Egocentric Motion Guidance in Mixed Reality

A comparison of visualizations guiding bilateral arm movements

Master thesis

by

Rebecca Weber

at the

Universität Konstanz

Department of Computer and Information Science

1. Evaluated by Professor Dr. Harald Reiterer

2. Evaluated by Professor Dr. Falk Schreiber

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SELBSTSTÄNDIGKEITSERKLÄRUNG

Ich versichere hiermit, dass ich die anliegende Arbeit mit dem Thema:

„Egozentrische Anleitung in Mixed Reality –
Ein Vergleich von Visualisierungen zur Anleitung von beidseitigen Armbewegungen“
“Egocentric Guidance in Mixed Reality –
A comparison of visualizations guiding bilateral arm movements”

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Konstanz, 17. September 2018

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Rebecca Weber

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ABSTRACT

Support through motion guidance is important for many fields in which conscious motor learning takes place. Traditional ways to learn a movement can be broadened by systems which make use of current Mixed Reality technologies. They enable motion guidance from an egocentric perspective.

This thesis presents an egocentric motion guidance system in which different visualizations have been implemented to guide the user's bilateral arm movements from an egocentric perspective. The visualizations differ in their appearance as well as in the way the movement is visualized. In a study, these different visualizations are compared with respect to their effect on performance and user experience and preference.

The results of the study showed only few statistically significant differences between the movement visualizations which do not produce a profound outcome. This might be caused by several aspects influencing the measurements, e.g., the selection of movement tasks. However, results showed a statistically significant difference between the different ways of appearance indicating that realistic looking visualizations result in a better performance of the movement with guidance as well as in the repetition of the movement without guidance.

ZUSAMMENFASSUNG

Für viele Bereiche, in denen bewusstes motorisches Lernen stattfindet, ist die Unterstützung durch Bewegungsanleitung wichtig. Herkömmliche Wege, eine Bewegung zu erlernen, können durch Systeme erweitert werden, die aktuelle Mixed Reality Technologien nutzen. Sie ermöglichen eine Bewegungsanleitung aus einer egozentrischen Perspektive.

Diese Arbeit stellt ein System für egozentrische Bewegungsanleitung vor, in dem verschiedene Visualisierungen zur Anleitung von bilateralen Armbewegungen des Nutzers aus der egozentrischen Perspektive implementiert wurden. Die Visualisierungen unterscheiden sich sowohl in ihrem Aussehen als auch in der Art, wie die Bewegung visualisiert wird. In einer Studie werden diese verschiedenen Visualisierungen hinsichtlich ihrer Auswirkung auf die Ausführung und auf User Experience und Nutzerpräferenz verglichen.

Die Ergebnisse der Studie zeigten nur wenige statistisch signifikante Unterschiede zwischen den Bewegungsvisualisierungen, die kein umfassendes Ergebnis liefern. Eine Ursache hierfür können verschiedene Aspekte sein, die die Messungen beeinflussen, z. B. die Auswahl von Bewegungsaufgaben. Die Ergebnisse zeigten jedoch einen statistisch signifikanten Unterschied zwischen den Varianten bezüglich des Aussehens, welche darauf hindeuten, dass realistisch aussehende Visualisierungen zu einer besseren Ausführung der Bewegung mit Anleitung sowie bei einer Wiederholung der Bewegung ohne Anleitung führen.

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1 INTRODUCTION

From the first day of our lives, motor learning is something that affects all of us. It happens subconsciously, e.g., when we learn how to grasp an object or how to walk, but also consciously through repeated practice until it becomes subconscious. The latter can be observed during activities such as exercising a sequence of movements for sport, regaining motor skills after injuries, learning how to play an instrument or how to write.

The active, conscious learning of motion is often guided by another person like a teacher, coach, therapist or similar. They have the relevant expertise regarding the type of movement. Furthermore, they can provide personalized feedback and are available to answer individual questions as well. But, of course, their availability is limited by time or money. In addition to being guided by another person, it is possible to learn independently with the help of media such as videos, pictures, textual descriptions and other forms of media. However, in many cases, these ways to learn and exercise movements will complement and not replace the consultation of a teacher.

Today's technology enables new ways of supporting motor learning. In the last decade, gaming consoles and their respective accessories like Microsoft Xbox[1] with the Kinect[2] sensor, Nintendo Wii[3] / Wii U[4] with its controllers and other sensors, e.g. a balance board, or Sony PlayStation[5] and the PlayStation Move-Motion-Controller[6] came onto the market. These systems use motion-based interaction for

[1] https://www.xbox.com/ (Accessed: September 14, 2018)

[2] https://developer.microsoft.com/de-de/windows/kinect (Accessed: September 14, 2018)

[3] https://de.wikipedia.org/wiki/Wii (Accessed: September 14, 2018)

[4] https://www.nintendo.de/Wii-U/Wii-U-344102.html (Accessed: September 14, 2018)

[5] https://www.playstation.com/de-de/ (Accessed: September 14, 2018)

[6] https://www.playstation.com/de-de/explore/accessories/playstation-move-motion-controller/ (Accessed: September 14, 2018)

games but also for more “serious” purposes such as fitness applications or tai chi courses.

In fact, all of these applications of motion guidance have in common that they require a certain cognitive effort to transfer visual, textual or audible instructions to one’s own body movements.

Egocentric guidance (i.e., from the learner’s own perspective) can constitute a new form of supporting motor learning, especially, in situations where students want to exercise independently. Moreover, with egocentric guidance, it is possible to present visualizations guiding the student in an “on-body” or superimposed manner, so they become embodied in the learner. Hence, the student’s sense of presence while learning a movement might be increased (Sodhi et al. 2012).

Especially, Mixed Reality (MR) and Motion Capture (MoCap) technologies facilitate the creation of egocentric guidance systems.

1.1 Motivation

In the literature, there are different computer-based guidance systems implementing egocentric guidance, guidance through MR or mirror-like setups for motion guidance which will presented in detail in section 2.2.

Besides the point of view and the used technology, they differ in the way the guidance is visualized or how the movement is displayed in terms of pace. Furthermore, the field of application and the following type of movement as well as the guided and captured body parts are different.

However, most of the systems realizing an egocentric perspective implement one way of visualizing the guidance instructions which is then compared to conventional or other, exocentric ways of learning the movement. Therefore, the question arises in which way egocentric guidance should be presented to the user, what it should look like and how the movement can be visualized. With this in mind, it is necessary to compare different visualization techniques which provide motion guidance from an egocentric perspective. As a result, the overall goal of this thesis is to examine how different visualizations affect egocentric motion guidance.

In the associated Master-project, a system that allows guidance of different movements through different visualizations from an egocentric perspective has been developed. The scope of the project has been limited to the guidance of bilateral arm movements. The system is designed as a study prototype where the user's only task is to follow the given guidance and the remaining parts of the system are controlled by an expert, the director of a study. Based on this system, a study will be conducted which tries to answer the previously mentioned questions.

To facilitate an egocentric perspective, MR technology is used. Compared to conventional 2D displays, a stereoscopic 3-dimensional view, enabled through a MR headset, is able to provide more information on the movement and its directions in 3D space (Han et al. 2016). Further, the user's motion is tracked with a MoCap system which allows to record the motion data and to transfer it to a virtual environment in real time.

1.2 Outline

This section briefly outlines the present thesis.

The following chapter provides background information. First, it defines the scope of the motion guidance system and its evaluation. Second, it discusses related work with regard to several aspects which have been identified as relevant characteristic of motion guidance systems and leads to the specific research questions. Chapter 3 presents the egocentric motion guidance system which has been developed in the course of the associated Master-project. It provides an overview of the implementation which has been done in the previous work before elaborating on additions and changes which lead to the final study prototype. After the system has been presented, the subsequent chapter focuses on the study. It elaborates on the study design and presents the results of the study. In the discussion in chapter 5, the results are discussed with regard to the research questions and limitations of the study are emphasized. The final chapter concludes the thesis and gives an outlook on future research.

2 BACKGROUND

In this chapter, first, important terms are explained and define the scope. Then, the context and the specific research questions will be elaborated by reviewing related work.

2.1 Definition of Scope

Several terms which will be used throughout this thesis or are relevant to inform the context will be specified and allow a classification of present work.

2.1.1 Mixed Reality

In this section, the term MR will be defined and set in relation to other common terms such as Augmented Reality (AR) or Virtual Reality (VR).

The "Reality-virtuality (RV) continuum" which is illustrated in Figure 1 has been developed by Milgram et al. (1994). In this continuum, two extremes are opposed to each other: the real environment which is limited by the laws of physics and the virtual environment (also referred to as VR) which is completely relying on virtual elements with or without physical limitations of space or time. Systems which contain elements of both extremes, thus cannot solely be assigned to the one or the other, are classified as MR.

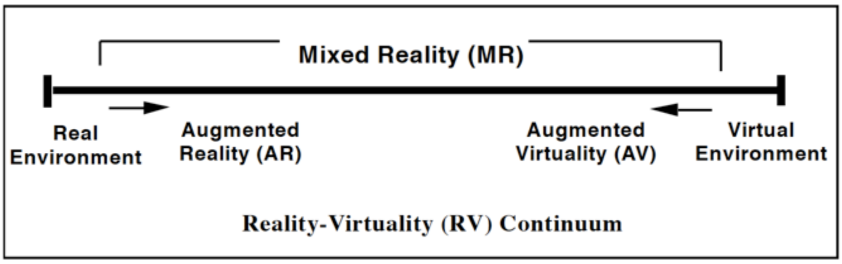


Figure 1: Representation of the Reality-Virtuality Continuum (Milgram et al. 1994, p.283)

Within MR it can be differentiated between AR and Augmented Virtuality (AV). AR describes a mainly real environment which is augmented with virtual elements. Whereas an AV is a mainly virtual environment which draws on a certain number of real elements.

Implementing the system for egocentric motion guidance in an AR environment means that the user can see their real body and the view is augmented with a virtual visualization for guidance. In an AV environment, for example, the user experiences a virtual world with virtual guidance including a virtual representation of their own body. However, their movements are controlled by the user's real world movements. The Master-project has been developed as an AV system because the current AR technology does not suffice. The field of view (FOV) of the available optical see-through AR headsets is rather small, so it cannot cover the whole movement. Video see-through solutions still have an offset. If not calibrated correctly, the offset between projected and real body parts is irritating.

2.1.2 Egocentric Perspective

This section explains the term egocentric perspective and compares it to other perspectives of displays. Figure 2 illustrates these perspectives on a continuum of egocentric and exocentric viewpoints.

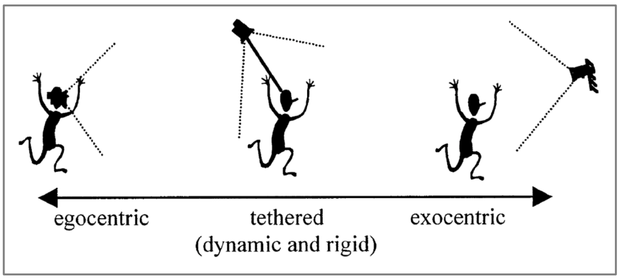


Figure 2: Continuum of egocentric to exocentric viewpoints (Wang and Milgram 2001, p. 1863)

When looking at a display, an egocentric perspective means that the observer views the displayed image from their own first-person viewpoint, as they are used to in the real world. The virtual camera is placed at a position as it were at the position of the observer's eyes. In Figure 2, the egocentric perspective is depicted on the left-hand side. In contrast to the egocentric perspective, the exocentric one is detached from the avatar (see right-hand side in Figure 2). It is like a bird's eye view on the whole or parts of the scenery and does not change when the avatar moves. Between the egocentric and the exocentric perspective, there is the tethered viewpoint. It describes a camera position above/behind an avatar which is moving in conjunction with it. Therefore, the direction is the same as for the egocentric viewpoint but there is more information visible, thus providing more overview. (Wang & Milgram 2001)

This thesis and the associated Master-project have been clearly restricted to examine an egocentric perspective for motion guidance. Yet, relevant literature addresses other viewpoints as well.

2.1.3 Motor Learning

Motor learning describes how humans acquire the performance of movements, so that they eventually develop an automatism to execute the specific movement.

The ways of motor learning can be very different depending on the movement, the situation, the goal, etc. Motor learning is separated into implicit and explicit learning where the former describes unconscious learning and the latter the conscious remembering of motion sequences. Implicit learning comprises the development of motor skills which are needed to live and manage everyday life, since every action is actually based on motion e.g. walking, grasping, eating, speaking, etc. Conscious, explicit learning refers to learning and repeatedly improving motion sequences for activities like a specific type of sport or playing an instrument.(Halsband & Lange 2006; Halsband 2006)

The process of motor learning can according to Halsband (2006) and Halsband & Lange (2006) be differentiated in three stages. The first stage is the initial stage in which the movement is performed slowly, in varying speed and by trial and error. The feedback of the sensory-motor system is relevant in the first stage and becomes less important in the following intermediate stage. Here, the performance of the movement becomes more and more stable and faster. At last, the advanced stage involves fast, fluent and automated performances.

The egocentric motion guidance system and its visualizations which are going to be compared in this thesis address the initial stage of motor learning. The scope is especially restricted to bilateral arm movements. Many movements are bilateral; yet, they are hardly approached in related work.

2.2 Related Work

This subchapter presents related work dealing with egocentric guidance, computer-based guidance, guidance in MR or similar. It links the related systems thematically and, finally, leads to the specific research questions of this thesis.

2.2.1 Appearance of Guiding Visualization

An important aspect of motion guidance systems is the way the guidance is visualized. This can be done in very different ways and also depends on the used technology or the type of movement. Researching related literature, one main difference in the appearance of the guiding visualization has been identified. The visualization can either have a realistic or an abstract appearance. This difference will be explained in more detail by reference to the related systems.

Realistic. The following figures show realistic looking visualizations of related systems. The avatars are realistic to the effect that they are humanoid. In other words, they are based on humans in shape, proportions, and motion patterns. The two tai chi coaching systems shown in Figure 3 and Figure 4 use virtual avatars as teachers which are placed in front of or surrounding the user either in an AR or VR environment. In both systems, the number of virtual teachers can vary so that the more teachers are displayed the more perspectives the learner has.

Figure 3: My Tai-Chi Coaches: virtual avatars as teachers in AR (Han et al. 2017)

Figure 4: Tai chi training in VR; left: student in real world, right: virtual avatars of student (white shirt) and teacher (black shirt) (Chua et al. 2003)

The system by Chua et al. (2003) also has two other options where a wireframe teacher is superimposed on the student(s). This approach is similar to the system AR-Arm (Han et al. 2016) depicted in Figure 5. The superimposed virtual representations draw on a ghost metaphor which is also described in Yang & Kim (2002) who implemented the system Just Follow Me. Another system using this approach is a guitar training system which supports the learner with virtual fingers showing the finger positions for different chords (Motokawa & Saito 2007).

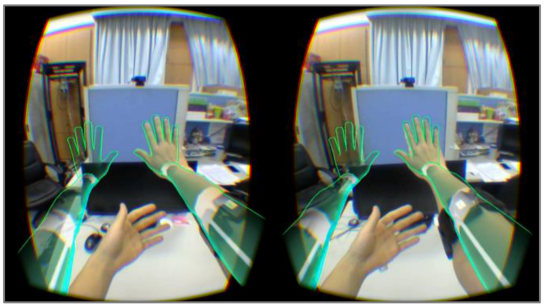


Figure 5: AR-Arm: semitransparent arms as guiding visualization in AR (Han et al. 2016)

Sticking to reality still more than with humanoid avatars is done with the use of images in OutsideMe (Yan et al. 2015). This AR-system allows self-practicing by observing themselves or practicing together with the pre-recorded image of a teacher (as in Figure 7) or dancing partner. The user sees these images from an exocentric perspective.

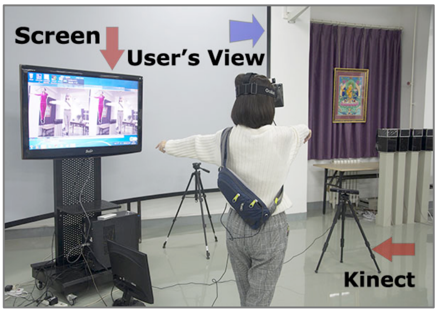


Figure 6: OutsideMe: Setting of cameras and displays (Yan et al. 2015)

Figure 7: OutsideMe: Images of a leading dancer and the student itself from the student's view in AR (Yan et al. 2015)

Abstract. In contrast, the visualizations referred to as abstract are based on stick-figures, arrows, or other shapes to indicate a direction or position. Sodhi et al. (2012) developed a system where different guiding hints are projected onto the user's hand. They compared several different visualizations from the 2D Follow Spot (see Figure 8) to the more complex 3D Pathlet (see Figure 9) and video. They found that participants could follow the projected hints more accurately than the video. The Follow Spot, for example, indicates directions through the movement of the spot itself combined with its size and an arrow for moving up or down. The 3D Pathlet indicates the next segment of the movement path where the third dimension is illustrated by a shadow.

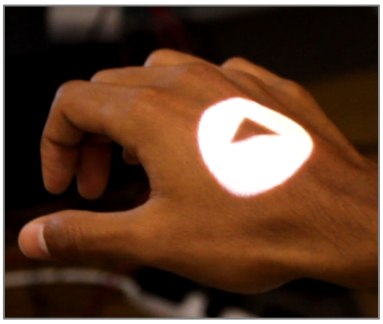


Figure 8: LightGuide: Follow Spot projected onto the user's hand (Sodhi et al. 2012)

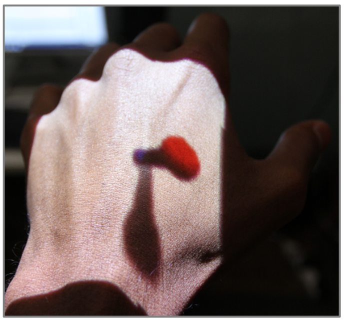


Figure 9: LightGuide: 3D Pathlet projected onto the user's hand (Sodhi et al. 2012)

A conceptually similar approach is implemented by Tang et al. (2014) in the system Physio@Home. The guiding visualizations used here were supposed to be “easy and quick to interpret” (Tang et al. 2014, p. 1653). They developed 2D and 3D versions of guiding visualizations for their mirror-like screen setup. The 3D arrow illustrated in Figure 10 focuses on directing the hand position similar to the LightGuide system described previously, whereas the 3D traces in Figure 11 represent and guide the forearm. Their informal evaluations revealed positive feedback on the simplicity of the visualizations. However, the visualization of depth information is complex for a mirror-like 2D display. Another interesting visualization for arm movement is implemented in the projection-based AR system SleeveAR (Sousa et al. 2016). They point out that the increased projection area (arm and floor, see Figure 12) compared to LightGuide improves the user’s awareness. Nonetheless, the approaches just presented would become more complex if both arms should be guided.

Figure 10: Physio@Home: 3D arrow in a mirror-like display (Tang et al. 2014)

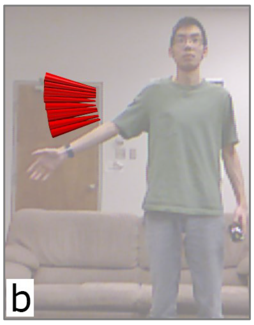


Figure 11: Physio@Home: 3D traces in a mirror-like display (Tang et al. 2014)

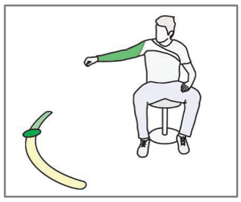


Figure 12: SleeveAR: projection-based arm guidance (Sousa et al. 2016)

So, for bilateral arm movements the following two related systems might be more suitable since they both guide the full body. YouMove (Anderson et al. 2013) is an AR mirror showing a pose or movement represented by a stick-figure (see Figure 13). This stick-figure is then overlaying the user’s mirror image. Green cues highlighted in Figure 13 are added when guiding a movement. Still, depth information is also hard to convey with this approach. The system Onebody is an egocentric VR remote training tool relying on a stick-figure model as well. It has been evaluated against other remote guidance systems and video. However, it has only been used for posture guidance, so there are no findings about using this approach for motion guidance.

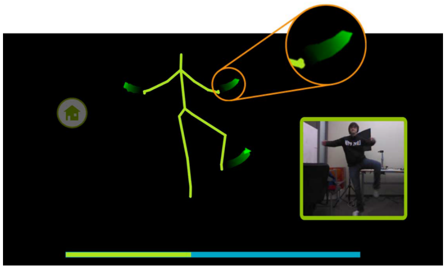


Figure 13: YouMove: stick-figure as guide in an AR mirror setup (Anderson et al. 2013)

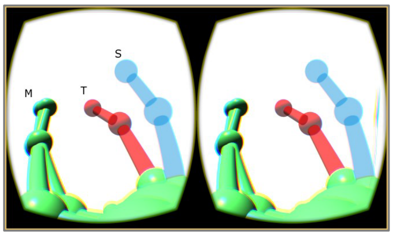


Figure 14: Onebody: VR stick-figures as representation of the user and a superimposed teacher (Hoang et al. 2016)

Conclusion. Various ways of designing the visual appearance to guide a movement have been found in the literature. They could be categorized as either appearing 'realistic' or 'abstract'. Yet, there is no system implementing both approaches and comparing them with each other. Therefore, an answer to the question what type of appearance works better for motion guidance might potentially convey valuable insights for the design of guiding visualizations.

2.2.2 Visualization of Movement

Another important aspect is the way the movement is visualized in terms of pace or continuity. The reviewed systems revealed different ways of implementing the visualization of movement which are presented in the following.

Continuous at given pace. Most of the related systems show the motion sequence to which the learner is guided as a naturally continuous movement at a defined pace. This approach is very intuitive since it is based on traditional ways to learn a movement, e.g. learning through imitation.

In the AR tai chi training systems AR-Arm (Han et al. 2016) and My Tai-Chi coaches (Han et al. 2017) and the VR tai chi training system by Chua et al. (2003), the virtual coaches perform the movement and the user's task is to follow this movement, whether observing it from an egocentric or an exocentric perspective. Likewise, LightGuide (Sodhi et al. 2012) and the older system Just Follow Me (Yang & Kim 2002) draw on this approach by letting the user follow the projected guiding visualization or the virtual ghost object, respectively.

In comparison, the SleeveAR system supporting physio therapy (Sousa et al. 2016) uses a recorded motion sequence of the teacher, here a therapist, as guide which the patient has to follow. However, the focus is not on timing but on performing the movement as correct as possible as it is providing feedback in great detail.

At last, the dancing system OutsideMe (Yan et al. 2015) has a similar concept to the previously mentioned systems. Here, in the mode of training with a virtual leading dancer, the speed of the pre-recorded movement can be configured before starting the exercise. The movement is then shown continuously at the given speed. When using another practicing, mode in which the user can practice the sequence together with another dancer displayed in the AR view, the speed is determined by the previously recorded sequence of the other dancer. In addition, they provide a self-practicing mode which lets the user observe their external self-projection from an exocentric perspective, which leads to the next way of movement visualization.

Self-paced. As mentioned above, OutsideMe has a self-practicing mode where users observe themselves, thus determining the tempo on their own. As a matter of fact, this mode cannot really be considered as providing guidance, it is rather a change of perspective.

Nonetheless, relying on the user's own pace is also implemented in other systems. For Physio@Home (Tang et al. 2014), it is a main aspect of the design scope to let the user determine their own pace to execute the movement. The guiding visualizations were particularly designed to allow this "self-pacing" as they always radiate from the actual hand / arm position. The authors identified this feature as being specifically relevant for the application in physio therapy since patients should perform the movements individually depending on their injuries or physical complaints.

Further, the LightGuide system (Sodhi et al. 2012) which is presenting several different guiding visualizations also has a condition in which the pace is not imposed by the system.

Discontinuous or combined. In contrast, to the previously presented ways of visualizing the movement, the system Onebody (Hoang et al. 2016) only guides and gives feedback to specific postures. They are detected as being held correctly with a threshold of 5 cm. As well, the guitar playing system (Motokawa & Saito 2007) seems to show only positions of fingers for the chords and no continuous, fluent motion sequence.

The implementation of YouMove (Anderson et al. 2013) combines discontinuous and continuous ways of motion guidance. The AR mirror training system for motion sequences is separated into stages addressing the different stages of motor learning. In the first stage, the motion sequence is demonstrated and the user only observes it to get an idea of the whole motion sequence. In the next stage, the user is guided to perform the motion sequence. However, the sequence pauses at predefined "keyframes" until the user holds this posture for a specific time and then continues playing. Anderson et al. (2013) define keyframes as "postures within the movement that are particularly important for a trainee to match during the movement". After the posture guide, there is the movement guide which shows the movement in real-time without interruption. The final stage does not provide visual guidance any more but the user is supposed to perform the movement on their own while observing themselves in the mirror. The system leads through the learning process following a gamified approach since the user receives scores and has to unlock one stage after another.

Conclusion. The different implementations play the motion sequences in various ways. The movement can be visualized either continuously or discontinuously, i.e. stepwise. Also, the pace at which the movement is shown plays a role. It can be determined by the system or it allows the user to execute the movement at their own pace. Yet, especially in regards to egocentric guidance, it has not been examined which way leads to a better performance or learning effect.

2.2.3 Application Fields and Body Parts

As mentioned right in the beginning of this thesis, the situations in which (conscious) motor learning happens are very diverse. Related work addresses different fields of application and parts of the human body. They are briefly elaborated by reference to related systems for motion guidance in the following section.

Tai chi & mostly full body movements. Several related systems are used to support tai chi training. Traditional tai chi movements involve the whole body and are executed slowly. They are usually taught in a group with one teacher standing in front of the students.

My Tai-Chi coaches (Han et al. 2017) shows full body movements which the user can observe with the aid of several virtual avatars placed around the user on an AR display. A similar setup is obtained in the VR training system by Chua et al. (2003). Here as well, several virtual avatars placed around the user perform full body tai chi movements. The only difference is that the environment is completely virtual including a virtual representation of the user.

The last tai chi training system is AR-Arm (Han et al. 2016) which, in contrast to the previously mentioned, implements egocentric guidance and only guides arm movements which are related to or part of tai chi forms. Onebody is an egocentric guidance system showing full body postures inspired by martial arts as well.

Dancing & full body movements. Dancing is another domain where movements of all body parts are integrated and which is usually taught by a teacher in groups. At least, in all situations where a group of dancers wants to perform a choreography together, there will be a leading dancer demonstrating the moves.

OutsideMe (Yan et al. 2015) is specifically designed to support dancers. It is based on an exocentric view on an image of either only their own body or together with an additional leading or extra dancer displayed next to them. A video recording can be used after practicing to analyze their own performance.

Further, YouMove (Anderson et al. 2013) is another system to guide the full body. Its design is not specifically restricted to support dancing. However, due to the mirror setup it blends in well with traditional ways of rehearsing in dance classes. In an experiment evaluating the system, Ballet movements and abstract movements have been used as tasks.

Physio therapy & unilateral arm movements. In physio therapy, often a specific body part, a single joint or limb is in the focus of the performed movement to support a patient after injuries or other symptoms. Therefore, the motion guidance systems related to physio therapy are designed to guide the movement of one arm, i.e. a unilateral arm movement.

Physio@Home (Tang et al. 2014), as indicated by the name, is designed to support performing therapeutic exercises at home. In a preliminary study, abstract movements performed with one hand / arm, e.g., writing letters in the air, have been applied as task which are similar to therapeutic exercises for the arm / hand. Also, the system SleeveAR (Sousa et al. 2016) wants to support patients in physio therapy, thus providing guidance for one arm.

Miscellaneous & unilateral arm movements. In this final section, three other systems with different fields of application are summarized. They all guide movements of a single arm or hand.

The projection-based system LightGuide (Sodhi et al. 2012) is motivated by the general benefit of guidance systems for many application areas. In the conducted experiment, participants were asked to perform movements following geometric forms or letters in different angles. The focus was set on guiding the hand to follow a specific path, comparing several variants of the guiding visualization using a distance metric.

A completely different domain is addressed by Just Follow Me (Yang & Kim 2002). The idea behind this system is to support the user in training postures and movements while holding a brush to learn oriental calligraphy. Yet, the tasks of the conducted experiment relied on abstract movements and considered different numbers of degrees of freedom (2-, 3-, or 6-DOF).

Finally, often mentioned is the application of learning an instrument, such as the guitar playing support system by Motokawa & Saito (2007). In the AR screen view, virtual fingers show the chords along the guitar neck. This is a very specific scenario since it involves another object (guitar) with its own characteristics.

Conclusion. The majority of related systems applies them to activities which have the physical exercise as an intrinsic goal (dancing, tai chi) or are done to regain physical mobility (physio therapy). Systems incorporating movements which are done for the purpose of accomplishing a specific task are scarce (oriental calligraphy, guitar playing). One system exists only to explore projection-based egocentric guidance and is detached from specific applications. All these fields of application entail a focus on the guidance of single specific parts of the body or the full body not including bilateral arm movements. However, bilateral arm movements are important for many tasks, e.g., in the industry. Among the related system, only AR-Arm (Han et al. 2016) provides guidance for bilateral arm movements. This emphasizes the importance of examining guidance for bilateral arm movements.

2.2.4 Evaluation and Measures

The related systems have been evaluated to varying extents. With some of them, elaborate experiments were conducted, while others were evaluated qualitatively in short preliminary studies. This section describes their evaluations and their measures.

Preliminary or informal evaluation. Some of the related systems, which have already been presented in this chapter, have been evaluated only in preliminary studies or informal situations.

Han et al. (2016) wanted to receive feedback about AR-Arm and test if it has the desired effect and thus conducted a small preliminary study. Users were asked to use the system and perform several movements. Subsequently, they conducted an interview with a few questions about the experience with the system and its features.

The dancing system OutsideMe (Yan et al. 2015) has been evaluated in a preliminary study as well in order to assess the acceptance and scope of application. Several dancers were asked to use the system and answer a questionnaire afterwards. The questionnaire contained 5-point Likert-scales to receive feedback about the different modes. Participants were also asked to compare the experience with OutsideMe to their traditional way of training.

Physio@Home (Tang et al. 2014) has been designed in an iterative process in collaboration with physio therapists. Then, a preliminary study has been conducted with members of the research lab comparing the system to video guidance. They let their colleagues perform several arm movements with both conditions and asked them for feedback afterwards.

The guitar playing support system (Motokawa & Saito 2007) and My Tai-Chi coaches (Han et al. 2017) have been evaluated informally. They were both presented at a conference or exhibition in the form of live demos so that people could try the system and give feedback afterwards.

Experiments. Also, experiments with a complex study design in some cases were conducted to evaluate the developed guidance systems comprehensively. Several systems have been compared to the use of video guidance, a traditional way of learning a movement independently (Anderson et al. 2013; Sousa et al. 2016; Hoang et al. 2016; Sodhi et al. 2012). The studies' conditions of LightGuide (Sodhi et al. 2012) and Just Follow Me (Yang & Kim 2002) cover the different modes available in their respective implementations. In addition, most of the evaluations comprise qualitative feedback as well. Yet, they all involve at least one quantitative measure.

The dependent variable which has been used as a measure most often is the accuracy of the participant's performance of the motion sequence in comparison to the guide. However, the definition of accuracy is not trivial. Different measures of distance or deviation are used. To avoid order effects, conditions are counterbalanced or randomized.

Anderson et al. (2013) used the Root Mean Square Error (RMSE) of the positions of several joints to assess the user's performance. They rate the use of this measure as a limitation of their work, especially when defining it as a measure of learning. This is problematic when a movement is performed correctly although it is not matching the absolute positions movement path.

The evaluation of Onebody (Hoang et al. 2016) includes the measures of accuracy, task completion time and a subjective score given by a teacher. It is explicitly limited to assessing the user's performance and preference but not the effect on motor learning. The accuracy measure is based on angles between bone segments, comparing the user's values to the superimposed teacher's values. However, it only compares postures and not motion sequences.

LightGuide (Sodhi et al. 2012) is evaluated by assessing accuracy, measured in two parts, and timing. To measure accuracy, first, the Euclidian distance of the user's hand to the closest point on the target movement path is measured. Second, the similarity of the targeted and executed movement paths (their "shape") is analyzed using the Iterative Closes Point (ICP) algorithm (Zhang 1994). In addition, they conducted interviews to get feedback from the users. The findings let them come to the conclusion that the ICP algorithm is more representative to measure the accuracy achieved with their guiding visualizations than the raw unscaled Euclidean distance.

Chua et al. (2003) measure the error of the user's motion with regard to the teacher's motion. They calculate a relative (normalized) difference between bone ends and sum up these values of all limbs. For their calculation, they considered only the last four of the total twelve repetitions. Furthermore, a questionnaire was used to obtain some subjective feedback from the participants.

SleeveAR (Sousa et al. 2016) is assessed in regards to user preference and task performance. The former is achieved through Likert-scale questionnaires. The latter is measured making use of the Dynamic Time Warp algorithm (DTW) (Kruskal & Liberman 1983). The DTW generates a discrete measurement to determine the similarity of two sequences or time series that may vary in length. Therefore, the exact timing of the executed movement is not as important as for other distance measures.

The only experiment in which an attempt of measuring the learning effect was made is the one conducted with Just Follow Me (Yang &

Kim 2002). They asked participants to perform the task on one day and then repeat the learned movement on the following day without guidance. So, they were able to detect a potential difference in the effectivity of the respective conditions. As performance measure, they also used an algorithm, similar to DTW, to determine the similarity between two sequences. In addition, they developed a metric to assess the user's performance in matching the "timing and rhythm of the motion". Again, a questionnaire was handed out to receive subjective feedback.

Conclusion. The evaluations of the related systems, whether formal or informal, have one aspect in common: they always ask for the user's subjective feedback. Measuring the "learnability" through evaluating the retention of the movement without guidance is hardly done. The more complex experiments, that have been conducted, mostly focus on measuring the user's performance when using the system. Different measures have been introduced to assess the performance, e.g., various distance or similarity measures which are used to determine accuracy.

2.2.5 Resulting Research Questions

The previous sections outlined different aspects or features of related work in a thematic order. This information helps to formulate specific research questions supporting the overall goal of the thesis. The goal is to find out how different visualizations affect egocentric motion guidance.

The characteristics of visualizations guiding the user are separated into two aspects: the appearance of the guiding visualization (realistic or abstract) and the visualization of the movement (i.e., continuous or discontinuous, self-paced or not). Hence, these two aspects are defined as independent variables. Regarding the different visualizations' influence on the motion guidance two measures are of interest forming the dependent variables: the user's performance and the user's preference and experience. Consequently, the following research questions result:

RQ1: How do different guiding visualizations affect the performance of a guided motion sequence?

RQ2: How do different guiding visualizations affect the user experience and preference?

Moreover, it is interesting to observe how the different visualizations affect the ability to recall learned movements without guidance. Results potentially lead to indications about the learnability of the visualizations. However, this is not the focus of this thesis since it rather addresses the last stage of motor learning. Focusing on the evaluation of learnability would require a more complex longitudinal study design.

3 SYSTEM

This chapter explains the system for egocentric motion guidance used in the study. First, the associated Master-project's state of the system and the main aspects of its implementation will be outlined. In a second step, the changes made to the existing system in the course of the study preparation will be described and the resulting final prototype used to conduct the study will be presented.

3.1 Implementation

The goal of the system is to provide several visualizations which guide the user's bilateral arm movements from an egocentric perspective. Non-satisfying AR headsets, especially due to the small FOV, led to the decision to pursue an AV approach. Therefore, a MoCap system is necessary to transfer the user's real world motion data into the virtual environment as well as to record movements serving as guide. Finally, the user is supposed to see a guiding visualization for a certain movement and an avatar representing themselves in a virtual environment. The gender, the type of visualization and the type of movement can be controlled by the director of the study.

This section gives an overview of the components forming the system. Technical details about the implementation can be found in the report to the associated Master-project, which is available on the attached USB thumb drive.

The system has been developed with Unity[7], a game engine widely-used for current MR development. Several components shape the architecture of the system. The components and their relations are illustrated in Figure 15.

[7] https://unity3d.com/ (Accessed: September 14, 2018)

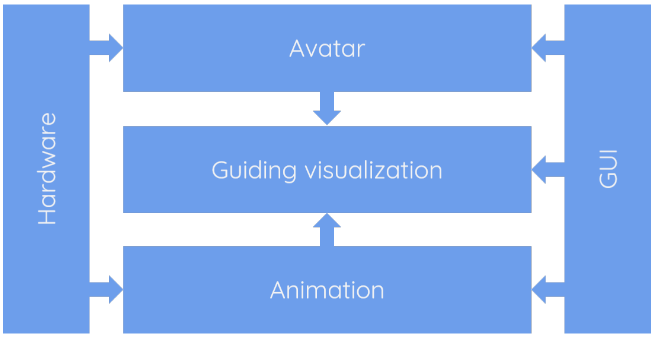


Figure 15: Overview of system components

Hardware. The hardware component comprises everything that relates to the MR headset and the MoCap system. At first, the mobile MoCap system Perception Neuron[8] by Noitom Ltd. which is based on inertial measurement units (IMUs) was planned to be used for the system. However, after extensive testing and unsatisfying tracking results due to its high sensitivity on magnetic interferences, the camera-based OptiTrack[9] system by NaturalPoint Inc. has been used for the further development of the system.

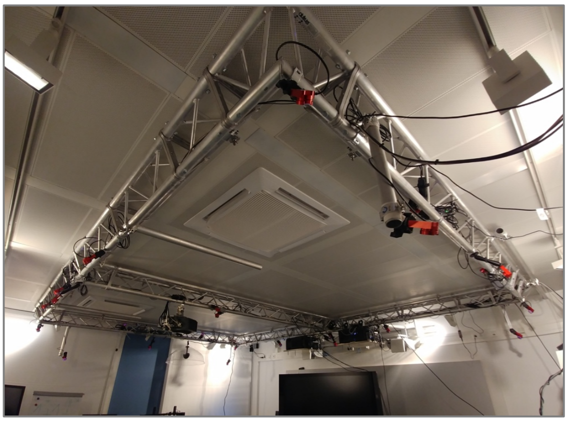


Figure 16: OptiTrack camera setup

Figure 17: OptiTrack full body suit and Oculus Rift headset

[8] https://www.noitom.com/solutions/perception-neuron (Accessed: September 14, 2018)

[9] http://optitrack.com/ (Accessed: September 14, 2018)

In the present configuration, 24 cameras (see Figure 16) capture the tracking volume inside which reflective markers are detected. . For full body tracking, the person to be captured has to wear a suit with reflective markers attached to it at predefined positions on the body, shown in Figure 17. Although admittedly lacking mobility caused by the complex camera setup, this system is much more accurate.

The most suitable head-mounted displays (HMDs) for the stereoscopic view on the guiding visualization in a virtual environment were the Oculus Rift[10] headset and the HTC Vive[11] (Pro[12]). Being supported by the software Motive, which is accompanying the OptiTrack system, the Oculus Rift head-mounted display (HMD) was used. Correspondingly, NaturalPoint Inc. provides a Unity plugin for the OptiTrack system that enables the motion data to be streamed to Unity in real-time. Also, the headset can be used with Unity. After having installed the Oculus runtime on the same computer, simply VR support has to be enabled in the Unity player settings.

For more information on the setup and calibration of the hardware devices refer to the technical report to the Master-project. With this setup, it is possible to record motion data and to stream real-time motion data to Unity.

Animation. The animation component is influenced by the animation component since the OptiTrack system has been applied to create the animations for the guidance in Unity. As movement tasks to be performed by the user, basic movements to conduct different musical meters (triple and quadruple meter) have been recorded with the Motive software. The recordings can be exported as FBX files which in turn can be used in Unity as an animation.

Avatar. Besides, the MoCap system also plays an important role within the avatar component. With a character system for Unity by

[10] https://www.oculus.com/rift/ (Accessed: September 14, 2018)

[11] https://www.vive.com/de/product/ (Accessed: September 14, 2018)

[12] https://www.vive.com/de/product/vive-pro-full-kit/ (Accessed: September 14, 2018)

Morph3D[13], which is available in the Unity Asset Store, a male and a female character have been added to the Unity scene. They represent the user's body in the virtual environment. Being a first-person avatar in VR, the heads should be removed from the character. Thus, their heads' materials have been replaced with a transparent material.

The Unity plugin for the OptiTrack system provides several scripts allowing to stream the captured motion data to Unity in real-time and map it to the avatar. The position of the camera, which determines what the user actually sees on the HMD, is also captured by the OptiTrack system. As mentioned in the paragraph about the hardware component, the Motive software supports the use of the Oculus Rift headset. Therefore, markers had to be attached to the headset and it is tracked as a rigid body object in Motive. The software features an HMD calibration tool which uses the data of the Oculus Rift to translate the pivot point of the rigid body object. This object's motion data is streamed to Unity as well. Its pivot point then determines the camera position.

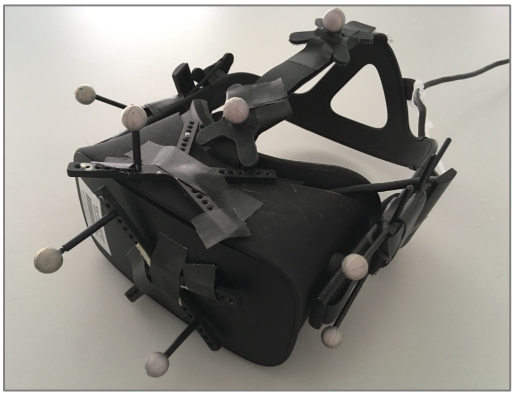


Figure 18: Oculus Rift headset with OptiTrack markers

Another important aspect which has been implemented to support the immersion in the avatar is the resizing functionality. Since the Morph3D character system allows to morph various different body

[13] https://assetstore.unity.com/publishers/13832 (Accessed: September 14, 2018)

parts directly from the Unity editor or via script, it is possible to change, e.g., the height or arm length of the avatar. Thus, to let the virtual avatar's body measurements approximate the real user's dimensions, a script has been written which adjusts the arm, torso, and leg length based on given measurements for these body parts.

Guiding visualization. The next component to be described is the guiding visualization. It is related to the avatar since it is subordinated to the avatar's hip and therefore always placed in front of the avatar. Moreover, its movements are controlled by the animations mentioned above.

Two different types of appearances for the guiding visualization have been created: an abstract and a realistic one, displayed in Figure 19 below.

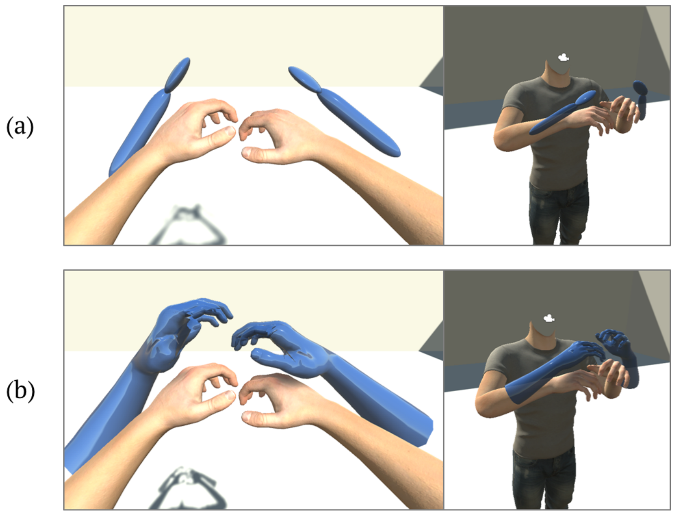


Figure 19: Appearance of guiding visualizations from egocentric (user's) and exocentric perspective; (a) abstract appearance, (b) realistic appearance.

The abstract visualization consists of standard 3D objects (capsule and sphere) with a transparent blue material representing the forearm and the palm which are attached to the related body parts of an invisible full body model. The realistic visualization has been created with the software Character Creator v2.3 for iClone. It is a full body rig with a mesh only showing the hands and forearms. The same transparent blue material has been applied to the mesh after having imported the model into Unity as an FBX file.

Another important aspect is the visualization of the movement which the guiding visualization is showing. Three different conditions have been developed. The first condition called “path” is showing the movement path in one piece in its given pace. Another condition referred to as “points” only shows some defined points along the movement path. The next point shows up as soon as the current point is reached by the user. The last condition is a combination of the previous two and therefore termed “points with path”. The next point along the movement path is shown and at the same time the segment of the path pausing at the point’s position. Again, as the user reaches this point, the next point and the next path segment are shown. In each case, the user can decide on their own when to start the guidance. There are two green indication points (“starting points”) for the left and right hand. Holding the two hands in this position at the same time will let the visualization start the guidance of the arm movement.

Graphical User Interface (GUI). Finally, to set all configurations as desired, there is a small GUI with several input options. The gender of the avatar can be set to either male or female and the body measurements for the leg, torso and arm length can be entered respectively. Further, it can be selected between the abstract and the realistic appearance of the visualization as well as between the three conditions for the visualizations of the movement. At last, the desired movement to be learned can be chosen.

Limitations. The system has technical limitations regarding the tracking. It can happen that markers of the OptiTrack system are not detected or matched properly so that the virtual avatar is showing a wrong, sometimes also unnatural, pose or the VR headset is slightly shifted. Usually, such errors only last for a few seconds. The tracking is further influenced by individual aspects such as calibration or the fit of the OptiTrack suit. Still, the OptiTrack system is precise and reliable compared to other tracking systems which have been considered. Another limitation is that there is no finger tracking which forces the avatar’s hands to stay in a fixed posture. Apart from these issues regarding the tracking, the virtual representation of the user is not perfect in regards to the appearance of the skin and the proportions. The resizing is only an approximation and not perfectly fitting all proportions.

3.2 Final Study Prototype

This section describes the final prototype used to conduct the study. Several changes and additions have been made to the system, from adding a logging script to the definition and implementation of tasks and the definition of the final appearance and movement visualization conditions. Finally, the procedure of using the system is described in short.

3.2.1 Logging

To be able to assess the user's performance with different visualizations, logging functionality has been added to the system, which will be described in the following.

The movements performed by the user as well as the movement of the guiding visualization are supposed to be logged, so that they can be compared later on. However, the full body models forming or underlying the realistic and abstract guiding visualizations respectively were different in their hierarchical structure of body parts. To make log data of both visualizations comparable, the underlying model of the abstract guiding visualization has been changed to the same model used for the realistic visualization. In fact, the realistic visualization has been copied, made invisible and the elements composing the abstract guiding visualization (capsule and sphere) have been attached to it as children of the respective body parts' objects (forearm and hand).

Then, a C# script has been added to handle log data generated within a session (the script *SessionLogHandler.cs* can be found under './Assets/Scripts/' inside the UnityProject on the attached USB thumb drive). It contains methods to create a directory for the session as well as directories for each task. Further, there is a method to write text to a session log file including a timestamp. This method is called at various events occurring during a session, e.g. when starting a task, pausing an animation, reaching a point, etc., to log the processes of a session. For the script to be executed, it is added as a component to an empty *GameObject* called “Session”.

The actual logging of the motion data is done in the script *Logger.cs* (also located under ‘./Assets/Scripts/’ inside the UnityProject on the attached USB thumb drive). The script needs to be added as a component to the *GameObject* desired to be logged. It has a variable to enter a name or identifier of the logged object. As soon as the script component is enabled, it creates a file path for the log file to be written containing a timestamp and the identifier. During runtime, as long as the script is enabled, the Update-Method, which is by definition called once per frame, is used to collect the data. A timestamp, position values (X, Y, Z) and rotation values (Euler angles X, Y, Z) of the respective *GameObject* are stored in an incrementally extending string. In short, there is one string variable containing all data log lines. This string is written to a text file using the created file path when disabling the component.

Some logic has been added to the main scripts controlling the task (*TaskManager.cs*) and animation of the guiding visualization (*AnimationHandler.cs*). A method “ToggleLogging” in the *TaskManager* script enables the log components on the start task event and disables them when the animation is stopped. The method takes two Boolean parameters: the first determining whether the motion data of the guiding visualization is supposed to be logged, and the second stating whether starting or stopping the logging. It iterates through the child objects of the avatar’s root object and, depending on the first parameter, the animation’s root object to find all *Logger* components. This way, all body parts having a *Logger* component are logged automatically. The option to exclude the logging of the motion data of the guiding visualization while still recording those of the avatar is used for a “recall task” where the user is asked to perform a movement without guidance (see section 3.2.3).

The *Logger* script is added to eight body parts, four on each side: middle finger, hand, forearm, elbow.

3.2.2 Guiding Visualizations

This section describes slight changes which have been made to the appearance of the visualizations. Further, it presents three types of movement visualizations to be compared in the study.

Appearance of visualization. The movement visualization "points with path" consists of two "hands" indicating a point on the movement path and two "hands" showing the continuous movement path segment until reaching the next point. Therefore, the user sees four hands in total. Feedback received in the context of the Master-project indicated that the two parts are hard to distinguish which might be irritating. Therefore, the representation of the points has been changed slightly. The blue material used for the guiding visualizations has been made more transparent for the points. In addition, an outline has been added to the points visualization. As a result, the two parts of the guiding visualization are set apart from each other and are more distinguishable. The result of these changes is depicted in Figure 20.

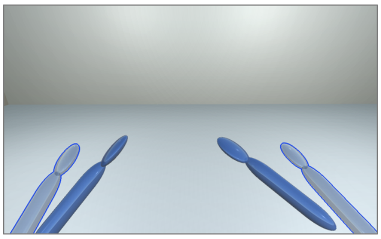
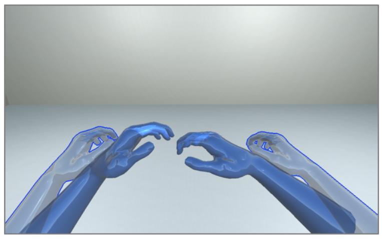
(a)  (b) 

Figure 20: Distinguishable „points" and „path" elements for the combined guiding visualization; (a) abstract, (b) realistic.

Movement visualization. Further, the final ways of visualizing the movement to be compared in the study have been developed. In section 2.2.2 on visualizations of movement in related work, different approaches to convey a motion sequence have been presented. They differentiate between continuous and discontinuous representations as well as guiding the motion sequence at a system-imposed or the user's own pace.

The three movement visualizations and their characteristics are shown in Table 1. The first characteristic "continuous" signifies whether the movement is shown continuously or discontinuously, e.g. as a sequence of static postures. The second characteristic referred to as “points” indicates whether the visualization contains an emphasis on important or logical points along the movement path dividing the path into path segments. The definition of these points can be different depending on the movement and the field of application. In YouMove (Anderson et al. 2013), “keyframes” were introduced as important postures to be matched by the user. For conducting music, a logical segmentation of the movement path is given by the beat. The last characteristic depicted in the table is describing whether the movement is performed in a self-paced manner or not, i.e. pace is given by the system.

	Continuous	Points	Self-paced
Path	X		
Points with path	X	X	
Points with path waiting	(X)	X	(X)

Table 1: Characteristics of the three different movement visualizations

The first movement visualization “path” shows the movement in a continuous way without pausing or highlighting important points on the movement path. Further, the movement is shown at a given pace. Figure 21 depicts a short motion sequence visualized as “path” exemplary with an abstract appearance.

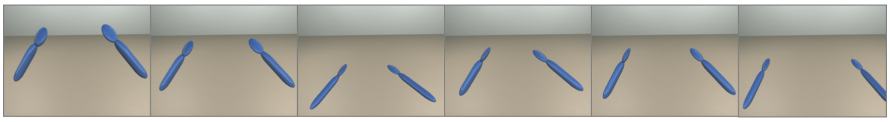


Figure 21: Motion sequence visualized as "path" with abstract appearance

“Points with path” is a second movement visualization which is continuous and system-paced as well. However, the path is segmented by the definition of important points. The upcoming point is shown and at the same time the continuous path segment is played (see Figure 22). As soon as the path reaches the defined point on the movement path, the upcoming point is displayed and the next path segment is shown automatically. This movement visualization is continuous and emphasizes the points on the movement path at the same time.

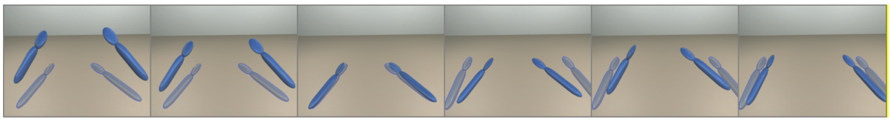


Figure 22: Motion sequence visualized as "points with path" with abstract appearance

The last movement visualization “points with path waiting” is quite similar to “points with path”. It also shows the upcoming point as well as the path at the same time. Notably, here the movement as a whole is not shown continuously but the path visualization stops when reaching the point. Only the path visualization of each segment in itself can be considered continuous. Therefore, the characteristic “continuous” only applies halfway. The next point is highlighted as soon as the user reaches the point with their avatar’s hands (Figure 23). This behavior makes the movement visualization self-paced to the degree that the user can determine when the next point shows up. However, the pace of the shown path segment is still given by the system.

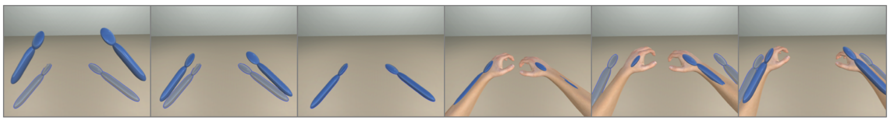


Figure 23: Motion sequence visualized as "points with path waiting" with abstract appearance

These three different movement visualizations address different aspects which can be found in the related work and might have a different effect on the user’s performance and experience while learning a movement. Still, they all convey information about the whole movement path.

3.2.3 Tasks

In this section, the selection and implementation of tasks is explained. This involves the selection of movement tasks to be learned with the guidance system in order to compare the different visualizations. Second, the implementation of a demo task and a task to recall the movement without guidance is described.

Movement tasks. As indicated in section 3.1, in the associated Master-project basic movements to conduct different musical meters were used for guidance. The movements suit well to guide bilateral arm movements since they can be performed within the HMD's FOV. As mentioned above, the beats which are illustrated by the movement form logical points along the movement path to be emphasized. The following figure shows typical schematic representations of movements for different meters. The illustrated path describes the movement of the right hand. The left hand is supposed to perform the same movement mirror-symmetrically at the same time. The respective beats are highlighted and labeled with numbers.

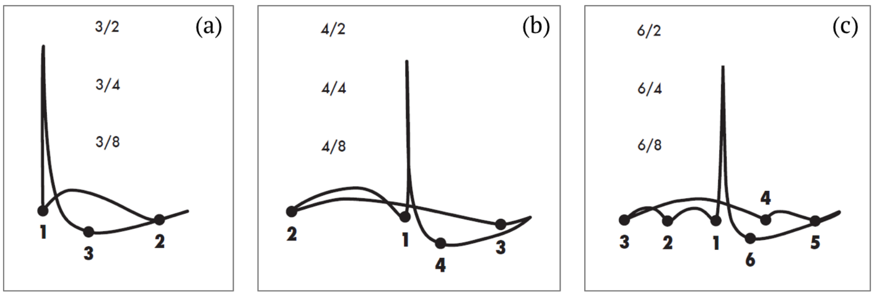


Figure 24: Illustration of basic movements for different meters[14]; (a) triple meter, (b) quadruple meter), (c) sextuple meter.

To avoid learning effects in the study, each guiding visualization has to be used with a different movement task. The three meters (triple, quadruple, and sextuple meter) shown in Figure 24, are used as tasks for the study. These basic movements are not too complex to be learned but not too easy as well; they still demand some cognitive effort. While having a similar structure, they are still different. Being able to perform one of them does not imply being able to perform another. This way, potential learning effects are tried to be avoided.

[14] https://www.cvnrw.de/fileadmin/user_upload/dokumente/d-massnahmen/D2-GrundkenntnisseDirigat.pdf (Accessed: September 14, 2018)

The triple and quadruple meters have already been recorded in the course of the Master-project. So, in addition, the sextuple task has been recorded with the OptiTrack system in preparation of the study. For all three recordings of the movements, one sequence has been extracted and is repeated 10 times after having started the guidance task.

Demo task. In addition, a movement for a demo task has been recorded. This demo task is supposed to let the participant get familiar with each guiding visualization before performing the actual task. During the demo task, the user can concentrate on the guiding visualization, understand how it works and has the opportunity to ask questions meanwhile or afterwards. The movement itself is subsidiary. An abstract movement has been chosen inspired, by the LightGuide system which has been presented in the related work (Sodhi et al. 2012). One of the abstract movements used with LightGuide was to follow a line back and forth, for example. The movement for the demo task is performed with both arms mirror-symmetrically just as the actual task. The movement is starting with both hands in front of the chest, then the arms are stretched out to the front and back again to the chest. Then, they are moved away from the body sideways, stretched out upwards, and finally, back again in front of the chest. This sequence is repeated 10 times as well. It covers several dimensions and ranges of motion. Proceeding with the actual task, the participant knows what to expect and can concentrate on learning the conducting movement.

Recall task. Besides the movement tasks with guidance, there is a "recall task" in which the participant is asked to perform the movement without guidance. An evaluation of the participant's performance of the learned movement without guidance can provide first indications about the learnability of movements with the different visualizations. In order to get comparable log data, the recall task needs to be performed in the virtual environment. A "start recall" and "stop recall" button have been added to the system's GUI, which is used for condition and task configurations. The "start recall" button serves to deactivate the guiding visualizations and set a Boolean variable in the *TaskManager* script to handle the animations and the logging accordingly. As for the other tasks, the green starting points appear in front of the user as well, allowing them to decide when to start performing the movement. This will trigger the "start task" event and initialize the logging. Only stopping the logging has to be done manually when the participant finished performing the movement.

3.2.4 Usage Procedure

This section gives a short overview on the necessary steps to use the system in a study. Figure 25 illustrates these steps and their iterations beginning from the outside.

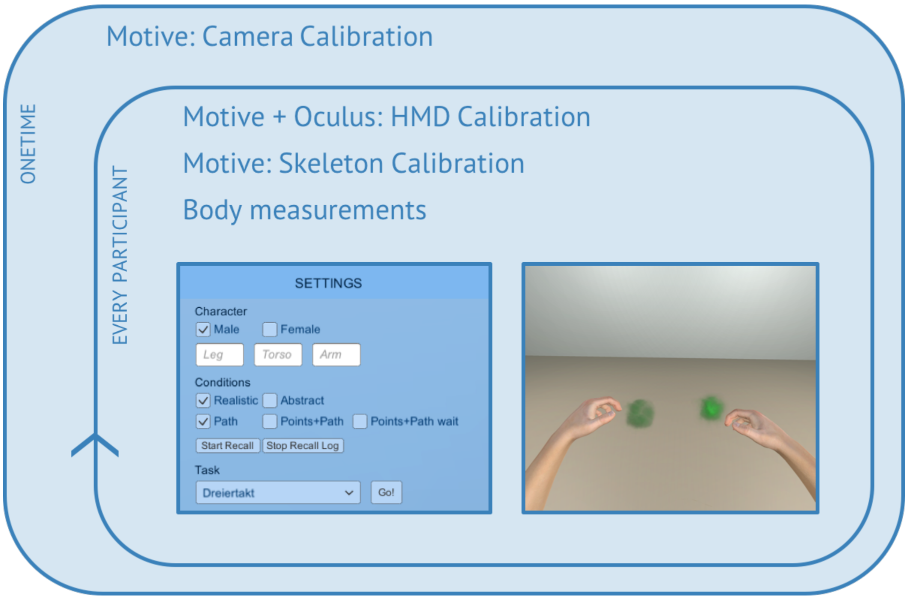


Figure 25: Usage steps of the system

Calibrating the capture volume of the OptiTrack system with its software Motive is the first (most outer) step which has to be completed to be able to use the tracking system. It has to be done only once, as long as the camera setup is not changed. All further steps have to be repeated for each participant. Still using the Motive software, the rigid body object for the Oculus Rift headset has to be created and calibrated with the HMD calibration tool. Moreover, also the full body tracking of the participant needs to be set up. To perform the calibration, the participant has to put on the OptiTrack full body suit and all necessary markers have to be attached at the right positions. Then, the skeleton can be calibrated in Motive. After having taken the relevant body measurements, finally, the Unity application can be started. Then, the director of the study has to use the GUI (see picture on the left-hand side in Figure 25) to select the gender, enter the measured values for the body parts and select the desired conditions for the visualization and the exercise. After the setup has been completed, the user can put on the Oculus Rift headset and will see the avatar from the egocentric perspective with the green starting points displayed in front of them (see picture on the right-hand side in Figure 25).

4 STUDY

As mentioned in the motivation of the present thesis (section 1.1), its goal is to learn how different visualizations affect egocentric motion guidance. Different aspects and characteristics of such visualizations have been identified in the related work. These led to the following specific research questions with regard to an egocentric motion guidance system for bilateral arm movements.

RQ1: How do different guiding visualizations affect the performance of a guided motion sequence?

RQ2: How do different guiding visualizations affect the user experience and preference?

The implementation of a system providing different visualizations for motion guidance addressing these aspects has been presented in chapter 3. The independent variables (IV) defining the guiding visualizations are the appearance of the visualization and the visualization of movement. The former has two levels: ABSTRACT and REALISTIC; the latter has three levels: path (P), points with path (PP), and points with path waiting (PPW). As tasks to examine the differences between the visualizations, movements to conduct musical meters have been selected (triple, quadruple, and sextuple meter). Besides the two research questions and their respective dependent variables (DV) *performance* and *user experience and preference*, the *learnability* of movements with the different visualizations is assessed on a very tentative level.

In the following, it will be elaborated on the study design. This involves the selection of participants, the experimental setting, the procedure and data collection methods, as well as the execution and results of a pilot study. Afterwards, the results of the study will be presented.

4.1 Study Design

In this section, different aspects from the selection of participants to data collection methods to be considered for the study design are explained.

4.1.1 Selection of Participants

There are not many restrictions regarding the characteristics of the participants in order to be allowed to take part in the study. Yet, since they are supposed to perform motion sequences with the arms and must be able to go through the calibration process of the OptiTrack system, they must not have any limitations regarding their range of motion. Additionally, they should have a good eyesight without glasses or be able to wear contact lenses during the study so that the VR headset can be worn without problems. Finally, an exclusion criterion is having good or excellent knowledge in conducting music. It will not be a problem, if a candidate plays an instrument, maybe even in an orchestra, or is part of a choir and thus is used to observe a conductor. However, being able to perform the movements to conduct different musical meters on their own would give them a crucial advantage in the performance of the task. Since the recruitment of participants will be done in German (via emails, flyers, social media, or personally), it is ensured that the participants have good German language skills.

4.1.2 Experimental setting

In order to examine the different guiding visualizations, a 2 x 3 factor split-plot design has been chosen. The visualization's appearance with two levels (ABSTRACT and REALISTIC) is the first IV considered between-subjects and the movement visualization with three levels (P, PP, and PPW) is the second IV considered within-subjects. This results in splitting the participants into two groups, one seeing only the realistic guiding visualizations and the other one seeing only the abstract guiding visualizations. In both groups, the remaining three conditions will be fully counterbalanced to avoid order effects. Additionally, to avoid learning effects, each condition will be performed with a different movement task. The three selected movements are combined with the three conditions of movement visualization following a Graeco-Latin square. Nonetheless, to keep the number of participants small and since the task itself is not a variable to be measured, only the conditions will be fully balanced but not the task. Table 2 (a) schematically shows the first Graeco-Latin square of conditions (A, B, C) and tasks (1, 2, 3) and Table 2 (b) the second distribution with the same order of conditions but another order of tasks.

A1	B2	C3
A1	C2	B3
B2	A3	C1
B3	C1	A2
C2	A3	B1
C3	B1	A2

(a)

A2	B3	C1
A2	C3	B1
B3	A1	C2
B1	C2	A3
C3	A1	B2
C1	B2	A3

(b)

Table 2: Two different distributions (a) and (b) of conditions (A, B) and tasks (1, 2, 3); each row represents the order of conditions and tasks for one participant

This means that each participant will go through three different movement tasks, each with a different visualization of movement. The complete mixed design for this experimental setting is depicted in Table 3. “Triple”, “quadruple” and “sextuple” refer to the different meters and their movements, which the participant is supposed to learn. The design demands a minimum total of 24 participants.

	Group: Realistic			Group: Abstract			
1	P triple	PPW quadruple	PP sextuple	P triple	PPW quadruple	PP sextuple	1
2	P triple	PP quadruple	PPW sextuple	P triple	PP quadruple	PPW sextuple	2
3	PPW quadruple	P sextuple	PP triple	PPW quadruple	P sextuple	PP triple	3
4	PPW sextuple	PP triple	P quadruple	PPW sextuple	PP triple	P quadruple	4
5	PP quadruple	P sextuple	PPW triple	PP quadruple	P sextuple	PPW triple	5
6	PP sextuple	PPW triple	P quadruple	PP sextuple	PPW triple	P quadruple	6
7	P quadruple	PPW sextuple	PP triple	P quadruple	PPW sextuple	PP triple	7
8	P quadruple	PP sextuple	PPW triple	P quadruple	PP sextuple	PPW triple	8
9	PPW sextuple	P triple	PP quadruple	PPW sextuple	P triple	PP quadruple	9
10	PPW	PP	P	PPW	PP	P	10

	triple	quadruple	sextuple	triple	quadruple	sextuple	
11	PP	P	PPW	PP	P	PPW	11
	sextuple	triple	quadruple	sextuple	triple	quadruple	
12	PP	PPW	P	PP	PPW	P	12
	triple	quadruple	sextuple	triple	quadruple	sextuple	
24 participants							

Table 3: 2 x 3 factor split-plot design with a two-level between-subjects variable and a three-level counterbalanced within-subjects variable

4.1.3 Procedure

Table 4 describes the procedure of one study session. It shows the final procedure as used in the study. A former version of the part involving the task execution will be discussed in the section 4.1.5 on the pilot study. A checklist containing the steps in this table has been created to be used in each session in order to ensure a consistent procedure (see Appendix A.1). Moreover, a schema overview is used to ascertain the respective order of tasks and conditions for each participant (see Appendix A.2). One session takes about 90 minutes and participants are compensated with 15, - EUR.

The study is conducted in the department's Media Lab in which the OptiTrack system is installed. Figure 26 shows the setup of the study in the lab.

Figure 26: Study setup in the Media Lab

In the beginning, the participant will be welcomed in the lab and asked to read a welcome letter. Subsequently, they will be asked to read and sign consent forms as well as to fill in the demographic questionnaire.

As part of the introduction, all necessary calibration steps and measurements are performed, so that in the end of this part, the user wears the OptiTrack suit, the MoCap is working, the Unity application is running with respective gender and body measurements, and the Oculus Rift is fitting and working.

Following, the part involving the task execution will be performed for each condition which means that it is repeated three times. It involves the collection of log data during the performances of the movements. Each part starts with the demo task so the participant can understand and adjust to the condition of movement visualization. Then, the actual movement task, the conducting of the musical meter, is performed. Afterwards, the forms of a NASA TLX questionnaire and the UEQ are handed out and filled in by the participant. Subsequently, the previously learned motion sequence is performed again but from memory without any guiding visualization. Finally, the subjective performance rating and the short interview are completed for the respective task.

In a terminal part, the follow-up interview is conducted and the participant receives their compensation before saying goodbye.

Details on the collected data will be outlined in more detail in the following section.

Welcome and introduction	5-10 min.
▪ Welcome participant ▪ Welcome text / procedure description (Appendix A.3) ▪ Informed consent (Appendix A.4) and photo permission (Appendix A.5) ▪ Demographic questionnaire (Appendix A.6)	
Calibration and measurements	**20-30 min.**
▪ Explain tracking system, how it works and what needs to be taken care of ▪ Put on OptiTrack suit and check marker positions ▪ Calibrate skeleton in Motive software	

▪ Take body measurements ▪ Start Unity application and screen recording, enter gender and measurements ▪ Put on Oculus Rift and make it fit correctly	
Task execution (repeated for the three tasks)	15 min. (x3)
▪ Explain condition ▪ Start video recording ▪ Demo task ▪ Actual task (with respective condition) ▪ NASA TLX questionnaire (Appendix A.7) ▪ UEQ (Appendix A.8) ▪ Recall task (without guidance) ▪ Stop video recording ▪ Subjective performance rating and interview (Appendix A.9)	
Terminal part	5-10 min.
▪ Follow-up interview (Appendix A.10) ▪ Put off the suit ▪ Pay compensation (receipt: Appendix A.11)	
Total:	75-95 min.

Table 4: Procedure of the study; steps marked with this symbol [15] are performed wearing the Oculus Rift HMD

4.1.4 Data Collection

In order to be able to answer the research questions, different data is collected in different ways.

Log data. First, the log data has to be mentioned. As explained in section 3.2.1, the values obtained from the transform component (position and orientation) of different body parts (middle finger, hand, forearm and elbow) are logged by the system. The data is collected at each frame for the visualization as well as for the avatar, so that the values of both can be compared later on. A distance score is calculated from the values to measure the accuracy of the performance.

Questionnaires. In the beginning of each session, demographic data and data about the participant's exercising behavior and prior

[15] Icon made by Pixel perfect from www.flaticon.com (Accessed: September 14, 2018)

knowledge of music (conducting, playing an instrument, etc.) and sports is collected. The questionnaire created to retrieve this information is shown in Appendix A.6.

For the purpose of assessing user experience, the NASA TLX developed by Hart & Staveland (1988) will be used. It is a widely-used questionnaire to measure the perceived workload, or task load, of the participant when performing a task. Here, the so-called "Raw TLX", where only the subscale rating itself is conducted but not the weighting of the subscales, is used since it is much shorter, therefore easier to apply, and seems to show equally valid results compared to the "full" NASA TLX (Hart 2006). The paper form used for the NASA TLX in German can be found in Appendix A.7.

Further, the quality of the experience the participant during each task execution is measured using the User Experience Questionnaire (UEQ) (Laugwitz et al. 2008). The questionnaire consists of 26 contrary pairs of adjectives and a 7-level scale for each pair describing the agreement to the one or the opposing attribute to a certain extent (see Appendix A.8, German version of the UEQ). The resulting values yield information about six subscales which are used to assess the user experience.

In addition, four custom questions about the subjective rating of the own performance regarding the task are asked. The first two questions are used to assess performance with guidance and the last two without guidance. Here, a 5-level Likert scale is used to determine the agreement to the following sentences. (The original sentences used in the study are given in German.)

- I was able to follow the guidance.
- I performed the motion sequence precisely <u>with guidance</u>.
- I was able to memorize the motion sequence.
- I performed the motion sequence precisely <u>without guidance</u>.

On the same form (see Appendix A.9), two further questions are asked. These questions are open questions and serve as a basis for a short interview after each task. They provide qualitative data which leave room for individual notes, ratings, or explanations. The first question is about how the participant liked the just seen way of learning a movement, what was positive and what negative. The second question asks to compare the present method to conservative ways of motor learning, what was better or worse?

Finally, a questionnaire with open questions for an interview at the end of each session has been created (see Appendix A.10). Again, they provide some qualitative data which can help to discuss the results. The first question asks for an order of preference of the three conditions and giving reasons for that decision. The second question asks whether the participant can imagine using a similar system in the future to learn motion sequences independently. Further scenarios or applications areas the participant can think of to use such a system are questioned in the third question. Finally, the last question is a very open question asking for improvements and other notes.

Video recording. Additionally, video and screen recordings will be taken during the sessions. However, this data is only supposed to support the data analysis and will not be evaluated itself. In case there were inconsistencies in the data, it could help to comprehend these.

4.1.5 Pilot Study

Before recruiting participants and starting the study, a pilot study has been executed in order to test the procedure and verify the estimated time slots.

In the pilot study, a former version of the procedure plan has been used. Here, the order of the task execution part was as follows:

- Explain condition
- Start video recording
- Demo task
- Actual task (respective condition)
- Recall task (without guidance)
- Stop video recording
- NASA TLX questionnaire
- UEQ short version and subjective performance rating

As can be seen, the three movement tasks are immediately consecutive. They are marked with the symbol to indicate that they are performed while wearing the Oculus Rift HMD. The idea behind this ordering was to simplify the procedure since putting on and off the headset several times is time-consuming on the one hand and inconvenient on the other hand. Further, in order to save time, only the short version of the UEQ was used and the two questions of the short interview after each task were part of the follow-up interview in the end.

The pilot study revealed that, contrary to the initial concerns, the planned time would be enough while still providing some buffer for the calibration phase. The duration of this phase is quite individual and can be successful instantly or after several trials. Therefore, the short version of the UEQ was replaced by the standard version. The two questions mentioned above were rated more relevant to be answered with respect to the single conditions instead of the system as a whole, thus they were moved from the terminal part to the task-related part in the form of a short interview. Finally, the order has been rearranged to the order reflected in Table 4. The problem with the former order was that it was not clear whether the questionnaires (NASA TLX and UEQ) refer to the actual task, the recall task, or both considered as a whole. To avoid this ambiguity, the recall task is instead performed after the two questionnaires entailing a bit of inconvenience when switching between VR and paper forms several times.

In addition to the procedural insights, the participant of the pilot study remarked that the design and composition of the virtual environment could be more appealing, e.g. the room could be more realistic. This remark has been incorporated and a minimalistic but more realistic room has been created. Figure 27 shows the old version and Figure 28 the new version of the room.

Figure 27: Old room (state of the Master-project)

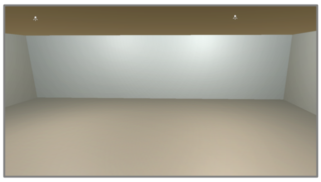


Figure 28: Revised room

Furthermore, the participant remarked that it would be helpful if the green starting points appear only when the conditions are set and the user is allowed to start the task, so the user does not accidently start a wrong task. Therefore, one step has been added to let the starting points appear by clicking the button "Go!" on the GUI. This new behavior simplifies the procedure, avoids misunderstandings and the director of the study can calmly check whether all conditions are set correctly before clicking the button.

4.2 Results

In the following subsections, the results of the study are presented beginning with information about the participants. Afterwards, the measurements of the DVs performance and user experience and preference are analyzed, followed by the results measuring learnability. At last, the interview data is summarized.

A test for normality showed that the measured data is not normally distributed. Therefore, non-parametric tests have been used for analysis. Within-subjects measurements regarding the movement visualizations have been analyzed by applying a Friedman test. If the Friedman test showed a statistically significant result, a post-hoc analysis has been conducted using a Wilcoxon signed-rank test including a Bonferroni correction for pairwise comparisons. Between-subjects measurements regarding the appearance of the visualization have been analyzed with the help of a Mann-Whitney-U-Test.

4.2.1 Participants

Twenty-five participants were recruited of which one session had to be cancelled due to hardware issues and is not further taken into account in the analysis. One participant had to come to the lab a second time after the OptiTrack skeleton calibration did not work within the available time during the first trial. Altogether, 24 sessions, as required by the experimental setting, have been conducted successfully. Besides directly approaching students on the campus, flyers, social media postings, and e-mail lists were used to recruit participants.

All recruited participants were students of various disciplines, except for one participant, who has already entered into employment. Their mother tongue was German which has already been ensured during the recruiting to be sure all instructions and questionnaires are understood correctly. The group of participants is divided into half male and half female. The mean age of the participants was 23.75 years with a range of 19–32 and a standard deviation of 3.49. The majority (14) had normal eye-sight, five were wearing contact lenses and five took part without corrective lenses affirming that they could see everything sharp in the virtual environment. Apart from that, one participant had an astigmatism and the rest had no further limitations in terms of their visual acuity. In regard to limitations in the range of motion, there was one participant with a not yet fully healed capsular rupture at a finger which, however, did not have an influence on the usage of the system since there are no finger movements and no finger tracking. The remaining participants did not have any limitations in mobility.

Experience with VR was rare: nine participants did not have any, 14 had tried a VR device once or only a few times at a demo or when participating in other studies, one participant was very familiar with several VR devices due to regular use. The participants had more experience in playing instruments. One participant plays several instruments daily, six practice at least once a week, one practices at least once a month, ten play an instrument rarely or not actively any more, and six have never played any instrument. However, as depicted in Figure 29, the majority can read music and knows the triple and quadruple meters. The sextuple meter is less known among the participants.

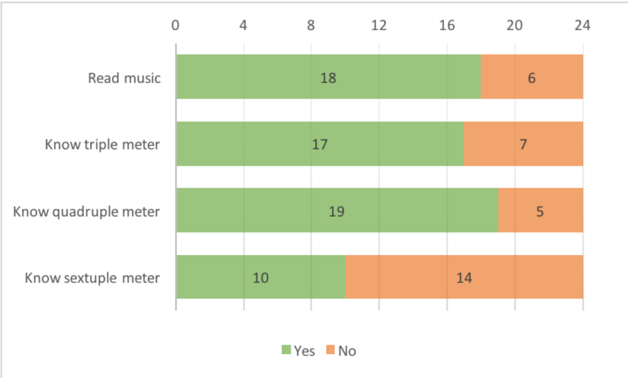


Figure 29: Distribution of the participants' knowledge of reading music and the musical meters

Further, participants were asked about their experience with participating in an orchestra or choir and about their familiarity with the movements of conducting music. There were four participants taking part in an orchestra or choir rehearsal at least once a week and one participant at least once a month. Eight participants do not participate in an orchestra or choir anymore and 11 never did. Half of the participants stated that they have seen conducting movements before, one participant practiced the movements themselves, and the remaining 11 participants did not know the movements.

Finally, to assess their familiarity with conscious motor learning, the participants were asked about their sporting activities. Except for one, all of them stated that they do sports on a regular basis, most of them at least once a week (17), five daily, and one participant once a month.

4.2.2 Performance

The analysis of performance consists of the measured accuracy computed from the log data as well as a subjective assessment on whether the participant felt they were able to follow the guiding visualization and whether they think they performed the movement correctly with guidance.

Accuracy. The log data used to assess the user's performance accuracy comprised position and orientation values of four body parts, namely the middle finger, hand, forearm and elbow for each frame during a task. For each body part, one log file has been created, resulting in eight files for one 'body' (four for each side – left and right). Each of the 24 sessions consisted of three tasks each resulting in 24 log files: eight files for the avatar, another eight for the guiding visualization, and again eight files for the avatar during the recall task without guidance. So, in total 1,728 log files have been generated during the study (not counting log files of the demo task).

Figure 30 exemplary shows the first three lines of a log file of one body part to illustrate its structure. The first line is a header describing each comma-separated column. The rest of the file contains one line for each frame with a timestamp, position values tX, tY, tZ, and orientation values rX, rY, rZ.

```
time,tX,tY,tZ,rX,rY,rZ
2018080110223696,0.6482325,1.416565,0.9024667,12.4452,324.479,34.75339
2018080110223697,0.6493973,1.414948,0.9040138,12.1447,324.1296,34.82883
```

Figure 30: First three lines of a log file for one body part

In order to measure the performance accuracy, the Dynamic Time Warping algorithm (DTW) (Kruskal & Liberman 1983) is used. The algorithm is a measure for similarity of time series by detecting similar shapes occurring at different points in time. It has been widely-used in speech recognition (Sakoe & Chiba 1978), for example. Figure 31 illustrates the matching of similar points on two curves.

A two-dimensional array dtw of the first sequence's length in the first dimension n and the second sequences' length in the second dimension m is used to create a cost matrix. The last element of the array $dtw[n][m]$ is the minimum cost to find the optimal match. The cost is made up of adding absolute distances of the compared values of each sequence. The complete algorithm is shown in Figure 32. The matching of two values can be restricted to a specified window w of the time series, so that one value will only match values within this window.

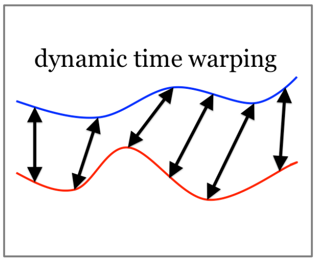


Figure 31: Illustration of the dynamic time warping algorithm[16]

```
int dtw_distance(a: array [1..n], b: array [1..m], w: int) {
   dtw := array [0..n, 0..m]

   w := max(w, abs(n-m))

   for i := 0 to n
       for j := 0 to m
           dtw[i, j] := infinity
   dtw[0, 0] := 0

   for i := 1 to n
       for j := max(1, i-w) to min(m, i+w)
           cost := distance(a[i], b[j])
           dtw[i, j] := cost + minimum(dtw[i-1, j  ],
                                        dtw[i  , j-1],
                                        dtw[i-1, j-1])

   return dtw[n, m]
}
```

Figure 32: DTW distance calculation in pseudo code

[16] https://de.mathworks.com/matlabcentral/mlc-downloads/downloads/submissions/43156/versions/5/screenshot.jpg (Accessed: September 14, 2018)

The algorithm has been implemented in a Ruby script (*dtw.rb*). Here, the window size has been specified as 10% of the length (number of logged frames) of the visualization sequence. The distance between two logged frame pairs is computed as the Euclidean distance of the positions (tX, tY, tZ in Figure 30). Two Ruby scripts have been created to iterate through the directories and files and write the computed DTW distances into an Excel sheet. The file *scoring.rb* identifies the log files of the guiding visualization and the avatar which are supposed to be compared; the file *scoring_recall.rb* identifies the avatar's log files of the recall task and the log files of the guiding visualization of the corresponding guidance task. The scripts can be found on the attached USB thumb drive.

The resulting Excel sheets contain the DTW distances for all eight body parts and the corresponding information on the task conditions. For the further analysis, the sum of the eight DTW distances has been used. So, there is one value representing the accuracy of the user's performance for each task. Since the DTW distance between two identical sequences equals 0, a smaller value indicates more similarity between the user and the guiding visualization, thus a better performance.

Table 5 shows the mean values of the DTW distance sums and the standard deviation (SD) for the three movement visualizations and the two types of visualization appearance.

	P	PP	PPW
M_{TOTAL}	3724.92 (1563.98)	3133.13 (1230.15)	3523.25 (1155.73)
$M_{ABSTRACT}$	4472.25* (1725.96)	3688.92* (1306.29)	3996.92 (1251.61)
$M_{REALISTIC}$	2977.58* (957.56)	2577.33* (885.29)	3049.58 (858.39)

Table 5: Mean DTW distance sums and SD in brackets; an asterisk indicates statistically significant differences for between.

A Friedman test showed no statistically significant difference between the three movement visualizations P, PP, and PPW; neither irrespectively of the visualization's appearance ($\chi^2(2) = 2.25$, $p = 0.325$), nor for ABSTRACT ($\chi^2(2) = 0.5$, $p = 0.779$), nor for REALISTIC ($\chi^2(2) = 2.0$, $p = 0.368$).

Comparing the appearance of the visualizations, a Mann-Whitney-U-Test showed a statistically significant difference for P ($U = 29.0$, $p = 0.013$) and for PP ($U = 32.0$, $p = 0.021$) indicating a better performance for REALISTIC. It showed no statistically significant difference for PPW.

Subjective assessment. After each task block, the participants were asked to which extent they agree or disagree to the following statements about their performance using a 5-point Likert scale:

- I was able to follow the guidance.
- I performed the motion sequence precisely with guidance.

The answers have been coded as 0 = "strongly agree" to 4 = "strongly disagree".

The mean values regarding the assessment of the ability to follow the guidance are shown in Table 6.

A Friedman test showed no statistically significant differences depending on the movement visualization, irrespectively of the visualization's appearance ($\chi^2(2) = 3.836$, $p = 0.147$), nor for REALISTIC ($\chi^2(2) = 0.812$, $p = 0.666$). However, there was a statistically significant difference between the movement visualizations on the level of ABSTRACT ($\chi^2(2) = 6.276, p = 0.043$). Applying a Wilcoxon signed-rank test including Bonferroni correction as a post-hoc analysis showed that with P participants felt statistically significantly more able to follow the guidance than with PP ($Z = -2.456, p = 0.042$).

The results of a Mann-Whitney-U-Test showed a statistically significant difference for the visualization's appearance comparing the agreement values on the level of PP ($U = 28.0, p = 0.006$). There is a higher agreement to the statement for REALISTIC than for ABSTRACT.

	P	PP	PPW
M_{TOTAL}	2.67 (1.27)	3.13 (0.99)	3.08 (0.83)
$M_{ABSTRACT}$	2.75[a] (1.29)	3.67[a,*] (0.49)	3.25 (0.97)
$M_{REALISTIC}$	2.58 (1.31)	2.58* (1.08)	2.92 (0.67)

Table 6: Mean values of agreement (ability to follow guidance) and SD in brackets; statistically significant differences are indicated by raised letters for within and by an asterisk for between.

Mean values for the second statement about the precise performance of the motion sequence with guidance can be found in Table 7.

No statistically significant differences in the rating of agreement were found within the movement visualizations (TOTAL: $\chi^2(2) = 5.171$, $p = 0.075$, ABSTRACT: $\chi^2(2) = 5.871$, $p = 0.053$, REALISTIC: $\chi^2(2) = 5.128$, $p = 0.077$).

Also, a Mann-Whitney-U-Test did not show any statistically significant differences in the rating of agreement between the two levels of visualization appearance.

	P	PP	PPW
M_{TOTAL}	2.25 (1.07)	2.79 (0.88)	2.75 (0.85)
$M_{ABSTRACT}$	2.42 (1.08)	3.17 (0.39)	2.58 (0.79)
$M_{REALISTIC}$	2.08 (1.08)	2.42 (1.08)	2.92 (0.90)

Table 7: Mean values of agreement (performed motion sequence precisely) and SD in brackets.

4.2.3 User Experience and Preference

The experience the user has with the different guiding visualizations and their preference have been assessed by the quantified measures of task load (NASA TLX) and user experience (UEQ), and a ranking, respectively.

Task load. The NASA TLX questionnaire has been used to measure the participants' task load without weights of the subscales, which is also referred to as "Raw TLX" (Hart & Staveland 1988; Hart 2006). The questionnaire consists of the six subscales *mental demand*, *physical demand*, *temporal demand*, *performance*, *effort*, and *frustration*. The scales reach from 0 (e.g., "very low") to 100 (e.g., "very high") with steps of five.

Table 8 shows the overall mean values of the participants' task load throughout all subscales.

	P	PP	PPW
M_{TOTAL}	42.01 (20.2)	37.29 (17.23)	40.66 (14.83)
$M_{ABSTRACT}$	40.97 (23.71)	30.49 (14.62)	39.93 (13.06)
$M_{REALISTIC}$	43.06 (16.99)	44.1 (17.5)	41.39 (16.97)

Table 8: Overall mean values of task load and SD in brackets; statistically significant differences are indicated by an asterisk for between.

Testing for differences within the movement visualizations by applying a Friedman test did not show any statistically significant effect (TOTAL: $\chi^2(2) = 1.284$, $p = 0.526$, ABSTRACT: $\chi^2(2) = 2.167$, $p = 0.338$, REALISTIC: $\chi^2(2) = 3.362$, $p = 0.186$).

A Mann-Whitney-U-Test showed no statistically significant difference between the appearance of the visualizations for the movement visualizations P ($U = 62.0$, $p = 0.563$), PP ($U = 40.0$, $p = 0.065$, and PPW ($U = 70.5$, $p = 0.931$).

Further, the analysis of the mean values for each subscale showed no statistically significant differences comparing the movement visualizations.

However, a Mann-Whitney-U-Test showed a statistically significant difference between the appearance of the visualizations for *temporal demand* ($U = 31.0$, $p = 0.017$) and *performance* ($U = 30.0$, $p = 0.019$) both when using PP. Participants rated the *temporal demand* they felt higher for REALISTIC ($M_{REALISTIC}$ = 46.25, SD = 25.18) than for ABSTRACT ($M_{ABSTRACT}$ = 22.5, SD = 16.14). They also rated their performance better for ABSTRACT ($M_{ABSTRACT}$ = 30.0, SD = 17.91) than for REALISTIC ($M_{REALISTIC}$ = 51.25, SD = 16.22). Mean values of the remaining subscales showed no statistically significant differences.

User experience. To measure the user experience, the UEQ (Laugwitz et al. 2008) has been applied. The questionnaire consists of 26 pairs of contrary adjectives with a 7-point Likert scale in between. The pairs are assigned to the six subscales *attractiveness*, *perspicuity*, *efficiency*, *dependability*, *stimulation*, and *novelty*. For further analysis based on the subscales, the subscale means obtained from the UEQ Data Analysis Tool[17] have been used.

Friedman tests for each subscale comparing the movement visualizations P, PP and PPW regardless of the visualization's appearance showed no statistically significant differences, except for *efficiency*: $\chi^2(2) = 8.187$, $p = 0.017$. The mean values for this subscale are shown in the following table.

	P	PP	PPW
M_{TOTAL}(*efficiency*)	1.17 (0.73)	1.18[a] (0.57)	0.83[a] (0.63)

Table 9: Mean values of TLX subscale efficiency and SD in brackets; statistically significant differences are indicated by raised letters for within.

A post-hoc analysis with a Wilcoxon signed-rank test and Bonferroni correction showed that *efficiency* was statistically significantly higher for PP compared to PPW ($Z = -3.194$, $p = 0.0042$). Yet, there was no statistically significant difference between P and PPW after Bonferroni correction.

Mann-Whitney-U-Tests were conducted for each subscale but none of them showed statistically significant differences between the appearance of the visualizations.

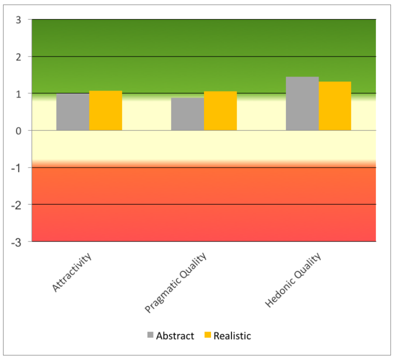


Figure 33: Mean values of the quality aspects for ABSTRACT and REALISTIC regardless of the visualization of movement

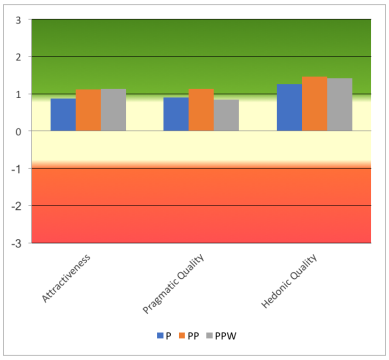


Figure 34: Mean values of the quality aspects for P, PP, and PPW regardless of the appearance of the visualizations

[17] https://www.ueq-online.org/ (Accessed: September 14, 2018)

The subscales of the UEQ can be grouped by different quality aspects. Pragmatic quality comprises the task related subscales *perspicuity*, *efficiency*, and *dependability*; *stimulation* and *novelty* describe the hedonic quality. The mean values for the quality aspects are shown in the following figures, each regardless of the respective other conditions. All of the mean values are > 0.8 which can be summarized as an overall positive user experience.

Ranking. Finally, in the follow-up interview of the study session, the participants were asked to rank their preference of movement visualization P, PP, or PPW. The ranking has been coded from 1 being the most preferred movement visualization to 3 as the least preferred.

Mean values for the ranks are shown in Table 10.

There were no statistically significant differences in the ranking within P, PP, and PPW, irrespectively of the visualization's appearance ($\chi^2(2) = 3.250$, $p = 0.197$) and on the level of REALISTIC ($\chi^2(2) = 2.167$, $p = 0.338$). However, the Friedman test showed a statistically significant difference in the ranking on the level of ABSTRACT ($\chi^2(2) = 8.667$, $p = 0.013$). The pairwise comparison in the post-hoc analysis with a Wilcoxon signed-rank test showed no statistically significant difference for P compared to PP after Bonferroni correction. Nonetheless, PP was statistically significantly ranked better than PPW for ABSTRACT visualizations ($Z = -2.81, p = 0.0149$).

	P	PP	PPW
M_{TOTAL}	2.21 (0.83)	1.71 (0.81)	2.08 (0.78)
$M_{ABSTRACT}$	2.17 (0.84)	1.33[a] (0.49)	2.50[a] (0.67)
$M_{REALISTIC}$	2.25 (0.87)	2.08 (0.9)	1.67 (0.65)

Table 10: Mean values of preference ranking and SD in brackets; statistically significant differences are indicated by raised letters for within

In total, PP was ranked best by 12 out of 24 participants. Most of them liked the points because they provide feedforward information and give an orientation about where to move next. Another aspect for their decision was that the movement is "fluent" and "coherent" or “being in a flow” and “feeling encouraged by the given tempo” when using PP. Aside from that, several participants based their decision on “being able to follow” and “not being overextended”.

Six participants preferred P. This decision was repeatedly based on the movement visualization being “fluent”, as well. In addition, the mode was denoted to be more natural: “it’s about the movement itself and therefore, it was easier to follow”. When participants ranked PPW as the preferred mode, which was the case for the remaining six participants, they mostly stated the self-paced approach as a reason. They liked that the system somehow adapted to the user.

The movement visualization level ranked worst most often was P (11 out of 24). The most common reasons were not feeling able to follow, “lagging behind”, being “stressed” or “frustrated”. Participants often had difficulties to “follow and memorize the movement at the same time”. It was also perceived as being “like a video” by two participants and not exhausting the possibilities of the technology. Some also missed the static points and the support they provide compared to the other modes.

Naturally, the remaining eight participants ranked PPW as the least preferred movement visualization. Mostly it was described as being “confusing”, “irritating”, or “distracting” because “the points had to be matched exactly”. For some, it was “too static” or “too slow” and there was “no rhythm”. The reasons for disliking PP were similar. Participants felt “frustrated” or “overextended” and “confused” because there were “too many hands”.

4.2.4 Learnability

This section presents the results regarding measurements of learnability or more precisely the ability to recall the movement without guidance. Yet, these measurements and their results are not the focus of the thesis and should not be claimed to represent a comprehensive assessment of learnability. First, the results of the measured accuracy of the movement performed without guidance are presented. Second, an evaluation of the subjective assessment on whether the participant felt they were able to memorize the motion sequence and whether they think they performed the movement correctly without guidance follows.

Accuracy. As already mentioned under "Accuracy" in section 4.2.2, the DTW was used to calculate a score for the participant's performance of a task. Here, the log data of the participant's avatar collected during the recall task is compared to the log data of the guiding visualization of the corresponding task with guidance for the same motion sequence. Again, the score used for analysis is the sum of the DTW distances of all logged body parts.

The mean values of the similarity scores are shown in Table 11.

A comparison of the sums of DTW distances within the three movement visualizations (P, PP, PPW) by applying a Friedman test showed no statistically significant differences regarding the total number of samples or the levels of the visualization's appearance, respectively.

Also, the Mann-Whitney-U-Tests conducted to compare the sums of DTW distances between the appearance of the visualizations (ABSTRACT and REALISTIC) showed no statistically significant differences for any of the movement visualizations.

	P	PP	PPW
M_{TOTAL}	10091.75 (6864.34)	12741.42 (7257.65)	11235.63 (6617.09)
$M_{ABSTRACT}$	10792.17 (5309.63)	12760.33 (8543.32)	10525.08 (5760.45)
$M_{REALISTIC}$	9391.33 (8322.23)	12722.50 (6094.76)	11946.17 (7567.57)

Table 11: Mean DTW distance sums of recall task and SD in brackets.

Subjective assessment. In addition to the measurement of accuracy, the participants were asked to rate their agreement to the following two statements:

- I was able to memorize the motion sequence.
- I performed the motion sequence precisely <u>without guidance</u>.

The agreement has been coded from 0 = "strongly agree" to 4 = "strongly disagree".

Table 12 shows the mean values of agreement for the first statement on the ability to memorize the motion sequence.

Results showed no statistically significant differences in the rating of agreement depending on the three movement visualizations, neither for ABSTRACT ($\chi^2(2) = 4.732$, $p = 0.094$), nor for REALISTIC ($\chi^2(2) = 1.590$, $p = 0.452$), nor regardless of the visualization's appearance ($\chi^2(2) = 3.475, p = 0.176$).

A Mann-Whitney-U-Test showed no statistically significant differences in the rating of agreement comparing the appearance of the visualization for P or PPW. However, when using PP, the test indicated a statistically significantly higher ability to memorize the motion sequence for REALISTIC visualizations ($U = 24.0$, $p = 0.004$).

	P	PP	PPW
M_{TOTAL}	2.21 (1.25)	2.50 (1.14)	1.87 (0.99)
$M_{ABSTRACT}$	2.25 (1.22)	3.17* (0.72)	2.00 (1.04)
$M_{REALISTIC}$	2.17 (1.34)	1.83* (1.12)	1.75 (0.97)

Table 12: Mean values of agreement (ability to memorize motion sequence) and SD in brackets; statistically significant differences are indicated by an asterisk for between.

Mean values of the rating for the second statement on the precise performance of the motion sequence without guidance are shown in Table 13.

Again, the results of Friedman tests for differences in the rating of agreement depending on the movement visualization showed no statistical significance, whether regardless of the visualization's appearance ($\chi^2(2) = 0.775$, $p = 0.679$) or regarding ABSTRACT ($\chi^2(2) = 3.707, p = 0.157$) or REALISTIC ($\chi^2(2) = 0.667, p = 0.717$).

Nonetheless, a statistically significant difference in the rating of agreement was found between ABSTRACT and REALISTIC for PP ($U = 31.0$, $p = 0.014$), indicating a better perceived performance without guidance on the level of REALISTIC. There were no differences comparing the visualization's appearance on the levels of P or PPW.

	P	PP	PPW
M_{TOTAL}	1.71 (1.197)	1.96 (1.197)	1.58 (1.176)
$M_{ABSTRACT}$	1.75 (1.215)	2.58* (0.900)	1.58 (1.165)
$M_{REALISTIC}$	1.67 (1.231)	1.33* (1.155)	1.58 (1.240)

Table 13: Mean values of agreement (performed motion sequence precisely without guidance) and SD in brackets; statistically significant differences are indicated by an asterisk for between.

4.2.5 Interview Data

After each task execution part as well as in the end of the study session, interviews have been conducted addressing different aspects. This section summarizes the answers given by the participants.

Task-related interview. In the short interview which has been done after each task, two questions were asked. In the first question, the participant was asked what they liked about the way of learning the movement; what was positive, what was negative? The second question asked for a comparison to traditional ways of motor learning.

Irrespectively of the visualization's appearance, the total number of positive aspects which were named for each movement visualization were similar (P: 26, PP: 28, and PPW: 25). Regarding the negative aspects, there are more differences between the movement visualizations (P: 24, PP: 22, PPW: 33).

Table 14 gives an overview of the positive and negative aspects for each movement visualization which have been mentioned by more than one participant. The numbers in front of each aspect indicate the number of mentions.

How did you like this way of learning a movement; what was positive, what was negative?				
Mov. Vis.		Positive aspects		Negative aspects
P	8	Directly see hands and empathize with them	4	Too fast & not being able to keep up
	5	Easy to learn and memorize	4	Difficult to follow
	4	Clear & not confused by points	3	Perspective and information of depth not clear
	3	Fluent	3	Too close
	2	Slow	2	Movement is not clear
			2	Difficult to memorize
			2	Not liking the [abstract] appearance & would be better if it looked more realistic
PP	6	Predictable where to move the hands due to the points	5	Too fast, "stressful", feeling overwhelmed
	5	Easy to understand and follow	5	Points are confusing
	3	Good to memorize	4	Difficult to understand movement as whole
	3	Easier than PPW (forgiving)	2	Difficult to memorize
	2	Directly seeing if performing correctly or not		
	2	Fluent		
PPW	6	No time pressure, own tempo	8	Difficult to match the hand posture, concentrate on matching
	5	Allowing to think about the movement and learn it precisely	7	Difficult to memorize since not being able to concentrate on the movement
	4	Encouraging & feeling good	4	Halting & fragmented
	2	Good to know direction in advance	4	Too many hands, confusing
			3	Sometimes accidently matching points
			2	Movement not clear, missing overview
			2	Too little time / repetitions

Table 14: Positive and negative aspects about the three levels of movement visualization which have been mentioned by more than one participant; numbers for each aspect indicate the number of mentions.

The second question asking about a comparison of the respective movement visualization to traditional ways of motor learning has been answered in the same way for each of the three levels by many participants. Therefore, the answers will be summarized.

Compared to learning a movement independently with help of a video, participants think that the system in general is better, because of the egocentric perspective and “directly seeing whether oneself is doing the movement right or not”. Also, in comparison to textual or pictorial descriptions of a movement, they think the system works better, is more vivid, interactive, and fun to use.

A teacher is preferred by the participants in regard to several aspects. The main reason is that a teacher can response to the student individually and give feedback as well as answer questions. Compared to the egocentric guidance system, they also miss a “supervisor”, someone who can confirm that one is performing the movement correctly. One participant also mentioned “mistrust of technology” (A06) as a disadvantage of the system. They also stated, that in addition to the visual guidance, audio instructions, explanations or motivational support could be very helpful and are missing. However, as advantage compared to a teacher it was mentioned that “due to the egocentric perspective, no transfer is necessary”.

In general, several advantages and disadvantages of using the egocentric guidance system have been mentioned. Participants approve the egocentric perspective and therefore directly seeing where to go and being able to compare whether one is following the guidance correctly or not. Some also stated that performing the movement yourself, being active and involved from the beginning is good to learn the movement. Further, the system has been described as less distractive and “cool”. One participant mentioned that one does not have to feel embarrassed when using the system as opposed to learning with or in front of other people.

However, participants also stated that they would rather practice together with another person. Observing another person or oneself (in a mirror) to get an overview of the movement was important for many participants. Further, they often criticized the missing feedback. Other disadvantages named by the participants were having little control, no real interaction and not being able to pause. Regarding the virtual environment, some participants stated that they are not used to it (including wearing the headset), they felt insecure in the room and were missing orientation. In addition, the smaller FOV was seen as making difficult since one has to turn the head to see the hands if they are outside the FOV.

Three participants said that they would prefer a combination of exocentric and egocentric guidance in the system. For example, they would like to observe a (virtual) teacher in the beginning to get an idea of the movement and then go on with the egocentric guidance to perform the movement on their own. Also, giving feedback with colors such as green or red indicating being right or wrong was suggested to further improve the system compared to traditional ways of motor learning.

Follow-up interview. In the follow-up interview, participants were asked to rank the three movement visualizations. These results have already been reported in section 4.2.3. The remaining questions asked whether they can imagine using such a system in the future to learn movements independently, what other scenarios or fields of application they can think of to use the system, and finally if they have suggestions for improvement.

Table 15 summarizes the answers given to the question on whether they can imagine using such a system in the future to learn movements independently. The given answers have been grouped into four categories. The category “yes, definitely” describes answers with a clear statement. “Yes, if affordable or available” summarizes answers in which participants stated that such a system might be too expensive and is too complex but they would use it if they had the resources. The next category is “yes, depending” which comprises rather vague answers setting some conditions for a future usage and mostly preferring a real environment. Negative responses from participants clearly preferring traditional ways of motor learning come under the last category “no, rather not”. The two columns on the right hand-side describe how often an answer coming under the respective category has been given sorted by ABSTRACT and REALISTIC.

As the numbers indicate, there is no difference between the conditional positive answers but a clear positive answer has been given more often by participants of the REALISTIC group and a clear negative answer has been given more often by participants of the ABSTRACT group.

Can you imagine using such a system in the future to learn movements independently?		ABST.	REAL.
Yes, definitely	▪ Good support, helpful ▪ Egocentric perspective ▪ Good for gross motor skills	2	5
Yes, if affordable or available	▪ Would not buy it ▪ Could imagine using it to support independent learning if it was less expensive and complex	3	3
Yes, depending	▪ Prefer real environment and social contacts or a teacher ▪ Helpful depending on the goal and field of application ▪ Some improvements needed regarding tracking, fault tolerance, and attractiveness	3	3
No, rather not	▪ Prefer real environment and social contacts or a teacher ▪ At most using it as support but it does not replace training in class ▪ Too expensive and without added value	4	1

Table 15: Statements about whether a participant can imagine using such a system in the future, grouped into four categories; numbers on the right hand-side indicate how often a statement of the respective category has been made regarding ABSTRACT or REALISTIC.

Asking for other scenarios or fields of application in the third question of the follow-up interview led to many different ideas. The suggestions have been grouped by sports, occupational applications, and other knowledge & skills and are listed in Table 16.

Are there other scenarios or application fields for which you can imagine to use such a motion guidance system?		
Sports	▪ Dancing ▪ Yoga ▪ Gymnastics ▪ Archery ▪ Qi Gong ▪ Martial arts, self-defense (with virtual opponent) ▪ Boxing ▪ Frisbee ▪ Javelin throw	▪ Table tennis ▪ Tennis: serve ▪ Basketball: shoot hoops ▪ Score a goal, different ball sports ▪ Ski jumping ▪ Paragliding: how to fold the paraglider ▪ Climbing ▪ General: optimize motion sequences
Occupational applications	▪ Medicine, surgery (simulations) ▪ Rescue center, emergency room, mountain rescue (simulations) ▪ Therapy (physio therapy, ergo therapy) ▪ Production processes ▪ Processes in laboratories (learn without consuming resources)	▪ Clock maker ▪ Repair instructions ▪ Control panel ▪ Arrange circuits (physics)
Other knowledge & skills	▪ Driving school: learn to drive ▪ Sign language ▪ Children: fine motor skills ▪ Children: Draw letters in the air ▪ Acting	▪ Learn to play an instrument ▪ VR games ▪ Conjuring (with a wand) ▪ Leisure and fun

Table 16: Possible fields of application for an egocentric motion guidance system mentioned by the participants

In the very end of the study session, participants were asked for suggestions for improvements and other comments. The suggested improvements are shown in Table 17, sorted by mentions regarding ABSTRACT and REALISTIC appearances of visualizations. Statements made for both levels are combined in the bottom part of the table.

Do you have any suggestions for improvements?	
ABSTRACT	REALISTIC
▪ Highlight the beginning of the meter's sequence with colors or music ▪ Short countdown after matching the green starting points ▪ Technology should be more reliable ▪ Make the room more appealing ("clinical") ▪ View a recording of the performance retrospectively ▪ More orientation, adapt VR room ▪ Add an exoskeleton to control posture	▪ Hide visualization in between to become more aware of the own arms ▪ Add finger tracking (finger posture is irritating) ▪ Show one more point in advance ▪ Indicate the performed movement with a tail ▪ Have a separate summer tracking suit (too warm) ▪ VR headset is heavy ▪ Feedback, acoustic signals (more motivation)
▪ Higher fault tolerance, improve detection of point matching, problems with tracking ▪ Too fast to be able to follow, self-paced would be better ▪ Add music (more realistic), add metronome, rhythm is difficult without music ▪ Enhance environment: stage, orchestra, concert hall, class room, audience; (depending on application) ▪ See own body from a distance, start with exocentric perspective then egocentric perspective ▪ Guiding visualization farther away from body (more inside FOV) ▪ Add a mirror (in the virtual room) ▪ Sextuple meter was not clear / difficult (start with an easier one)	

Table 17: Suggestions for improvement given by the participants divided into statements made for ABSTRACT and for REALISTIC, or applying for both (bottom part).

In addition to the suggestions for improvement, a few general comments about the system have been made. Regarding the ABSTRACT visualizations, one participant said that the system is structured, tidy, and good to understand and further pointed out that the OptiTrack markers are variable for different users (A09). A participant from the REALISTIC group stated being impressed by the precision of the tracking (R08) and another participant commented on the UEQ that some of the words were odd (R05).

5 DISCUSSION

This chapter discusses the results of the study with regard to the research questions. Thus, the performance and the user experience and preference are addressed. Further, indications for the effect of the different visualizations on the learnability of the movements are discussed before concluding with limitations of the study and possible improvements.

5.1 Performance

The first research question (RQ1) was, how different guiding visualizations affect the user's performance of a guided motion sequence. The performance has been evaluated measuring accuracy as well as using a subjective assessment of the user's own performance.

The comparison of the between-subjects variable appearance of visualization yielded congruent statistically significant differences in both, accuracy and the subjective assessment. The results of the accuracy measurements show that REALISTIC visualizations have a statistically significant positive effect on the accuracy for the movement visualizations P and PP compared to ABSTRACT. This finding recurs for PP in the subjective assessment of performance. Participants felt more capable to follow the guidance using a REALISTIC visualization.

In addition, these findings are supported by statements made by three participants which were exposed to ABSTRACT visualizations without knowing about the REALISTIC condition. One participant using PP with an ABSTRACT visualization said: "more realistic hands/arms would be better" (A08). Two participants using P with an ABSTRACT visualization stated that "the 'hands' are not so pretty" (A01) and "it is difficult to see what the 'blue sticks' are doing, maybe it would be better if they were more realistic" (A02). Especially, the latter indicates a negative effect of ABSTRACT on the performance with P. Further, with regard to REALISTIC, participants positively remarked that they can empathize with the visualization well.

Regarding the three movement visualizations, a statistically significant result has been found in the subjective performance assessment. With P, participants felt more able to follow the guidance compared to PP using ABSTRACT visualizations. The second subjective question asking whether the user felt having performed the movement precisely did not show a statistically significant result. Still, comparing the mean values for these two conditions points into the same direction. The accuracy measurements, however, could not show any statistically significant difference indicating which of the three types has a greater impact on the user's performance in comparison to the others. Yet, the mean values of the accuracy measurement point into a contradicting direction when comparing P to PP on the level of ABSTRACT. Here, the mean value of the summed DTW distances describing the accuracy is higher for P than for PP implying a lower accuracy based on average.

In addition, none of the other examined aspects showed a significant result indicating a difference between P and PP with ABSTRACT visualizations. Also, looking at the qualitative data, no clear tendency has been observed. The collected statements include comparable amount of positive and negative aspects for each argument.

In short, performance is affected by the appearance of the visualizations. REALISTIC visualizations positively influence accuracy over ABSTRACT visualizations for the movement visualizations P and PP. Additionally, REALISTIC visualizations also lead to a higher subjective performance for PP. Besides, the movement visualization affects performance: in case of ABSTRACT visualizations, P leads to a higher subjective performance than PP.

5.2 User Experience and Preference

The second research question was, how different guiding visualizations affect the user experience and preference. The user experience has been measured using the NASA TLX questionnaire (Hart & Staveland 1988) to determine the task load and the UEQ (Laugwitz et al. 2008) to assess the user experience. In addition, a ranking of preference in regard to the three movement visualizations has been inquired.

Results of the task load measurement hardly showed statistically significant differences. Only the analysis of the questionnaire's subscales revealed that the *temporal demand* was lower for ABSTRACT visualizations using PP. *Performance* was rated better for ABSTRACT when using PP as well. The latter contradicts the results regarding performance discussed in the previous section, which showed that the performance using PP was better for REALISTIC visualizations in terms of accuracy as well as in the subjective ability to follow the guidance. However, the finding on *temporal demand* yields some support in participants' statements made in the short interview after using PP. Four participants of the REALISTIC group stated that the guidance was too fast, they felt stressed or similar. In contrast, only one participant from the ABSTRACT group stated, that they felt pressed for time using this movement visualization. This finding is dissenting with the fact that the movement visualization PP relies on a system-imposed pace and the pace does not change between the conditions of appearance.

According to the results of the task load analysis, the different movement visualizations did not have a statistically significant effect on the task load. Yet, following the results of the UEQ (Laugwitz et al. 2008), there is a statistically significant difference between PP and PPW in the *efficiency* subscale measured by the UEQ. This difference was measured regardless of the visualization's appearance. According to this result, participants perceived a higher efficiency with PP compared to PPW. This observation is also reflected in the participants' statements about the different movement visualizations. There were considerably more negative aspects mentioned for PPW than for PP, and also less positive. With respect to PPW, several participants stated that they had difficulties matching the points so the next point is shown. Or, on the contrary, some also stated that the avatar's hands matched the points unintentionally. According to the positive aspects of PP, it has also been stated several times that following the guidance using PP is easier than using PPW because it is "forgiving". The finding could be replicated in the ranking of preference. Participants from the

ABSTRACT group ranked PP significantly higher than PPW. Regarding the total numbers of the ranking PP was chosen for the first place by half of the participants (12 out of 24), followed by P (6) and PPW (6).

To conclude, the appearance of the visualization has an impact on user experience: ABSTRACT requires less (subjective) *temporal demand* and a higher (subjective) *performance* when using PP. Further, PP was found to have a positive effect on the user experience and preference compared to PPW.

5.3 Indications for Learnability

In this section, the results of the recall task in which participants performed the just learned movement without guidance will be discussed. The accuracy of the performed movement in comparison to the previous guiding visualization and a subjective assessment have been measured.

Results show that the visualization's appearance influences the learnability. REALISTIC visualizations led to the perception of a statistically significantly higher ability to memorize the movement than ABSTRACT visualizations after using the movement visualization PP. The same has been found for the subjective assessment of having performed the movement precisely. As well, this finding statistically significantly rather applies to REALISTIC visualizations after using PP. These findings correspond with the effects measured regarding the performance of a movement task with guidance.

The measurements did not indicate a statistically significant difference between the movement visualizations on the ability to memorize and recall the movement. The statements in the short interview about positive and negative aspects indicated that memorizing might be more difficult with PPW than with P or PP. Regarding P and PP, more participants stated that the movement visualizations were good to memorize the movement in comparison to the number of participants feeling it was difficult. In contrast, multiple participants stated it was difficult to concentrate on performing and memorizing the movement with PPW. This indication is contradicted by the mean values of the subjective assessment using Likert scales. For both statements (about the ability to memorize and about the precise performance without guidance), the participants, on average, agreed more on both statements for PPW than for P or PP.

To sum up, REALISTIC visualizations positively influence the perceived learnability of movements when using PP.

5.4 Limitations and Conclusion

As the movement visualization is considered within-subjects in the mixed study design, the evaluation focuses on the evaluation of this variable. However, there are more statistically significant findings concerning the effect of the between-subjects variable appearance of the visualization. Perhaps, the movement visualizations P, PP, and PPW were not different enough. One participant said that they did not recognize a difference between P and PP. Some also indicated that they would use them one after another to learn a movement, e.g., beginning with PPW in their own tempo, then using PP still with the support of the points but being able to concentrate more on the movement as a whole, and finally exercise with P, which multiple participants perceived as fast. In general, the opinions on the different movement visualizations are very diverse and individual. Several aspects might have influenced this.

One aspect which is likely to be a relevant influence is the movement task. Although they are very similar in their characteristics, individual participants stated that one movement task was more difficult than another. Also, when asked for the ranking, they sometimes tended to place the condition of which they liked the movement task most on the first place. So, it seems the tasks were not fully comparable.

The characteristics of the movements, especially of the sextuple meter, which was least known by the participants prior to the study, also entailed that sometimes two consecutive points were very close together. The movement path, however, runs a curve instead of going straight from one point to the other. When using PPW, this could cause the second point to be matched accidentally while the avatar's hands still were at the position of the first point. Regarding this movement visualization, also the opposite was often the case. Participants tried to match a point with their hands but it was not recognized. Here, a trade-off has been made between the sensitivity in terms of time and in terms of distance. If the time threshold for detecting a match was bigger it would be harder to match but it would happen more rarely by accident. The same holds for the collider determining the overlap which is required to detect a match.

It would be interesting to conduct the experiment with other movement tasks and see if it would lead to more significant results.

Another aspect to be considered is the adjustment of body measurements and the placement of the guiding visualization in front of the user. Several participants declared that the visualization was too close in front of them. Further, the resizing of the virtual avatar to match to the user's body measurements is only an approximation and the guiding visualization is adjusted on a percentage basis. Therefore, the avatar and the visualization probably felt more convenient for some participants and less for others. Having a more exact calibration to match the avatar proportions and the position of the visualization could eliminate these differences.

Results regarding the effect of the appearance of the visualizations indicated that realistic looking visualizations are better for this egocentric form of motion guidance regarding performance and learnability. They seem to lead to a higher identification with the guiding visualization and to attract less negative attention as observed with abstract visualizations.

Participants made many suggestions to improve the system. Regarding the visualizations, they wished for more overview on the movement. To obtain more overview, they often stated that they would have liked an exocentric perspective on the movement by either observing another person or themselves in a mirror in addition to or before starting the egocentric guidance. Another idea was to add a tail to the avatar's hands to make the path which has been performed more visible. Further, being able to record the performance and view the recording afterwards to analyze the performance has been mentioned as another helpful way to support learning.

With respect to the field of application, participants added that the system should be more appealing and contain other elements depending on the field of application. For example, music, an orchestra, or a concert hall, etc. could be added to support learning to conduct music. A more elaborate surrounding would also address the missing orientation in VR which some participants mentioned.

From a technical perspective, the tracking could be more reliable which is a known issue. Some participants also stated that they would like to have finger tracking since the hand posture was irritating at times. This could be achieved by combining different tracking technologies, e.g. adding a Leap Motion camera to the setup. Participants also criticized that the current setup with the suit and cameras is very complex and they could rather imagine using such a system if it was more convenient.

6 CONCLUSION

The present thesis compared different visualization for egocentric motion guidance of arm movements to find out how they affect the guidance. Initially, important terms defining the scope have been explained. Then, important aspects of motion guidance systems have been elaborated on by reference to related systems. The aspects of a guiding visualization's appearance as well as the visualization of the movement and their effect on the guidance have been addressed through the following research questions:

RQ1: How do different guiding visualizations affect the performance of a guided motion sequence?

RQ2: How do different guiding visualizations affect the user experience and preference?

An egocentric motion guidance system pursuing an AV approach has been developed in which a VR headset is utilized to display a virtual environment. The system shows a virtual representation of the user's body in the virtual environment through MoCap technology. The user is confronted with different visualizations guiding a bilateral arm movement from the egocentric perspective in the virtual world. The guiding visualizations differ in their appearance: a realistic and an abstract visualization have been designed and implemented. Further, different visualizations of movement have been realized addressing characteristics such as continuity, pace, and the emphasis of significant points on the movement path: "path", "points with path", and "points with path waiting". Basic conducting movements of standard musical meters were utilized as movement tasks. They are performed with both arms simultaneously and mirror-symmetrically.

The research questions have been addressed in an experiment with a 2 x 3 factor split-plot design. The effect of the appearance with two levels was examined between-subjects and the effect of the three-level movement visualization was considered within-subjects. Twenty-five participants were recruited of which 24 could be considered for the analysis of the measurements. Results showed only few statistically significant differences between the different visualizations. Regarding RQ1, one of the major findings is that realistic visualizations led to a better performance in case the movement is visualized continuously and system-paced (“path and points with path”). Additionally, “path” was found to entail a better performance than “points with path” for abstract visualizations. However, there is not much support for this finding in the other measurements.

Answering RQ2 resulted in a finding with respect to the effect of the visualization’s appearance on task load which is opposing the previous finding about the effect on performance. When visualizing the movement as “points with path”, abstract visualizations had a positive effect on the scales *temporal demand* and *performance*. Besides, “points with path” has a positive effect on user experience independently of the appearance and on preference either for abstract visualizations.

In addition to the two research questions, it was also tried to find indications for an effect of the different visualizations on learnability. It has been found that realistic visualizations are subjectively assessed to lead to a higher performance in the absence of guidance.

In summary, it can be said that realistic visualizations show better results with and without guidance. The movement visualizations did not show a clear outcome and should be reviewed more closely in future research.

In general, future work on this topic can go into many directions. As indicated in the discussion, repeating the study with other movement tasks could be interesting. Also, focusing on the combination of egocentric and exocentric guidance seems reasonable.

Since with bilateral arm movements not always both arms are inside the FOV of the HMD as, e.g., in tai chi or yoga movements, it makes sense to further develop visualizations which take this into account.

Participants made many suggestions for other fields of application to utilize egocentric guidance. Multiple sports were mentioned such as ball sports, dancing, yoga, gymnastics, archery or ski jumping.

Further, interesting application fields are simulations of surgeries, emergency cases, or other critical situations in which each hand movement must be correct as well as therapy or learning processes in production or laboratories. Additionally, it can also be used to learn sign language or how to write, for example. The possibilities are manifold and each field of application has its own characteristics and challenges to thoroughly convey motion guidance from an egocentric perspective.

Literature

Anderson, F. et al., 2013. YouMove: Enhancing Movement Training with an Augmented Reality Mirror. In *Proceedings of the 26th annual ACM symposium on User interface software and technology - UIST '13*. pp. 311–320. Available at: http://dl.acm.org/citation.cfm?id=2501988.2502045.

Chua, P.T. et al., 2003. Training for physical tasks in virtual environments: Tai Chi. In *Proceedings of the IEEE Virtual Reality*. pp. 87–94.

Halsband, U., 2006. Motorisches Lernen. In S. Gauggel & M. Herrmann, eds. *Handbuch der Neuro- und Biopsychologie*. Göttingen: Hogrefe Verlag GmbH & Co. KG, pp. 265–273. Available at: https://books.google.de/books?id=5RUV7YXulywC&printsec=frontcover&hl=de#v=onepage&q&f=false.

Halsband, U. & Lange, R.K., 2006. Motor learning in man: A review of functional and clinical studies. *Journal of Physiology Paris*, 99(4–6), pp.414–424.

Han, P.-H. et al., 2016. AR-Arm: Augmented Visualization for Guiding Arm Movement in the First-Person Perspective. In *Proceedings of the 7th Augmented Human International Conference 2016*. pp. 31:1-31:4. Available at: http://doi.acm.org/10.1145/2875194.2875237.

Han, P.-H. et al., 2017. My Tai-Chi Coaches: An Augmented-Learning Tool for Practicing Tai-Chi Chuan. In *Proceedings of the 8th Augmented Human International Conference on - AH '17*. New York, New York, USA: ACM Press, pp. 1–4. Available at: http://dl.acm.org/citation.cfm?doid=3041164.3041194.

Hart, S.G., 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 50(9), pp.904–908.

Hart, S.G. & Staveland, L.E., 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Human Mental Workload*, 52, pp.139–183.

Hoang, T.N. et al., 2016. Onebody: Remote Posture Guidance System Using First Person View in Virtual Environment. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction*. p. 25:1--25:10. Available at: http://doi.acm.org/10.1145/2971485.2971521.

Kruskal, J.B. & Liberman, M., 1983. The Symmetric Time-Warping Problem: from Continuous to Discrete. In D. Sankoff & J. B. Kruskal, eds. *Time Warps, String Edits, and Macromolecules - The Theory and Practice of Sequence Comparison*. CSLI Publications, Stanford, CA 94305, pp. 125–161.

Laugwitz, B., Held, T. & Schrepp, M., 2008. Construction and evaluation of a user experience questionnaire. In *Proceedings of the 4th Symposium of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer Society (USAB'08)*. pp. 63–76.

Milgram, P. et al., 1994. Augmented Reality: A class of displays on the reality-virtuality continuum. *Proc. SPIE (International Society of Optics and Photonics) Conf. Telemanipulator and Telepresence Technologies*, 2351(34), pp.282–292. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.83.6861&rep=rep1&type=pdf.

Motokawa, Y. & Saito, H., 2007. Support system for guitar playing using augmented reality display. In *Proceedings - ISMAR 2006: Fifth IEEE and ACM International Symposium on Mixed and Augmented Reality*. pp. 243–244.

Sakoe, H. & Chiba, S., 1978. Dynamic programming algorithm optimization for spoken word recognition. *IEEE Transactions on Acoustics, Speech and Signal Processing*, 26(1), pp.43–49.

Sodhi, R., Benko, H. & Wilson, A.D., 2012. LightGuide: Projected Visualizations for Hand Movement Guidance. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*. New York, New York, USA: ACM Press, pp. 179–188. Available at: http://dl.acm.org/citation.cfm?doid=2207676.2207702.

Sousa, M. et al., 2016. SleeveAR: Augmented reality for rehabilitation using realtime feedback. In *International Conference on Intelligent User Interfaces, Proceedings IUI*. pp. 175–185. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84963749228&partnerID=40&md5=74a39e80a809934c7cefb29c61b43ded.

Tang, R. et al., 2014. Physio@Home: Exploring visual guidance and feedback techniques for physiotherapy exercises. In *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14*. pp. 1651–1656. Available at: http://dl.acm.org/citation.cfm?id=2611780.2581197.

Wang, W. & Milgram, P., 2001. Dynamic Viewpoint Tethering for Navigation in Large-scale Virtual Environments. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 45(27), pp.1862–1866. Available at: http://journals.sagepub.com/doi/abs/10.1177/154193120104502702.

Yan, S. et al., 2015. OutsideMe: Augmenting Dancer's External Self-Image by Using A Mixed Reality System. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*. pp. 965–970. Available at: http://doi.acm.org/10.1145/2702613.2732759.

Yang, U. & Kim, G.J., 2002. Implementation and Evaluation of "Just Follow Me": An Immersive, VR-Based, Motion-Training System. *Presence: Teleoperators and Virtual Environments*, 11(3), pp.304–323. Available at: http://www.mitpressjournals.org/doi/abs/10.1162/105474602317473240.

Zhang, Z., 1994. Iterative point matching for registration of free-form curves and surfaces. *International Journal of Computer Vision*, 13(2), pp.119–152.

Appendix A: Study documents

A.1 Procedure checklist

Checkliste Ablauf

Rebecca Weber | AG Mensch-Computer-Interaktion, Universität Konstanz

- Teilnehmer begrüßen
- Kurz Ablauf ansprechen
- Ablaufplan + Einverständniserklärung + Fotogenehmigung
- Demografischer Fragebogen
- Systemerklärung
  - OptiTrack System: Kameras und Anzug => reflektierende Marker
  - Skeleton kalibrieren (T-Pose erklären)
  - Körpermaße
  - Oculus Rift Brille: Achtung Marker!
  - Drei Aufgaben: Verschiedene Taktarten dirigieren, spiegelsymmetrische Bewegung
  - Blaue Visualisierung (Realistisch / Abstrakt je nach Gruppe)
  - Drei unterschiedliche Varianten, vor jeder Variante eine Übungsaufgabe
  - Aufgabe aus dem Gedächtnis wiederholen
  - Noch Fragen?
- Skeleton kalibrieren
- Unity starten + Bildschirmaufnahme starten
- Körpermaße abmessen, notieren + eingeben
- Oculus Rift aufsetzen (ggf. Fokus anpassen)
- Übungsaufgabe mit Kondition 1 | noch Fragen?
- Erste Aufgabe:
  - Taktart ansagen
  - Konditionen korrekt? Aufgabe korrekt?
  - Videoaufnahme gestartet?
  - Motive Aufnahme gestartet?
- NASA TLX + UEQ
- Recall von erster Aufgabe (Taktart nochmal ansagen)
- Bewertung + Mini-Interview
- Übungsaufgabe mit Kondition 2 | noch Fragen?
- Zweite Aufgabe:
  - Taktart ansagen
  - Konditionen korrekt? Aufgabe korrekt?
  - Videoaufnahme gestartet?
  - Motive Aufnahme gestartet?
- NASA TLX + UEQ
- Recall von zweiter Aufgabe (Taktart nochmal ansagen)
- Bewertung + Mini-Interview
- Übungsaufgabe mit Kondition 3 | noch Fragen?
- Dritte Aufgabe:
  - Taktart ansagen
  - Konditionen korrekt? Aufgabe korrekt?
  - Videoaufnahme gestartet?
  - Motive Aufnahme gestartet?
- NASA TLX + UEQ
- Recall von zweiter Aufgabe (Taktart nochmal ansagen)
- Bewertung + Mini-Interview
- Nachbefragung

A.2 Schema overview

Schema

Participant	Group		1. Task	2. Task	3. Task	Code	Date + Time	Notes
01	Realistic	1	Path triple	Points & path waiting quadruple	Points with path sextuple	R01_x		
02	Abstract	1	Path triple	Points & path waiting quadruple	Points with path sextuple	A01_x		
03	Realistic	2	Path triple	Points with path quadruple	Points & path waiting sextuple	R02_x		
04	Abstract	2	Path triple	Points with path quadruple	Points & path waiting sextuple	A02_x		
05	Realistic	3	Points & path waiting quadruple	Path sextuple	Points with path triple	R03_x		
06	Abstract	3	Points & path waiting quadruple	Path sextuple	Points with path triple	A03_x		
07	Realistic	4	Points & path waiting sextuple	Points with path triple	Path quadruple	R04_x		
08	Abstract	4	Points & path waiting sextuple	Points with path triple	Path quadruple	A04_x		
09	Realistic	5	Points with path quadruple	Path sextuple	Points & path waiting triple	R05_x		
10	Abstract	5	Points with path quadruple	Path sextuple	Points & path waiting triple	A05_x		
11	Realistic	6	Points with path sextuple	Points & path waiting triple	Path quadruple	R06_x		
12	Abstract	6	Points with path sextuple	Points & path waiting triple	Path quadruple	A06_x		
13	Realistic	7	Path quadruple	Points & path waiting sextuple	Points with path triple	R07_x		
14	Abstract	7	Path quadruple	Points & path waiting sextuple	Points with path triple	A07_x		
15	Realistic	8	Path quadruple	Points with path sextuple	Points & path waiting triple	R08_x		
16	Abstract	8	Path quadruple	Points with path sextuple	Points & path waiting triple	A08_x		
17	Realistic	9	Points & path waiting sextuple	Path triple	Points with path quadruple	R09_x		
18	Abstract	9	Points & path waiting sextuple	Path triple	Points with path quadruple	A09_x		
19	Realistic	10	Points & path waiting triple	Points with path quadruple	Path sextuple	R10_x		
20	Abstract	10	Points & path waiting triple	Points with path quadruple	Path sextuple	A10_x		
21	Realistic	11	Points with path sextuple	Path triple	Points & path waiting quadruple	R11_x		
22	Abstract	11	Points with path sextuple	Path triple	Points & path waiting quadruple	A11_x		
23	Realistic	12	Points with path triple	Points & path waiting quadruple	Path sextuple	R12_x		
24	Abstract	12	Points with path triple	Points & path waiting quadruple	Path sextuple	A12_x		

A.3 Welcome text / procedure description

Studienablauf „Egozentrische Bewegungsanleitung“

Rebecca Weber | AG Mensch-Computer-Interaktion, Universität Konstanz

Liebe(r) Studienteilnehmer(in),

zunächst vielen Dank, dass Sie sich für eine Teilnahme an meiner Studie und der damit verbundenen Unterstützung meiner Master-Arbeit bereiterklärt haben.

In dieser Studie geht es darum, verschiedene Visualisierungen zur Anleitung von Armbewegungen aus der egozentrischen Perspektive zu untersuchen. Das System basiert auf Virtual-Reality und „Motion Capture“ Technologien. Für die Bewegungserkennung ist es notwendig einen Ganzkörperanzug anzuziehen. Bei manchen Menschen können bei der Verwendung einer Virtual-Reality-Brille Unwohlsein, Übelkeit, Orientierungsverlust oder ähnliche Beschwerden auftreten. Sollte dies bei Ihnen der Fall sein, sagen Sie bitte umgehend Bescheid und setzen Sie die Brille ab. Außerdem möchte ich darauf hinweisen, dass das System getestet wird und nicht Ihr Können, Sie können hier also keine Fehler machen. Eventuell auftretende Fehler sind dem System geschuldet.

Zu Beginn erhalten Sie einen Fragebogen mit einigen Fragen zu Ihnen und Ihrer Vorerfahrung mit relevanten Themen. Im Anschluss werde ich Ihnen das System zur egozentrischen Bewegungsanleitung und Ihre Aufgabe erklären.
Es gibt insgesamt drei verschiedene Aufgaben und Varianten der Bewegungsanleitung. Jede der drei Sequenzen besteht zunächst aus einer kleinen Übungsaufgabe, der eigentlichen Aufgabe und zwei Bewertungsbögen im Anschluss. Danach sollen Sie die gelernte Bewegung noch einmal ohne Anleitung ausführen und einige abschließende Fragen zu der Sequenz beantworten. Währenddessen werde ich eine Videoaufnahme und ggf. Notizen machen. Nachdem Sie alle drei Aufgaben ausgeführt und bewertet haben, möchte ich Ihnen abschließend noch einige Fragen zur Nutzung des Systems stellen.
Sie können jederzeit Fragen stellen oder die Teilnahme an der Studie beenden. Geben Sie bitte kurz Bescheid, wenn Sie die VR-Brille absetzen möchten.

Die Teilnahme an der Studie dauert ca. 1,5 Std. und Sie erhalten dafür eine Vergütung in Höhe von 15,- Euro.

Zuletzt möchte ich Sie bitten, eine Einverständniserklärung über die Verwendung der erhobenen Daten zu unterschreiben.

Haben Sie noch Fragen zum Studienablauf?

A.4 Informed consent

Einverständniserklärung

Studie zum Thema „Egozentrische Bewegungsanleitung“

Studienleitung

Rebecca Weber
AG Mensch-Computer-Interaktion, Universität Konstanz

Datenerhebung

Im Rahmen dieser Studie werden Daten in Form von Fragebögen, Notizen, Bewegungsdaten (Log-Daten), Fotos und Videoaufnahmen erhoben. Diese Daten werden anonymisiert ausgewertet, vertraulich behandelt und nicht an Dritte weitergegeben. Die Daten werden ausschließlich für die Auswertung zu unten genannten Zwecken verwendet und für die Analyse, Dokumentation, Präsentation und Publikation von wissenschaftlicher Arbeit genutzt.

Verwendung

Die Studie zum Thema „Egozentrische Bewegungsanleitung“ dient der Evaluation verschiedener Visualisierungen zur Bewegungsanleitung von Armbewegungen aus der egozentrischen Perspektive. Die erhobenen Daten werden in einer Master-Arbeit ausgewertet und präsentiert und können auch später noch für eventuelle wissenschaftliche Veröffentlichungen verwendet werden.

Einverständnis

Hiermit erkläre ich mich mit folgenden Punkten einverstanden:

- Ich wurde über die Ziele, den Ablauf und die voraussichtliche Dauer der Aufgaben und Befragungen sowie den Erhalt einer Vergütung aufgeklärt.
- Ich bin mit der Verwendung der Daten in anonymisierter Form für oben genannte Zwecke einverstanden und bin hiermit darüber aufgeklärt, dass alle Daten vertraulich behandelt und nicht an Dritte weitergegeben werden.
- Mir ist bekannt, dass die Teilnahme an der Studie freiwillig ist und ich sie jederzeit ohne Angabe von Gründen beenden kann. Die Einverständniserklärung kann jederzeit widerrufen werden. Jedoch können anonymisierte Daten, welche bereits in wissenschaftliche Arbeiten eingeflossen sind, nicht mehr gelöscht werden.

______________________	______________________	______________________
Studienteilnehmer(in)	Ort, Datum	Unterschrift

Hiermit verpflichtet sich die Studienleitung, sämtliche gewonnenen Daten lediglich wie oben beschrieben zu verwenden:

Rebecca Weber	______________________	______________________
Studienleitung	Ort, Datum	Unterschrift

A.5 Photo permission

Fotogenehmigung

Ich erkläre mich damit einverstanden, dass Standbilder aus Videoaufnahmen oder Fotos von mir, die nach vorheriger Absprache während der Studie zum Thema „Egozentrische Bewegungsanleitung“ entstanden sind, in folgenden Arbeiten abgebildet werden:

- ☐ Master-Arbeit zum Thema „Egozentrische Bewegungsanleitung“ von Rebecca Weber
- ☐ Wissenschaftliche Veröffentlichungen der AG Mensch-Computer-Interaktion, Universität Konstanz

Das Einverständnis kann jederzeit, jedoch nur vor der jeweiligen Einreichung, widerrufen werden.

______________________	______________________	______________________
Name	Ort, Datum	Unterschrift

Fotos oben genannter Person werden ausschließlich in den angegebenen Arbeiten verwendet und nicht an Dritte weitergegeben:

______________________	______________________	______________________
Name	Ort, Datum	Unterschrift

A.6 Demographic questionnaire

ID: ___________

Demographischer Fragebogen

Alter: ________

Geschlecht: ☐ weiblich ☐ männlich ☐ keine Angabe / sonstiges

Deutschkenntnisse: ☐ Muttersprache
☐ Fremdsprache, Niveau: ________________________

Beruf / Studiengang: ____

Tragen Sie eine Sehhilfe? ☐ ja ☐ nein

Wenn ja: ☐ Brille ☐ Kontaktlinsen

Dioptrien: ________________________

Haben Sie sonstige Einschränkungen bzgl. Ihrer Sehfähigkeit (z.B. Farbenblindheit)?

☐ nein ☐ ja, folgende: ____

Haben Sie sonstige körperliche Einschränkungen (insbesondere bzgl. Armbewegungen)?

☐ nein ☐ ja, folgende: ____

Haben Sie bereits Erfahrungen mit Virtual Reality (VR)? ☐ ja ☐ nein
Wenn ja:
Wie häufig verwenden Sie VR? ☐ täglich
☐ mind. einmal pro Woche
☐ mind. einmal pro Monat
☐ selten / wenige Male getestet

Wofür verwenden Sie VR? ____

Welche(s) VR-Gerät(e) verwenden Sie? ___________________________________

Bitte wenden!

Spielen Sie ein oder mehrere Musikinstrument(e)? (Auch Gesang zählt! Bitte kreuzen Sie, auch wenn Sie nicht mehr aktiv spielen, ‚ja' an und beantworten die darauffolgenden Fragen.) ☐ ja ☐ nein
Wenn ja:
Welche(s) Musikinstrument(e) spielen Sie? ______________________________

____

Wie häufig spielen Sie diese(s)?
☐ täglich
☐ mind. einmal pro Woche
☐ mind. einmal pro Monat
☐ selten / nicht mehr aktiv

Spielen Sie in einem Orchester oder singen Sie in einem Chor?
☐ ja, mind. einmal pro Woche
☐ ja, mind. einmal pro Monat
☐ ja, wenige Male pro Jahr
☐ nein, nicht mehr
☐ nein, habe ich noch nie

Können Sie Noten lesen? ☐ ja ☐ nein

Kennen Sie folgende verschiedenen Taktarten?
Dreiertakt: ☐ ja ☐ nein
Vierertakt: ☐ ja ☐ nein
Sechsertakt: ☐ ja ☐ nein

Kennen Sie klassische Dirigierbewegungen?
☐ ja, selbst mal geübt
☐ ja, gesehen
☐ nein

Machen Sie Sport? ☐ ja ☐ nein
Wenn ja:
Welche Sportart(en)? ____

Wie häufig trainieren Sie diese?
☐ täglich
☐ mind. einmal pro Woche
☐ mind. einmal pro Monat
☐ weniger als einmal pro Monat

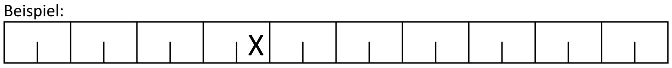
A.7 NASA TLX questionnaire

ID: ___________

Beanspruchung

Geben Sie jetzt für jede der untenstehenden Dimensionen an, wie hoch die Beanspruchung war. Markieren Sie dazu bitte auf den folgenden Skalen, in welchem Maße Sie sich in den sechs genannten Dimensionen von der Aufgabe beansprucht oder gefordert gesehen haben.

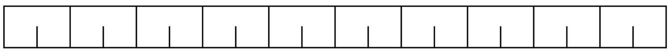
Beispiel:



Gering Hoch

Geistige Anforderung

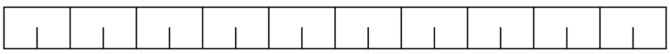
Wie viel geistige Anforderung war bei der Informationsaufnahme und bei der Informationsverarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen ...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex, erfordert sie hohe Genauigkeit oder ist sie fehlertolerant?



Gering Hoch

Körperliche Anforderung

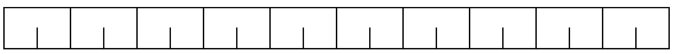
Wie viel körperliche Aktivität war erforderlich (z.B. ziehen, drücken, drehen, steuern, aktivieren ...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?



Gering Hoch

Zeitliche Anforderung

Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt mit dem die Aufgaben oder Aufgabenelemente auftraten? War die Aufgabe langsam und geruhsam oder schnell und hektisch?



Gering Hoch

Bitte wenden!

Leistung

Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

Gut Schlecht

Anstrengung

Wie hart mussten Sie arbeiten, um Ihren Grad an Aufgabenerfüllung zu erreichen?

Gering Hoch

Frustration

Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

Gering Hoch

Kontrollieren sie bitte, ob Sie zu allen Fragen Angaben gemacht haben. Bei Unklarheiten wenden Sie sich bitte an die Versuchsleiterin / den Versuchsleiter.

A.8 User Experience Questionnaire

ID: ___________

User Experience

Bitte füllen Sie außerdem den nachfolgenden Fragebogen aus. Er besteht aus Gegensatzpaaren von Eigenschaften, die das System haben kann. Abstufungen zwischen den Gegensätzen sind durch Kreise dargestellt. Durch Ankreuzen eines dieser Kreise können Sie Ihre Zustimmung zu einem Begriff äußern.

Beispiel:

attraktiv	○	⊗	○	○	○	○	○	unattraktiv

Mit dieser Beurteilung sagen Sie aus, dass Sie das System eher attraktiv als unattraktiv einschätzen.

Entscheiden Sie möglichst spontan. Es ist wichtig, dass Sie nicht lange über die Begriffe nachdenken, damit Ihre unmittelbare Einschätzung zum Tragen kommt.

Bitte kreuzen Sie immer eine Antwort an, auch wenn Sie bei der Einschätzung zu einem Begriffspaar unsicher sind oder finden, dass es nicht so gut zum System passt.

Es gibt keine „richtige“ oder „falsche“ Antwort. Ihre persönliche Meinung zählt!

Bitte wenden!

Bitte geben Sie nun Ihre Einschätzung des Produkts ab. Kreuzen Sie bitte nur einen Kreis pro Zeile an.

	1	2	3	4	5	6	7		
unerfreulich	○	○	○	○	○	○	○	erfreulich	1
unverständlich	○	○	○	○	○	○	○	verständlich	2
kreativ	○	○	○	○	○	○	○	phantasielos	3
leicht zu lernen	○	○	○	○	○	○	○	schwer zu lernen	4
wertvoll	○	○	○	○	○	○	○	minderwertig	5
langweilig	○	○	○	○	○	○	○	spannend	6
uninteressant	○	○	○	○	○	○	○	interessant	7
unberechenbar	○	○	○	○	○	○	○	voraussagbar	8
schnell	○	○	○	○	○	○	○	langsam	9
originell	○	○	○	○	○	○	○	konventionell	10
behindernd	○	○	○	○	○	○	○	unterstützend	11
gut	○	○	○	○	○	○	○	schlecht	12
kompliziert	○	○	○	○	○	○	○	einfach	13
abstoßend	○	○	○	○	○	○	○	anziehend	14
herkömmlich	○	○	○	○	○	○	○	neuartig	15
unangenehm	○	○	○	○	○	○	○	angenehm	16
sicher	○	○	○	○	○	○	○	unsicher	17
aktivierend	○	○	○	○	○	○	○	einschläfernd	18
erwartungskonform	○	○	○	○	○	○	○	nicht erwartungskonform	19
ineffizient	○	○	○	○	○	○	○	effizient	20
übersichtlich	○	○	○	○	○	○	○	verwirrend	21
unpragmatisch	○	○	○	○	○	○	○	pragmatisch	22
aufgeräumt	○	○	○	○	○	○	○	überladen	23
attraktiv	○	○	○	○	○	○	○	unattraktiv	24
sympathisch	○	○	○	○	○	○	○	unsympathisch	25
konservativ	○	○	○	○	○	○	○	innovativ	26

A.9 Performance rating and interview

ID: ___________

Bewertung

Bitte bewerten Sie Ihre Zustimmung zu folgenden Aussagen in Bezug auf die zuletzt ausgeführte Aufgabe:

Ich konnte der Anleitung gut folgen.

☐ trifft vollkommen zu ☐ trifft eher zu ☐ teils / teils ☐ trifft eher nicht zu ☐ trifft gar nicht zu

Ich habe die Bewegung mit Anleitung exakt ausgeführt.

☐ trifft vollkommen zu ☐ trifft eher zu ☐ teils / teils ☐ trifft eher nicht zu ☐ trifft gar nicht zu

Ich konnte mir die Bewegung gut einprägen.

☐ trifft vollkommen zu ☐ trifft eher zu ☐ teils / teils ☐ trifft eher nicht zu ☐ trifft gar nicht zu

Ich habe die Bewegung ohne Anleitung exakt ausgeführt.

☐ trifft vollkommen zu ☐ trifft eher zu ☐ teils / teils ☐ trifft eher nicht zu ☐ trifft gar nicht zu

Wie hat Ihnen diese Art Bewegungen zu lernen gefallen? Was war positiv, was negativ?

Was hat Ihnen besser / schlechter gefallen im Vergleich zu herkömmlichen Möglichkeiten Bewegungen zu lernen? (Unterricht, Videos, Bilder, Text, ...)

A.10 Follow-up interview

ID: ___________

Nachbefragung

1. Welche der drei Varianten hat Ihnen am besten / am schlechtesten gefallen? Warum?

☺ ____________________ 😐 ____________________ ☹ ____________________

2. Können Sie sich vorstellen solch ein System in Zukunft zu nutzen, um selbstständig Bewegungen zu lernen?

3. Gibt es weitere Szenarien / Anwendungsfälle, für die Sie sich solch ein System zum Lernen von Bewegungen vorstellen können?

Bitte wenden!

4. Haben Sie Verbesserungsvorschläge oder sonstige Anmerkungen?

A.11 Receipt

Empfangsbestätigung

Ich habe für die Teilnahme an der Studie zum Thema „Egozentrische Bewegungsanleitung“ eine Vergütung in Höhe von 15,- EUR erhalten.

Studienteilnehmer(in):

___________________________	Konstanz, den______________	___________________________
Name	Ort, Datum	Unterschrift

Studienleitung:

Rebecca Weber	Konstanz, den______________	___________________________
	Ort, Datum	Unterschrift

Appendix B: Contents of the USB thumb drive

The attached USB thumb drive contains the following files and directories:

- master_project_report_Rebecca-Weber_07-2018.pdf
- master_thesis_Rebecca-Weber_09-2018.pdf
- Directory "unity_project" contains the Unity project as a ZIP file
- Directory "study_documents" contains the documents used in the study
- Directory "study_data" contains several files containing the collected data and a ZIP file "scoring" which contains the log files and scripts for the accuracy measurement