EGuide: Investigating different Visual Appearances and Guidance Techniques for Egocentric Guidance Visualizations

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Figure 1: (a) shows a user with EGuide. Infrared cameras track the user's movements. A virtual-reality head-mounted display provides output. (b) gives an overview on the independent variables *visual appearance* and *guidance technique* that we investigated in a user study. (c) and (d) show two of the investigated guidance visualizations: One with an abstract (*VA_ABSTRACT*) and one with a realistic (*VA_REALISTIC*) visual shape. The figures also show two of the three investigated guidance techniques: In (c) the guidance visualization moves along a movement without pause (*GT_CONTINUOUS*). The user is supposed to follow the moving blue arms continuously. In (d) additionally, half-transparent arms are shown at the next keyframe (*GT_KEYFRAME*). Keyframes are particularly important postures within a movement. When the moving arms reach a keyframe, the visualization of the keyframe disappears and the next keyframe is shown. In the third investigated guidance technique, the visualization additionally pauses at each keyframe until a user reaches it (*GT_PAUSING*). For an illustration of *GT_PAUSING* see Figure 3.

ABSTRACT

Mid-air arm movements are important for various activities. However, common resources for their self-directed practice require practitioners to divide their focus between an external source (e.g., a video screen) and moving. Past research

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found benefits for egocentric guidance visualizations compared to common resources. However, there is limited evidence about how such visualizations should look and behave. EGuide supports the investigation of different egocentric visualizations for the guidance of mid-air arm movements. We compared two visual appearances for egocentric guidance visualizations that differ in their shape (look), and three guidance techniques that differ by how they guide a user (behavior). For visualizations with a continuously moving guidance technique, our results suggest a higher movement accuracy for a realistic than an abstract shape. For user experience and preference, our results suggest that visualizations with an abstract shape and a guidance technique that visualizes important postures should not pause at important postures.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → *Education*.

KEYWORDS

egocentric guidance, virtual reality, learning, arm movements

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1 INTRODUCTION

Various activities related to sports, music, and other domains require the learning and conduct of mid-air arm movements. For example, a musical conductor needs to learn multiple mid-air arm movement sequences to guide an orchestra in playing different beats. Instructions provided by a human teacher can be useful to perform and internalize such movements. However, the availability of human teachers is restricted by factors like time, place, and financial resources. If a human teacher is not available, the learning and conduct of movements are commonly supported by videos, texts, pictures, and similar. Although these common resources can help to increase understanding, they usually lack in terms of direct support during practice: When using resources like videos, texts, and pictures, practitioners usually need to divide their focus between an external source (e.g., a video screen) and the conduct of a movement. Furthermore, practitioners need to transfer exocentric depictions or textual descriptions to physical actions mentally.

In this work, we explore a different approach to provide guidance during the practice of mid-air arm movements. Building on past research, we investigate in-situ guidance from an egocentric, first-person perspective. In this case, instructions are not represented on a separate external source like a video screen. Instead, related systems make use of technology like a head-mounted display (e.g., [28]) or a projector (e.g., [22]) to directly superimpose guidance visualizations on a practitioner's view. Compared to common resources that deliver movement instructions, a system that provides egocentric guidance visualizations can allow users to move freely in space as well as to focus their attention directly on the guided body-part.

But, how should egocentric guidance visualizations look and behave? Existing research found benefits for the use of superimposed egocentric guidance visualizations in contrast to the use of common resources like videos to support the learning and conduct of movements [10, 22]. However, there is limited empirical evidence that demonstrates how users' movement accuracy, experience, and preference are affected by different egocentric guidance visualizations depending on their visual appearance (look) and the way in which they guide a user (behavior). To address this research gap, we present *EGuide*, a virtual reality (VR) system that facilitates the comparative investigation of egocentric guidance visualizations for mid-air arm movements (see Figure 1). A VR head-mounted display (HMD) is used to superimpose an egocentric guidance visualization on a user's view. When interacting in the virtual environment, users see themselves in the form of an avatar. Our work contributes by presenting and discussing the empirical results of a comparative user study that we conducted with *EGuide*. In our study, we focused on the guidance of mid-air arm movements. Our study made use of movement tasks from musical conducting. We compared two different *visual appearances* for egocentric guidance visualizations that differ in terms of their visual shape (look), and three *guidance techniques* that differ in the way in which they guide a user (behavior). The conditions of our study were inspired by previous work. The results of our investigation can inform the future design of egocentric guidance visualizations. Furthermore, although our implementation of *EGuide* is not technologically novel, it provides a solid ground for the investigation of different aspects related to egocentric guidance visualizations. Our implementation might inspire future systems that support the investigation of different aspects related to egocentric guidance visualizations.

In the following, we give an overview on related work, present *EGuide*, and discuss the results of the conducted user study.

2 RELATED WORK

Various previous work investigated the computer-aided learning and conduct of movements with different technologies, including electric muscle stimulation (e.g., [9, 25]), augmented reality (AR; e.g., [7]), and VR (e.g., [5]). In many cases, visualizations were employed to guide users. Based on related work, the system and user study presented in this paper address multiple aspects that are important related to movement guidance visualizations: (i) the visual perspective on the visualization, and (ii) the visual appearance of and the guidance technique provided by the visualization.

Visual Perspective

Technology allows for the representation of guidance visualizations from different visual points of view, including an exocentric third-person and an egocentric first-person visual perspective.

Exocentric, Third-Person Visual Perspective. There are many examples of previous work that used an exocentric visual perspective to provide movement guidance. YouMove [1] makes use of an augmented-reality (AR) mirror to provide visual guidance for arbitrary movements. Relatedly, Motokawa and Saito [18] created an AR mirror that provides guidance for guitar playing by overlaying a virtual hand model and lines onto the camera captured image of a guitar. Tang et al. [26] introduced Physio@Home, a system to support physiotherapy exercises. They used a screen to augment guidance information over the live-camera feed of a user. Velloso et al. [27] presented MotionMA. Movement guidance is supported by a side-by-side view of a prerecorded demonstration video and a stick figure that shows a user's own movement. Chan et al. [2] used head-worn glasses and a large screen. Users can view a 3-dimensional avatar that demonstrates a dance movement from different angles by physically moving in front of the screen. Their own movement is shown next to the demonstration. Using a CAVE virtual environment, Kyan et al. [16] supported the recording, assessment, and visual display of ballet-dance movements. Chen et al. [3] presented Immertai. The system supports immersive visual guidance for Tai Chi movements. Movements are demonstrated by a remote-located teacher and mapped to a virtual avatar that users can follow. Users can simultaneously see other avatars that reflect the movement of different students, including their own.

Egocentric, First-Person Visual Perspective. To superimpose guidance visualizations on a user's body, can allow users to move freely in space and to focus their attention directly on the guided body-part. Yang and Kim [28] used a VR HMD to show a "ghost" visualization that can demonstrate a movement from a first-person perspective. A user is supposed to follow the "ghost." Chua et al. [5] used VR technology to investigate visual layouts for guidance visualizations to support Tai Chi training. The investigated layouts either guided users from an exocentric perspective or mixed an egocentric and exocentric view on the guidance information. None of the layouts had a substantial effect on learning. LightGuide [22] supports the guidance of mid-air hand movements by projecting hints on a user's hand. The authors found participants' movement accuracy to be significantly higher when they were guided by LightGuide, compared to a video. Hoang et al. [10] presented Onebody. The VR system supports the remote guidance of postures from a

first-person perspective. The authors found a higher posture accuracy for Onebody compared to the delivery of instructions by a prerecorded video, a video conferencing tool, and a third-person view on the movement guidance. Other work investigated AR-based approaches related to posture training [12], telerehabilitation [4], climbing [14], and Tai Chi [7] and rehabilitation exercises [23].

Although past findings suggest that egocentric guidance visualizations can provide a higher movement and posture accuracy than other forms of guidance [10, 22], there is limited empirical evidence that demonstrates how users' movement accuracy, experience, and preference are affected by different visualizations depending on their visual appearance and the way in which they guide users. Many of the past work that considered visual guidance from an egocentric perspective investigated only one guidance visualization (e.g., [28]). We address this gap in existing research by presenting EGuide, a system that allows for the investigation of different visual appearances and guidance techniques for egocentric guidance visualizations.

Movement Guidance Visualization

In this paper, we use EGuide to investigate two visual appearances that differ in their visual shape, and three guidance techniques that differ in the way in which they guide a user. In the following, we show how related work inspired the conditions of our user study.

Visual Appearance. There are multiple aspects by which the visual appearance of the egocentric guidance visualizations that were investigated by past work differ. One essential aspect is the guidance visualization's *visual shape*. Most past work either employs a *realistically* or an *abstractly* shaped guidance visualization. We consider the visual shape as realistic if it closely resembles the real-world shape of the elements that are part of the guided movement (e.g., realistically shaped virtual arms [7]). In contrast, we see the visual shape as abstract if it reflects an abstraction of the real-world elements that are part of the guided movement (e.g., virtual stick-figure arms [10]). Some related work also *mixed* realistically and abstractly shaped elements (e.g., [12]). Katzakis et al. [12] compared two visual and two visiohaptic approaches to guide the training of postures. The first visual condition had an abstract visual shape. Stick-figure elements showed a user's current posture and the target posture. The second visual condition was mixed. It added realistically shaped virtual hands that pushed the user towards the correct posture. Their results show a significantly lower task completion time for the mixed condition. There is also previous research that suggests benefits for a realistic in contrast to an abstract visual appearance of a user's *own* hands in VR. Schwind et

al. [20] found that users perceive realistic hands with five fingers as more human-like than abstract hands and realistic hands with fewer fingers. In relation, for realistic hands the authors' results suggest that users' presence decreases in line with the number of fingers. The results of another study suggest a lower eeriness rating for a visualization of users' hands whose shape and texture correspond to their gender, in contrast to an abstract visualization [21]. Also related, Knierim et al. [13] found realistic looking hands causing the lowest workload and highest presence scores between different hand visualizations for keyboard typing. However, it is unclear to what extent findings that are valid for the visual appearance of a user's *own* hands can be adopted to the visual appearance of egocentric guidance visualizations. As mentioned before, previous work mostly employed either a realistic or an abstract visual shape for egocentric guidance visualizations. In contrast, we focused on the direct comparison between the two conditions (see Figure 3). To our knowledge, our user study is the first that provides empirical evidence for significant differences between the two different visual shape conditions.

Guidance Technique. Much previous work related to egocentric guidance visualizations, made use of a guidance technique which provides a *continuous demonstration* of a movement that a learner should follow (e.g., [28]). Other previous work focused on the guidance of users towards important postures that are part of a movement (e.g., [10]). These systems usually *visualize* important postures that a user should match. For example, in OneBody [10], users are supposed to position their own body so that it matches an egocentric stick-figure visualization. The AR mirror YouMove [1], facilitates posture guidance by briefly *pausing* the movement of the guidance visualization at *keyframes*—particularly important postures within a movement to match—to give learners time to reach these postures. The visualization of and the pausing at keyframes may support the guidance of movements. However, to our knowledge, past research did not investigate the provision of keyframes for egocentric guidance visualizations. In contrast to previous related work, we explicitly considered this aspect. As much previous research used a continuous demonstration of the guided movement without highlighting of keyframes, we implement this approach as baseline condition *GT_CONTINUOUS*. Inspired by past work that considered the guidance of postures, we compared *GT_CONTINUOUS* with the two guidance techniques *GT_KEYFRAME* and *GT_PAUSING*. In *GT_KEYFRAME*, keyframes are visualized, but the movement guidance is still continuous. In *GT_PAUSING*, keyframes are visualized, and the movement guidance pauses at each keyframe for a user to match it. Figure 3 illustrates all three conditions.

Figure 2: User representation for (a) a female, and (b) a male.

3 EGUIDE IMPLEMENTATION

In the following, we present EGuide, a system that supports the investigation of different egocentric guidance visualizations. We also describe how we implemented the conditions of our user study.

Infrastructure

EGuide employs 24 ceiling-mounted Optitrack cameras to track a user's full body except finger movements. A desktop PC with a 7th generation Intel i7 CPU, 32 GB RAM, and a GeForce GTX 1080 is used to process the tracking data and compute the visual output for display on an Oculus VR HMD. We used the HMD Calibration Tool from NaturalPoint Inc. [11] to merge the coordinate systems of the cameras and the HMD. Tracking data are captured and forwarded to a Unity application that handles the representation of the user and the guidance visualizations for the different study conditions.

User Representation

Past research already highlighted the importance of considering users' diversity during the design of VR experiences [21]. EGuide represents a user's body in the form of a gender-specific human avatar that is adapted to participants' body size (see Figure 2). The material of the used female and male avatars' heads was made transparent, as the head is of no relevance for a user representation from an egocentric visual perspective. We decided to use a VR display for output, instead of an AR approach which would have made a virtual representation of the user unnecessary. The reason for this decision is the prevailing limitations of AR display technology. Existing optical see-through displays provide only a small field-of-view which can have a negative effect on egocentric guidance [12]. Although video see-through displays can provide a larger field-of-view, there is an offset between the cameras used for the see-through effect and a user's eyes. This offset is usually compensated by a distortion of the output image which is likely to influence the perception of an egocentric guidance visualization.

Figure 3: The three investigated guidance techniques (*GT_CONTINUOUS*, *GT_KEYFRAME*, and *GT_PAUSING*; see left), and the two visual appearances (*VA_ABSTRACT*, and *VA_REALISTIC*; see bottom right). The guidance techniques are illustrated for the visual appearance condition *VA_REALISTIC* (realistic visual shape).

Movement Guidance Visualizations

Our study was focused on the investigation of users' movement accuracy and experience with different egocentric guidance visualizations. We implemented different visualizations for the guidance of mid-air arm movements, including movements of the left and right forearm and hand. Finger movements were not considered for the study. The guidance visualizations provide support for changes in position and orientation that are naturally supported by the considered body parts. All of the guidance visualizations are scaled dependant on a user's body size. The visualizations differ in their visual appearance and the guidance technique they adopt.

*Visual Appearance Conditions (*VA_ABSTRACT*, *VA_REALISTIC*).* Based on related work, we investigated two different visual appearances for the guidance visualizations: An abstract visual shape (condition *VA_ABSTRACT*), and a realistic visual shape (condition *VA_REALISTIC*). Figure 3 shows both conditions. Related to past work (e.g., [5]), we have separated the visual appearance of the egocentric guidance visualization from the user representation by use of a distinct color. The blue color was not changed between any of the conditions, as our focus was on investigating the difference in shape. For condition *VA_ABSTRACT* the forearm and hand were each visualized as a flat, elongated ellipse. The thin side of the ellipses reflects the sides of the forearm or hand respectively, whereas the flat sides reflect the top and bottom. The visual shape is based on the approach of previous work that employed an abstract visualization in the form of a stick-figure (e.g., [10]). We adapted the visual shape slightly so that it provides an additional cue for the orientation of the forearm

and hand. However, it is noteworthy that this cue is limited, as it does not indicate which side of the arm faces up and which down. We selected this approach as a tradeoff between staying close to the stick-figure approach for comparability to past work, but on the other hand, not neglecting it to provide a hint for changes in orientation. To mitigate potential side-effects of not reflecting the difference between facing up and down, the movement tasks that were selected for the study only require limited rotations of the arm and forearm. Complete turns of the hand or forearm were not part of the movement tasks. As Figure 3 illustrates, related to previous work (e.g., [28]), condition *VA_REALISTIC* closely reflects the real-world shape of the elements that are part of the guided movement. In our case, a virtual representation of the forearm and hand.

*Guidance Technique Conditions (*GT_CONTINUOUS*, *GT_KEYFRAME*, and *GT_PAUSING*).* Figure 3 shows the three guidance techniques that we implemented for our study. The guidance techniques are exemplarily illustrated for the visual appearance condition *VA_REALISTIC* (realistic visual shape). *GT_CONTINUOUS* provides a user with a continuously moving guidance visualization. Similarly to previous work (e.g., [28]), a user can step into the visualization and follow it with his or her own movement. Keyframes—i.e., particularly important postures within the movement—are not visualized in this condition. *GT_KEYFRAME* is equal to *GT_CONTINUOUS* in the sense that the movement is not paused, but differs in the way that it continuously visualizes the next keyframe which the moving part of the guidance visualization will reach. *GT_PAUSING* extends the concept of *GT_KEYFRAME* in the way that the moving part of the guidance visualization pauses

at each keyframe until the user reaches it. As soon as this happens, the next keyframe is visualized, and the moving part of the guidance visualization continues moving towards this keyframe.

4 USER STUDY

Our user study aimed at investigating how the implemented visual appearance and guidance technique conditions affect users' movement accuracy, and users' experience, including their preferences. We investigated two independent variables: (i) the *visual appearance* of the guidance visualization with the two levels *VA_ABSTRACT* and *VA_REALISTIC*, and (ii) the employed *guidance technique* with the three levels *GT_CONTINUOUS*, *GT_KEYFRAME*, and *GT_PAUSING*. Figure 1b provides an overview on the independent variables. We used a 2x3 factor split-plot design. The first independent variable *visual appearance* was considered between-subjects, and the second independent variable *guidance technique* within-subjects. The within-subjects conditions (*GT_CONTINUOUS*, *GT_KEYFRAME*, *GT_PAUSING*) were fully counterbalanced for each of the between-subjects conditions (*VA_ABSTRACT*, *VA_REALISTIC*).

Task

To avoid learning effects between the within-subjects conditions, our study used three different movement tasks which were recorded prior to the study. During the study, the guidance visualizations followed the recorded movement paths with a fixed pace. A Graeco-Latin square was used to balance the assignment of the movement tasks to the different within-subjects conditions. In order to increase the ecological validity of our study, we made use of three mid-air arm movements from a real-world task. We selected musical conducting as a good real-world example for a motor learning task that requires active practice. Furthermore, conducting movements can be performed within a VR HMDs field-of-view. Neglecting this aspect might have affected the accuracy and perception of the movement guidance. We made use of the following three movements from musical conducting: the movements for the (i) triple meter, (ii) quadruple meter, and (iii) sextuple meter (see Figure 4a). To avoid it that the participants are overtaxed, we focused on an easy form of the musical conducting movements, in which both arms follow the same meter. As musical beats reflect important positions within the conducting movements, the respective positions were used as keyframes for the within-subjects conditions *GT_KEYFRAME* and *GT_PAUSING*. Our study was focused on arm movements, including movements of the forearm and hand, so we did not take finger movements into account. We set a constant finger posture for the user representation, and for the visual appearance of the guidance visualization in condition *VA_REALISTIC*. The constant posture was based on

Figure 4: (a) the paths of the movement tasks for the right arm (green lines). The numbers enumerate the beats (black points) and show the direction of the movement. (b) The constant avatar finger posture. Green particle clouds indicate the position to start a task. (c) The avatar finger posture is based on the finger posture of a conductor. (Conducting meters in (a) and (c), ©Königin der Nacht/Wikimedia Commons; Musical Conductor in (c), ©Dron/stock.adobe.com)

the finger posture of a musical conductor (see Figure 4b–c). During the study, the start position for the movement tasks was equal for all conditions. To start a movement task, participants had to move both hands at the position of two particle clouds that indicated the start position (see Figure 4b). During the study, a movement task was always guided ten times in sequence for the condition it was assigned to.

Measures

To measure movement accuracy, we recorded the 3-dimensional position and rotation of the center of the left and right hand and forearm, which resulted in four time series per recorded task. During the study, participants' movement speed was not necessarily consistent with the speed of the guidance visualization they used. Considering this aspect, we used the dynamic time warping (DTW) algorithm [15] to compute the similarity between the prerecorded movements and the movements conducted by the participants. The algorithm computes a minimum error distance for a match between two time series that may vary in their speed. The search of similar points between two time series can be locally constrained to a specified window. We used a window size of 10% of the number of frames of the analyzed time series. For each movement, the computed error distance in regard to each of the four time series was summed up to a total error distance. User experience was measured with the User Experience Questionnaire [17] and supplemented by measuring users' workload with the NASA TLX [8]. We

further created a short Subjective Accuracy Questionnaire with 5-point Likert Scale questions to ask participants how well and how precise they could follow a guidance visualization, after they used it. We supplemented our data with semi-structured interviews. During the analysis, interview statements were first grouped, based on the study conditions they were related to (e.g., *GT_CONTINUOUS*, *VA_ABSTRACT*). In a second step, we inductively formed clusters with similar statements and labeled these. In the last step, we analyzed the final clusters in a quantitative manner by counting similar statements of each cluster.

Participants

Related to the study's task, persons with good knowledge of conducting movements were not accepted as participants. In total, 24 persons participated (12 female, 12 male). The participants were between 19 and 32 years of age ($M = 23.75$, $SD = 3.49$). Most had no visual impairment ($N = 14$). Five of the 10 participants that had a visual impairment wore contact lenses during the study. The other five affirmed that they do not need any visual aids to see everything sharp in the virtual environment. None of the participants had health implications that influenced their ability to move their arms and conduct the movements that were part of the study. One of the participants was familiar with VR displays. The others either had tried a VR display only once or on a few occasions ($N = 14$) or had no experience with the technology at all ($N = 9$).

Procedure

Participants were asked to put on a marker suit and do a T-pose to calibrate the body tracking. The gender of the user representation was set dependent on the participant's gender. For each of the within-subjects conditions (*GT_CONTINUOUS*, *GT_KEYFRAME*, *GT_PAUSING*), participants first conducted the assigned movement task in VR. After the task conduct, they filled the NASA TLX Questionnaire, the User Experience Questionnaire, and the Subjective Accuracy Questionnaire with Likert Scale questions, in the given order. In a brief interview, participants were additionally asked for positive and negative aspects related to their experience with the used guidance technique. After the participants completed all of the within-subjects conditions, we conducted a final semi-structured interview in order to ask for participants' preferences, and their interest in using a system with ego-centric guidance visualizations in the future. Each session took about 1.5 hours. Participants had to stand during the conduct of the movement tasks. They were paid 15 Euros as compensation.

Figure 5: As described in Section 4, for each movement task, the DTW error distances for four time series (left hand, right hand, left forearm, right forearm) were accumulated to a total DTW error distance. The bars show the mean total DTW error distances for the tasks which were performed for different study conditions. An asterisk indicates statistically significant differences. All error bars show the standard error of the mean.

Results

All study documents and spoken dialogues with participants were in German. All study results described in this paper are translated from German to English. To analyze the collected quantitative data, a Friedman's ANOVA was used to reveal differences between the guidance techniques for all movement tasks in total, and separately for tasks conducted with condition *VA_ABSTRACT*, and tasks conducted with condition *VA_REALISTIC*. If a Friedman's ANOVA showed a statistically significant main effect, post-hoc Wilcoxon Signed-Rank Tests were applied for pairwise comparisons. Between-subjects measurements for differences between condition *VA_ABSTRACT* and *VA_REALISTIC* for each of the three guidance techniques, were analyzed with Mann-Whitney U Tests. All Pairwise cross-factor comparisons are Bonferroni corrected. The significance level α is at .05. We report the test results that revealed a statistically significant difference. All other results were not statistically significant (all $p > .05$).

Movement Accuracy.

DTW Error Distances. Figure 5 provides an overview on the calculated mean total DTW error distances for all investigated guidance techniques. For each guidance technique, the mean total DTW error distance for all movement tasks (both visual appearance conditions), for all tasks that used an abstract visual shape (*VA_ABSTRACT*), and for all task that used a realistic visual shape (*VA_REALISTIC*), is reflected as a bar. Lower DTW error distances correspond to a higher movement accuracy, i.e., the participants' movement was closer to the movement of the guidance visualization. A Mann-Whitney U Test revealed a statistically significant difference between the conditions *VA_ABSTRACT* ($M = 2105.67$,

SD = 814.59) and *VA_REALISTIC* (M = 1452.92, SD = 473.16) for *GT_CONTINUOUS* ($U = 31.0$, $p = 0.018$), and also between the conditions *VA_ABSTRACT* (M = 1740.67, SD = 623.42) and *VA_REALISTIC* (M = 1228.58, SD = 451.37) for *GT_KEYFRAME* ($U = 31.0$, $p = 0.018$), in both cases indicating a higher accuracy for *VA_REALISTIC* (also see Figure 5).

Subjective Accuracy Questionnaire. Regarding the subjective movement accuracy, a Friedman's ANOVA ($\chi^2(2) = 6.276$, $p = .043$) showed a significant main effect between the guidance techniques for condition *VA_ABSTRACT* in the ranking of the 5-point Likert Scale statement "I was able to follow the guidance" (from 0 = strongly agree, to 4 = strongly disagree). A post-hoc Wilcoxon Signed-Rank Test showed that participants felt significantly more able to follow the guidance with *GT_CONTINUOUS* (M = 2.75, SD = 1.29) than *GT_KEYFRAME* (M = 3.67, SD = 0.49), for condition *VA_ABSTRACT* ($Z = -2.456$, $p = .042$). Pairwise comparisons with Mann-Whitney U Tests revealed that participants felt significantly more able to follow the guidance with *GT_KEYFRAME* ($U = 28.0$, $p = 0.006$), if the visual shape is realistic (M = 2.58, SD = 1.08) instead of abstract (M = 3.67, SD = 0.49). We found no statistically significant differences for the Likert Scale statement "I perform the motion sequence precisely with guidance" (all $p > .05$).

User Experience and Preference.

User Experience Questionnaire. A Friedman's ANOVA for the subscale *efficiency* of the User Experience Questionnaire showed a significant main effect between the three guidance techniques ($\chi^2(2) = 8.187$, $p = .017$). A post-hoc analysis with a Wilcoxon Signed-Rank Test revealed that the rating for *efficiency* (from -3 = lowest possible ranking, to 3 = highest possible ranking) was statistically significantly higher for *GT_KEYFRAME* (M = 1.18, SD = 0.57) than *GT_PAUSING* (M = 0.83, SD = 0.63) in total ($Z = -3.194$, $p = .0042$). No further statistically significant differences were found for any of the questionnaires subscales (all $p > .05$).

NASA TLX Questionnaire. Related to users' task load, we analyzed the mean values of all subscales of the NASA TLX. For *GT_KEYFRAME*, a Mann-Whitney U Test revealed a higher ranking of the subscale *temporal demand* (from 0 = very low, to 100 = very high; $U = 31.0$, $p = 0.017$) for condition *VA_REALISTIC* (M = 46.25, SD = 25.18) than condition *VA_ABSTRACT* (M = 22.5, SD = 16.14), and a lower ranking of the subscale *performance* (from 0 = perfect, to 100 = failure; $U = 30.0$, $p = 0.019$) for condition *VA_REALISTIC* (M = 51.25, SD = 16.22) than condition *VA_ABSTRACT* (M = 30.0, SD = 17.91). No further significant differences were found for any of the NASA TLX subscales (all $p > .05$).

Figure 6: Mean user preferences for guidance techniques. An asterisk indicates statistically significant differences. All error bars show the standard error of the mean.

Subjective User Preference Ranking (Interview). In total, 6 participants named *GT_CONTINUOUS*, 12 participants *GT_KEYFRAME*, and 6 participants *GT_PAUSING* as their most preferred guidance technique. Figure 6 provides an overview on the mean preference ranking of all three guidance techniques by each participant (from 1 = most preferred, to 3 = least preferred). A Friedman's ANOVA showed a significant main effect between the guidance techniques for condition *VA_ABSTRACT* ($\chi^2(2) = 8.667$, $p = .013$). A post-hoc analysis with a Wilcoxon Signed-Rank Test revealed that *GT_KEYFRAME* (M = 1.33, SD = 0.49) was ranked significantly higher than *GT_PAUSING* (M = 2.50, SD = 0.67) for condition *VA_ABSTRACT* ($Z = -2.81$, $p = .0149$). Mann-Whitney U Tests on the ranking values also revealed statistically significant differences for *GT_KEYFRAME* ($U = 106.0$, $p = 0.032$) and *GT_PAUSING* ($U = 29.0$, $p = 0.008$) between condition *VA_ABSTRACT* and *VA_REALISTIC*. The preference ranking of *GT_KEYFRAME* is statistically significantly higher for condition *VA_ABSTRACT* (M = 1.33, SD = 0.49) than for condition *VA_REALISTIC* (M = 2.08, SD = 0.9). The preference ranking of *GT_PAUSING* is statistically significantly higher for condition *VA_REALISTIC* (M = 1.67, SD = 0.65) than for condition *VA_ABSTRACT* (M = 2.50, SD = 0.67). No further statistically significant results were found for the preference ranking (all $p > .05$).

Positive and Negative Usage Aspects (Interview). Figure 7 provides an overview on participants statements in regard to positive and negative aspects that are related to differences between the three guidance techniques. The amount of participants who stated an aspect is written behind each of the aspects enlisted in the boxes of Figure 7.

Future Use (Interview). When asked if they could imagine using a system that provides egocentric guidance visualizations to learn movements independently in the future, 11 of 12 participants who used condition *VA_REALISTIC* were positive. For condition *VA_ABSTRACT*, eight out of 12 participants answered positively.

GT_CONTINUOUS	+ easy to learn and memorize (N = 5) + clear, not confused by keyframes (N = 4) + fluent (N = 3)	- too fast, not being able to keep up (N = 4) - difficult to follow (N = 4) - movement is not clear (N = 2) - difficult to memorize (N = 2)
GT_KEYFRAME	+ predictable due to keyframes (N = 6) + easy to understand and follow (N = 5) + good to memorize (N = 3) + easier than GT_PAUSING (N = 3) + fluent (N = 2)	- too fast, stressful, overwhelming (N = 5) - keyframes confuse (N = 5) - difficult to memorize (N = 2)
GT_PAUSING	+ no time-pressure, own tempo (N = 6) + allows to think and move precise (N = 5) + predictable due to keyframes (N = 2)	- difficult to match posture (N = 8) - difficult to memorize as one cannot concentrate on the movement (N = 7) - halting and fragmented (N = 4) - keyframes confuse (N = 4) - accidental matching of keyframes (N = 2)

Figure 7: Positive (+) and negative (-) aspects which are related to differences between the three guidance techniques.

5 DISCUSSION

In the following, we discuss our results for (i) movement accuracy, and (ii) user experience and preference.

Movement Accuracy

Our results showed a significantly higher movement accuracy for guidance visualizations with a realistic visual shape (condition *VA_REALISTIC*) if the used guidance technique provides a continuous movement of the guidance visualization (conditions *GT_CONTINUOUS* and *GT_KEYFRAME*). For *GT_KEYFRAME* this discovery is strengthened by the finding that participants who used *GT_KEYFRAME* in combination with a realistic visual shape felt significantly more able to follow the guidance than participants who used *GT_KEYFRAME* combined with an abstract visual shape. Although the difference in the movement accuracy between an abstract and a realistic visual shape is not significant for *GT_PAUSING*, the mean values also point towards a higher movement accuracy for the realistic condition. These findings are also supported by statements from participants who were exposed to the abstract visual shape condition without knowing of condition *VA_REALISTIC*. For example, one participant stated “it is difficult to see what the ‘blue sticks’ are doing, maybe it would be better if they were more realistic” (quote translated from German).

Previous research already suggested benefits for a realistic in contrast to an abstract visual appearance of a user’s own hands in VR (e.g., [13, 20, 21]). Our findings suggest that there are not only benefits for a more realistic visual appearance of a user’s own hands in VR. They indicate that users can also follow guidance visualizations with a realistic visual shape with a higher accuracy than abstractly shaped guidance visualizations, if the guidance visualization moves continuously.

We found no statistically significant differences for the measured movement accuracy between the different guidance techniques. Only on a subjective level, our results show that

the participants felt significantly more able to follow the guidance with *GT_CONTINUOUS* than with *GT_KEYFRAME*, if the visual shape is abstract.

Implication: Use a Realistic Visual Shape for Continuous Guidance Techniques to gain a higher Movement Accuracy

Based on our findings, we suggest to use a visual appearance with a realistic visual shape, if a guidance technique which provides a continuous movement similar to *GT_CONTINUOUS* and *GT_KEYFRAME* is used, and if a high movement accuracy is of relevance. However, as the main discovered differences are between-subjects for a sample size of 24 participants, we also suggest to reinvestigate our findings with a larger sample size or as a within-subjects condition in order to strengthen our conclusions in the future.

User Experience and Preference

The results of the NASA TLX questionnaire revealed a higher subjective *temporal demand* (question: “how hurried or rushed was the pace of the task?”) and a lower subjective *performance* (question: “how successful were you in accomplishing what you were asked to do?”) for *GT_KEYFRAME*, if a visual appearance with a realistic visual shape instead of one with an abstract visual shape was used. This is contradictory to our findings for movement accuracy, but goes in line with participants preference ranking of the three guidance techniques: *GT_KEYFRAME* was ranked significantly higher, by participants who used guidance visualizations with an abstract visual shape instead of a realistic one. Also related to this, four of the five participants who stated the negative usage aspect “too fast, stressful, overwhelming” for *GT_KEYFRAME*, used the condition *VA_REALISTIC*. Interestingly, for *GT_PAUSING* our results show the same effect as for *GT_KEYFRAME* vice versa. That is, *GT_PAUSING* was ranked significantly higher by participants who used guidance visualizations with a realistic visual shape. As we investigated the two visual appearance conditions between-subjects, the participants did not directly compare the two conditions. This makes it difficult to draw a conclusion for the identified effect. Considering the interview data and the responses to the NASA TLX questionnaire, one explanation for *GT_KEYFRAME* could be that the condition was harder to use if the visual shape was abstract instead of realistic. This might be because the visual shape is more complex than the abstract one, and this larger complexity of the shape had a larger effect on the condition *GT_KEYFRAME* than the condition *GT_PAUSING*. However, to draw a well-founded conclusion, we suggest that future work may investigate the identified effect in more detail. This could be done by

reinvestigating our findings as a within-subjects condition.

Analyzing the User Experience Questionnaire revealed a significantly higher subjective rating of the subscale *efficiency*, for *GT_KEYFRAME* than *GT_PAUSING*. Related to this finding, half of the participants ($N = 12$) mentioned *GT_KEYFRAME* as their most preferred guidance technique. Only six preferred *GT_PAUSING* the most. This is also reflected in participants' statements about the positive and negative aspects of the different guidance techniques. There were considerably more negative aspects mentioned for *GT_PAUSING* and more positive aspects for *GT_KEYFRAME*. For example, four participants saw it as a disadvantage that *GT_PAUSING* was halting and fragmented, seven participants mentioned that it was difficult to memorize the movements with *GT_PAUSING* as they found it hard to concentrate on them, and three participants even explicitly stated that they found it easier to use *GT_KEYFRAME* than *GT_PAUSING*. However, when looking at the preference ranking on the level of condition *VA_ABSTRACT* and *VA_REALISTIC*, our results show that *GT_KEYFRAME* was only preferred significantly more than *GT_PAUSING* by participants who used the abstract visual shape condition.

Implication: Use a Continuous Movement Visualization for Guidance Visualizations which visualize Important Postures and provide an Abstract Visual Shape to gain a higher User Experience and Preference

Our results for user experience and preference revealed only few statistically significant insights and should thus be treated with care. We found no statistically significant differences between *GT_CONTINUOUS* and any of the other guidance techniques. Our significant findings suggest that, when considering the use of a guidance technique that visualizes important postures, as *GT_KEYFRAME* and *GT_PAUSING* do, a continuously moving visualization like *GT_KEYFRAME* seems to be preferable in terms of user experience and preference if an abstract visual shape is used. For a realistic visual shape, we cannot make a clear suggestion between a continuously moving visualization (condition *GT_KEYFRAME*) and a visualization that pauses at keyframes to wait for the user (condition *GT_PAUSING*). For this case, our study results are not fully conclusive: The efficiency of a visualization similar to *GT_KEYFRAME* is still likely to be higher than the efficiency of a visualization similar to *GT_PAUSING*. However, using a visualization similar to *GT_KEYFRAME* with a realistic instead of an abstract visual shape might decrease users' subjective performance and increase their subjective temporal demand.

6 LIMITATIONS & FUTURE WORK

Movement behaviors can be classified into discrete, continuous, and serial movements [19]. Discrete movements are movements with a clear beginning and end (e.g., throwing a ball). Continuous movements have no clear beginning and end (e.g., running). Serial movements consist of multiple discrete movements in sequence (e.g., a musical conducting movement). Our work explored guidance visualizations for serial arm movements. Although such movements are relevant for various tasks like musical conducting or Tai Chi exercises, there also exist tasks with other requirements. Future research may extend our findings by investigating differences between different movement behaviors and body parts.

Based on previous research, for our investigation of the visual appearance of egocentric guidance visualizations, we focused on differences in the visual shape. However, there are also other aspects related to the visual appearance of egocentric guidance visualizations that might have an effect on users' movement accuracy, experience, and preference (e.g., color or texture). These aspects might also be interesting in relation to augmented feedback, which was not within the focus of our user study. EGuide can serve as a basis for future research that explores related aspects.

Our work focused on the exploration of different aspects related to visual movement guidance. Past work also found benefits for the use of other modalities like haptics (e.g., [24]), and audio (e.g., [6]) to guide movements. However, only few previous research investigated the combination of egocentric guidance visualizations with other modalities (e.g., by using a visuohaptic guidance [12]). It would be interesting to extend EGuide with support for other modalities and explore related aspects in the future. In relation, other modalities and application features might also be required to support movement learning for different use cases. Our work did not attempt to create a holistic system that supports the learning of movements that are required for a specific use case. Future work might make use of our insights, and extend them with context-specific requirements to create adequate egocentric guidance visualizations for different use cases.

When developing EGuide, instead of aiming at high mobility, we focused on a setup with good tracking and visual output quality for our user study. In order to make the widespread use of egocentric guidance visualizations feasible in the future, future research should investigate the applicability of mobile technology for the creation of mobile egocentric guidance systems. Previous work already took first steps into this

direction (e.g., [7]). However, there is still much room to improve the tracking and output quality for mobile approaches.

EGuide already provides a solid ground for many of the named aspects. We plan to extend EGuide in the future, in order to investigate other aspects related to egocentric guidance visualizations.

7 CONCLUSION

On the grounds of past research that found benefits for the use of egocentric guidance visualizations, we addressed the question how such egocentric guidance visualizations should look and behave. We presented EGuide, a VR system that supports the investigation of different egocentric visualizations for the guidance of mid-air arm movements. In a user study, we used EGuide to compare two visual appearances for egocentric guidance visualizations that differ in their visual shape (look), and three guidance techniques that differ in the way in which they guide a user (behavior). For visualizations with a continuously moving guidance technique (study conditions *GT_CONTINUOUS*, *GT_KEYFRAME*), our results suggest a higher movement accuracy for a realistic visual shape (study condition *VA_REALISTIC*) than for an abstract visual shape (study condition *VA_ABSTRACT*). Although, we find few significant insights for differences in user experience and preference, our results suggest that visualizations that have an abstract visual shape (study condition *VA_ABSTRACT*) and use a guidance technique that visualizes important postures (study conditions *GT_KEYFRAME*, *GT_PAUSING*), should preferably not pause at important postures to wait for a user (as study condition *GT_PAUSING* does).

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