This manuscript has been accepted for publication in the Proceedings of the 2020 Human-Computer Interaction International Conference, J. Y. C. Chen and G. Fragomeni (Eds.), LNCS 12190, pp. 1–11, 2020.

Assessing the Role of Virtual Reality with Passive Haptics in Music Conductor Education: A Pilot Study

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Abstract: This paper presents a novel virtual reality system that offers immersive experiences for instrumental music conductor training. The system utilizes passive haptics that bring physical objects of interest, namely the baton and the music stand, within a virtual concert hall environment. Real-time object and finger tracking allow the users to behave naturally on a virtual stage without significant deviation from the typical performance routine of instrumental music conductors. The proposed system was tested in a pilot study (n=13) that assessed the role of passive haptics in virtual reality by comparing our proposed "smart baton" with a traditional virtual reality controller. Our findings indicate that the use of passive haptics increases the perceived level of realism and that their virtual appearance affects the perception of their physical characteristics.

Key words: Virtual Reality, Passive Haptics, Music Conductor Education

1 Introduction

The use of computer systems in instrumental music conductor education has been a well studied topic even outside the area of virtual reality [1]. Several systems have been proposed that offer targeted learning experiences [2,3] which may also combine gamified elements [6]. In the past decades, several visual interfaces have been designed using the available technologies at each given period of time [4,5,7], which most recently included eye tracking [8] and augmented and virtual reality platforms [3].

Recent advances in real-time object tracking and the availability of such systems as mainstream consumer products has opened new possibilities for virtual reality applications [13, 14,]. It has been shown that the use of passive haptics in VR contribute to a sensory-rich experience [15,16], as users have now the opportunity to hold and feel the main objects of interaction within a given immersive environment, such as tools, handles, and other instruments. For example, tracking the location of a real piano can help beginners learn how to play it using virtual reality [20]. However, the use of passive haptics in virtual environments for music education is an understudied area, because it requires precise real-time tracking of objects that are significantly smaller than a piano, such as hand held musical instruments, bows, batons, etc.

In this paper, we present a novel system for enhancing the training of novice instrumental music conductors through a tangible virtual environment. For the purposes of the proposed system a smart baton and a smart music stand have been designed using commercially available tracking sensors (VIVE trackers). The users wear a high-fidelity virtual reality headset (HTC VIVE), which renders the environment of a virtual concert hall from the conductor's standpoint. Within this environment, the users can feel the key objects of interaction within their reach, namely the baton, the music stand, and the floor of the stage through passive haptics. A real-time hand and finger motion tracking system continuously tracks the left hand of the user in addition to the tracking of the baton, which is usually held in the right hand. This setup creates a natural user interface that allows the conductors to perform naturally on a virtual stage, thus creating a highly immersive training experience.

The main goals of the proposed system are the following: a) Enhance the traditional training of novice instrumental music conductors by increasing their practice time without requiring additional space allocation or time commitment from music players, which is also cost-effective. b) Provide an interface for natural user interaction that does not deviate from the traditional environment of conducting, including the environment, the tools, and the user behavior (hand gesture, head pose, and body posture), thus making the acquired skills highly transferable to the real-life scenario. c) Just-in-time feedback is essential in any educational setting, therefore one of the goals of the proposed system is to generate quantitative feedback on the timeliness of their body movement and the corresponding music signals. d) Last but not least, the proposed system recreates the conditions of a real stage performance, which may help the users reduce stage fright within a risk-free virtual environment [9,10,11,12].

A small scale pilot study (n=13) was performed in order to assess the proposed system and particularly the role of passive haptics in this virtual reality application. The main focus of the study was to test whether the use of passive haptics increases the perceived level of realism in comparison to a typical virtual reality controller, and whether the virtual appearance of a real physical object, such as the baton, affects the perception of its physical characteristics. These hypotheses were tested using A/B tests followed by short surveys. The statistical significance of the collected data was calculated, and the results are discussed in detail. The reported findings support our hypotheses and set the basis for a larger-scale future study.

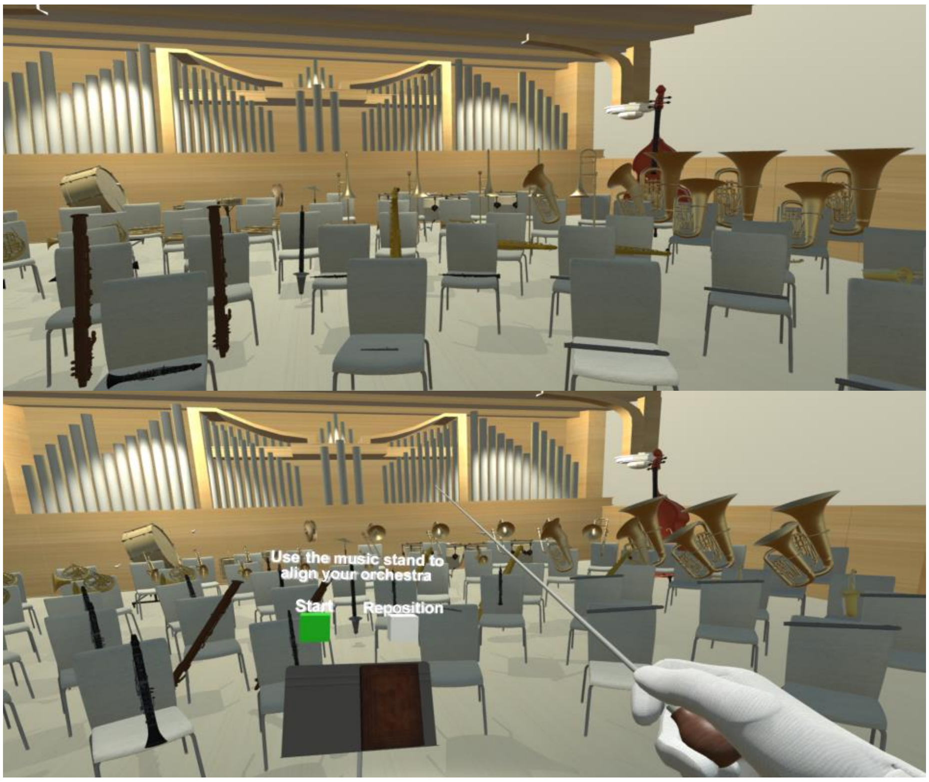

Fig. 1. Top: screenshot of the virtual reality orchestra, bottom: screenshot of the virtual reality graphical user interface with the smart music stand and the smart baton.

2 Methods

A virtual reality orchestra environment was developed by imitating the architectural design of the University of Florida Auditorium (Fig. 1 top). The virtual environment featured a large instrumental ensemble arranged in a typical semi-circle layout with 5 rows of chairs. In order to minimize the 3D modeling and animation needs for this project, avatars of music players were not included in this environment. Instead, the instruments were animated using a motion sequence that approximated the expected motion pattern for each type of instrument during performance [19]. By default, the instruments were in a resting position on their respective chairs (except for percussion instruments), as shown on the top panel of Fig. 1. In the main activity of this simulation the virtual band performed the 1st suite in E flat for military band op. 28 no. 1 by the British composer Gustav Holst. During the performance the instruments were animated right above their respective chairs as shown on the bottom panel of Fig. 1.

Fig. 2. A) HTC VIVE controller, B) Smart baton with VIVE tracker, C) Test baton with same weight as B, D) Real conductor's baton.

The system allowed the user to interact with the virtual environment using a virtual reality headset and controllers (HTC VIVE), which were tracked in real time (6 DOF for each device). In addition, two VIVE trackers were firmly attached to two real physical objects, a music stand and a wooden handle, in order track the position and orientation of these objects. A virtual representation of these objects was rendered within the virtual environment at their corresponding locations, thus allowing the user to hold and interact with these physical objects while observing their virtual image in real time.

More specifically, a VR-tracked baton with passive haptic feedback, dubbed here "smart baton," was created by attaching a wooden handle to a VIVE tracker with a ¼ inch bolt as shown in Fig. 2B. The total weight of this smart baton was 130 gr. (88 gr. tracker and 42 gr. handle with bolt), which was 64% of the weight of the HTC VIVE controller (203 gr.). The texture, size, and shape of the handle was selected so that its overall haptic feedback resembles that of a real baton (Fig. 2D). The user could hold the smart baton in a natural way without obstructing the tracker, while observing the 3D model of a real conductor's baton, which was rendered at the corresponding position within the virtual reality environment. Similarly, the user could touch the music stand or even reposition it on the virtual stage by interacting with the corresponding real physical object. The bottom panel of Fig. 1 demonstrates the use of the smart baton and the music stand within the virtual environment.

One of the features that were implemented in the proposed smart baton was real-time beats-per-minute (BPM) estimation by analyzing the motion pattern of the baton and identifying the local extrema of the baton's tip trajectory. The rolling BPM estimate was used to modify the playback speed of the music performance, thus providing the user-conductor with the ability to control the tempo of the performance in a natural way. Furthermore, the user could cue specific instruments by looking towards them (implemented using head tracking) or gesturing with their left hand (implemented using hand tracking with Valve Index controller).

A graphical user interface within the virtual environment provided instructions to the users as well as feedback with regards to their tempo and cuing. Additional features of the implemented system include: a) turning the pages of the score on the music stand by naturally using the left hand to perform a page-turning motion, b) repositioning the entire orchestra by moving the real music stand, so that it is better oriented within the user's physical space, and c) recording the complete data transcripts of a session, including the motion of the user (head, baton, and left hand), the detected cues, and the estimated tempo.

Although this virtual reality application was designed as an early prototype of an experiential learning system for novice instrumental music conductors, this paper does not focus on assessing its learning features. The main focus of the user study presented in the next section is to assess the role of passive haptics in this application and how their use may affect a user's perceptions.

3 User Study

A pilot study was conducted in the Reality Lab of the Digital Worlds Institute at the University of Florida, in order to assess the effect of passive haptics in the proposed virtual reality application (IRB 201902916). The study was designed to test the following hypotheses:

- The use of passive haptics increases the perceived level of realism in a virtual reality application.
- The virtual appearance of a real physical object affects the perception of its physical characteristics, such as weight and size.

During this study the subjects were presented with two sets of A/B tests that targeted the aforementioned hypotheses. In the first test, the users were asked to mimic conducting a virtual orchestra using our virtual system with two different types of batons: a) a virtual baton that was controlled by the HTC VIVE controller (Fig. 2A), and b) a virtual baton that was controlled by our smart baton (Fig. 2B). Both controllers were visualized in VR with the same 3D model of a real conductor's baton (Fig. 3 top).

In the second test, the users were asked to perform a similar task using two different versions of our smart baton: a) our smart baton visualized with the 3D model of a real conductor's baton (Fig. 3 top), and b) our smart baton visualized with the 3D model of its real appearance (Fig. 3 bottom). This was followed by an additional test that contrasted two similarly weighted but differently shaped controllers (B and C).

Fig. 3. The virtual baton models used in our user tests: 1) 3D model of a real conductor's baton, which was used in conjunction with the controllers A and B (Fig. 2) as test cases A1 and B1 respectively, 2) 3D model of the actual physical shape of our smart baton, which was used in conjunction with the controller B (Fig. 2) as test case B2.

In order to limit bias in this study the following measures were taken:

- The description of the study that was communicated with the subjects did not reveal the details of the hypotheses made in this study.
- The subjects did not have visual contact with the controllers/batons they were holding for the entire duration of the study session.
- The order of the two versions of controllers in each A/B test was randomized.
- The duration of exposure of the subjects to each controller was fixed.

Each A/B test was immediately followed by a survey conducted verbally, while the subject was still wearing the VR headset. The survey included the questions listed in Table 1. In each question, the subjects were given the following possible responses: 1) clearly the first controller, 2) slightly the first controller, 3) about the same, 4) slightly the second controller, 5) clearly the second controller. Finally, the subjects were asked to complete a short demographic questionnaire at the end of the session.

Q1	Did the 1st or the 2nd controller you held feel more like a real baton?
Q2	Did the 1st or the 2nd controller you held feel lighter?
Q3	Did the 1st or the 2nd controller you held feel bulkier?
Q4	Was the 1st or the 2nd controller you held more appropriate for this use?
Q5	Was the 1st or the 2nd controller you held clearer on how to operate?
Q6	Was the 1st or the 2nd controller you held more comfortable to use?
Q7	Was the 1st or the 2nd controller you held easier to move?
Q8	Could the 1st or the 2nd baton improve someone's skills in conducting?

Table 1. The bank of questions we used in our A/B tests.

Fig. 4. The results from the A/B tests between the HTC VIVE controller and the smart baton (top) and between the two virtual representations of the smart baton (bottom). Red and green indicate responses in favor of the respective cases A and B, while darker and lighter shades indicate strong and weak responses respectively.

In total, 13 subjects were enrolled in this study in the age group between 19-23. None of the subjects had used VR more than once, and the majority of the subjects did not have any prior experience in VR. Since this pilot study did not assess the educational aspect of our prototype application, the subjects were not required to have any level of instrumental music conductor training.

In the next section we present and analyze the collected data and discuss the key findings from this study.

4 Results

The data collected from the two main A/B tests in our study are shown in Fig. 4. The order of the metrics in the horizontal axis of this figure corresponds to the order of questions in Table 1. In each test, the A and B cases are denoted by a letter that indicates a hardware controller from Fig. 2 followed by a number that indicates a virtual appearance from Fig. 3. For example, “B1” denotes our proposed smart baton visualized in VR using the 3D model of a real conductor’s baton. According to the responses, our proposed smart baton felt more real, lighter, less bulky, easier to move, and more appropriate for this application compared to the HTC VIVE controller. In addition, more than 60% of the users felt that it was clearer how to operate the proposed smart baton, which could be attributed to the simpler interface and lack of buttons.

A chi-square test of independence was performed to examine the relation between the type of controller and the perceived level of realism. The relation between these variables was found to be significant, χ^2 (1, N = 13) = 12.46, p < .001. Users responded that our smart baton felt more real compared to the baton that was operated using the HTC VIVE controller, easier to move, and more appropriate for this application. It should be noted that in this test both controllers were visualized with the same 3D model in the virtual environment, and the only variable was the hardware controller. These findings support the first hypothesis of this study.

With regard to the second hypothesis, according to Fig. 4 (bottom) the users found that our smart baton felt less bulky, more comfortable, and more real when visualized using the 3D model of a real conductor's baton compared to using it while observing its real appearance. In addition, the same controller felt lighter to more than 60% of the users when visualized with the thinner 3D model.

A chi-square test of independence was performed to examine the relation between the virtual appearance of a controller and its perceived physical characteristics. The relation between these variables was found to be significant, χ^2 (1, N = 13) = 7.53, p < .01. It should be noted that in this test the same hardware controller was used, and the only variable was its appearance in the virtual environment. These findings support the second hypothesis of this study.

When comparing our smart baton with a same weight but differently shaped test baton (Fig. 2 C), we found that the small length of the baton in our proposed design reduces the torque applied to the handle as the user moves the baton. As a result, the subjects found that the proposed smart baton was lighter than the same weight test baton, χ^2 (1, N = 13) = 12.4, p < .001. The detailed results of the χ^2 tests of significance for each question and each A/B test in our study are reported in Table 2.

	A1 vs B1	B1 vs B2	B vs C
More real	**B1**, 12.4, p<.001	**B1**, 22.1, p<.001	B, 2.46, N/S
Lighter	**B1**, 7.53, p<.01	**B1**, 5.53, p<.02	**B**, 12.4, p<.001
Bulkier	**A1**, 18.6, p<.001	**B2**, 7.53, p<.01	B, 2.46, N/S
Appropriate	**B1**, 12.4, p<.001	**B1**, 26.0, p<.001	**B**, 9.84, p<.0025
Clear to operate	**B1**, 5.53, p<.02	**B1**, 12.4, p<.001	B, 1.38, N/S
Comfortable	A1, 1.38, N/S	**B1**, 7.53, p<.01	**B**, 12.4, p<.001
Easy to move	**B1**, 12.4, p<.001	B1, 0.61, N/S	**B**, 15.3, p<.001
Improve skills	B1, 0.65, N/S	**B1**, 9.84, p<.0025	**B**, 9.84, p<.0025

Table 2. The results of the χ^2 test of significance. Each cell contains the dominant choice in the respective A/B test, the χ^2 value, and the probability value.

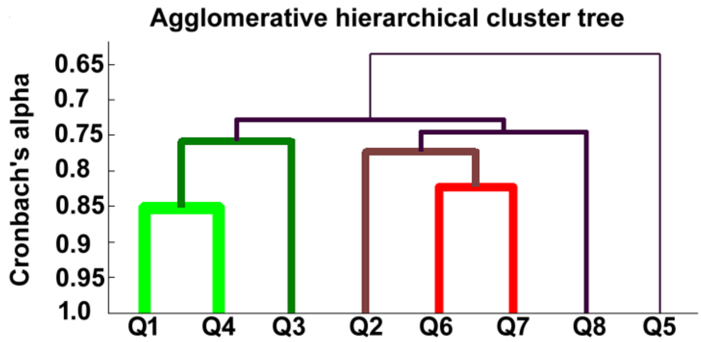

Fig. 5. Hierarchical clustering of the questions based on their internal consistency. Two clusters were found (shown here in green and red). Brighter colors indicate stronger connection.

Furthermore, the internal consistency of the 8 metrics that we used in our questionnaire was assessed by calculating Cronbach's alpha [17] from the responses of each individual A/B test (α=0.86, 0.85, 0.90) as well as from the cumulative responses across tests (α=0.86). In all cases, the calculated values exceeded the reliability estimates (α=0.70) recommended by Nunnally [18].

Finally, an agglomerative hierarchical cluster tree was created by computing the linkage between the questions using the largest affinity between two single elements from the respective clusters of questions (see Fig. 5). In our case, we employed Cronbach's alpha as the measure of affinity, which indicates the internal consistency between a pair of questions. According to Fig. 5, questions 1 and 4 were linked together at consistency level α=0.85 and were joined by question 3 at α=0.75. Similarly, questions 6 and 7 were also linked together at α=0.82 and joined by question 2 at α=0.77. This indicates that the questions about "how real" and "how appropriate" are associated with "less bulky", and the questions about "how comfortable" and "easy to move" are associated with "lighter." It should be noted that the questions about "easy to operate" and "improve skills" were connected with weaker links to the rest of the clusters (α<0.75).

5 Conclusions

In this paper we demonstrated how passive haptics can be used to enhance the user experience in a virtual reality application for instrumental music conductor training. A set of metrics was developed to assess various aspects of the user's experience after holding and using a baton within a virtual environment. The users in our pilot study found that our proposed smart baton felt more real, lighter, easier to move and operate, and more appropriate for this application. Our findings set the basis for a larger-scale future study that can be further developed in order to assess the educational aspects of this virtual reality application in terms of its learning outcomes as a tool that can supplement the traditional methods for instrumental music conductor training.

Acknowledgements. The authors would like to thank the anonymous volunteers who participated in this study. We would also like to express our appreciation to the University of Florida College of the Arts for providing funding for this project through the 2020 Research Incentive Award.

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