Auxiliary Means to Improve Motion Guidance Memorability in Extended Reality

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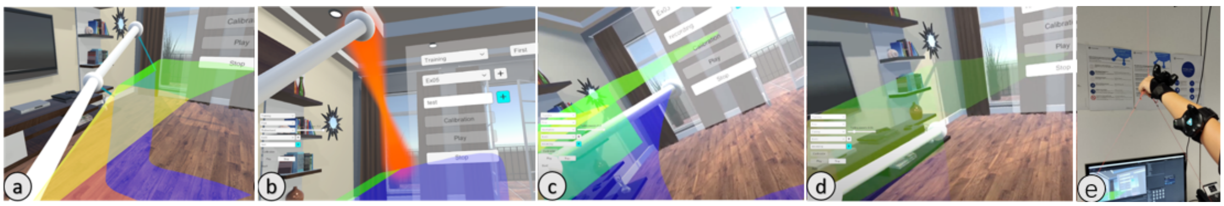

Figure 1: Auxiliary visualizations for VR motion guidance systems. (a) Baseline *Streamer* with the thin blue strings, (b) *Enhanced Error Feedback* with colored signaling cones, (c) *Asymptotic Path* gradually guiding the arm back, (d) *Increasing Difficulty* showing higher transparency, (e) *Haptic Constraint* in triangular setup.

Abstract

VR-based motion guidance systems can provide 3D movement instructions and real-time feedback for practicing movement without a live instructor. However, the precise visualization of movement paths or postures may be insufficient to learn a new motor skill, as they might make users too dependent and lead to poor performance when there is no guidance. In this paper, we propose to use enhanced error visualization, asymptotic path, increasing transparency, and haptic constraint to improve the memorability of motion guidance. Our study results indicated that adding an enhanced error feedback visualization helped the users with short-term retention.

Index Terms: Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

Traditionally, the training instructions are done by an on-site trainer. When the live coach is unavailable, a possible replacement is to use video tutorials. However, the trainee may still practice the movements in the wrong way and even hurt themselves, as video instructions on 2D screens cannot guarantee a complete perception of angle and depth. A promising approach to overcome these hindrances and to improve the perceived motion guidance is the use of extended reality (XR), where instructions can be visualized in 3D and users can freely switch viewpoints to fully understand the movement details. In existing XR-based motion guidance systems, users can follow precise instructions to practice movements and receive a score based on the movement errors they made during the practice. However, while practicing movements, the users may gradually rely on precise instructions and hence perform poorly when the guidance is removed.In this work, we explore the possible auxiliary techniques to avoid over-reliance and improve short-term retention of motion guidance, including (1) enhanced error feedback, (2) asymptotic movement path, (3) increasing difficulty during training, and (4) additional haptic constraint. We recruited 32 participants for an exploratory usability test, where we found positive evidence to support the usability of our "enhanced error feedback" approach, and collected design implications for others.

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2 System Design

We designed our system based on the previous work of Yu et al. [2]. In their **Streamer** guidance, the user's arm was represented by a simple ball-and-stick model. The instructions of the lower and upper arms are distinguished by different colors (blue & red). The colors of completed parts will be changed to green & yellow to visualize the progress of the movement. Since it is impossible for the user to perfectly follow the pre-recorded motion guidance, there is always a *tolerance* value during training. When the offset between the user's arm and the target posture is within the *tolerance*, the target posture will be considered complete and switch to the next posture on the movement path. If the user's arm deviates outside of the *tolerance* boundary of the target posture, they display blue strings connecting the user's arm joints and their target positions, which represent the movement errors and also guide the arm back to the path (Fig. 1 a). We designed four different auxiliary approaches to improve the memorability of this basic motion guidance system.

2.1 Enhanced Error Feedback

We attempt to improve memorability by amplifying the mistakes users make. Based on the **Streamer** system, we replaced the thin blue strings with a pair of colored cones. As the user's arm deviates from its desired path, the cones will change their color from yellow to red, with increasing size. To avoid visual clutter, the new error visualization is only displayed on the wrist, as seen in Fig. 1 b.

2.2 Asymptotic Path

When the user's arm deviates from the original path, instead of visualizing the blue strings for error amount or guiding-back instructions as in the **Steamer** system, we create a new smooth path between a future posture on the original path and the current position of the user's arm. Concretely, when the offset of the user's arm exceeds the *tolerance*, three future poses with fixed time intervals will be selected from the original movement sequence. These poses will be the input to the cubic Bezier equations outputting an asymptotic path that gradually guides the arm back to the original path. We assumed that this method would help the users better memorize and understand the metaphor behind the movement path (Fig. 1 c).

Table 1: The overview of data including a) system usability, where the usability of *Haptic* was significantly lower than baseline. b) normalized movement error in meters, where the movement error in the *Enhanced Error* condition was lower than baseline. c) movement reproduction in the examination phase, in which 7 out of 8 participants in *Enhanced Error* completely reproduced the movement in the examination phase.

Group	a) System Usablity			b) Movement Error (m)				c) Movement Reproduction
	Auxiliary	Baseline	p-value	Auxiliary	Baseline	Difference	p-value	
Enhanced Error	81.6(18.5)	82.8(16.6)	0.375	15.3(5.95)	25.0(4.82)	-9.71(4.51)	0.001	7
Asymptotic	80.3(16.1)	78.8(17.9)	1	40.3(16.8)	36.8(14.8)	3.55(18.6)	0.605	1
Incr. Difficulty	82.2(6.19)	84.7(6.19)	0.306	23.95(8.94)	30.91(11.41)	-6.96(12.73)	0.198	5
Haptic	61.2(26.6)	81.6(14.5)	0.046	31.2(10.8)	27.9(6.20)	3.29(12.9)	0.495	4

2.3 Increasing Difficulty

Unlike the previous approaches, we add no auxiliary visualization here. Instead, the transparency parameter of the **Streamer** is altered to change the difficulty of following the guidance during the training phase. As seen in Fig. 1 d, with the number of repetitions increasing, the transparency of the instructions will be altered in steps of 10% until completely invisible. With this, the user may feel less assisted, distracted, and dependent. We intended to verify whether the increased effort would lead to a better learning effect.

2.4 Haptic Constraint

Here we use a string-based device, called **Strive** [1], to provide force feedback as a haptic constraint during motion guidance. Concretely, we placed three **Strive** modules out of the user's range of movement, forming a triangular structure, and tied the other ends of the strings onto the user's wrist (Fig. 1 e). This triangular setup makes a tubular movement area, which blocks all movements as soon as they exceed the *tolerance* boundary and deviate too far from the predefined movement path.

3 Preliminary Study

To evaluate the usability of our proposed approaches, we conducted an exploratory study in VR involving 32 participants (15 female & 17 male). We divided the participants into four groups; each group corresponded to one of our proposed auxiliary methods and contained 8 participants. In each group, participants were required to fulfill the task in two conditions respectively: one is the corresponding auxiliary techniques (*Enhanced Error*, *Asymptotic*, *Increasing Difficulty*, or *Haptic*) and the other is the *Streamer* system as the baseline. Specifically, the participants were asked to do ten repetitions with the motion guidance system as the **training phase**, followed by one last repetition without any guidance as the **examination phase**. Following the guideline by Yu et al. [2], we designed five different movement sequences with the same difficulty and shuffled them between conditions. We calculated movement error, i.e. the total positional deviation of the wrist and the elbow to the given instructions computed by absolute Euclidean distance. And we normalized the movement error to compare different movement paths. We collected qualitative feedback through surveys containing free text answers and standardized questionnaires including the NASA Task Load Index and System Usability Scale after each system was tested, and a semi-structured interview after the study.

4 Results

We performed statistical analysis for each group separately. Specifically, we first ran the Shapiro-Wilk test for normality. For post-hoc tests, we performed pairwise t-tests with Bonferroni correction for the normal distributed groups and sign test for the unnormal distributed, as every participant experienced both our assistive techniques and the baseline. We summarized our results in Table 1. The tests reveal no significant difference regarding NASA TLX.

Haptic Constraint Among all system usability results, only the *Haptic* condition showed a significant lower score than the baseline (p=0.046, as seen in Table 1 a). The possible reason could be the poor connection of the Bluetooth modules between Strive and the computer where we ran our study. Besides, the participants preferred baseline over this condition because *Haptic* made them "visually free but physically restricted," which is unnatural.

Increasing Difficulty 4 of 8 participants found the increasing transparency more helpful, because "it gradually disappeared, leaving me on my own". However, since we did not set the appropriate step size for increasing transparency, most participants noticed the change only at the last few repetitions. Although there is no significant difference between the movement error of this condition and the baseline during the exam, 5 participants completed the reproduction of movements in the examination phase.

Asymptotic Path Two participants in this group preferred the *asymptotic path* to the baseline. Participants stated that it "felt more natural" and less stressful. However, according to the result of the examination phase, the participants in this condition performed worst at movement reproduction. One participant stated that this visualization "was not as tedious as the baseline, because one does not have to go back to the original path to continue after a deviation".

Enhanced Error Feedback For both the movement error and reproduction in the examination phase, the *Enhanced Error* condition outperformed the other techniques; that is, a significantly lower movement error and 7 out of 8 participants completed the reproduction. R18 indicated that "having the error correction through this color-altered transformable 'rubber band' on the hand helped track small mistakes because they enhanced the visual impact".

5 Conclusion

In this work, we proposed four different assistive techniques to improve the memorability of motion guidance in XR. We ran a preliminary study to verify the usability of our methods. According to both the subjective feedback and the participants' examination performance without any guidance, amplifying the users' mistakes during training is the most promising for improving short-term retention. We also noticed the potential of increasing difficulty during training for the same purpose. In the future, we will look more into the mechanics of human memory, and go further on the user study design, e.g. to set more appropriate parameters and evaluate our techniques for long-term retention.

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