Investigate the Piano Learning Rate with Haptic Actuators in Mixed Reality

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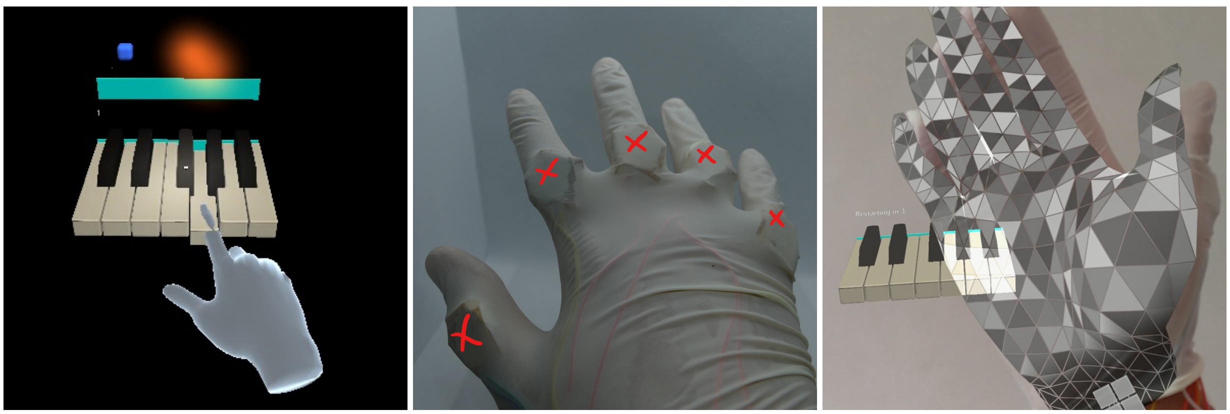

(a) Visual learning in Unity3D **(b) Haptic glove** **(c) Haptic learning with HoloLens**

Figure 1: Shows the visual and haptic piano learning application, as well as the haptic glove.

ABSTRACT

With mixed reality (MR) becoming widely available, it could enhance learning because special equipment like musical instruments or access to instructors will be less of a concern. Furthermore, passive haptic learning systems to learn piano are promising research subjects. We combine both trends of MR and haptic learning to build a piano learning application. Through a study with diverse participants, we evaluate the piano application. The study results show the potentiality of the on-skin actuators and we hope our work could foster the future iterations of the actuators for a fun and effective learning environment.

*Both authors contributed equally to this research.

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CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *Ubiquitous and mobile computing design and evaluation methods.*

KEYWORDS

Haptics, Wearable, Human-Computer-Interaction, Mixed Reality

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1 INTRODUCTION AND BACKGROUND

MR enriches the physical world by placing digital information into it. MR devices, like the Microsoft HoloLens [14] and the Magicleap [2], have created values for plenty of scenarios [4, 11, 12, 20]. Haptics is widely available and ubiquitous in daily life, for example, through smartphones. In the past, researchers explored different haptic hardware to simulate touch in MR environments[3, 10, 19, 20]. At the same time, researchers studied the use of MR for learning in other areas, for example, with medical students [18, 22], learning to play guitar visually [21], or learning to play piano [1, 5, 23]. The previous research on learning piano with MR uses overlays over physical pianos to show which key to play next.

A different research approach to teaching piano is the use of haptic gloves for passive haptic learning [8, 16]. In the field of haptic learning, previous research shows that haptic learning is better than auditory learning [9], that a combination of audio and vibration leads to a better learning outcome than audio or vibration alone [17], and that there is no significant difference in recall after three days with passive haptic learning [6]. Furthermore, the development of soft actuators [7, 13] and on-skin electronics [15] enable the haptic part of the learning application. Previous work reported in Fang et al. [7] guides the development of electromagnetic actuators for this work based on the Lorenz principle.

The previous works identify the two related research areas of (1) MR/visual only and (2) haptic only for learning piano. Furthermore, previous research establishes the superiority of multi-sense piano learning (haptic and auditory) over only audio or only haptic. As a result, combining MR and haptic leads to a novel piano learning application that, to our knowledge, has not yet been evaluated previously.

In our work, the implementation of the piano learning application uses visual cues (MR) and haptic cues (on-skin actuators) to teach a piano sequence. Two research questions are of interest. First, **RQ1**: How would our methods influence the effectiveness in teaching how to play a piano sequence via applying different cues? **RQ2**: Is there a difference in the learning outcome between haptic learning or visual learning in MR? We conducted a user study (N= 16) using the MR application to evaluate the research questions. To the best of our knowledge, we are the first to investigate the learning rate of learning piano with haptic actuators in MR. Hence, our contributions are: (1). Conduct a systematic experiment to evaluate the learning rate under two methods; (2). Show that there was little difference in learning rate between actively (visual cues) and passively (haptic cues) learned piano.

2 HOLOGRAPHIC PIANO

The piano learning application is a Unity application using the open-source Mixed Reality Toolkit to display a holographic piano at a fixed place in the room. Wearing a mixed reality device like the HoloLens, a person can play the holographic piano with the five fingers of the right hand through hand tracking. Pressing a key plays the sound associated with the key through the HoloLens' speakers. The piano has 12 keys of one octave that includes the middle C (C4 through C5 in the scientific pitch notation). The holographic piano is the foundation for two learning methods (1) visual, and (2) haptic.

2.1 Visual Learning

The visual learning method drops differently colored and shaped holographic objects 20 centimeters above the piano key to play next. A turquoise rectangle defines the target area. When a falling shape enters the target area, the same shape appears above the finger to press the piano key. If the person presses the piano key when the shape is in the target area, the piano plays the correct sound. Otherwise, it plays an error sound. The shapes visually indicate which keys to play to learn a song. Figure 1a shows the visual piano learning application running in the game engine Unity3D. At the moment, the piano player correctly plays the *G* key with the index finger. Hence, the orange shape entering the turquoise target area above the *G* key explodes. The dark blue cube falling signals the player to press the *G* key next.

2.2 Haptic Learning

In contrast to visual learning, haptic learning gives instructions on which finger to press down next by triggering vibration on the finger. The vibration has a frequency of 16 Hz, creating a sensation at the position of the on-skin haptic actuator placed below the proximal interphalangeal on each finger. Figure 1b marks the placement of each actuator on the fingers with red x's. Vibration on a finger is the cue for the learner to press the holographic piano's key below the vibrating finger. Without any visual indicator, this limits the playable keys with one hand to five piano keys. Five piano keys are sufficient to play the song for the evaluation. In the study, all participants know which of the five fingers corresponds to which key. This limitation leaves room for future work section 5. Each on-skin haptic actuator consists of (1) an off-the-shelf flexible electric coil [1], (2) a neodymium disc magnet with 3 mm thickness and 10 mm diameter, and (3) a 3D printed housing. An ESP32 microcontroller controls all actuators. The HoloLens can wirelessly trigger the actuators. When triggering an actuator, the coil creates an electromagnetic field that moves the magnet creating the vibration.

Figure 1c shows the haptic learning application running on the HoloLens with the piano in the background and the hand-tracking in the foreground. Note that the piano has no visual indicators as the visual piano learning application has. Instead, the player wears the haptic glove that vibrates the finger to play next.

3 EVALUATION

We conduct a between-subjects design user study to compare the haptic and visual learning of Beethoven's song *Ode to Joy*. Figure 2 shows the procedure for the study. First, each participant gets 5 minutes without knowing which song to learn to get familiar with the HoloLens. Before and after the learning session, each participant has three chances to play *Ode to Joy* which the HoloLens records. Each participant learns the song for 30 minutes visually (subsection 2.1) or with haptics (subsection 2.2). The error in the sequence of piano key presses and the error in the timing/rhythm of the piano key presses are the metrics for calculating the learning rate.

4 RESULTS

The study has 56% male and 44% female participants with n=16. Ages range from 18 to 56 years (mean=34 years, median=27 years) with 88% right-handed, and 12% left-handed participants. The majority (75%) say that they have not used a MR device like the HoloLens before. Of all participants, 62% say that they have listened to *Beethoven: Ode To Joy* before. Participants have eight, four, two and the remaining 13 participants have zero years of piano experience.

[1] https://flexar.io/

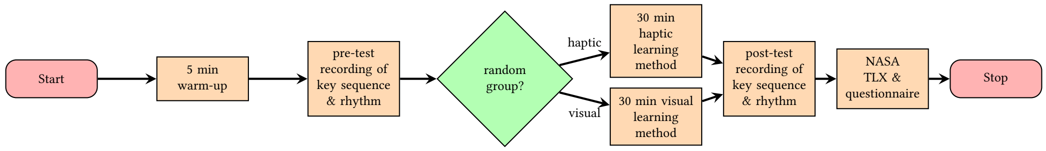
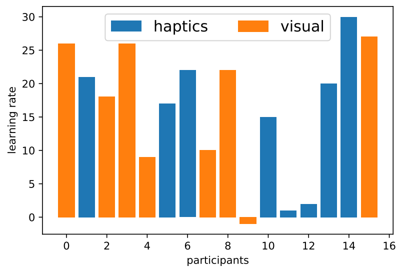
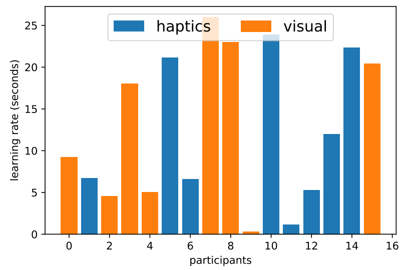


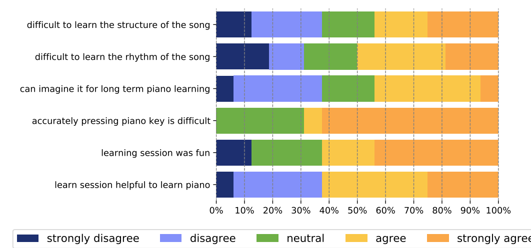
Figure 2: The flow chart of the study.



(a) Learning rates key sequence.



(b) Learning rates rhythm.



(c) Subjective Likert scale questionnaire results.

Figure 3: Improvements of the best try for each participant.

The bar charts Figure 3a and Figure 3b show the improvements for remembering the key sequence and rhythm for each participant individually. Lastly, Figure 3c shows the results of the subjective questions specific to the learning environment.

After 30 minutes visual learning one-sided paired t-test show significantly lower error in the key sequence ($t = -4.76, p = 0.001$ and Cohen's $d = 1.68$) and significantly lower error for the rhythm ($t = -3.88, p = 0.003$ and Cohen's $d = 1.37$). Likewise, for the *haptic* group the t-tests show a significantly lower error in the key sequence ($t = -4.54, p = 0.0013$ and Cohen's $d = 1.61$) and for the rhythm ($t = -3.95, p = 0.0028$ and Cohen's $d = .87$).

A two-sided unpaired t-test reveals that there is no statistically significant difference between the improvement in erroneous key-presses of the group receiving the *haptic* and the group receiving the *visual* learning session, $t = -0.223, p = 0.83$. There is also no significant difference of the rhythm errors between the *haptic* group and the *visual* group, $t = -0.197, p = 0.85$.

Mean NASA TLX scores for the *visual* and *haptic* are $mean_{TLX,visual} = 59.08$ and $mean_{TLX,haptic} = 56.83$. A two-sided unpaired t-test shows no difference in the mean NASA TLX of the *haptic* and *visual* groups, $t = -0.234, p = 0.818$.

5 CONCLUSION AND FUTURE WORK

We implement an MR piano learning application that can teach piano visually and through haptic. The current piano application limits the playable keys to only five, one for each finger. Adding visual indicators that show which area of the piano to place the five fingers on could address this limitation. Another solution could be using actuators for haptic feedback when pressing the correct piano key instead of using the vibrations as cues for which key to press. We find no difference in the learning outcome between the two learning methods. Further advances in hand tracking are necessary to make the holographic piano better. Another area for future research is to improve the comfort of the on-skin actuators and their vibration strength.

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