Prototyping a B-Bender Guitar for VR

Benjamin Esdor
KTH Royal Institute of Technology
Stockholm, Sweden
esdor@kth.se

Christian K.K. Lindberg
KTH Royal Institute of Technology
Stockholm, Sweden
ckkli@kth.se

Qinbai
KTH Royal Institute of Technology
Stockholm, Sweden
baiq@kth.se

Harits Nur Fauzan
KTH Royal Institute of Technology
Stockholm, Sweden
mhnf@kth.se

Mihaela Dinescu-Joe
KTH Royal Institute of Technology
Stockholm, Sweden
midj@kth.se

ABSTRACT

This study investigates some possibilities and limitations of AR/VR, the embodied experience and immersion of a virtual guitar experience. It contributes to the research area of VRMIs with three key findings that can guide future work. The study tried to answer the following question: "How could a normal guitar be mapped to a virtual representation of a B-Bender guitar, with the interaction of B-Bending, and provide an immersive experience?". Two specific technical guitar aspects were implemented, i.e., visual feedback of the guitar MIDI-notes in VR and the B-bending interaction in VR. These were in the focus of a user evaluation where six participants were given two tasks to perform, data was collected during a semi-structured interview and thematically analyzed. The analysis resulted in four themes that were discussed. The paper concludes with three key findings. First, holding a physical guitar improves the immersion, yet the precise mapping is important. Second, visualization of the hands is critical whereby the visual MIDI-note feedback not acting as a replacement. Thirdly, the b-bending worked satisfactory but needs to be tested out with professional musicians.

KEYWORDS

Virtual Reality; Guitar; B-bender; MIDI; Quest 2; User Evaluation

INTRODUCTION

One big challenge for museums is to let visitors get a first-hand experience with items on display as most collections in museums are behind display windows, for several reasons, inaccessible to first-hand interaction for visitors. Reports suggest that participatory experiences in museums have an increased focus and that museums are digitizing collections to increase access and visitor engagement, in the last few years [4, 5]. Finding ways for visitors to get a first-hand experience of their collections are therefore of interest to museums.

In recent years VR has become more accessible and ubiquitous, especially with the release of the Oculus Quest 2 [7], which is completely wireless. Today's accessibility of VR experiences therefore justifies the creation of remote exhibitions in VR by museums.

The guitar museum[2] in Umeå, Sweden, has several unique guitars on display that are inaccessible to a first-hand experience for visitors. A possible way for people to experience playing these guitars would be to extend reality with technology by presenting a virtual guitar visually while holding a physical guitar. The research field of Virtual Musical Instruments include software simulations, or extensions, of existing musical instruments with a focus on sonic emulation [3]. A subset of this field is in Virtual Reality Musical Instruments (VRMIs) where the instruments also include a simulated visual component, such as in a VR head-mounted display [10]. The related works we discuss in the background have been unable to replicate the real guitar playing experience in a virtual environment. Suggesting that ubiquitous technology is not yet at high enough fidelity for replicating the guitar playing experience in full VR. One approach would therefore be to use a real guitar that sends MIDI-data by which a virtual representation could react to.

The aim of this paper is to design a virtual application for the Quest 2 VR headset that reacts to the interaction of a physical guitar that sends MIDI-data. This does not seem to have been done before, neither with a B-Bender or normal guitar. The problem this paper will address is therefore how it could be done successfully in terms of usability and immersion and provide guidelines for future work. By designing and evaluating this implementation, this paper hopes to contribute to the research area of VRMIs.

Our research question is: "How could a normal guitar be mapped to a virtual representation of a B-Bender guitar, with the interaction of B-Bending, and provide an immersive experience?".

[2] https://www.guitarsthemuseum.com

Figure 1: Playing VRtuos in VR (top). Playing PianoVision in AR (bottom). [1]

Figure 2: Playing Unplugged VR with simple notes on the fretboard (top). Holding a real guitar while playing Unplugged VR (bottom). [2]

BACKGROUND

Related Commercial Applications

PianoVision and VRtuos are two examples of VR applications that let users play a virtual piano. The experience can be completely in VR, or with a Quest 2 it can also become AR by using the 'passthrough' technique. In complete VR, the piano, environment, and physical representation of the player's body is all virtual. By using the in-built hand tracking of the Quest 2 the virtual hands are mapped to the real hands, and you see your virtual-self pressing the piano keys. In the passthrough AR mode, the user sees the real world through cameras on the headset to which virtual objects can be overlaid on. The player can thus look at real piano keys and see their real hands, with virtual objects overlaid on desired parts. See **Figure 1**.

Unplugged VR[3] is a Quest 2 game that uses the hand tracking for players to play "air guitar" in complete VR. The position of the whole hand, and four of the fingers, determines what note is played. I.e., not a true representation of how real guitars are played. By holding a real guitar (that has no actual function) the user could get a more embodied experience of playing a real guitar.

Similarly, the game Rockband VR[4] lets a user experience guitar playing in VR by interacting with a physical game controller version of a real guitar. With a couple of buttons on the neck for playing notes and a single button that 'hits' all the strings on the guitar body. See **Figure 2**

Related Research

Serafin et al. [10] gave an overview of the field of VRMIs and presented a set of nine design guidelines, backed by previous research, focusing on the perspective of the performer. The guidelines were: (1) design for feedback and mapping, (2) reduce latency, (3) prevent cybersickness, (4) make use of existing skills, (5) consider both natural and magical interaction, (6) consider display ergonomics, (7) create a sense of presence, (8) represent the player's body, and (9) make the experience social. Serafin et al. used these guidelines to discuss how VRMIs should be evaluated. In their meaning, the evaluation is three-layered ranging from low to high. Starting with the first layer concerning the modalities of the interaction such as latency and ergonomics. The second layer concerns the VR-specifics such as cybersickness and presence. The third layer concerns the quality and goals of the interaction, coupled with the user experience.

One report [6] investigated how a synthetic guitar could be played with hand tracking sensors, called 'virtual air guitar'. However, the instrument does not have a visual, virtual, representation.

[3] https://unpluggedairguitar.com
[4] https://www.rockbandvr.com

Furthermore, the control of this instrument is not at the same resolution as that of a real guitar and was said to be more for entertainment than as a professional instrument.

Another paper [8] a VR guitar was developed that could be plucked by using a haptic device called “Sensable Phantom Omni”, which was then user-evaluated. The interaction only consisted of the pluck of the strings with one hand and could give haptic feedback through the device. It was not possible to use the other hand to push on the frets on the neck of the guitar. This prototype was user-evaluated in terms of realism, comparing four stimuli-conditions as the user plucked the virtual strings, ranging from no haptic feedback, to both vibrotactile & force feedback. Results could not give hard conclusions but suggested that the more haptic feedback that is provided, the more the realistic scenario. Furthermore, force feedback was the most impactful stimulus. Meaning the act of touching something in VR should give a physical force pushing back for more realism. Since this study will use a real physical guitar, the force feedback is already there.

METHOD

Design decisions

The project set up three requirements of the application. Firstly, considering one type of guitar, which is known as B-Bender. Typical for this type of guitar is that the second string (the B string) will bend by pulling on the forward strap, which enables the guitar player to transition fluently from one pitch to another. We wanted to translate this physical technique into VR. The original guitar model changes the pitch via a physical mechanism within the guitar, causing the bend by pulling the shoulder strap. However, we aimed to trigger the pitch by moving the guitar in a specific positional range in the VR. More is detailed in section ‘B-Bending Visualization’ below.

Secondly, we wanted to create a 3D model of the museum display at the guitar museum in Umeå, and one of their B-Bender guitars. The 3D model of the guitar needed to be mapped onto the physical guitar in the real world, so that the player feels that they are playing the virtual guitar. A correctly modeled guitar should not break the guitar playing experience. The modeling is explained in section ‘The Guitar Model’ below.

Lastly, we wanted to display the correct finger positioning on the guitar in VR with the Quest 2’s hand tracking. As Serafin et al. detailed in their design principle 8, giving a VR player a representation of their body is important. In our case, so that the player can see where to place their hands on the guitar. Even if experienced guitarists can play without looking at their hands, the B-Bending is likely an unfamiliar technique and can require the need to see their hands.

However, while working we became aware of the fact that the hand tracking of the Quest 2 is suboptimal for detailed operations such as pressing single notes on a guitar fretboard, with the fretboard also blocking the hand causing the Quest to lose the tracking. An optional approach would be to implement the Quest’s passthrough function to let the user see the real world in their near

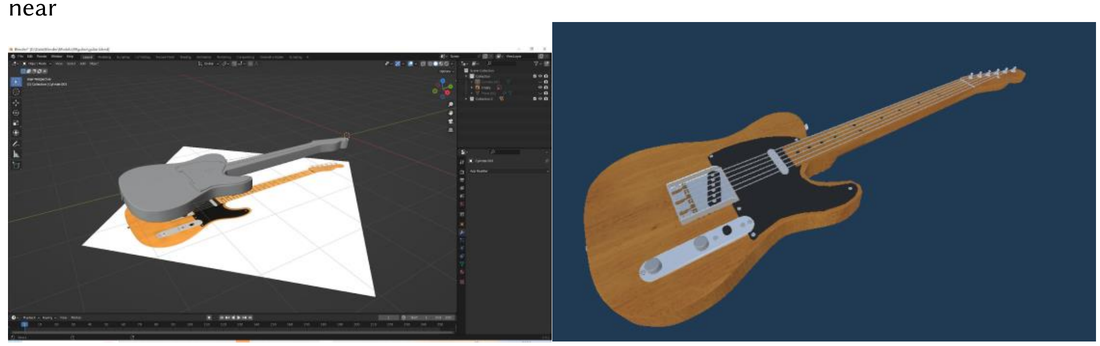

Figure 3: Process of modeling the guitar (top) and the final result (bottom).

vicinity, making the experience AR. However, we did not try implementing the passthrough for two main reasons: there was simply not enough time to implement it and it could have had a negative effect on the immersive experience of being at a museum exhibit. As a possible substitute we decided to implement visual feedback on which notes are being played on the fretboard as described in section 'Notes Visualization' below.

Communication Between the Server, the DAW, and the VR Application

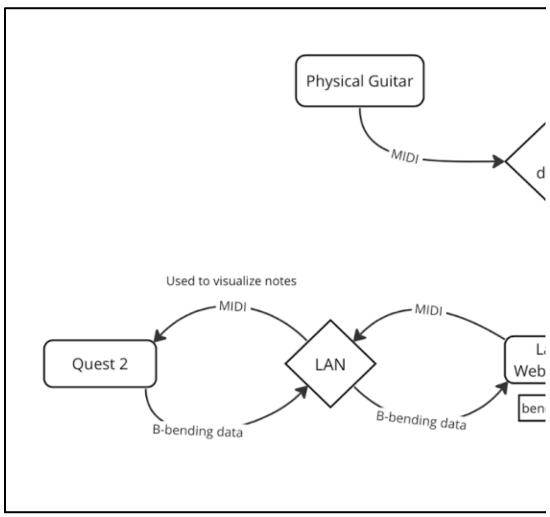

Figure 4: Data flow design

The system is running on top of three main applications: the VR application, the server, and the DAW. The VR application is responsible for displaying the virtual environment and acts as an input for the simulated B-Bending. The server acts as the middleman of the application: receiving input from the physical guitar with a MIDI pickup, sending and receiving input to and from the VR application, and sending input to the DAW. The DAW is used to produce the sound. The server is packaged as a desktop application that runs on MacOS, and we used Ableton Live 11 Lite as the DAW. We run the VR application using a Meta Quest 2 device and we developed the application using Unity 2020.3.18f1.

Figure 5: The virtual setup (left) and the physical setup (right) of the left-hand controller attached to the guitar head.

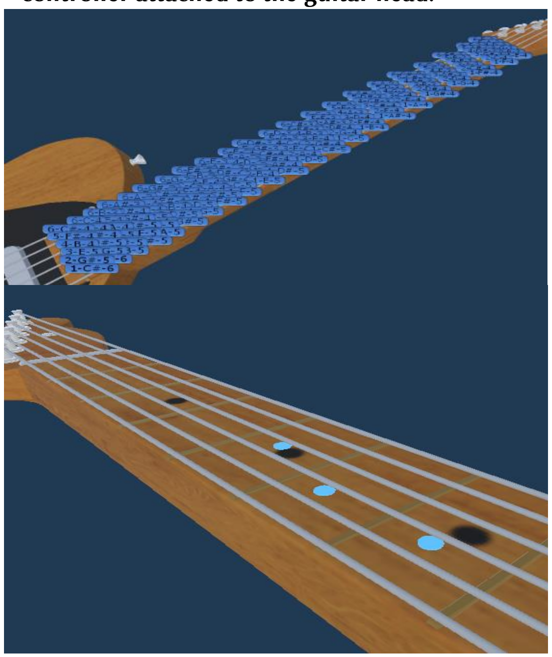

Figure 6: The notes mapping in Unity (top) and the dot visualization as seen by player (bottom).

The three applications are communicating with a locally hosted WebSocket server run on a laptop. See **Figure 4** for reference. The WebMIDI library[5] reads the input signals from the guitar MIDI-pickup. The WebMIDI library can intercept the MIDI input data and sending it to the VR application for visualization and simultaneously applying the simulated, virtual B-Bending.

We use three input types for processing the data: “noteon” is an input type that triggers when a note is first played by the MIDI input, “pitchbend” is an input type that triggers when bending is applied from the MIDI input, and “noteoff” is an input type that triggers when a note stops playing. The VR application uses the noteon and noteoff input types for visualization. Simultaneously, the VR application sends input back for the server to apply any B-Bending effect by using a pitch-bend manipulation on the MIDI channel corresponding to the B-string. Finally, the server processes the MIDI data and sends it to the DAW for generating the guitar sound.

The Guitar Model

The guitar model we used as a reference was from a website[6]. We used the free software Blender for modeling, shown in **Figure 3**. The model was imported into Unity and to map the position of the real guitar to the virtual guitar in VR, we put the guitar model as a child object of the Quest’s left-hand controller in the game, so that whenever the controller moves or rotates the virtual guitar will do the same. Since the user will be playing the guitar with both hands, the left Quest controller will only act as a tracker for position and orientation of the guitar. We attached the left-hand controller to the head of the actual guitar to achieve this effect, as seen in **Figure 5**.

Notes Visualization

Since the hand-tracking provided by Quest 2 is only viable when the hands are seen by the headset and whereas most of the time the hands are blocked by the guitar, we used visual dots to indicate which note the user played instead, as shown in **Figure 6**. Furthermore, after testing the hand-tracking we could conclude that the tracking was not precise enough to track fast moving hands with high spatial resolution.

We mapped the notes’ positions on the guitar and each note has a visual indicator, we called ‘dot’, on the fretboard, as shown in **Figure 6**. Unity receives WebMIDI input via a Websocket and finds the corresponding note to highlight on a ‘noteon’ message. The visual indicator is then disabled on a ‘noteoff’ message.

[5] https://webmidijs.org

[6] https://www.gear4music.se/sv/Gitarr-bas/Fender-American-Vintage-II-1951-Telecaster-Butterscotch-Blonde/54CC

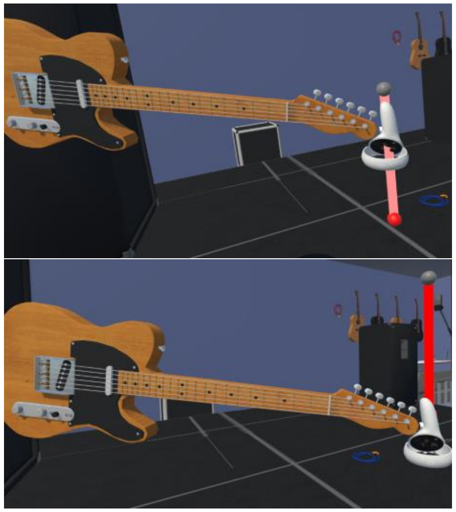

Figure 7: A vertical bar going from white to red as more B-Bending is applied (when the guitar head moves downwards). The bending is around 50% at top and 100% at bottom.

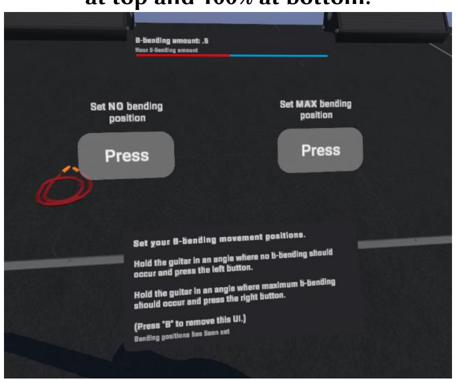

Figure 8: A blue bar getting filled with red, indicating the amount of B-Bending (top), two buttons to set the normal playing position and B-Bending position (middle), and a set of instructions (bottom).

B-Bending Visualization

The B-Bending visualization has two interfaces to indicate how much B-Bending is occurring, as shown in **Figure 7** and **Figure 8**. The user can set their normal play-position and a b-bending position with two virtual buttons, as seen in **Figure** 8. Moving the guitar up and down between these positions acts as performing a B-Bending movement, similar to how the strap is being pulled on a real B-Bender. The user is free to move around as they want horizontally, and the bending visualization will follow.

However, setting the B-Bending positions in a standing position and then moving to a seated position will require new B-Bending positions to be set, or maximum bending will most likely be performed all the time. A value ranging zero to one is sent as output to the WebMIDI, representing how much b-bending is occurring.

Study Design Methodology

To evaluate the implementation, we conducted a user study with six participants to gather qualitative data, that is participants' descriptions and explanations of their experience [9]. Hence, we chose to focus on open-ended questions, as they usually result in qualitative data that can be analyzed for categories or patterns of response, as stated by Preece et al [9].

We decided upon our study design based on guidelines from Preece et al. We chose the form of interviews, as, firstly, they are beneficial for exploring usability issues, secondly, the interviewer can guide the interviewee if necessary and lastly, it encourages contact between the researchers and the participants.

Also, we decided to focus solely qualitative data as we wanted to gain an in-depth analysis about the personal thoughts of participants regarding the technical aspects. Our decision to eliminate quantitative data was based on our focus of not drawing conclusions based on a larger population, but rather receive a brief usability and experience investigation to improve the design for an upcoming larger user study of the system.

Another option for interview would have been to a questionnaire to answer specific questions, however, we wanted to enforce the interaction between the participant and us to probe the user experience.

The participants were recruited from the researchers' university program, regardless of their knowledge in music theory or experience of playing the guitar. As the plan is to later test the implementation in a larger study with experienced guitar players, our user study places emphasis on the implementation of the technical and interaction aspects of the application. Therefore, is the guitar-playing experience of our participants deemed not as important. As large frictions will be shown regardless of experience. It can be argued that around five participants are enough to find large issues in the kind of system we want to evaluate [11, 12].

User Evaluation

The user evaluation consisted of two tasks, testing the visual feedback and the b-bending, respectively. For the first task, we gave each participant a basic guitar melody (the intro of 'Smoke on the Water' by Deep Purple) to practice for 5 minutes, without using the VR headset. This served as a baseline for the participants without knowledge in playing guitar. Hence, we assured that the participants could test the instrument in a conventional way close to the actual playing of a guitar. The participants were then asked to play the same melody with the VR headset on, for about 5 minutes. Within the VR environment, they are told to explore the visual feedback of the fretboard, i.e., the notes they play on the guitar.

For the second task, the participants were instructed to try out the b-bending mechanism. Each participant was given 5 minutes to practice a typical chord shape suited for a B-Bender guitar, without using the VR headset. We decided to take the A-Major chord shape, but lower on the second string, which is the b string, the C# two semitones down to a B. The effect that happens is that the physical push of the guitar will bend the note B on the b string two semitones back up to the C# and therefore into the A-Major chord. Next, the participants were asked to play this chord shape with the VR headset and instructed to use the b-bending interaction.

Finally, the participants were interviewed semi-structurally by one of the researchers. Data was collected by another researcher performing live transcription during the interview of the participants. A thematic analysis was performed collaboratively by all the researchers on the data, forming themes around what the data said.

RESULT AND ANALYSIS

Table 1: Overview of coding

Theme	*Categories*	*Codes*
Immersive Experience (Could be Improved)	Experience	14
	Holding real guitar increased immersion	7
	No cybersickness	6
	Immersion Breaking	5
Feedback on Hand-position Varied	Note-visualization supportive but hard to see	13
	Hands	10
B-Bending functionable	Bending audio perceivable	12
	Bending UI success	7
Varied latency	Good latency	4
	Bad latency	2

This section presents the results of the analysis and provides excerpts from the data to support and describe our analysis. Of the six participants, two had 2-5 years of experience playing the guitar. The average age of the participants was 26.5 years. All participants had tried out VR before, with one using VR several times per week. **Table 1** shows an overview of the results from the analysis, with four themes, their categories and their number of codes associated. The themes are presented in order of most codes first.

Immersive Experience (Could be Improved)

This theme was predominant in the data. Under the category "experience" codes pertained to participants' comments on different aspects of their experience. No one said that they experienced any cybersickness when asked and most said that the experience was fun and interesting, which is to be expected, but there were also some other aspects. One participant said:

> *"Like what affected maybe was that I had no experience playing guitar. If I had experience I could maybe have held the guitar better." (P5)*

The participant pointed out that their inexperience with playing guitar affected their experience negatively. Another said:

> *"The mapping of the real guitar was good with the virtual guitar. It made it feel more immersive." (P1)*

Complimenting the mapping of the virtual guitar's position to the real one. Meaning that it made the experience of playing the virtual guitar more immersive. However, one participant felt the mapping was off stating:

> *"It was weird at the beginning. The bottom part of the guitar was a bit off, maybe because of it only being one controller on the top." (P4)*

Feedback on Hand-position is Important

Together with the bending mechanism, the visual feedback of the played notes on the fretboard is one of our focus points in this study. Since the Quest 2 finger-tracking is not precise enough for our implementation, the solution was to implement only visual feedback of played notes. However, this

turned out to be a main critical point for the participants. The common canon was: "I want to see my hands (or other visual feedback) in VR". One participant said:

> *"It felt difficult to position my hand in the position of the frets. When playing 'Smoke on the Water' I couldn't realize where to place the hands. The dots helped a bit to place the hand." (P2)*

Another participant said:

> *"It was confusing in the beginning, then just fun. I realized I'm so dependent on seeing my hands, instead of just going by feel. It was an interesting experience." (P3)*

Both participants state that they had difficulty playing without seeing their hands. Overall, the participants considered the visual note feedback as helpful, however, it became apparent that the displayed feedback was too late in terms of helping the player guide their hands. As one participant states:

> *"The UI didn't bother me anyhow. The dots sort of helped me, but not much. If I hit the correct notes I could see I played correctly." (P2)*

Meaning that the visual note feedback was helping, but only in terms of understanding which note was played. P5 pointed out:

> *"I saw the dots [with guidance]. I felt they were in the right place, but their mapping wasn't correct to my real hand position. The dots helped but I would still need feedback on where my fingers are." (P5)*

Meaning that the visual feedback was helpful, but they wished for feedback on where their hands were. This brings us to another point of attention, that the visual note feedback was hardly noticeable and required inconvenient bending of the neck to see them clearly:

> *"[...] I need to bend over my body. Maybe have a mirror in front to see what I play." (P2)*
>
> *"I noticed the blue dots [after being instructed]. It was awkward because I had to bend myself down to see the dots. In a normal position it was hard to see." (P3)*

Both participants state that they must bend over their upper body to see the visual feedback on the fretboard to properly see it.

B-Bending Functionable

This theme describes what participants had to say about the B-bending function regarding its UI and generated sound. When asked 'What are your thoughts about the simulated bending?' all participants said in some form that they could hear the bending and that it sounded as they expected it to. Some participants also expressed that they had good control of the bending and that the visual feedback helped them. For example:

> *"It was clear what I was doing. The color was nice and clear to show what I was doing." (P1)*

When asked about the simulated bending, P1 stated that he liked the interface and helped him stay in control of the bending. Another participant said something similar:

> *"The UI made sense. It made me realize how much up and down I should go." (P2)*

One participant with around five years of experience of playing guitar said this when asked about the bending:

> *"It was precise, and I got a similar sound to what I was expecting." (P6)*

The participant felt the bending simulation was precise and sounded as they expected it to.

Varied Latency

This theme describes the unstable and variable latency participants experienced. Important enough for us to give it its own theme even though the number of codes were not that many. Four out of the six participants stated that they did not experience any form of latency. The two who did said:

> *"There was some delay in the sound, from plucking to hearing." (P4)*
>
> *"There was a bit of latency in the sound. It appeared a bit later." (P2)*

The participants state that there was a latency in the audio. With P2 stating that it appeared later in their session. This suggests that the latency was varied throughout the test, sometimes good and sometimes bad. This is also in line with the researcher's experience of playing the guitar, that sometimes the latency is more prominent.

DISCUSSION

This study set out to answer the research question: "How could a normal guitar be mapped to a virtual representation of a B-Bender guitar, with the interaction of B-Bending?". The study came up with a design, implemented it and evaluated it with users. The qualitative data was thematically analyzed resulting in four themes, describing the key findings discussed below.

Theme 1: Immersive Experience (Could be Improved)

This theme describes how our implementation was fun and immersive but that some key points could be improved to make it even better.

One key finding is that holding a real guitar was immersive for the participants. Similar to how Passalenti et al. [8] showed that haptic feedback creates a more immersive experience when plucking guitar strings in VR. By having the user interact with a physical artifact, similar in shape to a virtual replica, the experience becomes truly immersive. However, the mapping of position and rotation of the virtual and real world artifact has to be more precise as some participants were noticing discrepancies in our implementation. Our implementation used the Quest 2 controller strapped to the head of the real guitar. Slight changes in the position of the controller could result in a large offset in the mapping of the real versus virtual guitar. This finding relates to design principle 1, 3 and 7 of Serafin et al. [10].

The next key finding is that participants inexperienced in playing the guitar would feel less immersed. We attest this to the next theme, in the sense that an inexperienced guitar player is more reliant on seeing their hands to play. But as Serafin et al. [10] points out with design principle 8, letting the user see their own body in VR is good for every user.

Theme 2: Feedback on Hand-position is Important

The results of this theme indicate two major problematic areas. Firstly, the physical hand position was not mapped into VR and therefore causing trouble finding the correct notes. And the visual MIDI feedback does not serve as replacement of the actual hand. Second, the visual note feedback is hard to see. We will discuss these areas respectively in the following paragraphs.

Issue of not seeing hand-position

The first major issue is the missing hand position in VR. Participants stated that it was difficult to position the hand on the frets and that it was confusing in the beginning. The results can be interpreted as follows: As soon as the participant dives into VR with the Quest 2, they can see the virtual environment, the b-bending UI and the virtual guitar. However, the most intuitive part is missing: the actual representation of the left and right hand. This is especially important for the left hand, as otherwise the only feedback is the point of physical contact, on the back of the guitar neck, to guide the guitar player's hand. A professional player might be able to play without seeing the fretboard as it is common to read from sheet music while not looking at the fretboard.

However, our participants, as most beginners, are heavily dependent on seeing where they place their hands and fingers. To get back to the point of the dive into VR: The participants were literally VR blind. Understandably, is the answer for the difficulty of finding the correct frets on the guitar. As Serafin et al. states in design principle 8, representing the player's body, especially hands in our case, is important for an embodied experience.

With reliable hand-tracking, a pair of virtual hands could be implemented in our application. We hoped to use it in the Quest 2 but found it too unreliable. Hence, we transferred the idea from the Fishman MIDI controller "Triple Play", which shows the played note as indication on a virtual fretboard on a computer monitor. We displayed the notes on the virtual fretboard, using a Unity canvas system. Participants stated that the visualization is helpful, yet not enough. The information was visible only at the very moment, when the correct (or wrong) note was already played, that is too late.

The participants still desired visual feedback of the hands. This is similar to the observation from [10], being unable to fully replicate the guitar experience in a virtual environment. By using visual feedback markers we hoped to mitigate the missing hands, but it did not replace the hand representation. A solution could be to implement the Quest 2's 'Passthrough' functionality, which lets the player see the real world through cameras on the headset. With this, the hands could be shown with a virtual guitar overlaying the real world.

Issue of note visualization

The second major issue is that the visual note feedback is hard to see. Participants stated that they needed to bend over, or down, to see the dots on the fretboard. One reason could be that the general head position in VR is different to the head position without a VR headset. The headset adds weight to the head, which is not the case when playing guitar without a headset. Participants showed rather a straight head position during the study. Further, the head, plus the headset had to be bent over, as the fretboard of the virtual guitar was vertical in contrast to the line of view. Two participants suggested a mirror function in VR which shows the fretboard in the opposite line of view, which could be a future development to investigate.

Theme 3: B-Bending Functionable

This theme describes that the B-Bending was satisfying and its visual feedback helpful. The results of the analysis suggest that the participants were able to satisfyingly control the B-Bending and that we manipulated the sound in a successful way. However, most of our participants had none, or just a few years of, experience of playing guitar, with none knowing what a B-Bender was. This has to be considered before saying that our implementation of the B-Bending is true to a real B-Bender guitar.

Further user testing with participants that have experience of playing guitar, specifically B-Bender guitars, is recommended. An important aspect though, was that the visual feedback was helpful to control the B-Bending.

Theme 4:Varied Latency

This theme describes the key finding of our implementation having variable audio latency. Sometimes it is low and sometimes high. This relates to Serafin's et al. [10] design principle 2, the importance of low latency. We cannot say with any degree of certainty as to what is the cause of the latency. There can be one or several of these three sources: the MIDI-pickup system, the LAN-network, or the WebMIDI and DAW communication.

Summary of Discussion

In the center of our research is the following research question: "How could a normal guitar be mapped to a virtual representation of a B-Bender guitar, with the interaction of B-Bending, and provide an immersive experience?". The answer is dependent on several aspects. For instance, questions such as: which technology is being used, who is the target group of the application, what is the level of experience of the user, how much time can be devoted into research, are the developer experienced in playing guitar or music theory and also, do the researcher have access to the original guitar which they try to replicate - are critical to answer the research question.

Hence, we can only give suggestions in regard to how we approached challenges for this project. With the Oculus Quest 2, a MIDI controller pickup, and a physical guitar we were able to pin down our technologies to establish a reliable connection between several nodes in order to transmit information between different channels. Further, by 3D modeling and replicating a virtual telecaster guitar, we were able to map this asset in VR to the Quest 2 controller, which was mounted to the physical guitar. With our target group of novice guitar participants, we were able test our application according to the specific user case. Time constraints and prioritization of immersion lead us to implement a note visualization on the guitar fretboard, which was assessed in the user evaluation. A sophisticated hand tracking would have been good in representing the player's hands but was not possible due to poor tracking capabilities. However, overall, we can say that our application does work and especially the bending shows great results and works according to the original B-Bender guitar.

CONCLUSIONS

In this research project, we wanted to overcome two barriers related to a museum setting: giving visitors a first-hand experience of trying a B-Bender guitar on display and exhibiting the museum collection remotely. We did this by designing an implementation with the aim of providing immersion, an embodied experience and with a usable B-bending interaction.

We ended up creating a virtual application for the Quest 2 VR headset that reacts to the interaction of a physical guitar which sends MIDI-data and evaluated the implementation with users. We hoped to provide guidelines for future research to contribute to the research area of VRMIs.

The report concludes with three key findings. Firstly, the holding of a physical guitar improved the immersion, but the mapping of the virtual guitar is important and could be improved in our implementation. Secondly, it is important to relay feedback of the player's actual hand positions. The fretboard note visualization was helpful but does not replace a virtual representation of the hands. Also, the notes visualization style we used was hard to see. We thus recommend future works to implement a different style. Thirdly, when it comes to the B-Bending, the functionality showed a positive experience and participants were able to produce their desired sound with it. However, a conclusive statement needs to be drawn with professional musicians.

Future Research

We propose for future research to improve our application based on the findings and conduct a future user evaluation with professional musicians. If the Quest 2's hand tracking is improved in the future, the application could be improved by adding virtual hands to represent the player's hands.

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