence, we will be using methodologies relevant to the first two phases of the UX design life cycle, namely, understanding user needs and creating design concepts. Most of the parts of understanding needs are covered in the previous sections. Here, we visualize those takeaways by following methodologies to make them a cohesive part of our later design stages.

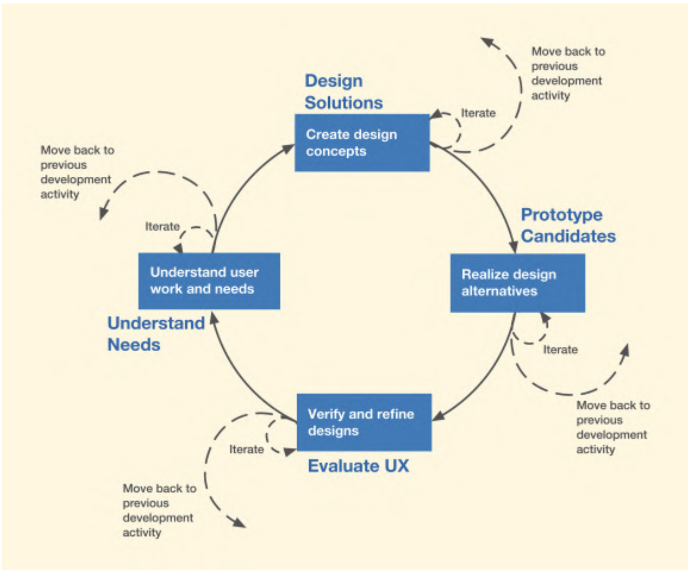

Figure 4.1.: UX Design lifecycle [43]

4.1.1. Persona

Lene Nielsen, in her book "Personas - User Focused Design" defines personas as a method that allows us to "get the same understanding of who the users are, and in what contexts they use the product" across all stages of a product development [44]. Personas are not just portraits, but they contain a textual description of a real-user. The picture plays an essential role as it can be used to address the user when considering certain system design decisions. A user persona was created as part of this work by getting participant descriptions from previous works in this domain [33] [7] [34]. Following are the details of the persona.

Figure 4.2.: Persona: Lina

Background: Lina is a 26 years old nursing care student at the medical academy in Konstanz. She lives in a shared flat with two other students. Besides studying nursing care, she also works at the City Hospital as a part-time nurse. In her spare time, she likes to read novels and play the piano.

Technical background: Being in her mid-20s, she is familiar with technologies like smartphones and tablets. She often uses a piano learning app on her tablet. She knows about the concept of virtual reality but has never used it before.

Kinaesthetics experience: As she is in the fifth semester of her studies, Lina has already attended the introductory Kinaesthetics course. The course took place over three days as a part of their curriculum. She was also provided with some theoretical knowledge during this course. However, Lina was not undergone any follow-up practical training. She is usually motivated to practice ergonomic patient transfers by herself. However, COVID restrictions and the lack of another member to role-play limits her ability to do so. If she finds a member to practice her workshop knowledge, Lina feels that she lacks relevant feedback. Although the Kinaesthetics coach is part of the staff hospital where she works, the COVID restrictions have led to extreme precautionary measures, limiting the coach's availability.

Goals: Lina is a self-motivated learner and would like to develop her skills to help her with better patient transfers during her work in the future. She wants to learn with appropriate feedback to avoid integrating inaccurate techniques within her. She is open to trying out newer technological solutions which would enable her to achieve her professional goals.

4.1.2. User journey

On clarifying the system's target user, we now generate some crucial parts of a user journey that would help us define a process for sketching the steps in the design exploration section. For this particular user journey, the user's goal (Lina's goal) is to train for ergonomic patient transfers by herself. Figure 4.3 shows the essential steps of the user journey and is described below.

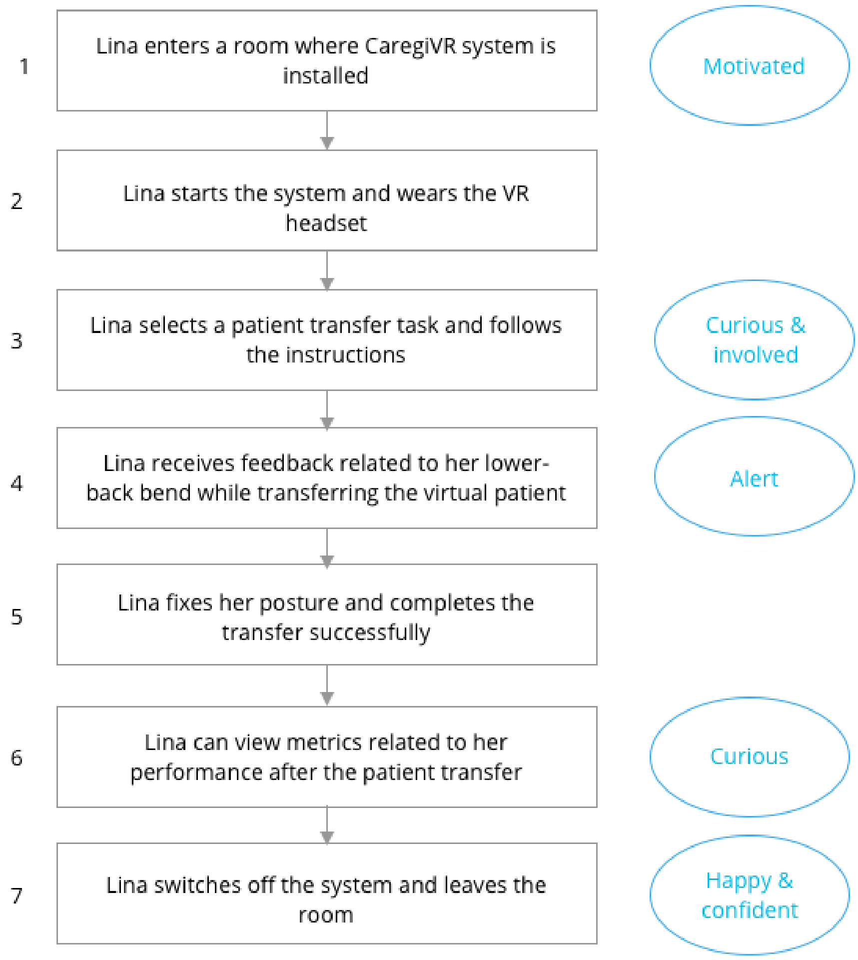

Figure 4.3.: Steps of the user journey

The user journey is divided into seven steps. The series of steps are performed in a sequence from top to bottom. The cyan-colored text enclosed in an oval depicts the emotion of the user during the corresponding step. This user journey map allows us to develop a system sequence and understand our system's emotional impact on its user.

4.1.3. Template design for sketching VR concepts

As a part of a usual design process, designers can directly move onto the next phase of exploration after defining a scenario or a user journey. This next phase usually involves sketching and generation of medium-fidelity wireframes. However, since CaregiVR is a virtual reality system, it was essential to have a basic template to sketch the system design's contextual aspects. This kind of template generation is significant as virtual reality is a 3D user interaction space, and depth plays a vital role in showing some elements better.

In their paper, Talbot et al. (2020) explain why free movement and immersive 3D pose challenges to traditional storyboarding methods. Virtual reality being a 3D interactive space, a sketch on blank paper lacks in maintaining spatial efficiency and intuitive reading of storyboard. A powerful suggested solution is to bind the several perspectives together to represent a specific point in time [45]. This would help balance the three-dimensionality, spatial efficiency, and ease of creation. This would, in turn, also help for an easier understanding of the virtual reality scene to the reader. After consolidating these ideas, a template was generated as a part of this work on which storyboard related to virtual reality can be sketched. The aspects taken into consideration were the field of view, comfortable head-turn zone, limits of depth perception (min. and max. distances).

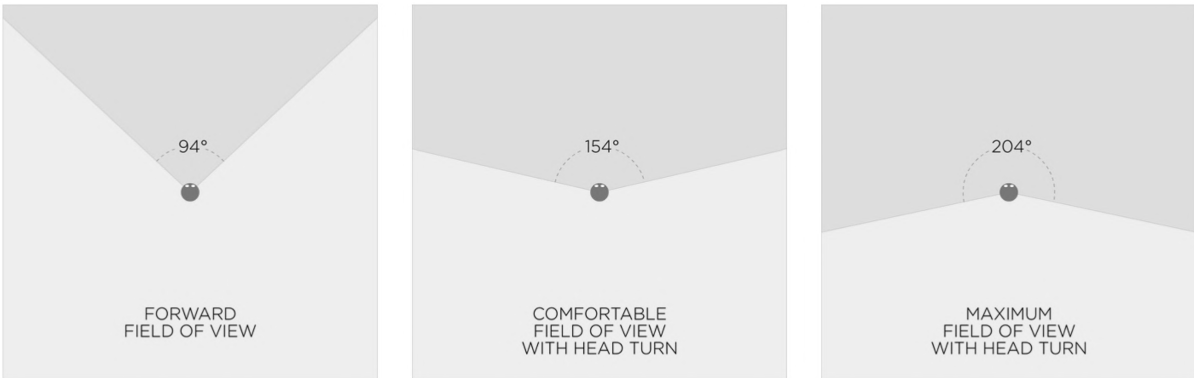

Figure 4.4.: Field of view based on comfortable head rotation ranges

Most of the commercial virtual reality headsets have a field-of-view of around 94-degrees [46]. The person wearing the headset can rotate their head comfortably to up to 30-degrees to the side. The maximum a head can be rotated without over-stressing the neck muscles is 55-degrees. The visual representation of this data is shown in figure 4.4.

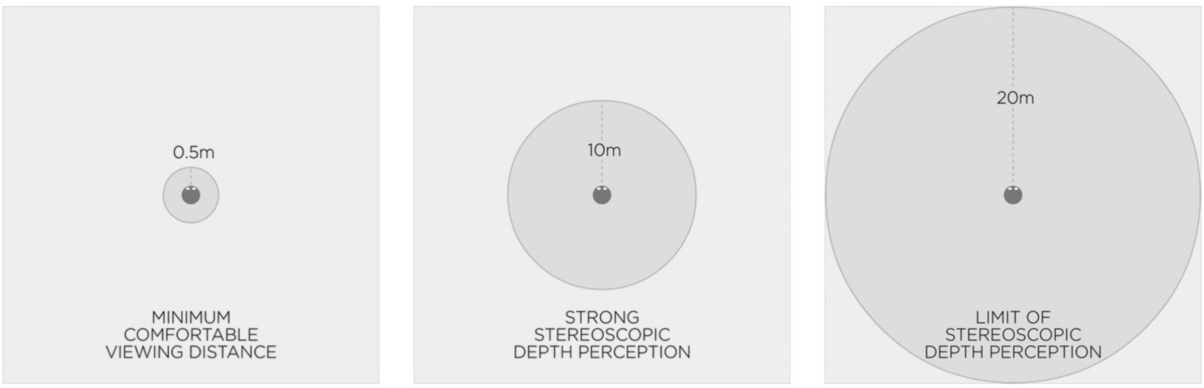

Figure 4.5.: Viewing distance based on comfort and strength of stereoscopic depth perception

Next, we look at the distance. Humans have evolved to pay more attention to objects that are closer. The minimum comfortable viewing distance in a Head-Mounted Display(HMD), before a user starts going cross-eyed, is 0.5-meters (Oculus now recommends a minimum distance of 0.75-meters [47]). Beyond 10-meters the sense of 3D stereoscopic depth perception diminishes rapidly until it is almost unnoticeable beyond 20-meters. So this gives us a sweet spot between 0.5-meters to 10.0-meters where we can place important content [Figure 4.5]. Furthermore, figure 4.6 shows a two-dimensional representation of a virtual scene by stitching several frames together. The labeling in the figure explains what each section of the 2D image represents in 3D.

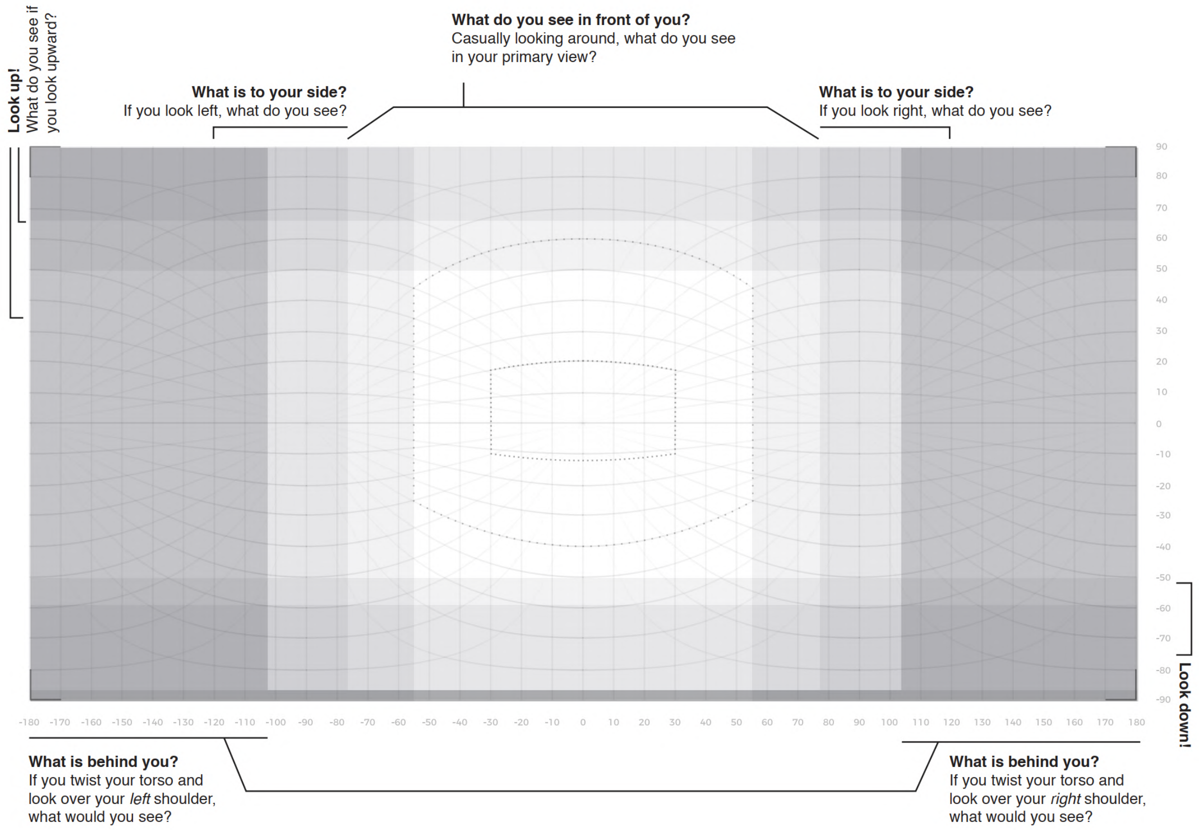

Figure 4.6.: 2D representation of the field of view sketching template with labelling

Now that each part of the template has been explained, it is easier to understand the upcoming section's sketches. Figure 4.7 unifies all the modules of the virtual reality storyboarding template. This template provides a necessary base that makes it easier to portray the ideas for design discussion and feedback. The next section explains the process of how the design exploration was conducted by looking into literature from other relevant domains and brainstorming ideas.

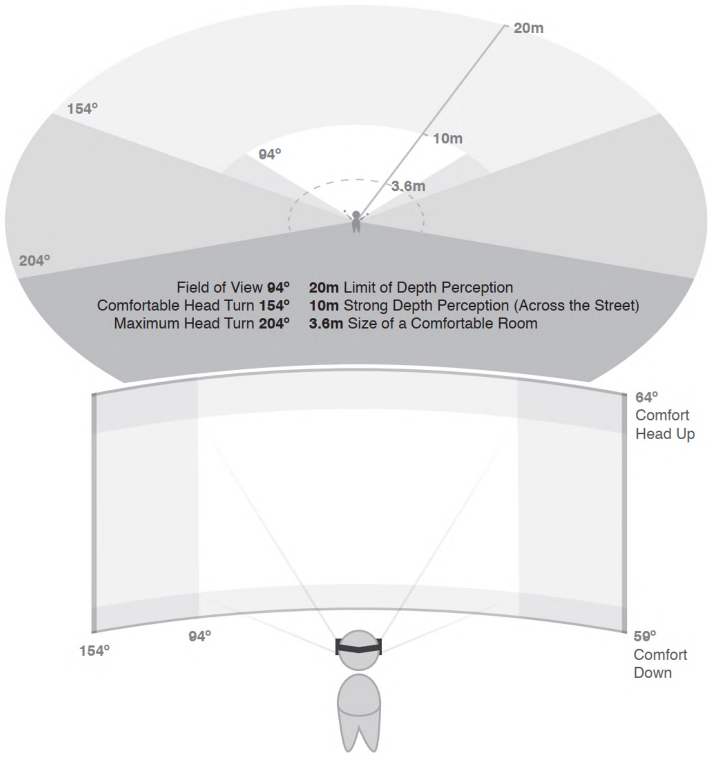

Figure 4.7.: Consolidated storyboard sketching template with guidelines

4.2. Design exploration

The main intent of the design exploration phase is to generate ideas of how the feedback delivery mechanisms of the CaregiVR system would function. The underlying assumption here is that we have a patient transfer task in virtual reality already available. This assumption was also clarified earlier as a part of the introduction.

In regards to concurrent feedback, researchers have shown that using multi-modal feedback for complex tasks could be beneficial [7]. According to the literature, a combination of audio-visual feedback modalities is considered a decent replacement for haptics [48]. For complex tasks like ours, the audio cue helps to gain the learner's attention since their visual senses are already engaged. At the same time, the visual cue provides the necessary system message to the learner. Another important aspect of the feedback system - The terminal feedback module. Terminal feedback plays a vital role in reflection and helps with longer retention [15] Since the training task has already been performed, this type of feedback can be more verbose. Furthermore, the learner now has a single point of focus - i.e., to analyze their performance.

As a part of this section, we will see some sketched ideas for delivering feedback to the user during different times. The later part of the section converts these sketches into a storyboard scenario based on our previously defined user journey.

4.2.1. Sketching ideas

There are multiple ways in which solutions can be designed. One of the common ways to visualize the ideas occurring in the brainstorming sessions is sketching. The *Sketching User Experiences* book by Bill Buxton [49] clearly suggests approaches that are useful for putting ideas onto the paper. There were multiple iterations of the design concept sketches. Also, some sketches were iterated once the prototyping staged was commenced. However, to simplify the understanding of this thesis document, the sketches are consolidated to deliver better reading experience.

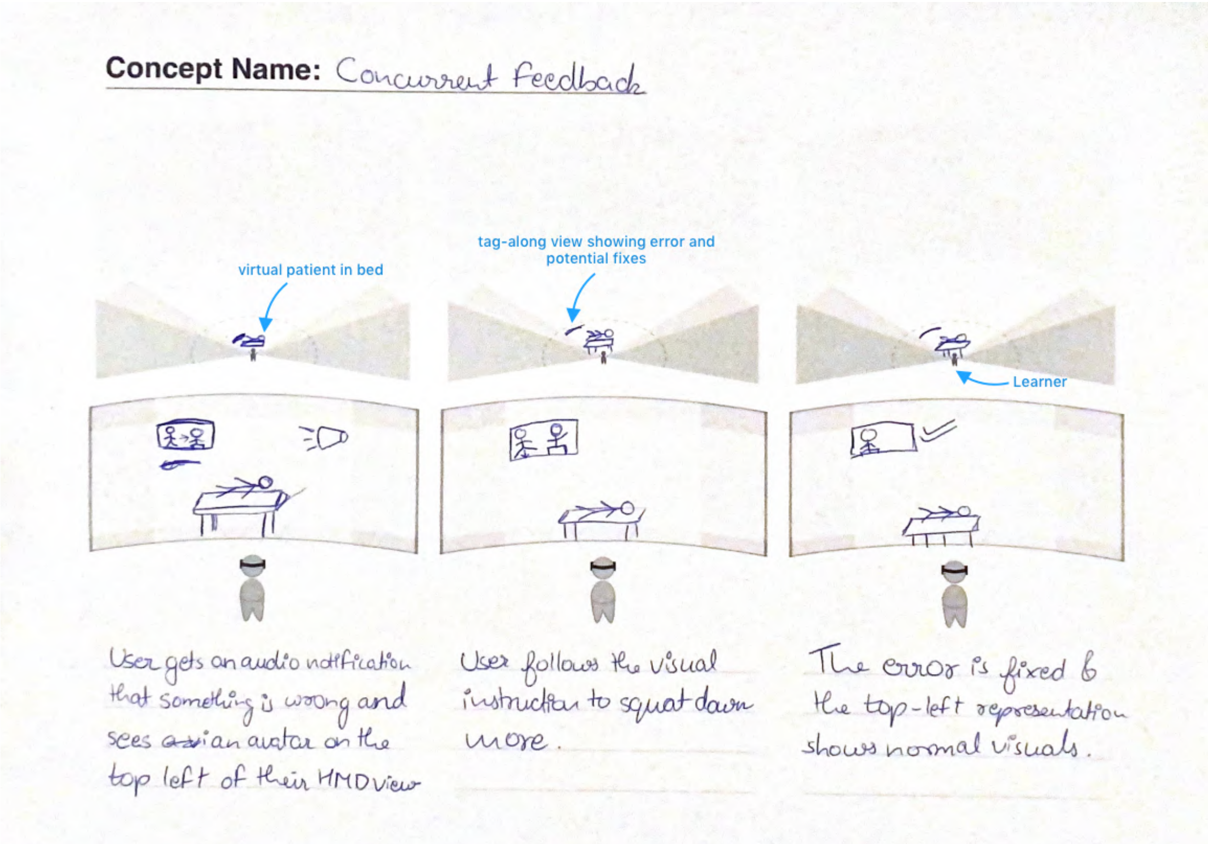

Figure 4.8.: Sketching the process of delivering concurrent feedback

Figure 4.8 shows the sketch of the concurrent feedback. The idea is to provide an audio cue to the learner if any risk metric error value(s) exceeds a certain threshold. Along with this cue, a window pops up in the top left view of the HMD. This view highlights the part of the body which is affected(in the left half). In the right half of the window, an animation is shown as to how the error in posture can be fixed. Figure 4.9 provides a sketch of a detailed first-person-view from the HMD.

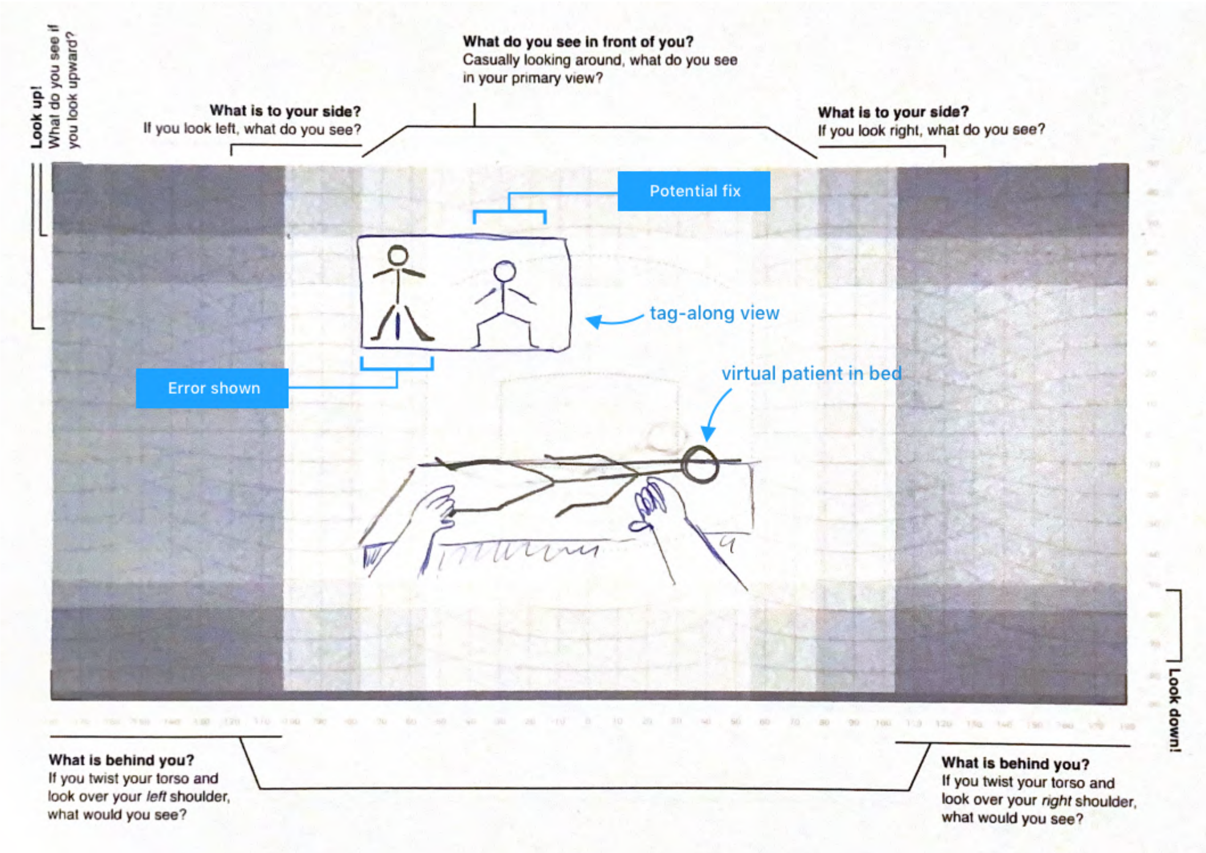

Figure 4.9.: Sketch showing concurrent feedback shown from the learner's point of view

This approach seemed good for showing errors to the learner in real-time while performing the patient transfer. However, on gathering feedback by conducting a cognitive walkthrough, it was realized that the task is already too complex. Hence, showing so much information to the user at once would cause cognitive overload. Also, in the sketch, we are looking at a particular moment in time. However, while performing patient transfers, the movements are carried out in one single flow. Hence the animation would not be able to account for the time synchronization required. The user would have already moved ahead until the animation of the potential fix would have been completed. So the right half of the tag-along window [50] was removed from the concept, and just the highlighting body part concept was taken forward with the implementation. This is also a good approach as our system's potential users will be nurses who already have had basic training in the Kinaesthetics-based patient transfers as a part of their curriculum. Hence just knowing which error to fix would help the learner to improve their movements via training.

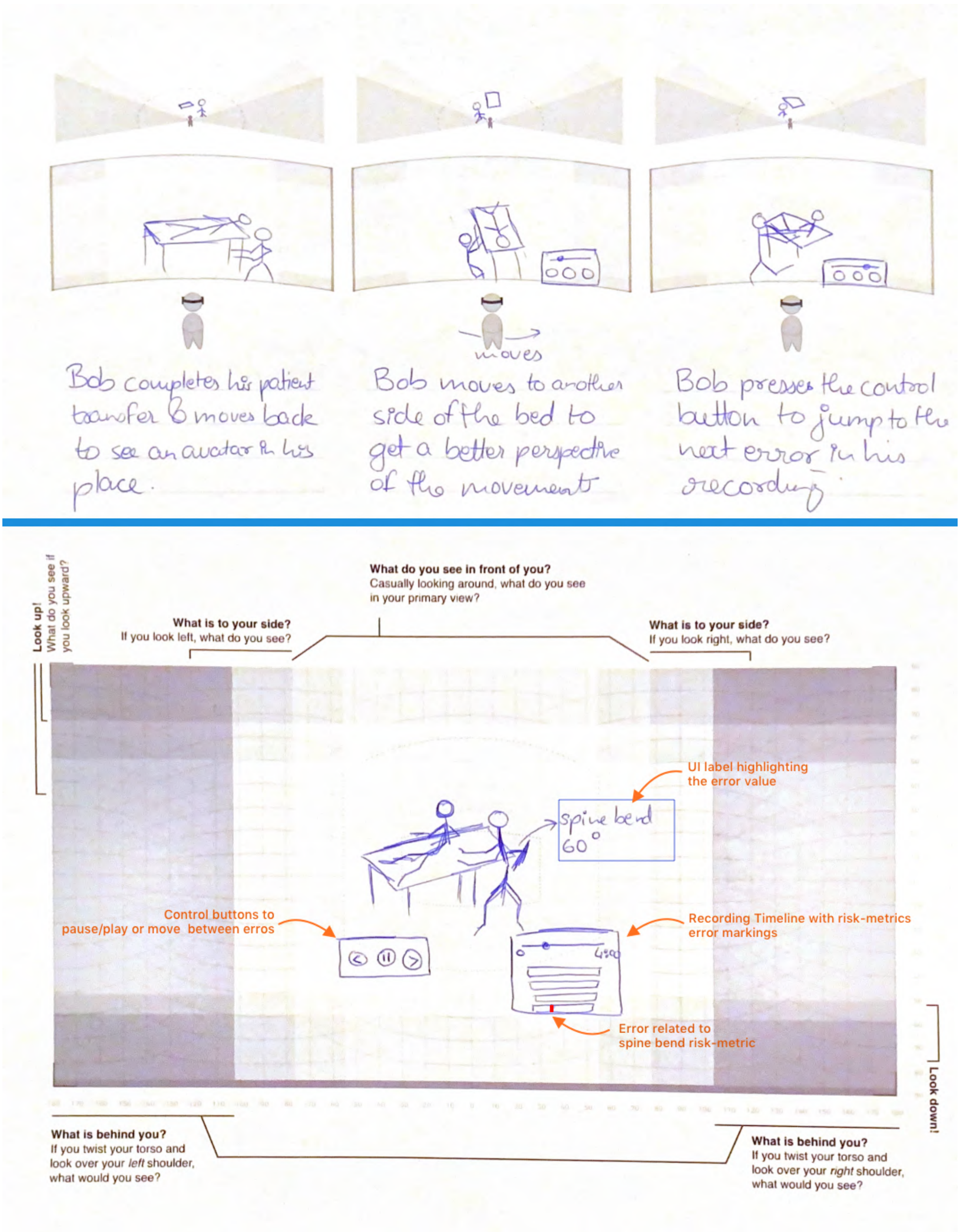

Figure 4.10.: Sketched concept for terminal feedback

Figure 4.10 shows a combination of frames representing the terminal feedback concept. The idea here is that, once the learner completes the virtual patient transfer, he can step back and see his own recorded movements. During this recording playback, the user has the ability to move in the virtual space and observe his recording from different perspectives. Also, during this playback, the learner is presented with two user interfaces(UIs). The UI canvas on the right is an animation timeline with spaces provided for error markings related to the four risk-metrics. The information association within this timeline is based on the visualization theory by Tamara Munzner [section 2.4]. While the UI canvas on the left is an animation controller that has options to play or pause the recording or traverse between the errors shown on the animation timeline. Taking inspirations from the visualizations theories [section 2.4], the user also sees a UI label specific to an error related to a body part. This information is context-based which depends on the user's position and gaze direction.

4.2.2. Storyboarding

The storyboard explains a scenario consisting of the target user. It also highlights the key features of the envisioned system. We utilize the previously introduced persona named Lina. Lina wants to practise patient-transfers by herself. At medical school, she is introduced to a new virtual training system using which a person can practice patient transfers by themselves. Lina decides to give this training system a try.

1. Lina enters the room that has the virtual patient transfer training system already setup. She starts the application and wears the HMD, the gloves along with all the sensors.

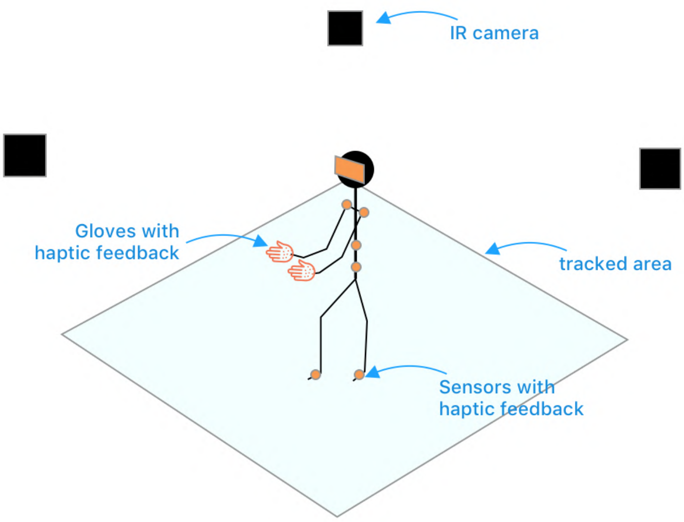

Figure 4.11.: Lina starts the virtual training application and wears the hardware

2. Lina enters the VR environment and sees a virtual patient lying on a bed. She sees some instructions and gets prepared.

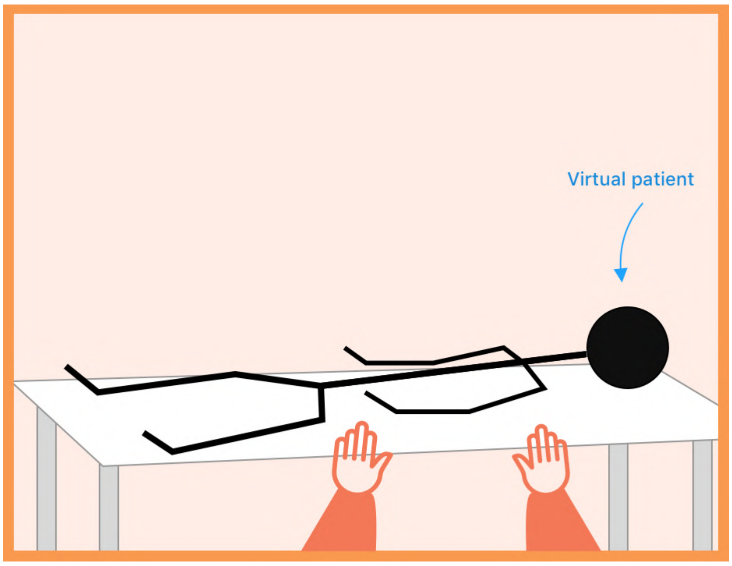

Figure 4.12.: Lina enters virtual reality and sees a virtual patient laying in the bed

3. Lina moves towards the patient and starts following the instructions to transfer the patient from the bed to chair.

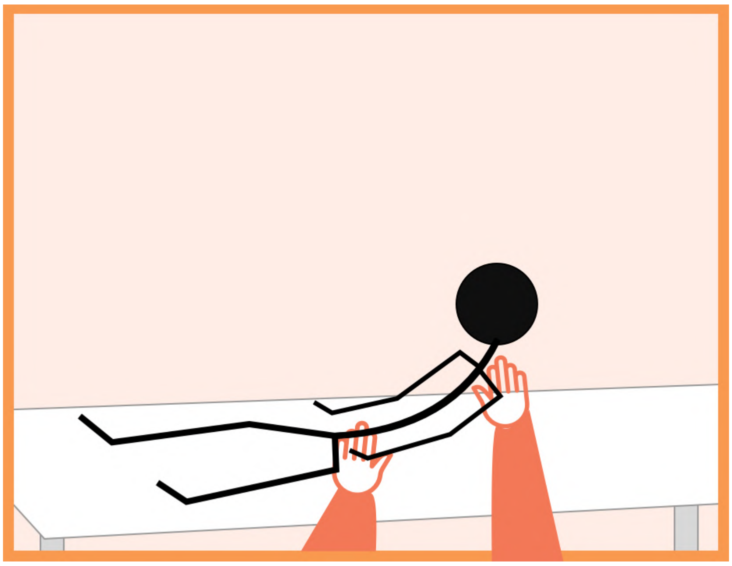

Figure 4.13.: Lina moves towards the virtual patient and start performing transfer movements

4. As Lina bends to move her hands further under the patient, she hears a sound and sees an avatar with back highlighted in her field-of-view. She immediately realizes that the feedback is because of her spine bend. She fixes the error instantaneously and continues with the patient transfer.

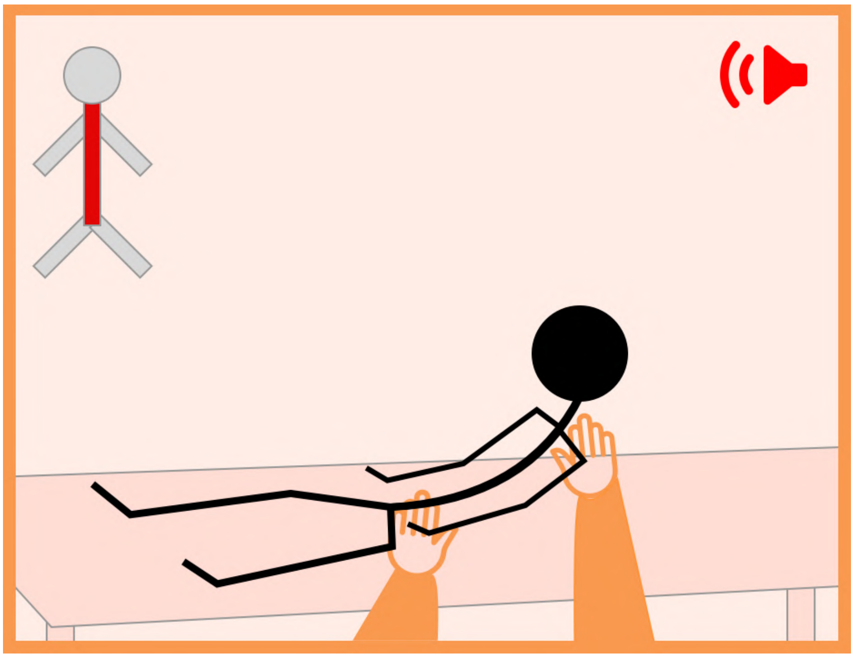

Figure 4.14.: Lina receives a visuo-audio feedback in her headset

5. Lina successfully moves the patient in a seating position and completes the transfer.

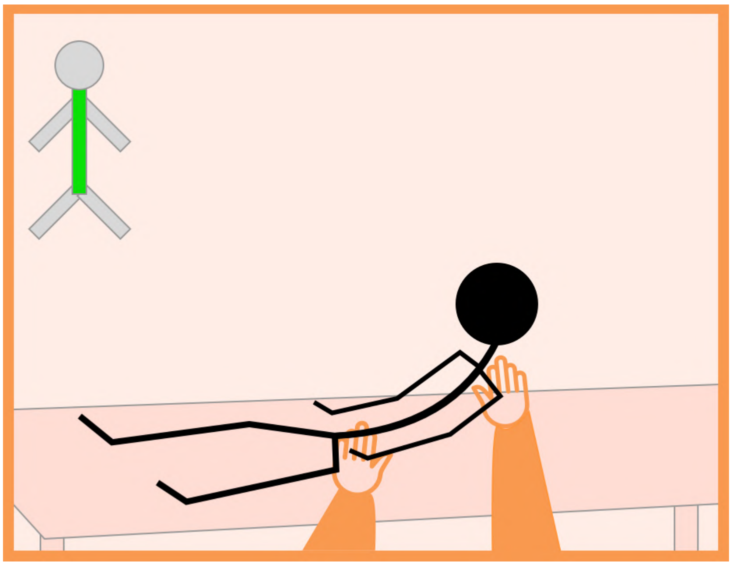

Figure 4.15.: Lina successfully completes the patient transfer

6. As Lina steps back from the virtual bed, he sees an avatar spawning at her initial location. At the same time a recording timeline UI pops up. Lina plays the animation and reaches her point of spine bend error. Here she pauses the 3D recording reconstruction.

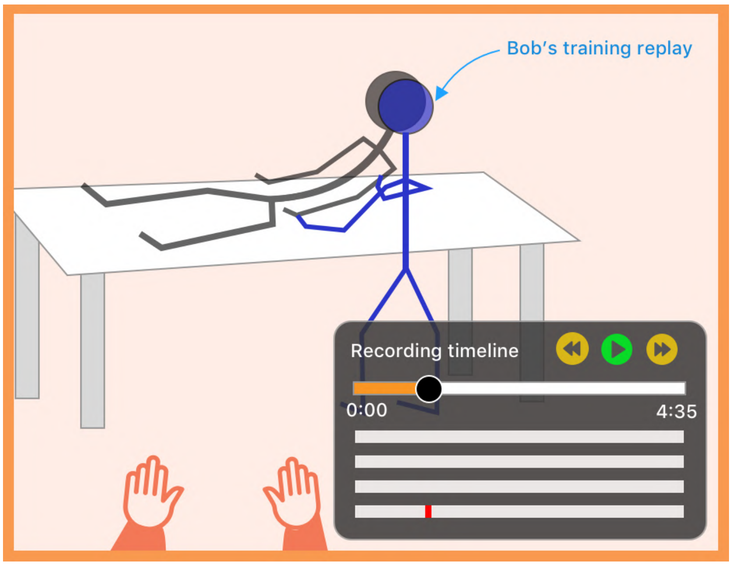

Figure 4.16.: Lina starts seeing her complete patient transfer movement in virtual reality

7. As Lina moves towards the bed again, the UI controls fade away and the system displays more contextual information. Lina can now see a tool-tip anchored to her avatar's lower back showing the error value of 60 degrees of spine bend. This was reported as a critical error by the system.

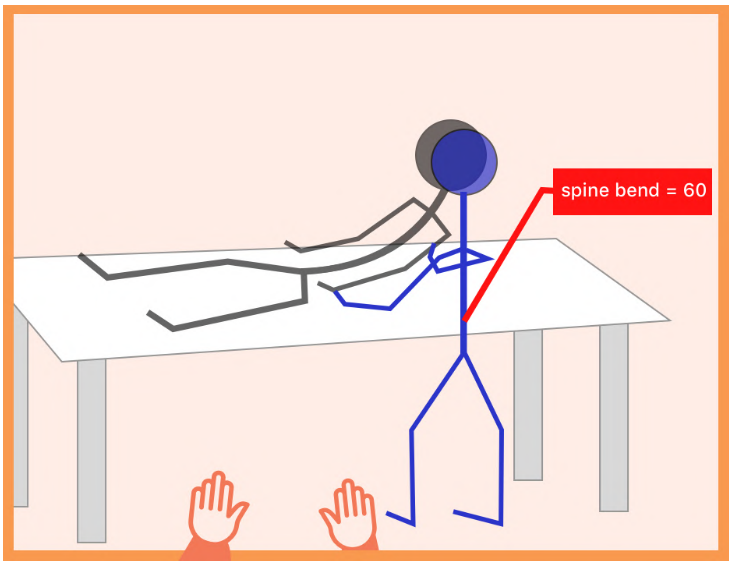

Figure 4.17.: Lina reflects on the errors she made during training

8. Lina reflects on her mistakes during the training session and now has a better understanding of applying kinaesthetics concepts in patient transfers. She feels more confident and is happy to practice by herself.

4.3. Conclusion

In this chapter, the methodologies used in the design thinking process were discussed. It also detailed a unique concept template for sketching ideas for VR concepts. Furthermore, the concept sketches generated were converted into a storyboard which covers the main user journey as a scenario. The storyboard will help us to finalize hardware requirements and other constraints for system development. The next chapter covers implementation of the concept as a prototype.

5. CaregiVR - Implementation

After visualizing the system, the prototype concept of CaregiVR was realized. We already knew that the platform for development would be Valve Index based on the SteamVR coordinate system. The choice was restricted because the patient transfer system developed by Daniel Schweitzer uses this platform. Also, Valve Index has a potential advantage in that it provides a microphone for speech input. Although some hardware decisions were pre-requisites concerning existing implementation, some other requirements needed finalization. This chapter includes the hardware requirements that were defined at the start of the prototype development. These requirements helped us to compare the existing technologies. Moreover, they assisted us in choosing a viable platform for developing our feedback system. In section 5.2, we discuss how the two feedback system modules were realized and their integration in the existing VR patient transfer task. Finally, we discuss certain limitations of the CaregiVR system in section 5.3.

5.1. Hardware requirements and comparison of existing technologies

The outcome of the design thinking process directs us in the direction that the requirements of the system can be segregated into two main criteria:

1. Body tracking

2. Output to the user

Body tracking

Body tracking means the positional measurement of bodies in a defined space. It is required since we need to calculate values for the four risk-metrics. These values can be calculated if data points for the body are available to us for development. When it comes to body-tracking, various specifications need addressing. These requirement specifications are as follows:

- Quality of tracking
  It represents how accurate/precise the tracking system is in varying conditions.

- Calibration
  The complexity involved in calibrating the system.

- Motion capture
  The complexity of storing leaner's body data points and retrieving them at a later stage for analysis.

- Experience
  The effect of tracking hardware on the user experience of the system.

- Flexibility of development
  Due to COVID-19 restrictions, it is important to understand whether the development and testing will always require a lab setting or be done remotely.

- Reliability
  If the hardware can track reliably for long periods of running times.

- Clothing restrictions
  The effect of user clothing on body tracking.

- Portability
  If the tracking system can be easily carried, set up, and used without hassle.

Output to the user

Output to the user covers the visualization part. This requirement criterion covers how the risk metrics data is displayed to the user. Since we are developing a feedback system for a virtual reality, it is evident that a head-mounted display would be necessary. Hence, this criterion mainly describes how well the tracking system could integrate with the HMD output. In our case, the HMD used will be HTC Vive or Valve Index, as it is used as a base by Daniel Schweitzer for his master project. The requirement specifications for this criterion are:

- Latency
  It covers the time delay between the learner's input to the instruction acknowledged by the system. This is necessary since there should be a minimum delay between the tracking of error related to the risk-metrics and the user getting informed about them. Output latency significantly impacts the realism and overall experience of the system.

- Playback of recorded movement
  It covers whether the motion capture data from the body-tracking be easily translated to the user's output environment.

5.1.1. Comparison of existing technologies

Multiple body-tracking technologies can work in conjunction with a virtual reality system. A detailed analysis of existing tracking technologies is a part of the master's project report. However, to keep this document concise, we will look at the summary of their comparison. Also, details of the tracking system utilized in development will be discussed. In total, four tracking platforms were tested and analyzed. Two of the tracking technologies that were tested works by tracking markers/trackers on the user's body using multiple infrared-based cameras. In contrast, the other two use single infrared(IR) depth-camera data to generate a virtual skeleton. Both types of approaches towards body-tracking have their own advantages and disadvantages. Table 5.1 mentions the names of the body-tracking systems tested according to their working principles. The overall key factors in deciding a platform were: how many body points can be tracked? *and* how well we can track the data related to the four risk-metrics [32].

Depth data from single IR camera	Body markers with multiple IR cameras
Microsoft Kinect iOS device using ARKit3	HTC Vive Opti-track

Table 5.1.: Tracking platforms based on their working principle.

Figure 5.1 provides an overview regarding which points on the body need to be tracked. These points are relevant to the four risk-metrics mentioned in related works [section 3.1.1]. Tracking these points of interest on the learner's body was critical in deciding the tracking platform for the development of the CaregiVR prototype.

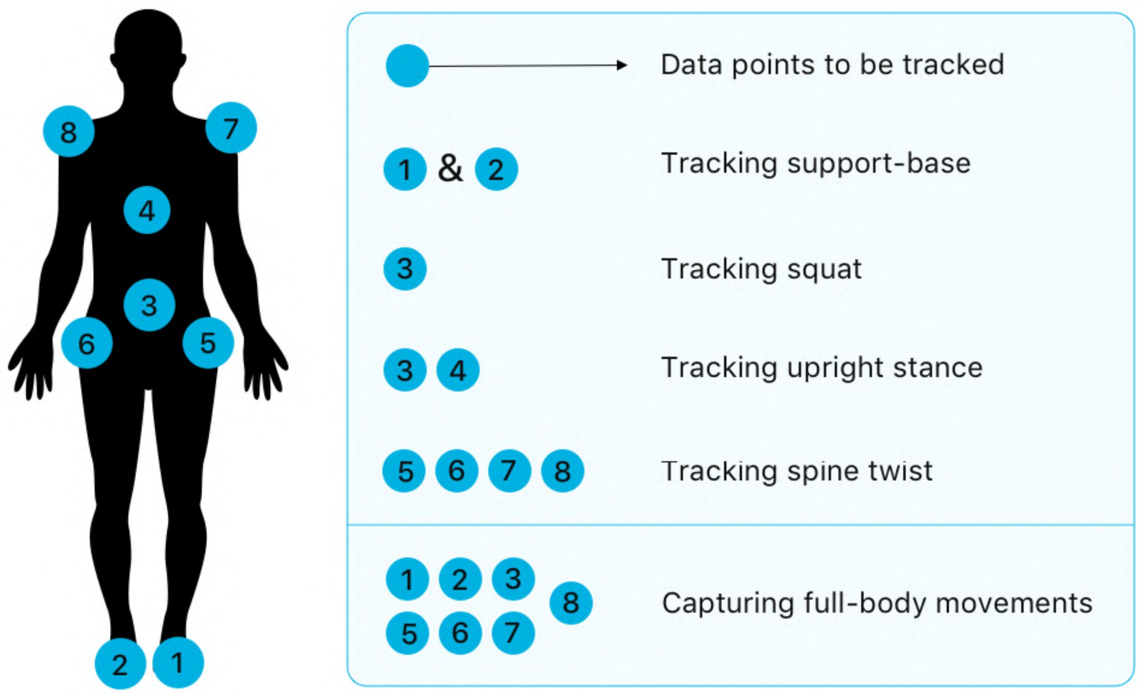

Figure 5.1.: Minimum required tracked data points from the body required to analyse the errors related to four risk-metrics [32]

	HTC Vive	Microsoft Kinect	ARKit3	Opti-track
Quality of Tracking	High precision	Lower but acceptable	Medium precision	Prone to noise
Latency	Low	Medium	High	Low
Reliability	High	Low	Medium	Low
Calibration	Easier to calibrate	Multiple steps required	Easier to calibrate	Multiple steps required
Motion Capture	5 Vive trackers covers whole body movement	Good for the frontal body. Loses lower body tracking on occlusion and rotation	Decent for frontal body. Side view tracking is better than Kinect.	No, only some workarounds
Playback of movements	Feasible (native HTC)	Complicated - requires translation	Complicated - requires translation	Quite decent natively. Difficult with Vive or Valve HMDs
Tracking risk metrics	High accuracy with less tolerance	Not-feasible	Feasible but restricted	Unreliable because of noise
Tracking experience	Unnatural (Weight of Vive trackers)	Natural	Natural	Slightly unnatural
Clothing restrictions	None	No wide pants or loose jackets	No wide pants or loose jackets	Suit required with attached markers
Portability	Less	More	More	Less
Flexibility of development	Less	More	More	Less

Table 5.2.: Comparison of existing technologies from implementation perspective.

Table 5.2 summarizes the comparison of all the tracking technologies that we discussed so far. The table helps to gain a holistic view of the pros and cons of each tracking methodology. As an overall conclusion, the HTC Vive trackers were found to be a better alternative to developing the feedback system ahead. Following is the detailed analysis of the HTC Vive platform concerning the hardware requirements.

HTC Vive

The HTC Vive tracking is based on SteamVR tracking technologies [51]. It has three main components: base stations, sensors on tracked objects, and a host.

Quality of tracking (Precision)
The tracking precision was good and had a tolerance of +-1cm for distances and +-2 degrees for angle calculations. Figure 5.2 shows how the test was performed. The top part of the image consists of 2 Vive trackers in a real-world setting. They were kept at a distance of 39cm in a lab environment. The figure's bottom part shows two cyan-colored spheres in a virtual reality environment (screenshot is taken from Unity editor). These two spheres are attached to the Vive tracker movements using the SDK provided by SteamVR. Hence the relative distance between the spheres provided us with the precision of the tracking system. The distance of the two blue spheres was shown to be 0.40m in the virtual environment. This test was performed multiple times, and the average tolerance value for distance between tracked points was found out to be +-1cm.

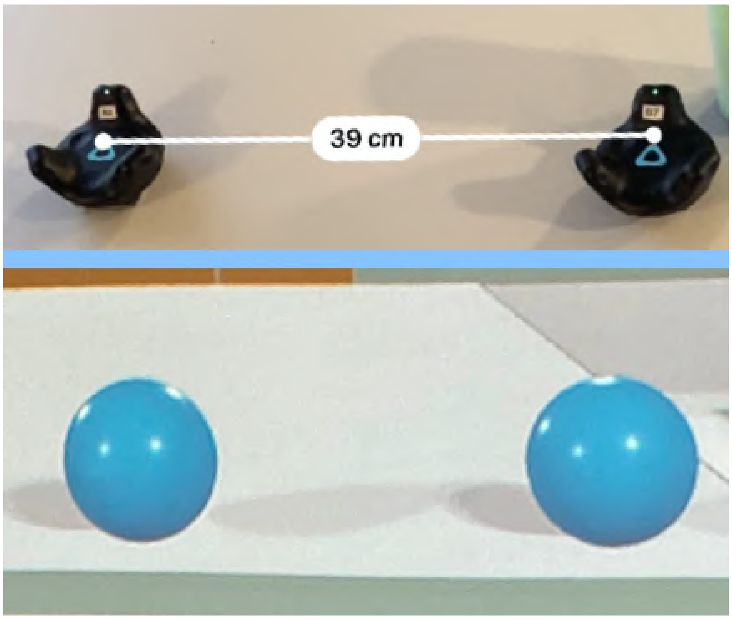

Figure 5.2.: Testing the accuracy of distance between the trackers in real world (up) to the tracked objects in virtual world (blue spheres)

Latency
The HTC Vive trackers [Figure 5.3] have a higher capture rate of 200Hz/device/second which results in really low delays [51]. During the testing latency was never an issue with Vive trackers.

Figure 5.3.: The palm-sized HTC Vive trackers

Reliability
A minimum of 2 base stations are required to track the sensors in the HTC Vive environment. The reliability of tracking increases with the increase in the number of base stations. For our testing, a setup containing four base stations was used. The tracking was not lost across multiple testing processes and was resistant to occlusion. This is also because of the fact that each base station contains a 120° multi-axis laser emitter.

Calibration
Easier one-time calibration of the system which retains the data and can be used multiple times until the location of setting is changed.

Motion capture
HTC Vive tracking environment facilitates maximum tracking of 9 data points. The motion capture of these points is supported by the VR environment and can also be translated to humanoid movements.

Playback of movement in virtual reality
Since the Vive trackers are native tracking solution of HTC Vive, the playback of movements does not require any coordinate system translation. This removes the necessity of writing an interfacing driver for the coordinate systems to function together.

Tracking risk-metrics
We need 8 tracked data points on the learner's body to extract the risk metrics [Figure 5.1]. Since Vive tracking environment can support up to 9 trackers, we should be successfully be able to track the risk-metrics.

Tracking experience
Although Vive trackers are palm-sized, mounting 8 trackers on the body will make the bodily movements feel unnatural.

Clothing restrictions
There are no clothing restrictions because Vive trackers can be mounted on the body over the learner's clothing.

Portability
The system is not highly portable but still can be moved from one place to another. The base stations can be easily removed and can be packed together to be taken to another location.

Flexibility of development
There are frameworks available such as Virtual Reality Toolkit(VRTK), which can allow standalone development of modules without requiring the constant access to a virtual reality HMD.

We found that although the Vive tracker system is less portable, the platform's pros provide a better trade-off than the rest available options. Also, the virtual patient transfer task implemented by Daniel Schweitzer uses SteamVR. It would later be feasible to integrate the feedback system into it and extend its functionalities. The initial focus of the system development was on the implementation of the core features. The first core feature being providing concurrent feedback to the learner using real-time risk-metrics calculations. The second core feature being delivering terminal feedback where the learner can retrace his movements in a 3D interactive virtual environment. HTC Vive tracking system focuses on these core features since the coordinate system does not require any translation/conversion. In the next section, we discuss the prototype's implementation details using HTC Vive trackers and Valve Index HMD.

5.2. The feedback system

On successfully choosing a body-tracking approach for the development, we move ahead with prototyping the storyboard scenario's feedback system. This section has three sub-parts; the first part provides an overview of the system, which will help gain an overall picture of the various modules. The second part discusses essential details of the feedback implementation. Lastly, the third part shows the outcome of integrating the feedback modules with the patient transfer task, which forms the CaregiVR system.

5.2.1. Overview of the system

A holistic view of the system is provided from two perspectives. Firstly, the figure 5.4 shows the overall setup necessary for the system to work as expected. The physical setup of the system requires 2 meters by 1.5 meters of free space (6.5ft x 5ft), and the maximum distance between base stations of 5 meters (16ft) [51]. These are the official guidelines provide for the SteamVR tracking which HTC Vive trackers use. For CaregiVR, we recommend four base stations for reliable tracking through-out the virtual patient transfer scenario. However, the system would also work with two base stations placed diagonally. During testing with two base stations, there were cases when the tracker location was detected incorrectly. The learner/user has to be in the area of tracking at all times. During the virtual patient transfer training, the learner has to wear 6 HTC Vive trackers [Figure 5.3] on their body while wearing the Valve Index HMD. The Vive trackers are held onto the learner's body by means of *TrackBelt* and *TrackStraps* mounts [Figure 5.5]. These mounts are easily available on a commercial website like *Amazon*. Apart from this, the learner holds the Index controllers in their hands. ManusVR gloves in the task integration step replace these controllers to provide a more natural experience.

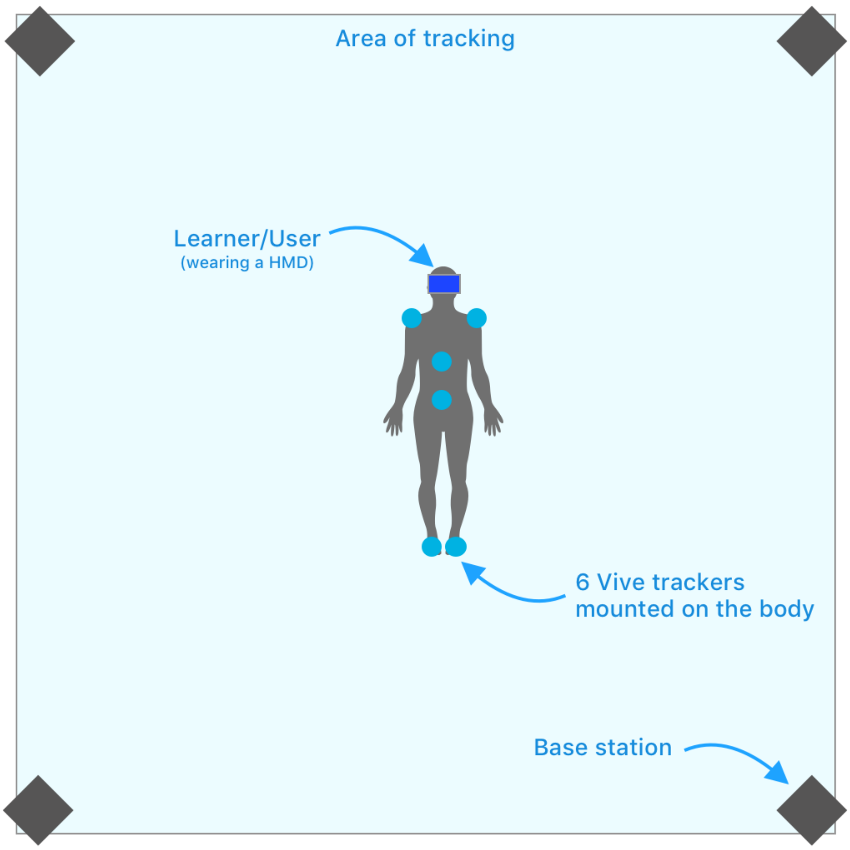

Figure 5.4.: Physical setup for the VR feedback delivery system

Secondly, the figure 5.6 shows the four most important modules of the feedback system. Each module is represented by a block. These blocks contain classes and storage files relevant to the correct functioning of each of the modules. As we have already discussed in the introduction, the main goal of the system is to deliver concurrent and terminal feedback. Hence, these two modules take most of the space and time in terms of complexity. Although these two are standalone implementations, most of the communication between the *concurrent feedback module* and *terminal feedback module* happens via the manager and database modules. The manager module is also responsible for the synchronisation of timing between the two main modules. The technical details of some of the modules is covered in the upcoming section.

Figure 5.5.: Belt and straps for mounting the Vive trackers on body

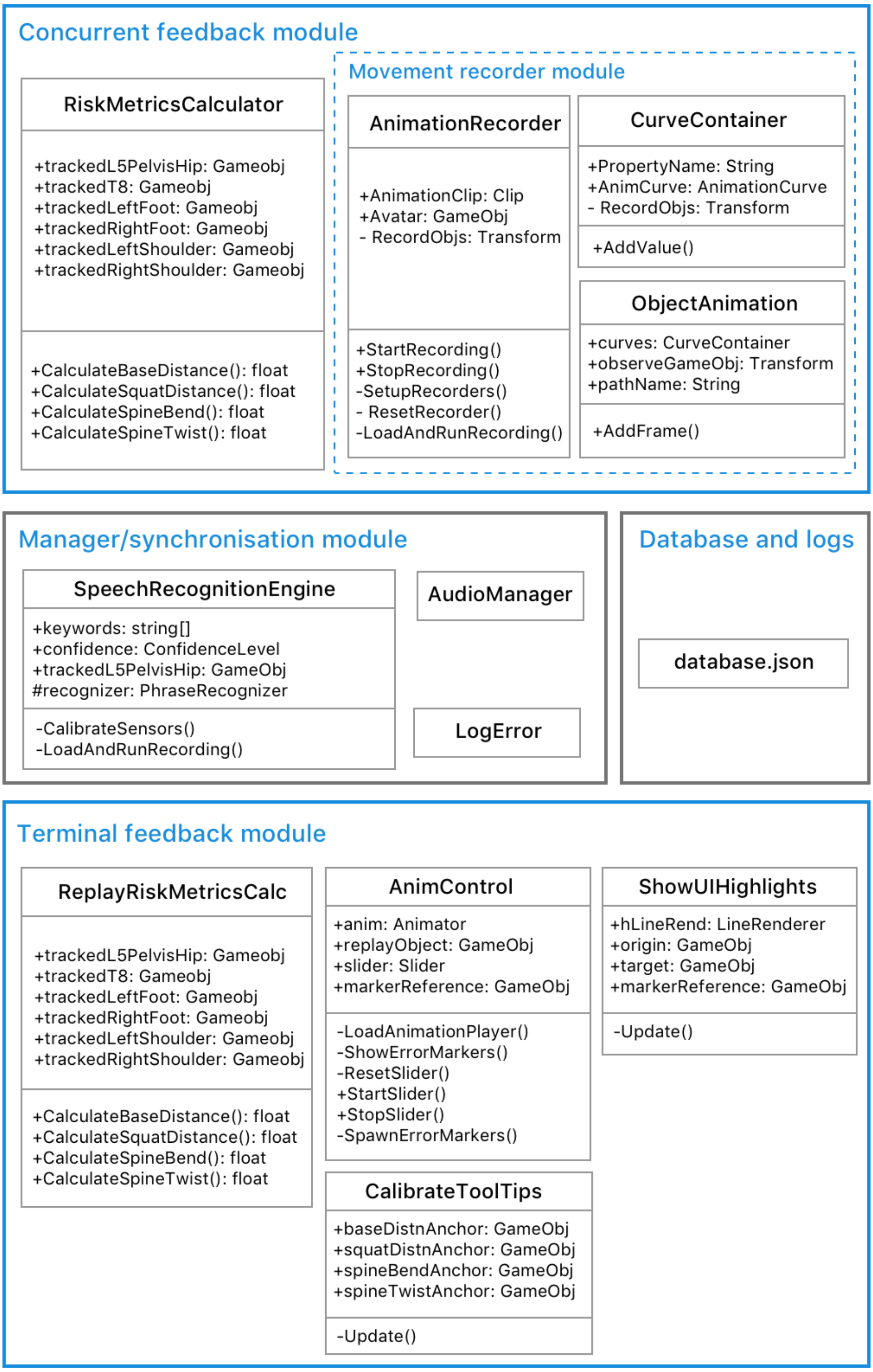

Figure 5.6.: Technical system overview

5.2.2. Feedback modules

We now dive into the technicalities and implementation details of how CaregiVR was developed. To keep the documentation content succinct, not all the minute details of the system implementation are discussed. A comprehensive explanation of every module is part of the master's project report. However, to provide some understanding of the internal workings, we will only talk about the feedback modules.

Concurrent feedback module

The main objectives of this module are:

- Track & store movement data
- Analyse the user movements according to the four risk-metrics [section 3.1.1]

These objectives are to be performed synchronously in real-time. In section 5.1, we already analysed the HTC Vive trackers for its precision. However before moving forward with risk-metrics calculations, trackers were also tested for their reliability in measuring angles. Furthermore, tracking the points of interest from the learner's body, Vive trackers are to be mounted. It was crucial to limit the number of Vive trackers on the body so as to reduce the unnatural feeling. After looking into literature related to human physiology, it was realized that the locations of the L5 lumbar spine vertebrae and pelvis are very close to each other [Figure 5.7]. Also, it was come to attention that an another name for pelvic bones is hip bones. This literature review helped us to reduce the number of Vive trackers required for tracking the risk-metrics. To clarify, according to Muckell et al. (2017) the four risk metrics are tracked as follows:

1. Base distance - The distance between the two feet.
2. Squat distance - The distance of *pelvis* from the floor.
3. Spine bend - The angle of bend between the vertical axis and the line joining the L5-T8 vertebrae.
4. Spine twist - The angle between the line joining the shoulders and the line joining the *hips*.

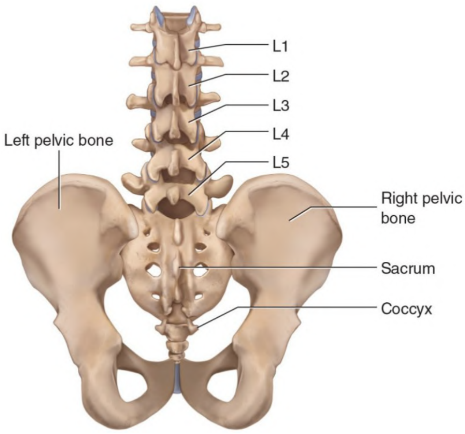

Figure 5.7.: Human skeletal structure showing the close proximity of L5 vertebra and pelvic bones

Now it can be clearly seen that the second, third, and fourth risk metrics have one tracking point in common. In figure 5.8, the tracker number 3 can provide data relevant for 3 risk-metrics. This was a substantial improvement in design, as we reduced the redundancy and chances of interference amongst the data points. The hip vector points are represented by dotted circles in the aforementioned image. These points are extrapolated using the values from tracker number 3 during the calibration step.

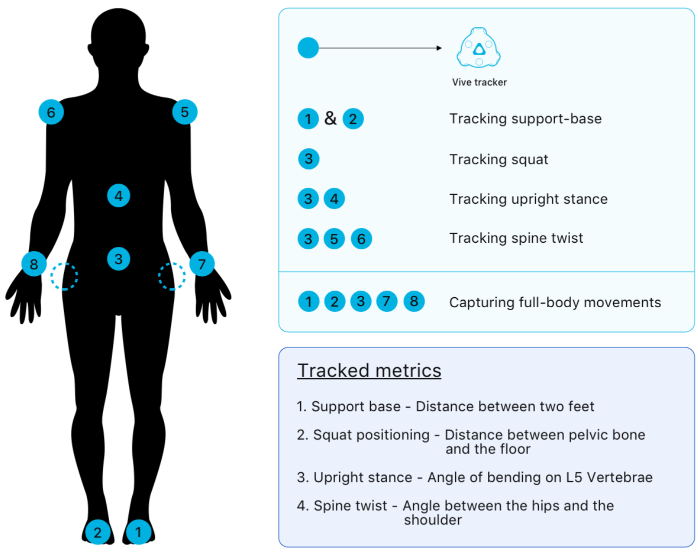

Figure 5.8.: Updated position of the Vive trackers for risk metrics calculations

Since we have the data points - the basis of calculations, we can look into the algorithms related to these risk metrics. The calculation for the first two risk-metrics are quite straight-forward. The base distance (first risk metric) simply applies the distance function to the tracked gameobjects linked to the feet of the user. *GameObjects* is a base class of Unity platform and all the entities inside Unity are of this type. From here on wards, you might encounter the word *'gameobject'* referring to as a type element in VR. The implementation looks similar to the testing process we showed in the HTC Vive technological analysis [Figure 5.2]. The second risk metric calculations are same as the first one. Instead of the calculating the distance between two gameobjects, the distance of the tracked pelvis tracker is calculated from the ground(x,0,z).

When it comes to the third and fourth risk metrics, calculations get a bit tricky. The third risk metric is for the upright stance. According to the paper by Muckell et al. (2017) - *"Upright stance metric is the angle of the lower back (L5-T8 vertebrate) compared to a perfect upright position"*. The paper provides an implementation explanation of how this angle calculation can be achieved. Figure 5.9 shows the process of how to calculate the spine bend angle. Tracker number 3 and 4 in figure 5.9 represent the location of L5 vertebra and T8 vertebra of the user respectively. The line joining these two tracked points is represented by 'a' on the triangle. We need to extrapolate a third point in the upward direction(in world coordinate space). The line joining the extrapolated point and tracked L5 vertebra is represented by 'b'. On joining all these three points, we get a triangle. All the sides of this triangle can be calculated using a simple distance formula. Furthermore, on applying the Law of Cosines on this triangle, we can find the angle 'C' which is the required value for spine bending.

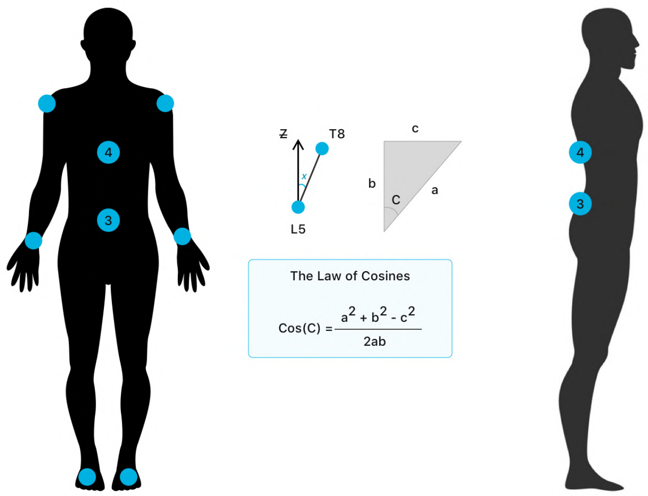

Figure 5.9.: Visual explanation of the calculation related to the third risk metric (Upright stance)

For the fourth and the final risk metric, we need to calculate the degree of spine twist. Figure 5.10, visually describes how the spine twist calculation algorithm works. In the aforementioned figure, the blue spheres represent the gameobjects linked to the shoulder trackers and the pink dotted spheres are the tracked hip sensors which are extrapolated using the pelvis sensor location. The dotted line joining the same colored pairs of spheres are the vectors joining them. On translating these vectors along the Y-axis towards each other, there will come a point when they will overlap. During that instance, the angle between these two vectors is calculated so as to get the amount of twist present in the spine of the learner.

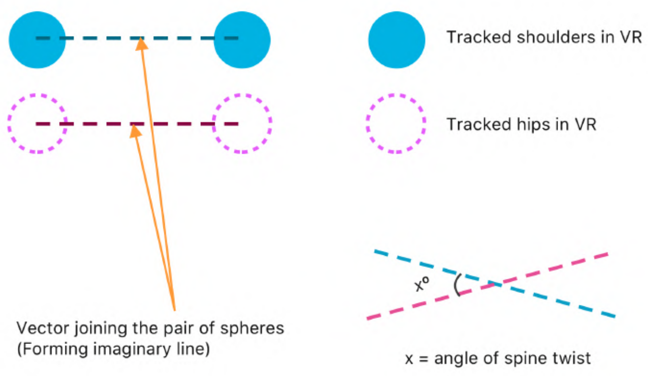

Figure 5.10.: Visual explanation of how spine twist risk metric is calculated

Our system was now successfully tracking the risk metrics and checking the posture values for any error. Next, we implemented an algorithm that answers *"What would happen if an error in risk metrics is detected?"*. Basically, we need a feedback delivery mechanism that can reflect the erroneous state in the output of the HMD. To realize our storyboard concept [Figure 4.14, we required an avatar with varying meshes for each body part to be highlighted. Figure 5.11 shows the avatar highlights in user's field-of-view inside of the HMD. This type of element behaviour in mixed reality is known as tag-along. A tag-along object attempts to stay in a range that allows the user to view it or interact with it comfortably [50].

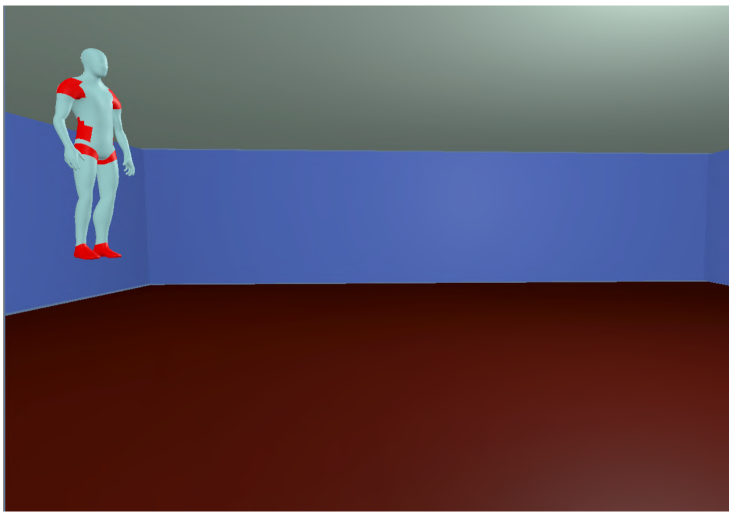

Figure 5.11.: Highlights in the avatar meshes depicting error related to each of the risk-metrics.

An important section of the concurrent feedback module is the movement recorder. This part of the module lays the foundation that will allow the user to view a replay of their movements in 3D virtual environment during the terminal feedback. Though movement playback is part of the terminal feedback delivery, all of the necessary information required for it is gathered during the virtual patient transfer is being carried out. For the ease of understanding the concept, let us clarify some terminologies.

Figure 5.12 is a visual pseudo code explaining the logic of how things are implemented. An animation curve is created for the gameobject. The transforms values of gameobject are added every time to a new key-frame using a *Update* function. The key-frame structure stores the transform values and time of the recording. These key-frames are held together on an animation curve chronologically according to the time parameter. This process is repeated for each tracked gameobject. All the time synchronised animation curves for different gameobjects are stored together into an animation clip.

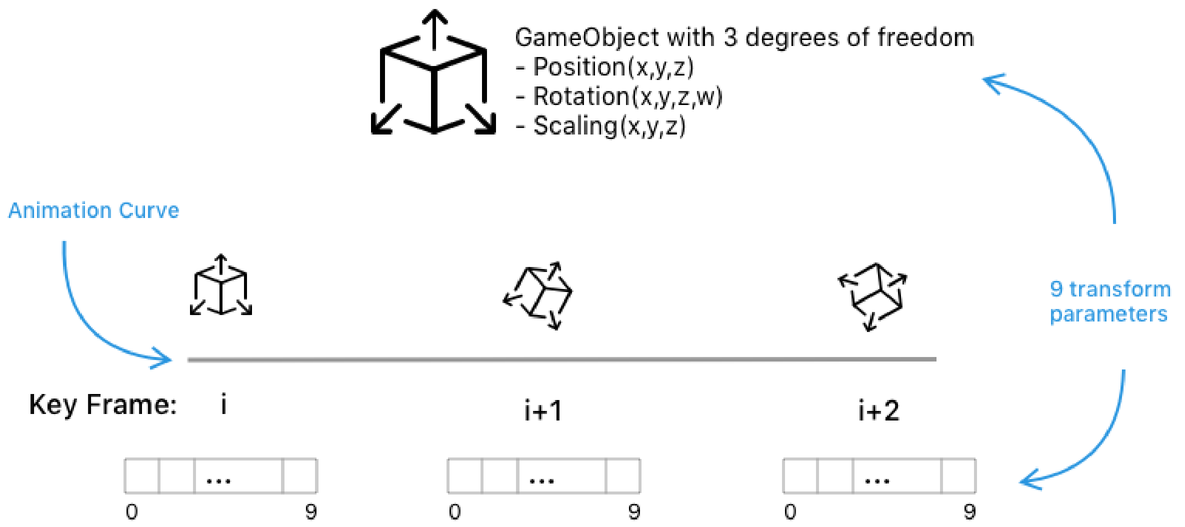

Figure 5.12.: Visual explanation of data storage for movement playback

This concludes one major module of our feedback system. In next part we will talk about the terminal feedback module and its key features.

Terminal feedback module

The main objectives of this module are:

- Parse and Load the data received from the concurrent feedback module.
- Load and update the VR user interface elements.
- Provide relevant risk-metric information to user in regards to their recorded movement.

This module will help the user to reflect on their patient transfer training. The implementation of this module enables the user to experience the post-session in a quite unique way. The system leverages the advancements in mixed reality technologies. It allows the learner to revisit a training session in their past by recreating the scene in virtual reality by the data we stored in the concurrent module. Let's take a detailed look into its various components.

An animation clip is generated at the end of each patient transfer training session. The animation clip is parsed and loaded into the Inverse Kinematics(IK) avatar [Figure 5.13]. Inverse Kinematics is the mathematical process of calculating the variable joint parameters that provides a desired configuration (position and rotation) for each body part of the humanoid 3D character. The Vive tracker data we collected from the learner's body joints is loaded into the IK avatar schema. On configuring the parameters like position weight, rotation weight and many more, the avatar replicates the movements very closely to how the learner performed those movements. The relative body part movements are calculated mathematically since Unity supports IK avatars natively.

The animation control shows an overview regarding the four risk metrics errors on a training timeline [Figure 5.14] . The four rows below the timeline indicate the four risk metrics. Any error at a particular moment is highlighted on the individual rows with a red marker.

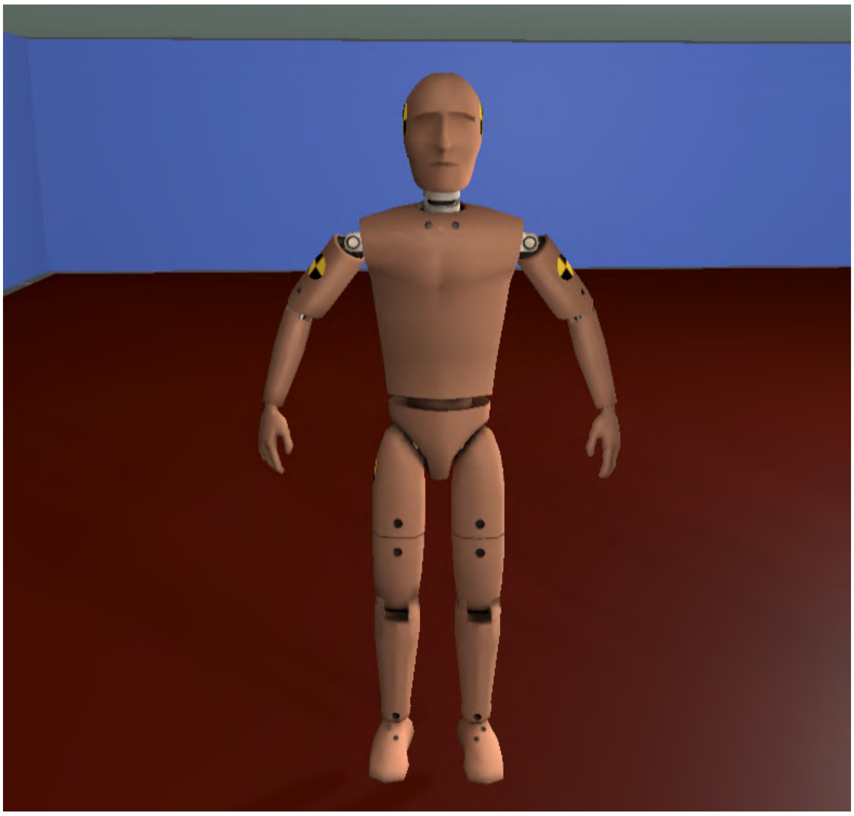

Figure 5.13.: Correctly configured inverse kinematics avatar for movement reproduction

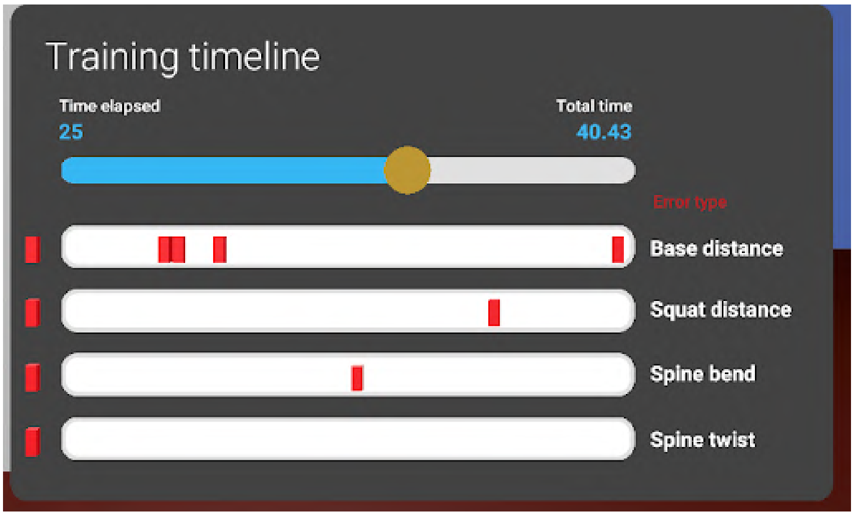

Figure 5.14.: User interface of the animation controller with error markers

```
This function spawns the error markers on the animation timeline
void SpawnMarkers(Hashtable) //Pseudo-code
{
  For all the values in the hashtable
  {
    Get reference location on Y-axis
    Calculate increment per second according to the length of animation
    Instantiate an error marker prefab in the scene
    Move the marker to the time of the error by calculating time*increment
  }
}
```

Finally, the UI labels are generated and linked to relevant locations on the avatar's body to show association of information. Figure 5.15 provides the highlights of what the learner sees in the terminal feedback. The cyan text and arrow markers in the figure are added later for providing explanations. For the purpose of explanation, the yellow and pink spherical gameobjects are shown. These gameobject represent the Vive trackers placed on the learner's body. During the actual demonstration these gameobjects are hidden. The text on the UI tooltips always follows the gaze direction of the learner/user. The user can play/pause the movements during this playback the user can walk around the virtual environment to analyse the errors from various perspectives. The UI tooltips colors are also highlighted in red when the values enter the error range.

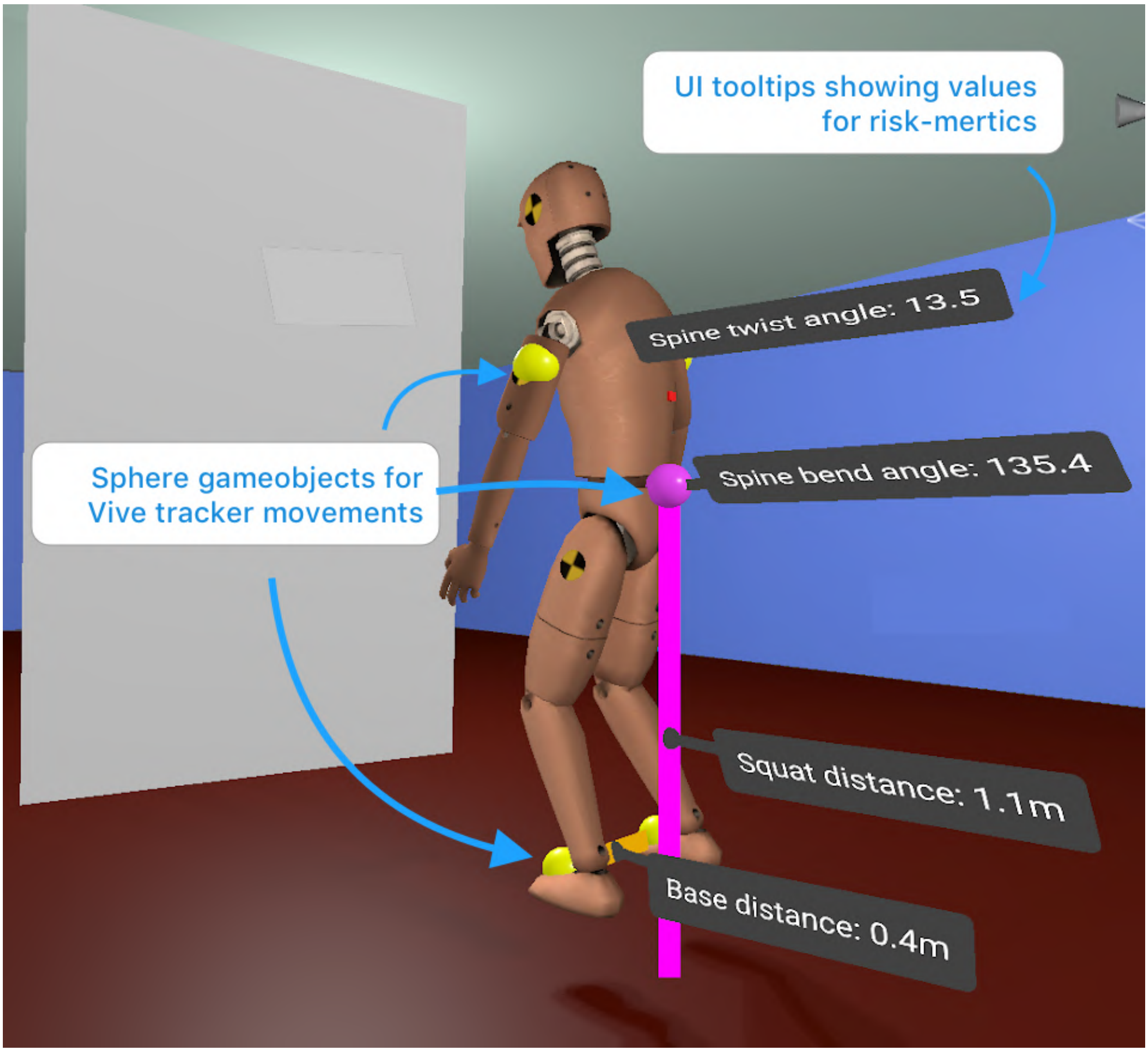

Figure 5.15.: Elements user sees as a part of recording playback

Both of these feedback module together with other supporting elements complete the CaregiVR feedback system. The upcoming section briefly extends this works integration process with an earlier project by Daniel Schweitzer.

5.2.3. Task Integration

At the end of the modules integration process, the standalone feedback system was complete. The feedback system mentioned above fulfills most of the main goals by having all the core features. However, to make it whole, this system was integrated with a virtual patient transfer task. Multiple challenges were encountered as a part of this process. The most crucial one was the hierarchy of the existing patient transfer system. As shown earlier in the figure 5.12, the hierarchy of the gameobjects should remain the same to have an accurate animation file export for replaying. However, the ManusVR gloves dependencies were causing trouble as it changed the hierarchy of the hand-held controllers at the start of the application. This caused a problem while integrating the terminal feedback module to the pre-existing task.

On exploring multiple solutions as a part of this exploration process, minute aspects of the recording algorithm had to be modified to fit the dynamically changing gameobject hierarchies. A comparison logic was added to determine the final sequence of the various body parts under the parent object. This resulted in a smoother integration process further.

Figure 5.16.: Integration of terminal feedback with the patient transfer task

Figure 5.16 shows a front view of the terminal feedback in the integrated system. There is a patient in white clothes lying on the bed. The pink overlay is the next position in which the user should move the patient. The dummy avatar conducting patient transfer is replaying the movements performed by the user during a session. The user can walk around and observe the recording from various locations in the virtual room. The user also can play or pause the movement recording using voice commands 'Play' or 'Pause', respectively. Thus we conclude our section for the implementation and integration of the feedback system.

5.3. Limitations

Although the system after integration is holistic and addressed this thesis's goal, certain limitations still exist. These limitations are due to technological constraints, limited availability of time and resources, or a combination of both. Thus as a responsibility of this work, we try to address certain limitations of this implementation.

The system that we have developed is limited in terms of scalability and flexibility. The detection of risk-metrics is a complex task in itself. However, if more risk-metrics are to be added, this system will not be able to scale because a maximum of 9 Vive trackers can be tracked at a time. Also, the trigger of risk-metrics is based on comparison with the threshold values. This results in loss of precision as regular movements(for example, walking, shifting,Etc.) are considered during error checking. This sometimes results in false-positives in the error log. Hence the system is mostly suitable for a relatively stationary patient-transfer tasks. Also, because of the base stations and Vive trackers involved, the system is not portable and one cannot train in their own space(for example, at house). The system requires multiple calibration steps and also requires the user to mount the Vive trackers on their body.

We tried to minimize the overloading effect of visual-audio feedback. Nevertheless, due to visual channel still being already engaged at various times of the training, it is hard to maintain a good balance between the two. Ideally as part of master's seminar research it was found out that haptic nudge at relevant body locations would be non-intrusive and could fulfill the system's purpose. However, this requirement was not realized as the technology in localized haptic feedback has not yet evolved. A detailed reasoning is available as a part of the master's project report.

The weight of the Vive trackers hinders the naturalness of the body movements for the user. Additionally, the weight of the HMD and trackers limit the training times because of the physical fatigue encountered. Furthermore, the naturalness of the user's movement is also affected because of the air gestures happening as a part of the system interaction. This is because the user only sees a virtual patient and senses touch using haptic gloves in the real-world. However, the actual weight of the patient is missing. This does not allow the user body to react to the patient's weight as it would in the real world.

This concludes the prototype implementation chapter and we move forward to the next discussion of user study and its details.

6. User Study

After implementing a prototype of the proposed system concept, a qualitative study was planned to be conducted with actual nursing students from the nursing-care school in Konstanz. Although the study was designed successfully, we were not able to conduct it due to the COVID lockdown restrictions. However, a pilot study was successfully conducted with a student participant from the HCI department. The feedback after the pilot study was used to improve study design. In the following section 6.1, we look into the specific features that were added to the system for study purposes. Next, section 6.2 outlines the study design and describes an iteration in study design after a pilot study was conducted. In section 6.3, we look at some proposed data analysis methods that could potentially be applied to our study. The concluding section 6.4 discusses the limitations regarding the study design.

6.1. Feature additions

Although the implemented feedback system after integration was usable to address our thesis goal, some aspects were improved to enhance the overall user experience. Additionally, some features were added to digitize and store the user data for future analysis. Figure 6.1 highlights the two modules (outlined in green) that were added additionally to facilitate a better study. Both of these new additions are discussed further.

6.1.1. 3D avatar creator

As already shown in figure 5.16, the integrated system shows a dummy inverse kinematics avatar in the terminal feedback. This extreme disresemblance between the avatar and an actual human was hampering the user experience(UX) of the movement playback. Especially because the avatar is a user's representation during the training session. To improve the UX of the CaregiVR, an avatar replication module was created. The module was developed using the APIs exposed by the Avatar SDK [52]. With the user's privacy in mind, the module did not share any data with the cloud servers for computing. All the data is locally computed and helps in the generation of the avatar. As the avatar was being generated in real-time, it was essential to integrate the mechanics with our system. This is where multiple challenges were faced. We look into those challenges and how they were resolved.

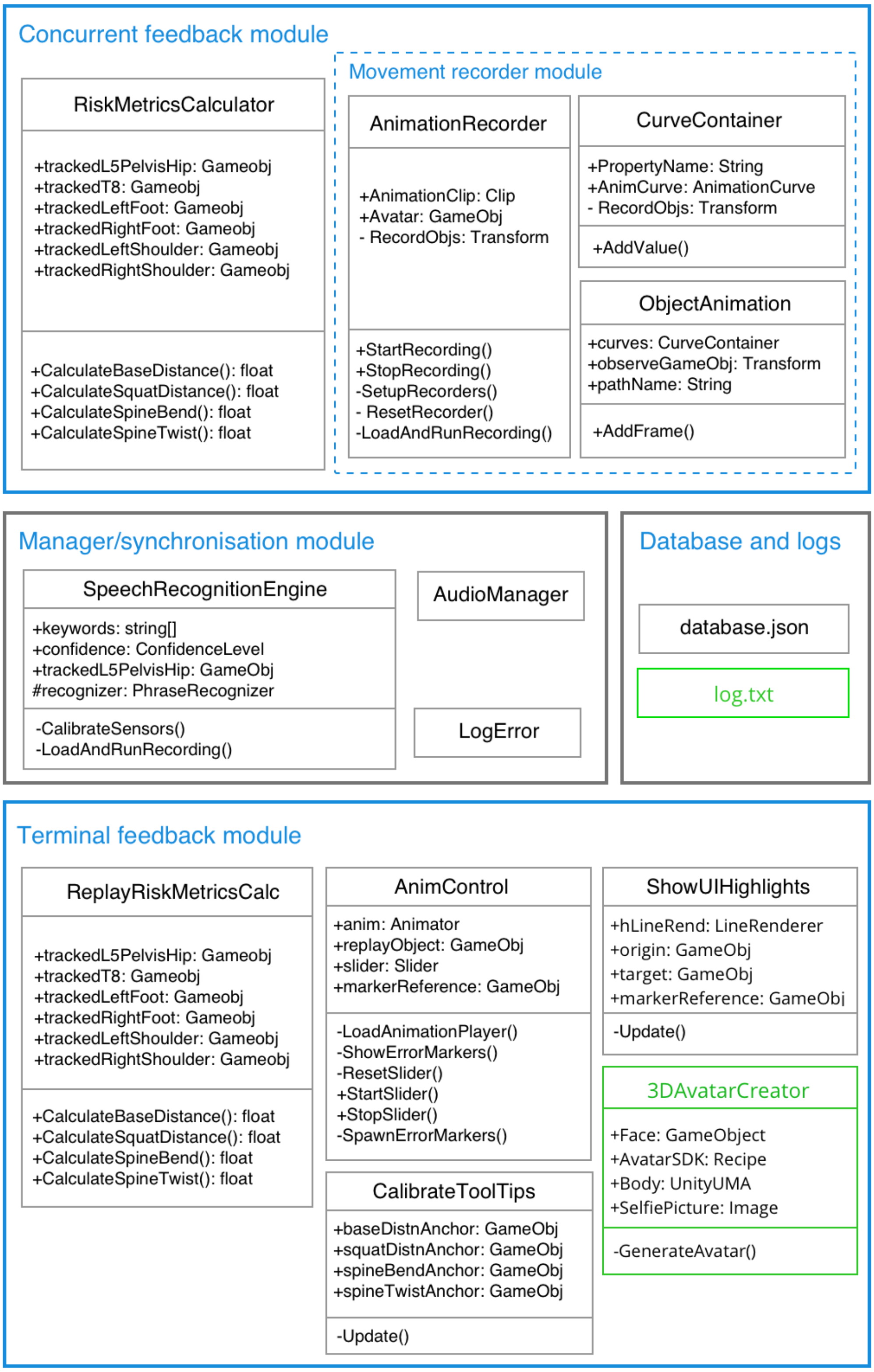

Figure 6.1.: Feature additions in CaregiVR

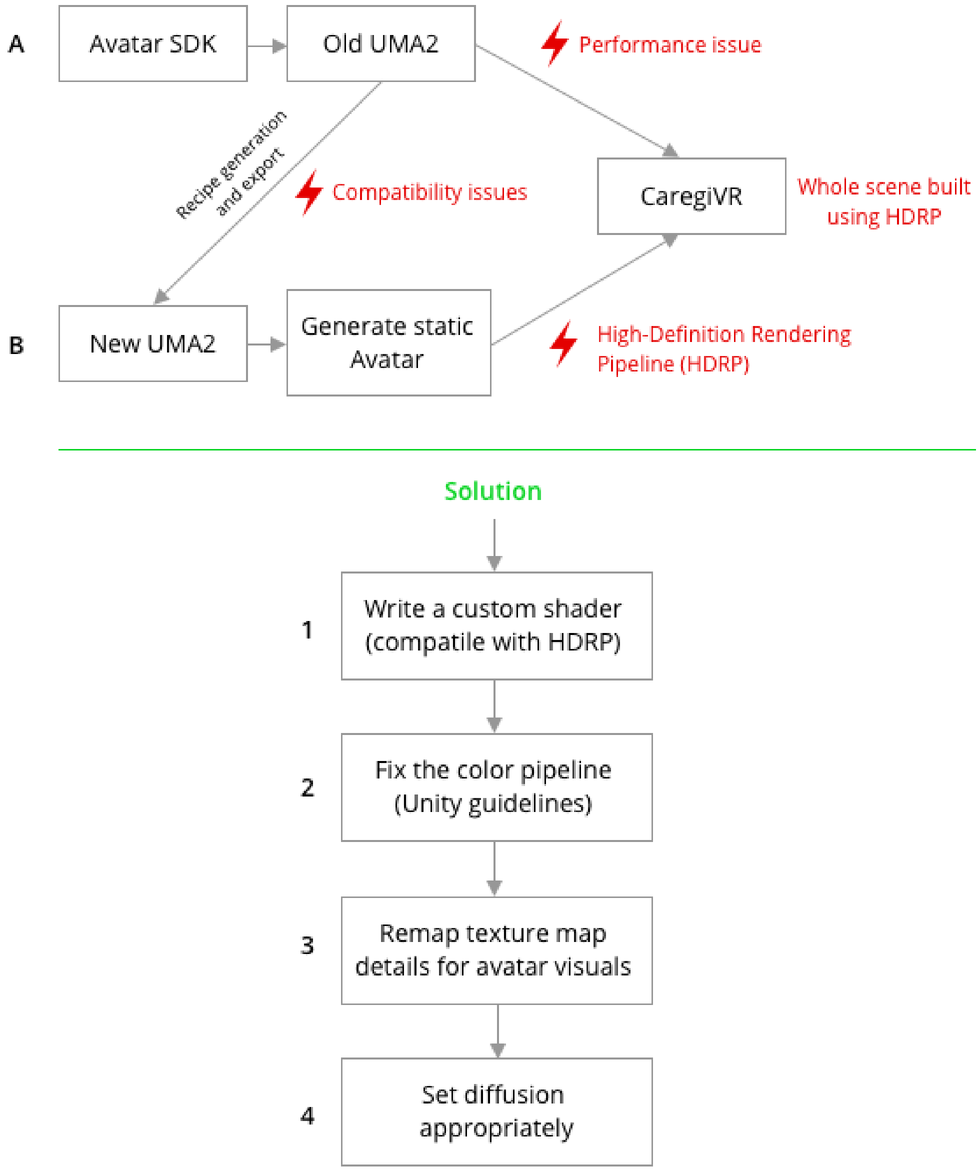

Figure 6.2.: Feature addition challenges overview

Challenges

A summary of the challenges and their solution can be viewed in figure 6.2. The red text with *bolt* icon represents the software limitations or constraints. **A** and **B** are the two methods that were tried to integrate the 3D avatar reconstruction logic into CaregiVR. The idea is to click a selfie picture of the study participant, and the system generates a humanoid avatar that looks like the participant during the terminal feedback. For this purpose, both methods used Avatar SDK [52] and Unity Multipurpose Avatar(UMA) package.

However, the default recommended **method A** felt short because of the performance issues. Although the computer used for CaregiVR was powerful, the run-time avatar calculations were causing unacceptable lag. Next, we tried **method B**, where UMA's new implementation allows us to export an Inverse Kinematics(IK) humanoid avatar as a static asset. This solution seemed feasible as it reduced the run-time calculations. Only study constraint being that the participant's avatar had to be generated before the study setting. Exporting the static avatar was tried using the newer version of UMA. However, the exported avatar did not support Unity's High-Definition Rendering Pipeline(HDRP). This was an issue because the patient transfer scenario built by Daniel Schweitzer heavily relied upon the HDRP model.

Solution

After multiple failed approaches, the solution approach that worked is shown as a four-step process in the figure 6.2. A custom Unity shader was written, which was compatible with HDRP. Color pipelines were corrected to translate exported avatar information to HDRP color space. Furthermore, the selfie image used by the Avatar SDK converts it into a texture map. On re-importing, these textures needed to be re-mapped on the avatar mesh. Finally, the diffusion values needed to be set to deal with the individual illumination of that avatar's body parts.

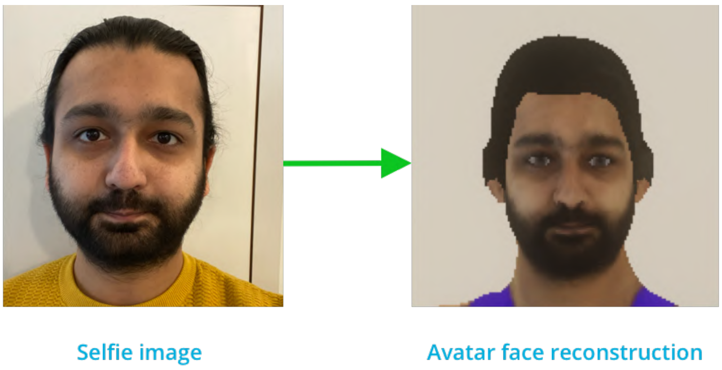

Figure 6.3.: Face reconstruction of avatar using a selfie image

Figure 6.3 shows how a user's 2D selfie image was transformed into a 3D avatar face. This face was then adjusted on a humanoid body using the *Head 2.0* algorithm of the Avatar SDK. The figure 6.4 shows how the overall similar-looking avatar to the user was generated for use in the terminal feedback session of CaregiVR.

Furthermore, the avatar was calibrated according to the inverse kinematics script to replicate the recorded movements appropriately. In figure 6.5, a realistic user representation in avatar form can be seen performing patient transfer movements. The figure as mentioned above is divided into two parts. The bottom part is a screenshot of the moment where the user's spine twist and base distance were erroneous while performing the virtual patient transfer. The respective UI labels are highlighted in red to signify an error state. The blue UI labels indicate that the user fixed something that was previously erroneous. While the top part of the figure also shows a populated training timeline behind with errors highlighted on their respective rows.

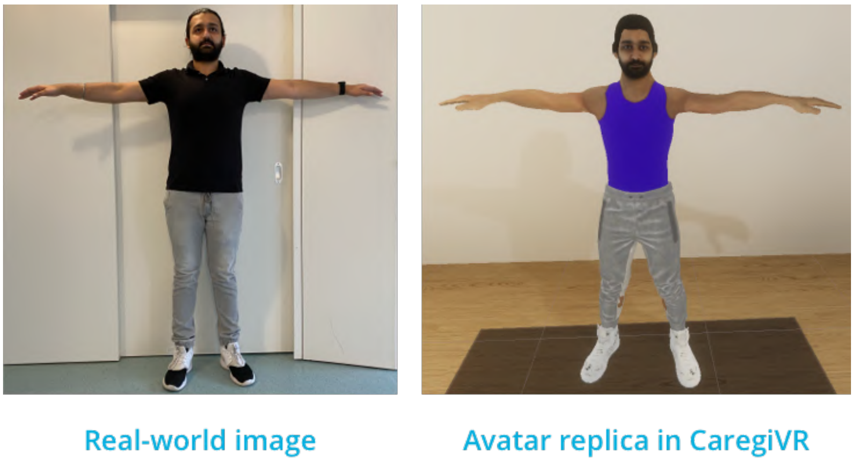

Figure 6.4.: T-pose replica of actual human in CaregiVR

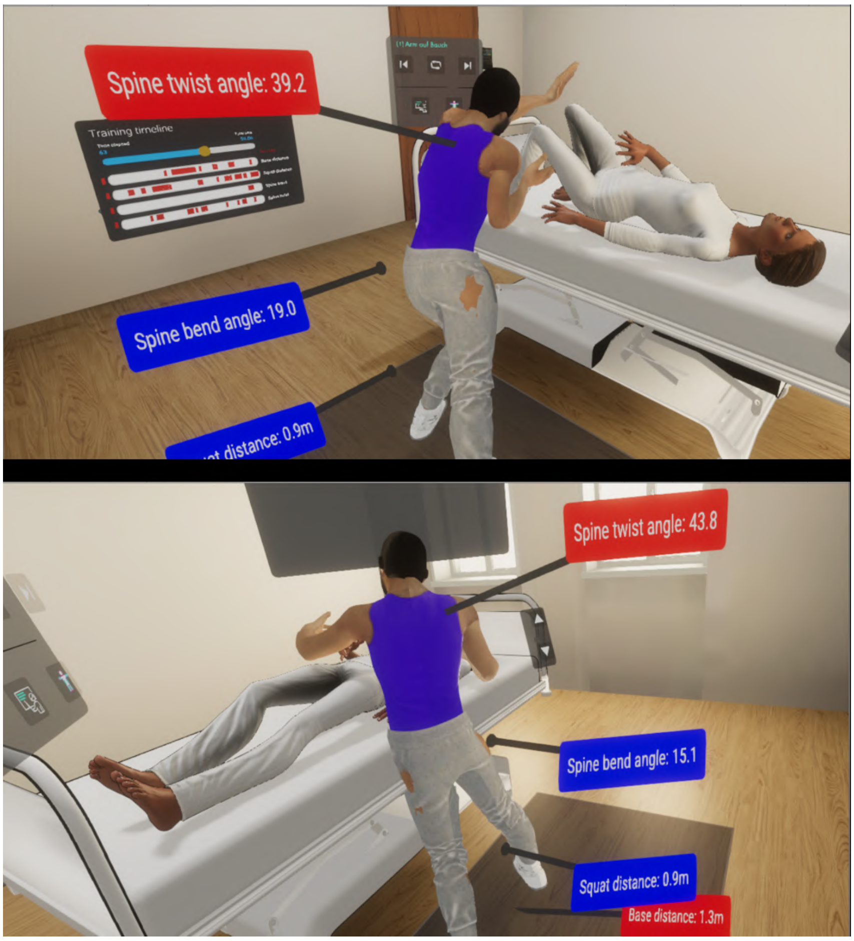

Figure 6.5.: Terminal feedback with a realistic looking avatar

6.1.2. Logging user data

After improving the user experience of the system for user study, it was necessary to add modules that would allow the collection of data. This data could later then be parsed and used for analysis purposes. A logging module was generated as a part of the feature addition process. This module allowed to log data specific to each participant.

The following parameters are logged into the log.txt file eight times for every second of the virtual training session:

1. **PID**

   Participant identification used for recognizing associated files.

2. **Time in mm:ss format**

   Time elapsed since the training has started

3. **Trackers transform information**

   XYZ translation and rotation positions of all the 8 trackers

4. **Error code (0 for no error)**

Error code	Risk metrics associated
1	1 (base distance)
2	2 (squat distance)
3	3 (spine bend)
4	4 (spine twist)
5	1 & 2
6	1 & 3
7	1 & 4
8	2 & 3
9	2 & 4
10	3 & 4
11	1,2 & 3
12	1,2 & 4
13	1,3 & 4
14	2,3 & 4
15	1,2,3 & 4

Table 6.1.: Error codes and the corresponding risk metrics associated to them.

5. **Voice command used by the user**

Could be one of the following commands: Ready, Done, Play, Pause.

6. **Interaction detail**

   User interaction with virtual scene elements. The logging is done based on the user's virtual hand colliding with other relevant gameobjects. For example, patient's different body parts, control panel buttons, buttons to adjust bed height, Etc.

7. **Step of the patient transfer**

   The active step of the patient transfer for user training.

This concludes the section of feature addition for our study setting. We look into the study design details in the upcoming section.

6.2. Study design

This section depicts the study design initially formed to conduct a participant study with the nursing-care school in Konstanz. However, due to the COVID-19 lockdown restrictions, we were not able to realize the study. Efforts were made to contact Konstanz's nursing-care school administration, ensuring that we can follow safety precautions and care. However, after a significant delay in their response and limited time to finish this master's thesis work, we only conduct a pilot study at the University of Konstanz. The pilot study facilitated as a feedback point which further helped in the improvements in the study design. So we structure this data and learnings in an easy-to-understand format. Some of the upcoming sub-sections related to study design are divided into three stages. In the first stage, we talk about the initial study design. Secondly, we briefly look into the issues found after conducting the pilot study. Finally, we look into the study design improvements for that particular sub-section.

The study is designed to be qualitative as there are no systems previously available that could be used as a point of reference. Also, there are too many variables in the current system that could reduce the significance of the quantitative study setting. While a comparative study is possible in theory, it is challenging to find nurses as more numbers. However, some quantitative data is collected as a part of this study.

The user study is planned to be conducted in a controlled setting in a lab at the university or a nursing-care school room. The details of the study setting and implications of the pilot study are discussed ahead.

6.2.1. Research questions

As outlined in the introduction, the overall goal of this thesis was the following:

> To determine the effect(s) of providing concurrent and terminal feedback during self-directed learning of patient transfers in virtual reality.

With this goal in mind, the CaregiVR system is developed by considering nurses as its end-user. Human-Computer interaction concepts were applied to design a usable system and a system that provides a decent user experience. We designed our study to address this initial goal. From our research goal, the following questions arise:

- **RQ1:** Does a system like CaregiVR provide a high user experience by delivering feedback during practical training?
- **RQ2:** Do nurses consider a system like CaregiVR to be supportive for self-directed training of patient transfer movements?

Implications of the pilot study

After conducting the pilot study, we found that the data collected later during the interviews was not holistically answering the thesis goal. Hence a third research question was added based on the feedback and discussion with the thesis supervisor.

- **RQ3:** How helpful the feedback is to improve the understanding and application of ergonomic patient transfer?

This research question also influenced the questions to be asked in the interview and questionnaires. However, it would result in better data collection and findings in the future.

6.2.2. Participants

The participants were planned to be recruited from the nursing-care school in Konstanz. The target participants were nurses who agreed to be contacted in the future as a part of the previously conducted studies. We planned to enroll 12 nursing-care students to participate in the user study. All the participants should have been studying at the nursing-care school. The minimum requirement for student enrollment was they were at least in their second year of nursing studies. They should also have acquired practical knowledge from the basic Kinaesthetics course as a part of their curriculum. These requirements were not influenced after the pilot study.

6.2.3. Apparatus

The user study is to be conducted in controlled environment within a room with at least of 4 meters by 4 meters of free space. The room should be equipped with 4 HTC Vive base stations mounted on a height of 6.5 feet or more. Two tables for keeping the sensors and chargers and two chairs for the participant and the study coordinator. A Valve Index HMD with 8 HTC Vive trackers was necessary, along with the Manus VR haptic gloves. Mounting straps as shown in the figure 5.5 of section 5.2.1. Minimum requirements of the computer to run the CaregiVR system are Intel i7-6700K CPU, 32.0 GB RAM, Nvidia GTX 1080 dedicated GPU, 64-bit Windows operating system, an additional PCIe USB 3.0 card (with eight unique USB slots), and a WiFi dongle for verifying Avatar SDK license over an internet connection. Also, two video recording cameras - one standard and one wide-angled are required to record participant's movement and conversation data in the real-world. Due to COVID-19 rules, additional hygiene equipment is mandatory: disinfectant cloth wipes, disinfectant spray/gel, disposable masks for the internals of the VR headset, FFP-2 face masks, and rubber gloves to wear beneath the ManusVR haptic gloves.

Implications of the pilot study

During the pilot study, the disposable masks beneath the VR headset were slipping and causing hindrances in the study process. Hence, the HCI department ordered a VR headset sterilizer called as *CleanBox* [53].

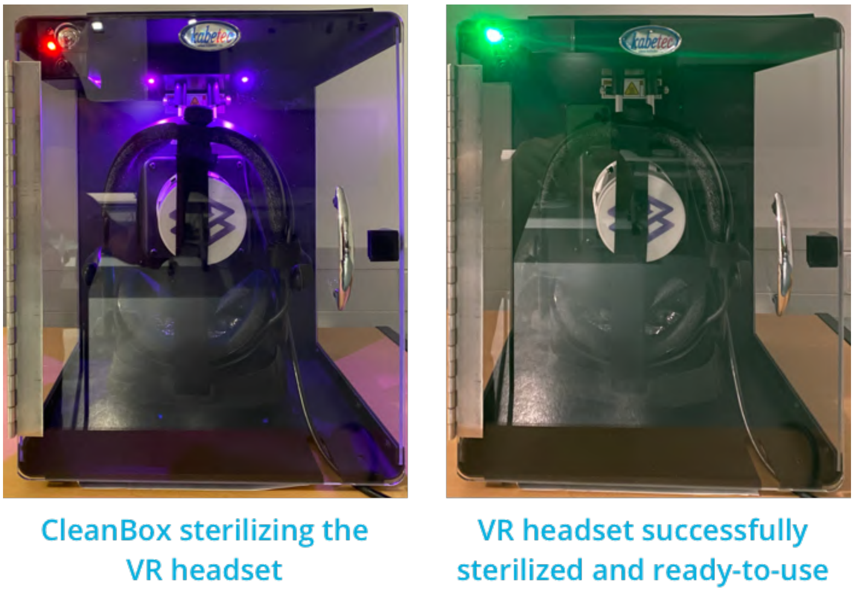

Figure 6.6.: Two states of CleanBox for sterilizing the VR headset

Figure 6.6 shows the product CleanBox in its two states. The VR headset is mounted inside the CleanBox, and the button is pressed. It takes 60 seconds to disinfect any equipment kept inside the CleanBox. The left image shows equipment under sterilization, and the right one shows the equipment that is now safe to use after 60 seconds. This addition to apparatus highly reduced the risks involved due to hygiene.

Additionally, it was observed that the Vive trackers mounted on the shoulder of the participant kept slipping off during the training task. This was a significant concern as it hampered the user's experience and led to the logging of false data values. This led to the exploration of a better alternative to mounting the Vive trackers on the shoulders.

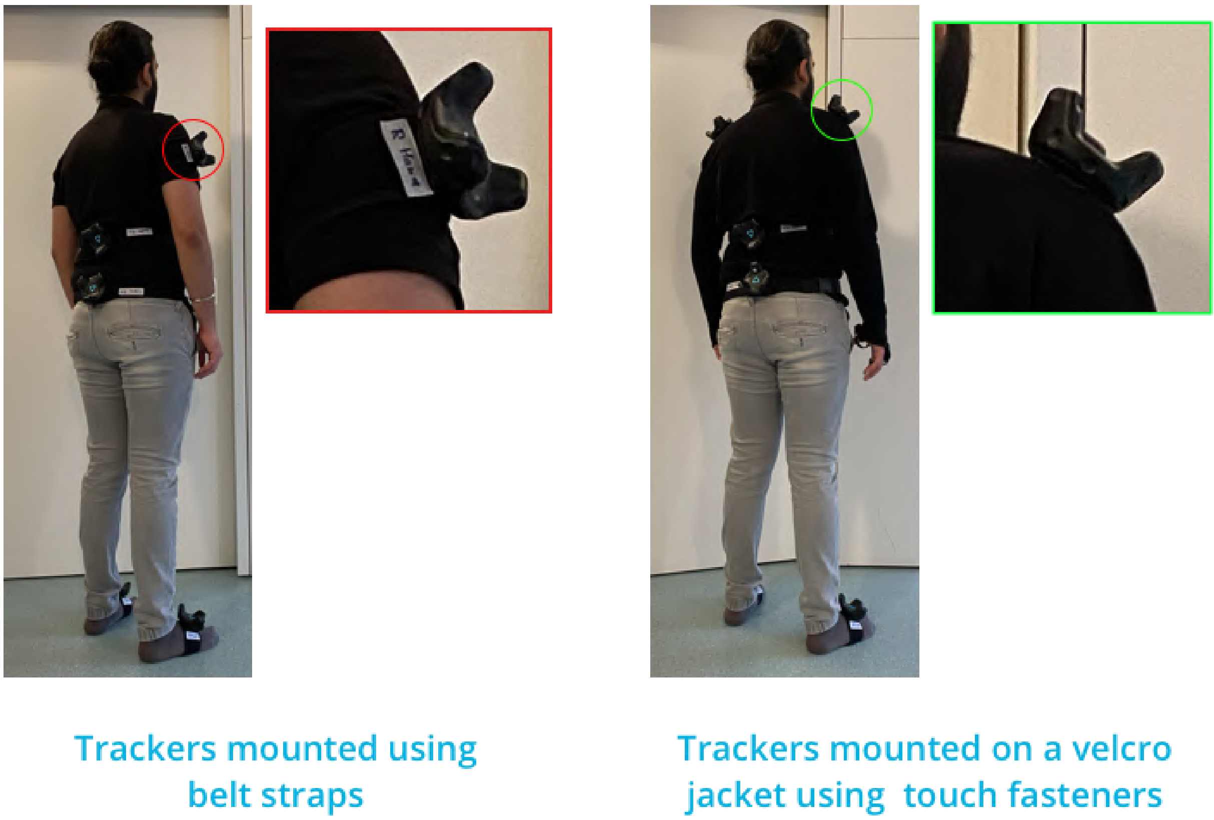

Figure 6.7.: Iteration of shoulder tracker mounting mechanism

Figure 6.7 provides a visual for the issue mentioned earlier. The figure's left part shows a Vive tracker on the user's shoulder-mounted using a belt strap. The belt strap is wrapped around the user's upper arm. This strap was getting loosened up during the virtual patient transfer was being conducted. The solution on the right side of the figure shows a user wearing a jacket made of a material that sticks to touch fastener(Velcro) surfaces. It resolved the issue with the sensors' dislocation and allowed us to properly mount the sensors at the exact location on the shoulders.

Overall, we added two new apparatus to our study setting, first is the CleanBox for sterilizing the equipment, and the second is the Velcro jacket.

6.2.4. Procedure

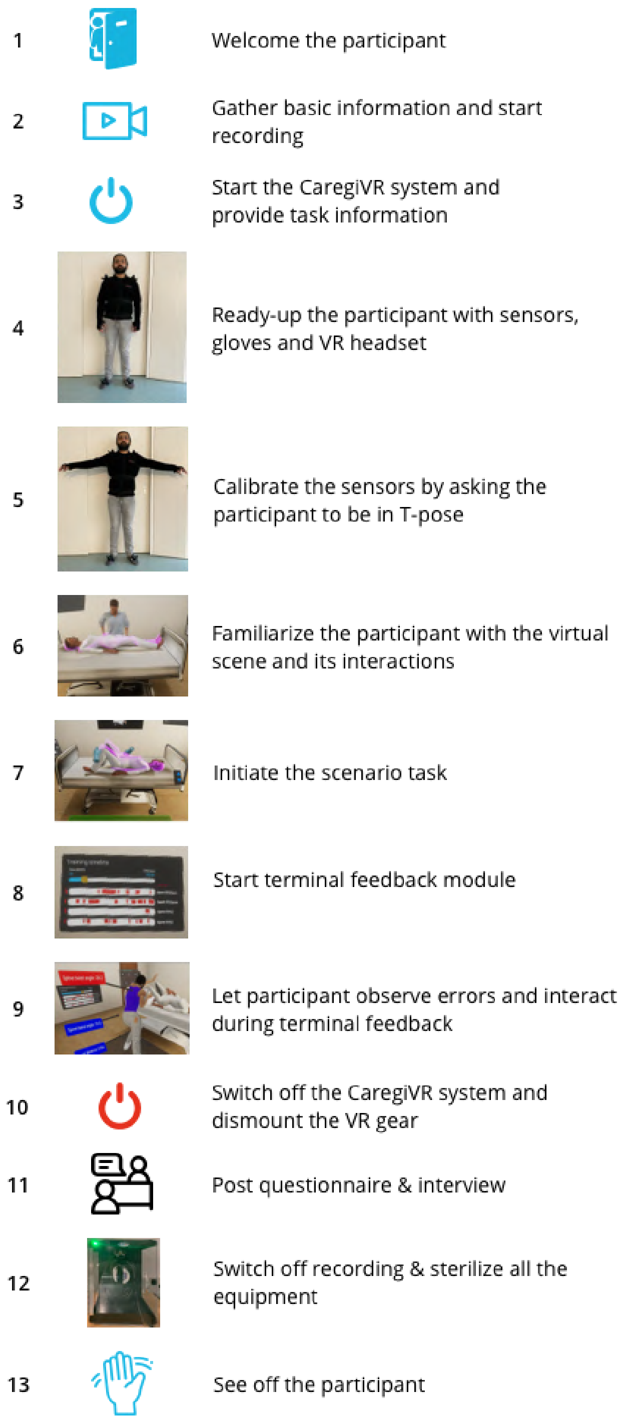

Figure 6.8.: Key steps of the study procedure

The average study duration is estimated to be around 60 minutes. Figure 6.8 shows key steps of the study procedure. A detailed procedure sheet was created as part of the study design attached at the end of this thesis.

Welcome: Initially, the participant is welcomed and ask to use a disinfectant gel to sanitize his/her hands. He/she consents to the gathering of the data in various formats for future analysis and research. Two copies of the consent forms are signed; one is documented with the research coordinator, and another is given to the participant. Participant ID(PID) is allotted, and from this moment, all the documents will have the same participant ID. Basic study descriptions are part of the welcome sheet.

Gather basic information and start recording: Video recording is started, and the participant is asked to fill the demographics questionnaire.

Start system and provide task information: CaregiVR system is initiated, and the participant is provided with written task information of what he/she will see and expects to do.

Sensors mounting and calibration: Participant is asked to wear the full-sleeved jacket and helped with the mounting of the Vive trackers. Next, we ask the participant to stand in T-pose to calibrate the inverse kinematics avatar in the VR environment. This stage also allows us to extrapolate the two hip locations with the help of the lower-back sensor.

Familiarization phase: Participant is given some time to walk around and get used to the VR environment. All the written instructions from the task information sheet earlier are repeated as a walk-through to the participant. This familiarization is provided verbally by the study coordinator.

Task initiation: Once familiar and comfortable with the CaregiVR's virtual surroundings, the task is initiated. Participant follows the instructions. The task completion has three end states - (i) The participant runs over the maximum time limit of 12 minutes, (ii) The participant successfully completes the five steps of the task at least one time, (iii) The participant gives up and voluntarily asks to end the task.

Terminal feedback phase: Upon completion of the task, the terminal feedback is started, and the participant can observe his/her movements from various perspectives. The endpoint here is when the participant informs the study coordinator that he/she is done with reflecting on his/her errors.

Switch-off and dismounting: The system is switched off, and the participant is helped with the dismounting of the gear. The participant is provided with a five-minute break to get comfortable before moving on to the next step.

Post questionnaire and interview: Two questionnaires are asked to be filled related to their experience with the CaregiVR system. A semi-structured interview is conducted to gain some insights related to our research questions. There is an opportunity provided for open comments to the participant.

Closing: The study session is ended with some final comments from the participant and recording their interest in participating in any future research studies. All the equipment is properly sterilized, and recordings from both the cameras are transferred to a personal computer.

Implications of the pilot study

The changes in the apparatus have already influenced some of the procedure steps. In addition, there were some concerns that were pointed out during the pilot study. The pilot study participant mentioned that the consent form should include text related to close bodily-contact with the participant. This is because while helping with the mounting and dismounting of the equipment, the coordinator had to come closer to the participant, making them uncomfortable. Also, an option *Diverse* was added to the question of gender in the demographics questionnaire. As per German law, a person could recognize themselves apart from the conventional categories of *Male* or *Female.* All these recommendations were considered and reflected in the final iteration of the study documents at the end of this thesis.

6.2.5. Measurement techniques

To investigate the research questions, it is necessary to introduce relevant measurement techniques to the study design. As previously mentioned, most of the study design is qualitative. Standard techniques for collecting qualitative data are interviews and questionnaires [54]. To help triangulate the research data, the following methods are used/recommended for the purpose of this investigation.

Questionnaires

In total, three questionnaires were used to gather information related to the research questions. Following are the details of those questionnaires.

Demographics questionnaire: It is used to gain general information of the participant such as age and gender. It is also used to gain information about physical restrictions they might have in their body movement. Furthermore, it also helps us to know immediately about any visual impairments that the participant might have. Additionally, it helps us gauge their experience with smartphones, virtual reality, and more.

User experience questionnaire(UEQ): This questionnaire helps us to capture the participant's experience with our system [55]. The questionnaire is based on a 7-point scale and consists of 26 questions. We utilize the non-modified standard version of the questionnaire for our study purposes.

System evaluation questionnaire(SEQ): In addition to the UEQ, a system evaluation questionnaire is also part of the study setting. The SEQ is a custom questionnaire with 5-point semantic differential scales, consisting of the following eight questions.

1. How helpful was the concurrent feedback provided while performing the patient transfer movements?

2. How helpful was the terminal feedback provided as a recording after performing the patient transfer?

3. To what extent is the feedback provided by the CaregiVR system comparable to an actual expert?

4. Could the CaregiVR system help you to improve the inaccuracies in your movements in daily work?

5. To what extent would you consider an integration of CaregiVR system in conventional practical training methods as desirable?

6. To what extent did the CaregiVR system support you with self-directed training of patient transfers?

7. To what extent did the feedback mechanisms help you overall to correctly understand the ergonomics associated with properly transferring a patient?

8. To what extent did the CaregiVR system help you to increase your understanding of transferring patients ergonomically?

We will detail the relation of these questions to corresponding research questions in the next section.

Semi-structured interview

A post-semi-structured interview is introduced to complement the aforementioned questionnaires. It helps us to understand or find any discrepancies in the participant's answers. This is because sometimes written questionnaires are broader or have broader explanations. It will also help us to gain insights into the overall UX that CaregiVR delivers. Furthermore, it allows us to comprehend the extent to which such a system supports self-directed training and helps develop an overall understanding of ergonomic patient transfers.

Video recording of transfer task

Two video cameras are used to capture the movements of the participant while performing the patient transfer task. One camera captures a diagonal side view of the participant, while another captures the participant's top-down view. Additionally, a screen recording software is used to record the participant's perspective in VR.

Data logs

All the values of the interactions and movements in virtual reality are recording by the system. These values are saved as a text file on the local storage. Previously in section 6.1.2, we already discussed all the details which are a part of this log file.

6.3. Proposed data analysis

As we could not conduct the user study for multiple reasons, we briefly discuss some methods and procedures that could be used for the proposed study design. This study design facilitates the collection of both qualitative and quantitative data. The following analysis approaches can be used for each type of data.

6.3.1. Qualitative data

Usually, it is not easy to deduce understandings from the qualitative data instantly. Therefore, Virginia Braun and Victoria Clarke, Authors and qualitative researchers in psychology, have introduced a procedure [56]. This procedure is called thematic analysis to identify patterns of themes in the interview data. The following steps could be followed to identify themes within the qualitative data.

1. Familiarize yourself with your data.
2. Assign preliminary codes to your data in order to describe the content.
3. Search for patterns or themes in your codes across the different interviews.
4. Review themes.
5. Define and name themes.
6. Produce your report.

Another type of qualitative data that we need to account for is the video recordings. We can code videos and generate critical points with software like BORIS [57]. This video coding would allow us to extract task times, false-positives for errors, technical difficulties, and participant's interaction with the virtual elements.

Additionally, a professional Kinaesthetics expert can be asked to analyze the videos subjectively. The expert can be asked questions related to the frequency of feedback provided. Also, he/she can provide insights into where the thresholding nature of the risk-metrics algorithm would be falling short. This will also help us to gain system improvement insights from a professional's perspective, as they usually provide feedback during training sessions.

6.3.2. Quantitative data

All the questionnaires, along with the log data, would provide us with quantitative data. The themes generated as a part of the qualitative process would provide us with a foundation of underlying categories of data. Extracting data from questionnaires would be straight-forward as it is on a scale. The differential scales can be quantified by providing numbers to the choices. Since UEQ uses a 7-point scale, the numerical values will be ranging from -3 (most negative value) to +3 (most positive value). At the same time, the 5-point scale in the system evaluation questionnaire can be quantified on a scale of 1 (most negative value) to 5 (most positive value). We can generate a mean score of both and compare it to the answers generate as part of the interviews. This will help us generate findings related to our research questions.

RQ1: Does a system like CaregiVR provide a high user experience by delivering feedback during practical training?

SEQ1: How helpful was the concurrent feedback provided while performing the patient transfer movements?

SEQ2: How helpful was the terminal feedback provided as a recording after performing the patient transfer?

SEQ3: To what extent is the feedback provided by the CaregiVR system comparable to an actual expert?

RQ2: Do nurses consider a system like CaregiVR to be supportive for self-directed training of patient transfer movements?

SEQ4: Could the CaregiVR system help you to improve the inaccuracies in your movements in daily work?

SEQ5: To what extent would you consider an integration of CaregiVR system in conventional practical training methods as desirable?

SEQ6: To what extent did the CaregiVR system support you with self-directed training of patient transfers?

RQ3: How helpful the feedback is to improve the understanding and application of ergonomic patient transfer?

SEQ7: To what extent did the feedback mechanisms help you overall to correctly understand the ergonomics associated with properly transferring a patient?

SEQ8: To what extent did the CaregiVR system help you to increase your understanding of transferring patients ergonomically?

Figure 6.9.: System evaluation questionnaire and its relation to corresponding research questions

Figure 6.9 shows the association of research questions to the questions from the system evaluation questionnaire. It would help to segregate data and relevant findings to specific parts of this thesis' goal. Furthermore, the log file data will provide us with an understanding of which interactions were most used by the participants. Also, it would help us to narrow down common points of difficulties in the particular task.

6.4. Limitations

Actual user findings were not possible without conducting an actual study. However, during the pilot study, the participant faced some issues while interacting with the virtual patient. Most of the feedback received was related to the inability to interact with the virtual patient appropriately. The participant also mentioned getting disturbed because of the audio instructions being received as a part of the task. The patient interaction issue significantly impacted the participant's experience with the system to such an extent that the participant was not able to grasp the concurrent feedback details.

From the perspective of the goal of this system, the study is limited in terms of time. It is not easy to analyze such a feedback system's long-term effects, such as retention, understanding, and learnings. Also, it is limited by the number of participants. However, getting more nursing-care students for user study is a difficult task. This is because of their limited availability and also currently due to the COVID-19 restrictions. Future research could look into the integration of CaregiVR in a real-world setting to analyze its long-term effects. This would also allow more nursing-care professionals to experience the system.

Additionally, the user study focuses on gaining subjective experience data from the nursing-care students. However, future work could investigate specific findings with more objective measures to confirm the aforementioned long-term effects.

The current study is limited to four risk-metrics from the literature and relies on a thresholding mechanism to report errors. Moreover, the system only addresses one patient transfer task for training. Additional research would be required to collect ergonomic data related to different kinds of patient transfer tasks. Future research could extend this system by including more ergonomics metrics and providing errors based on the movement's context.

Furthermore, the study only explores the effects of visual-audio feedback modalities in the context of ergonomic patient transfer. With improvements in technologies, future research could focus on including haptics as an additional feedback modality.

Finally, the current study focuses mainly on virtual reality in terms of technology. With advancements in other mixed reality technologies like augmented reality, a more integrated feedback system in a day-to-day setting can be realized. Future work could look into investigating the effects of providing in-situ feedback during real-world patient transfers.

7. Implications for future work

The implication of this inform the design of future systems that aims at providing feedback for self-directed training of ergonomic patient transfers and future research in these disciplines. We discuss in this chapter how the CaregiVR system could be extended in future. Section 7.1 discuss potential ideas for the redesigning the system implementation. While ideas for future study designs are proposed in section 7.2.

7.1. Design of the system

This section explores ideas of how the CaregiVR system can be improved by extending its functionalities using expertise in various fields.

7.1.1. Extension of machine learning

As a prototype in its earlier iterations, CaregiVR uses threshold-based error detection logic. This makes it pretty hard to detect the category of risk behavior. For example, when you try to adjust your position during a patient-transfer and try to step further, the system would detect it as an error of base distance. To resolve this issue, a system like CaregiVR could be extended by applying machine learning algorithms to understand the movement data. Caramiaux et al. discuss three approaches of how adaptive models could be used to support motor learning [58]. Such extensions with machine learning(ML) would also require parallel research to collect data about various bodily movements during patient transfers. One of the paper's challenges is the labeling of data for the experts would be a complex task.

On the other hand, such additions to motor learning would improve the detection of behaviors and allow detection of risk-metrics that are not threshold-based.

Machine learning extensions are not only limited to detecting risky movements. ML algorithms can also facilitate various patient profiles from partially-dependent to fully-dependent. This will allow the user to feel the difference in applying similar Kinaesthetic concepts in differing situations. In such cases, feedback delivered to the user can be more comprehensive as the virtual patient could react to certain incorrect behaviours by the user.

7.1.2. Extension of haptics

A commonly cited benefit of vibrotactile feedback is that it is useful when other modalities, such as hearing and vision, are under cognitive load (e.g., [59]). Also, vibrotactile feedback has been shown to induce faster reaction times in the learners than the exact instructions given verbally. System developed for complex tasks such as playing the violin [60], has shown to be effective in delivering silent hints to the learner. Thus future implementations can leverage the idea of delivering concurrent feedback using haptic nudge to the user. This idea was also conceptualized during the first iteration of our storyboard A. A wish for on-body feedback was also reported as a finding of previous researches in nursing-care [33].

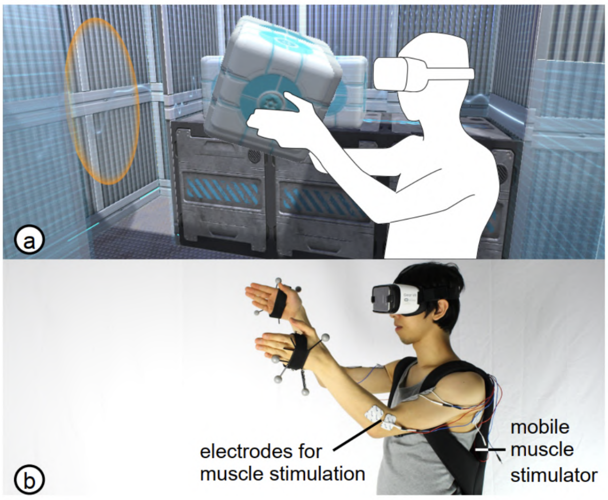

Figure 7.1.: Providing resistance using electrical muscle stimulation

One of the significant limitations while training in virtual reality is the lack of physical resistance. Haptics gloves are only enough to provide an effect of touch to the user. However, when it comes to complex tasks like patient-transfers, haptics stimulation feels inadequate. Figure 7.1 shows an implementation by Lopes et al. [61] that explores the possibility of providing realistic weight and resistance to the user using electrical muscle stimulation.

Vibrotactile feedback mechanisms have been explored in several different contexts, including collision avoidance in virtual reality games [62], navigation systems for pedestrians [63] and rehabilitation exercises for stroke patients [64]. Future works can take these researches as a basis and extend the realism factor of the patient-transfer movements. This would also result in proper body reactions to various resistances in the virtual environment.

7.1.3. Increasing system portability

One of the limitations of the current system that future work can address is the portability factor. As the CaregiVR system aims at self-directed training, there should be a possibility to use it at one's comfort instantly. However, the current hardware choice makes it infeasible.

Other mixed reality(MR) hardware like Oculus or Hololens can be considered for implementation. This would require additional means of tracking mechanisms to be interfaced with the MR headsets. It is a complex implementation strategy that has remained unexplored for a long-time. Future works could also look into using data from two IR cameras and stitching it to make a portable solution. This approach was already explored while conducting hardware analysis as a part of the master's project. There is potential in this approach. However, it was not considered further because of the time constraints for this thesis' work.

7.2. Study design

The recently mentioned future work implementations in the preceding section already add some questions that the CaregiVR system extension will need to address. Also, as a part of section 6.4, limitations in the current study setting were mentioned. This leaves an opportunity for future study designs to extend.

A study should investigate the overall experience that a virtual patient transfer delivers. This is because any feedback implementation heavily relies upon the accuracy of the task in the virtual setting. This could provide us with comparable insights as to the extent to which different elements of CaregiVR affect user experience.

Furthermore, another study setting exploring the long-term effects of self-directed training by receiving feedback would be attractive. This would allow us to understand how does muscle memory retention is affected in the long-term. Additionally, this study could be extended by comparing its results to the existing means of training at the nursing schools. After few months, an expert should be called to analyze the understanding and concept application improvements in the two groups.

Finally, the current study design is mostly qualitative. However, with improvements in virtual motor learning systems, a quantitative study setting should also be explored. This study setting is mostly dependent on improvements in data collection and a realistic patient transfer task in virtual reality. The study can focus on gaining accurate results related to one's movement. An extension of machine learning implementation would be suitable for such a study setting. This is because ML approaches would potentially lead to less inaccuracies in sensor data. Also, such implementations could reduce influence of changing variables on the findings if study data.

8. Conclusion

This thesis presented CaregiVR, a virtual reality system that provides concurrent and terminal feedback for self-directed training of ergonomic patient transfer. The goal of the system aims at addressing the issue of self-directed training with quintessential feedback. Relevant theories were introduced to provide foundational knowledge of the underlying concepts. The work touched the domains of virtual reality, Kinaesthetics, and information visualization, amongst many others. Relevant works from the field of nursing care helped to gain an understanding of the underlying requirements. Previous research in motor learning facilitated as a base for the understanding application of the various requirements. A novel sketching template was generated as a part of the design thinking phase, which helped to clearly define ideas in the earlier stages of the design lifecycle. On exploring various routes of the user journey, a key path was chosen to be implemented further. Finally, a complete prototype was developed to realize the concept.

Though the design user study was not conducted, this work contributes in many other ways. A foundational study design forms the basis for future research. To our knowledge, CaregiVR is the only prototype system that combines real-time and terminal feedback to facilitate the self-directed training of patient transfers in virtual reality. There are technical limitations of CaregiVR that need to be addressed. However, future works in this area can address them appropriately with improvements in technology. Furthermore, CaregiVR's feedback module can be quickly taken forward and adapted to another task in virtual reality.

Moreover, this work taps into the potential of reconstructing 3D movements in virtual reality. This standalone module paves the way for experimenting with different ideas in the Spatio-temporal space. The applications of facial reconstruction and self-representation could be taken further by future researchers in collaborative space.

Finally, self-directed training is still a big problem space to solve. The solution lies in developing new feedback methodologies with improving hardware. There is a need for such systems, mainly when practical training can get easily affected due to unforeseen circumstances like COVID-19. This thesis scratches the surface by narrowing the scope of the problem space. However, the work can be taken further into other domains where movement learning is crucial. With its limitations, CaregiVR is not a perfect system by itself, but it is a step in the right direction.

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A. First iteration of the storyboard

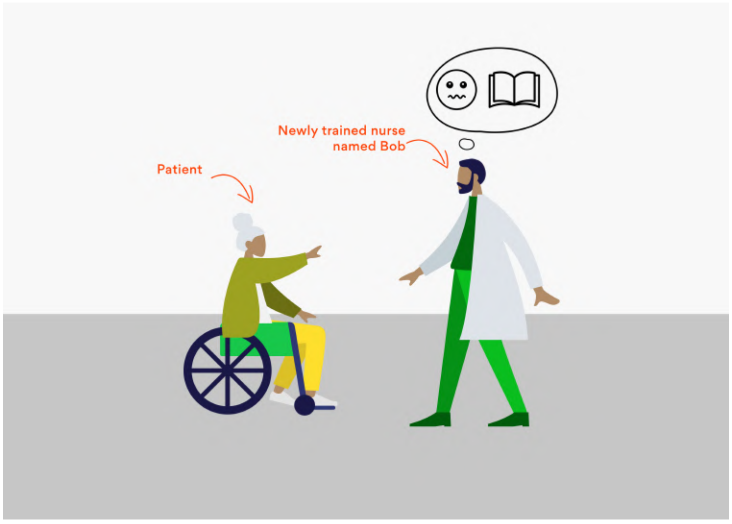

Figure A.1.: Storyboard introduction frame

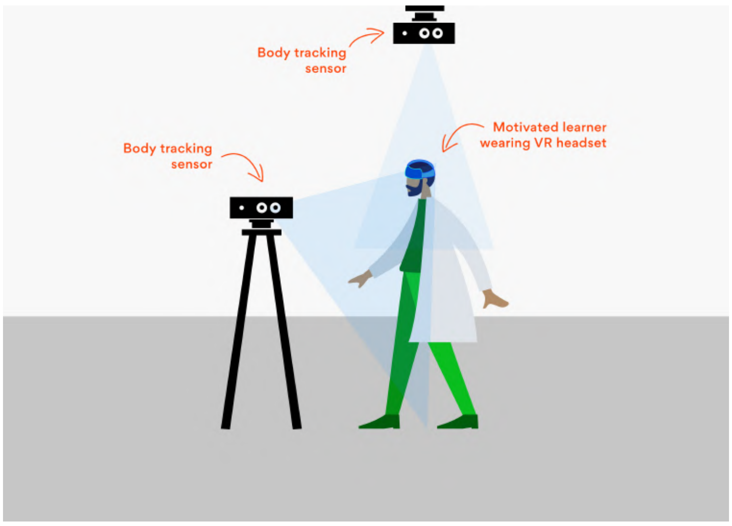

Figure A.2.: Storyboard - User wears the HMD and the system is initiated

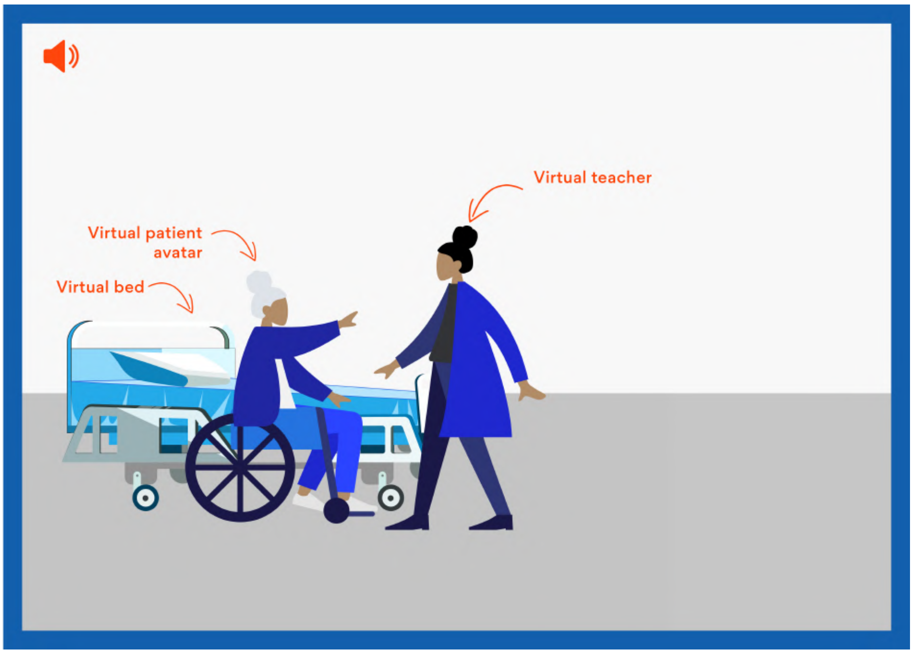

Figure A.3.: Storyboard - User observes a virtual patient transfer recording

Figure A.4.: Storyboard - User starts to perform the guided patient transfer.

Figure A.5.: Storyboard - User gets notified about the error in his posture

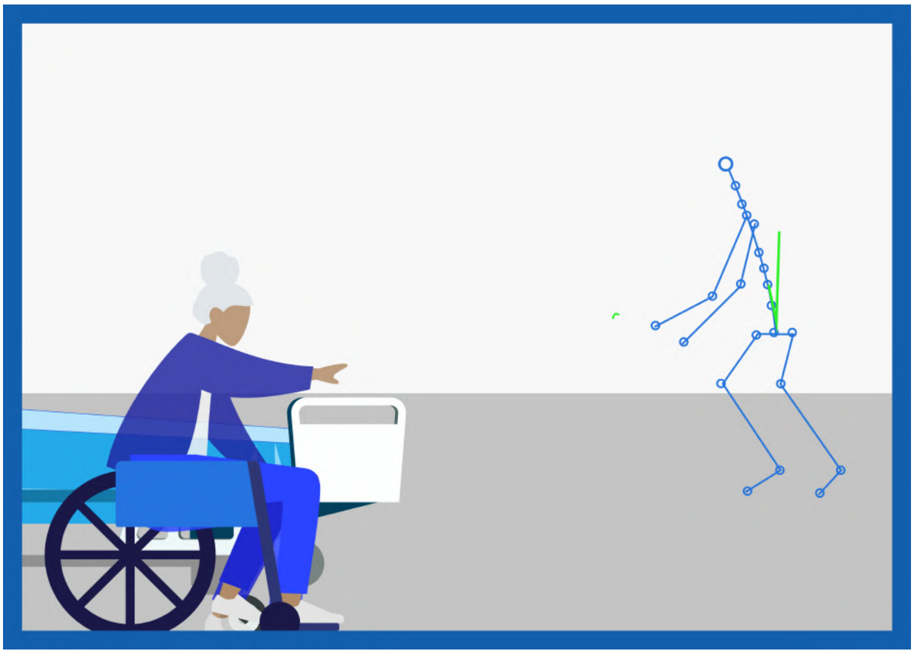

Figure A.6.: Storyboard - User fixes the erroneous posture and completes the movement.

Figure A.7.: Storyboard - User analyses his movements recordings and reflects on his learnings

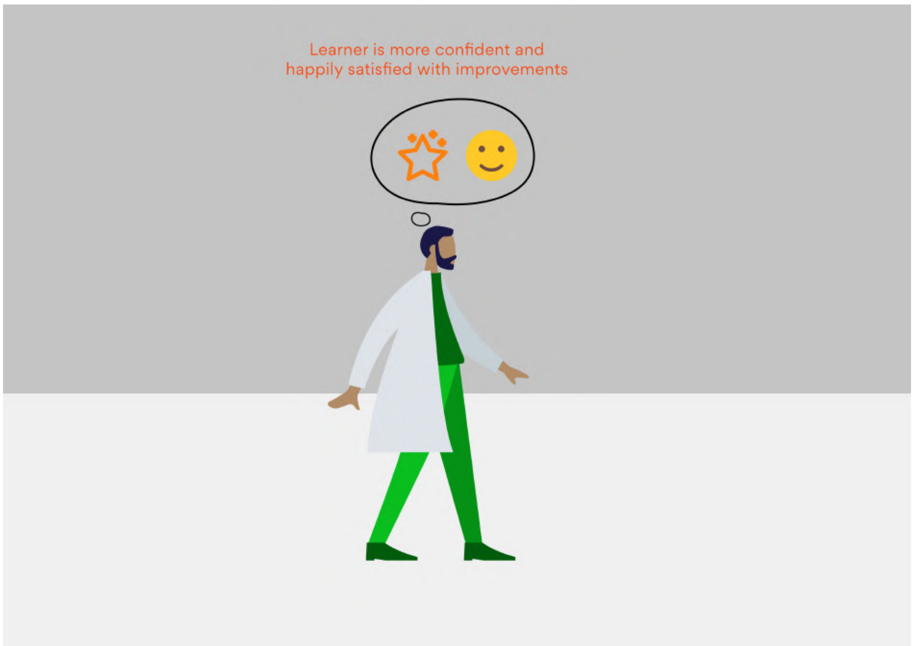

Figure A.8.: Storyboard - Satisfied and more confident user

B. Study documents

B.1. Welcome sheet

Welcome sheet for 'CaregiVR' study

Dear Participant,

Welcome to the CaregiVR research study. You are about to make a valuable contribution to my thesis project. This research is led and moderated by Tanveer Singh Mahendra under the guidance of Maximilian Dürr. Please carefully read the information below.

You will be using a virtual reality (VR) system. As part of my master's thesis at the University of Konstanz, I created a VR application that can be used by nurses or nursing care students for self-directed training of patient transfers.

VR is based on stereoscopy. Humans see the world in three dimensions because, among other things, depth information is obtained from the offset viewing angles of the eyes. To use a VR application, VR glasses are required that make use of the stereoscopic effect. You will experience the virtual world in 3D. If you move with the device in the real world, you move the same distance in the virtual one. The point of a typical VR experience is to make a virtual world seem "real".

I would like to emphasize that it is the application that is being tested and not you. Follow the system and instructions provided the best you can.

The procedure of the study is as follows:

- Welcome letter, consent form, demographic questionnaire.
- Task scenario description
- VR system familiarity and verbal explanation from the co-ordinator
- Training feedback system test
- Questionnaires
- Verbal interview

This study takes about 60 minutes to complete.

You have the option to abort this study at any time. To do so, please simply inform the study co-ordinator. If you have any questions or comments, please feel free to bring them up at any time during the study.

B.2. Detailed study procedure

Study procedure for CaregiVR

1. Greet the participant and ask them to sit down comfortably
2. Hand in the welcome sheet to the participant
3. Give the consent form to the participant to read and understand
4. Get participant's signature on two copies of the consent form
   - One copy is handed over to the participant
   - Document another copy for future reference
5. Write participant ID mentioned on the consent form on all the other associated documents
6. Switch ON the video recording camera
7. Ask the participant to fill in the demographics questionnaire
8. Hand in the task information sheet to the participant
9. Switch ON the vive trackers and the VR program
10. Ask the participant if they have any doubts before starting the study and if they are comfortable
11. Inform them that it is time to mount the tracking devices and if you can help them with this process (as it might require close physical contact)
12. Mount the vive trackers on the participant's body and help them to wear the Manus VR haptic gloves
13. Help the participant to wear the Valve Index VR headset
14. Switch ON the screen recording on the PC to record the participant's perspective
15. Ask the participant to look around in VR and if they are feeling comfortable
16. Give participant sometime to walk around and describe the scene to them verbally
   - Virtual patient laying on the bed
   - Where they would need to stand (on the blue floor in the virtual environment)
   - Where are the options available on the control panel
   - What each button on the control panel does
   - Explain them what is coming next (For ex. Instructions to follow, overlaying body on the avatar, two phases of the scenario)
17. Ask the participant if they are ready to start with the virtual patient transfer

18. Once ready, ask the participant to stand straight and press the ‘i’ key to calibrate the sensors
19. Press the ‘num 2’ key on the keyboard to initiate the scenario
20. After the scenario has started, the termination criteria are:
    - If the participant starts feeling uncomfortable or voluntarily asks to stop the study
    - If the participant spends more than 5 minutes on the task without even completing the scenario once
    - If the system breaks while the task is being performed
21. The success criteria is the whole patient transfer scenario is completed at least once
    - The participant has the option to go back certain steps in the training and re-perform some training steps
22. On successful completion press ‘f’ key to start the terminal feedback phase of the scenario
23. Let the participant see the replay of their movements in terminal feedback stage until they are satisfied by reflecting on the errors they have made
24. On participant’s satisfaction, shutdown the CaregiVR system
25. Help the participant remove the VR headset and all the other tracking devices on their body
26. Ask to participant to sit down and relax for a while (Offer water)
27. Disinfect the tracking devices and the Valve Index VR headset
28. Ask the participant if they are comfortable and ready for the next steps
29. Hand-in the User Experience Questionnaire (UEQ) and ask them to fill it
30. Ask them to fill the System Evaluation Questionnaire (SEQ) as well
31. Conduct a semi-structured interview using the following questions:
    - How do you feel about the feedback provided during the two phases of this scenario
    - Given a choice, would you prefer one type of feedback over another? If yes, which one and why?
    - How was the interaction with your own avatar in the terminal feedback phase?
    - How does the feedback felt as compared to the one provided by an expert trainer?
    - How can the feedback of the CaregiVR system be improved to facilitate self-directed practical training in your professional life?

- Did you feel limited by the feedback provided during different phases of the system use?

32. Ask the participant if there are any other comments that they have?
33. Thank them for their participation and ask them if they would be interested in being a part of such a study in future
34. See off the participant to the exit
35. Switch OFF the video recording devices and backup the data from the memory card

B.3. Consent form

Consent form for participation in the 'CaregiVR' study

Please read the following information carefully.

I, Tanveer Singh Mahendra of Computer and Information Science department is conducting today's study on behalf of The University of Konstanz's Human-Computer Interaction group. The research will being used to collect data for my master's thesis. The topic is concerned with the self-directed learning of ergonomic patient transfer in virtual reality.

As a participant in the session, I would like you to test a virtual reality system and provide me with feedback about it. The observations and information I collect today will help me with my research questions and will be used as part of my thesis work. If you have any questions, I encourage you to ask them.

The session will take approximately 60 minutes to complete. As your participation is entirely voluntary, you may choose to withdraw from the session at any time. Inform the co-ordinator immediately if you experience any discomfort during this study session. If you choose to withdraw from the study, your data will be excluded from the final analysis. This will not affect my study negatively.

Risk(s)

During this virtual reality study, you will not be able to see the real-world surrounding. This imposes the risk of potential physical injury if you stumble upon a wall or furniture in the experiment room. Measures have been taken for your physical security to minimize these kind of unexpected circumstances. However, neither I and nor the University of Konstanz takes any liability in case you injure yourself during this study.

Also, if you have any psychological condition which can get aggravated due to virtual reality experience I discourage you from participating in this study. Please inform so to the co-ordinator.

Your privacy, observers & recording of data

Please be assured that the information and opinions you provide today will be used only for research purposes.

I will record information while you interact within the virtual reality environment (including on videotape, audiotape, demographics, and feedback questionnaires). For any and all uses of this recorded data, I would take extreme care to pseudonymize the data. Your name will appear only on this form, which will be filed separately, and is kept only to verify your consent to participation in this session. The data recorded may be used for:

- Aggregation of data for trend analysis and documentation purposes
- Teaching or training purposes by researchers(of this or other institutes)
- Publishing or presenting in scientific publications, web pages, videos, and meetings

In future, you could request the deletion of this data. However, if your data have already been used as a contribution of the documented research until the time of your contact, the results can no longer be deleted.

Non-disclosure

By participating in this session, you may be privy to information that I regard as confidential - such as contents of the VR system, communication happened during using the system. You must not at any time after the session disclose to any other participant either directly or indirectly for any purpose.

If you have read the above information carefully and understand and consent to its contents, please complete and sign the following statement.

I, ____

(Participant's Name)

have read the above information form carefully and understand its contents. I had sufficient time to inform myself about the study and was able to ask any questions. I voluntarily agree to participate in this study conducted by student(s) at the University of Konstanz.

______________________________	______________
(Participant's Initials/Signature)	(Date)
______________________________	______________
(Researcher's Signature)	(Date)

If you have further queries you can contact me at

tanveer-singh.mahendra@uni-konstanz.de

____

(Participant ID)

B.4. Demographics questionnaire

Demographics questionnaire

Participant ID ________

1. What is your gender?
   - ☐ Male
   - ☐ Female
   - ☐ Diverse

2. What is your age?

   Answer:_________

3. Do you have any restrictions in the ability to move?

   Answer:

4. Are you visually impaired (for ex. colour blindness, short-sightedness, far-sightedness)?

   Answer:

5. Which semester of nursing-care education are you in

   Answer: _________

6. Have you ever had a virtual reality experience before?

☐ Yes
☐ No

If yes, please elaborate on your experience:

7. Do you have any previous experiences with digital learning/training tools?

☐ Yes
☐ No

If yes, please elaborate on your experience:

B.5. Task information sheet

Information sheet for the scenario task

This training system is now to be tested by you. This VR training session is divided into two phases:

Conduct a virtual patient transfer with concurrent feedback

Watch the replay of your own movements as terminal feedback

Phase 1: Concurrent feedback

During this training phase, your task is to shift a virtual patient from a laying position in the bed to a seating position in an ergonomic fashion. Instead of a freely flowing movement, the movement is divided into 5 steps. In VR, you will see a patient laying on the bed with pink highlight overlay. Also, in your view you'll see a blue avatar which highlight different body parts to inform you if you're making movements in a non-ergonomic fashion. To assist with the training, you will hear verbal instructions describing what needs to be done. Each step requires you to position the virtual patient similar to the pink overlay so as to successfully complete a step. On a successful overlap, the virtual patient will move into the next position. Your task is to follow the instructions as closely as possible. Make sure that you perform these movements ergonomically by keeping an eye on the avatar highlights. Once all the steps are completed, you have successfully completed the transfer. However, you have the ability to re-train all the movements or certain movements again. It's up to you to decide how much you want to train. On satisfaction, please inform the co-ordinator to start with the next phase.

Phase 2: Terminal feedback

During this phase, you'll be able to see a virtual human that looks like you replaying all the movements that you have performed. Also, in the environment, you'll see a video player that will be shown which highlights the errors you have made on a timeline.

You're allowed to move freely during this phase and observe your movements in 3D virtual environment from different angles. You also have the ability to play or pause the movement replay by simply saying the keywords 'Play' and 'Pause' to the system. The system has an integrated command recognition and would respond to your verbal command.

B.6. User experience questionnaire

Please make your evaluation now.

For the assessment of the product, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Example:

attractive	○	⊗	○	○	○	○	○	unattractive

This response would mean that you rate the application as more attractive than unattractive.

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression.

Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.

It is your personal opinion that counts. Please remember: there is no wrong or right answer!

Please assess the product now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

B.7. System evaluation questionnaire

System evaluation questionnaire

Participant ID ________

1. How helpful was the concurrent feedback provided while performing the patient transfer movements?

☐ ☐ ☐ ☐ ☐

Not helpful at all — Very helpful

2. How helpful was the terminal feedback provided as a recording after performing the patient transfer?

☐ ☐ ☐ ☐ ☐

Not helpful at all — Very helpful

3. To what extent is the feedback provided by the CaregiVR system comparable to an actual expert?

☐ ☐ ☐ ☐ ☐

Not at all — Very much

4. Could the CaregiVR system help you to improve the inaccuracies in your movements in daily work?

☐ ☐ ☐ ☐ ☐

Not helpful at all — Very helpful

5. To what extent would you consider an integration of CaregiVR system in conventional practical training methods as desirable?

☐ ☐ ☐ ☐ ☐

In no case — In any case

6. To what extent did the CaregiVR system support you with self-directed training of patient transfers?

☐ ☐ ☐ ☐ ☐

Not at all ... Very helpful

7. To what extent did the feedback mechanisms help you overall to correctly understand the ergonomics associated with properly transferring a patient?

☐ ☐ ☐ ☐ ☐

Not at all ... Very much

8. To what extent did the CaregiVR system help you to increase your understanding of transferring patients ergonomically?

☐ ☐ ☐ ☐ ☐

Not at all ... Very much

C. Content of flash drive

The attached flash drive contains:

1. Digital version of the thesis
2. Documents of the user study
3. Digital version of the project report