PIANX – A Platform for Piano Players to Alleviate Music Performance Anxiety Using Mixed Reality

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ABSTRACT

We present PIANX, a platform to assist piano players in alleviating Music Performance Anxiety (MPA). Our work is motivated by the ability of Virtual Reality (VR) to create environments closely resembling the real world. For musicians, settings such as auditions or concerts are of particular interest, since they allow practicing in situations which evoke stress as a result of stage fright. Current approaches are limited: while they provide a virtual scene, realistic haptic feedback (i.e. playing on a real piano) and an authentic representation of their hands is missing. We close this gap with the design of a Mixed Reality platform, consisting of a MIDI (Musical Instrument Digital Interface) stage piano and an HTC Vive Pro VR headset. The platform offers (a) two approaches to finger tracking and visualization – a virtual representation based on LeapMotion hand tracking (baseline) and a real representation using see-through VR; in addition, it provides (b) three different settings in which users can practice (home, audition, concert hall) and (c) a mechanism for real time feedback. We created a series of videos demonstrating the system and collected feedback from 23 participants in an online study, assessing their views towards our platform. Results reveal key insights for the design of virtual MPA training platforms from a scientific and consumer perspective.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Mixed / augmented reality**; **Virtual reality**.

KEYWORDS

virtual reality, music, performance anxiety

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1 INTRODUCTION

Trembling, perspiration and shortness of breath – to many musicians these symptoms are all too familiar and often induced by the task of performing in front of people [38, 46]. Due to its highly competitive environment, the music industry requires not only technical and instrument-specific motor skills but also high mental resilience [28]. A musician must be able to cope with the intense psychological pressure caused by the implicit expectation to meet personal and the audiences' standards. The term used to describe this state is "Music Performance Anxiety" [9] (oftentimes referred to as "stage fright"). However, various studies question the accuracy of using both terms interchangeably [7, 44]. If or when the Music Performance Anxiety reaches an excessive level, it can cause damage to the musician's mental well-being and impair performance skills [49]. Mental suffering can be short-term but potentially also accompany musicians for the rest of their lives [28].

Many studies have shown that Music Performance Anxiety is independent of age, gender, or years of private study [7, 20, 46]. This mental health issue affects musicians at amateur level just as much as professionals. In extreme cases, it can lead the musicians to pause or even terminate their musical career. An example is the famous Russian pianist Vladimir Horowitz, who avoided the limelight for multiple, longer periods of time [6, 24]. A survey conducted by the International Conference of Symphony and Opera Musicians questioned over 2000 professional musicians and found Music Performance Anxiety to be the most frequent non-musculoskeletal medical problem among them [13]. More than 20 percent of the questioned musicians take beta-blockers, medication that weakens stress hormones, before important performances in public. In another study, 190 students from a musical university were asked about the negative feelings of Music Performance Anxiety before performing [44]. The perception of stage fright as a problem was also assessed. Results of this study showed that a significant number of students experienced stage fright as a problem and imagined it to have a negative impact on their career. Additionally, the majority expressed a strong need for more support with this issue (65 percent) and wished to receive more education and information about stage fright (84 percent).

One approach to cope with the anxiety is by exposing users to computer-generated simulations. Aufegger et al., for instance, explored the user's perception and experience performing in stage fright triggering simulations [3]. Orman et al. [36] and Bisonnette et al. used Virtual Reality to enhance the immersion of stage fright evoking simulations [4]. While the latter provides evidence for virtual environments feeling of presence and may have provided the means for desensitization, the results indicate a significant decrease in performance anxiety for musicians in the treatment group for those with a high level of state anxiety, for those with a high level of trait anxiety, for women, and for musicians with high immersive tendencies. Their study results similarly indicate the great potential Virtual Reality bears in creating a sense of presence in virtual simulations and using it to desensitize MPA.

Two major challenges in using simulated settings are (a) providing haptic feedback as if playing on a physical keyboard and (b) a realistic representation of the user's hands. We extend state-of-the-art by providing an integrated **pian**o Mi**X**ed Reality platform (PIANX) which enables haptic feedback by allowing a real piano to be used and provide a way of realistically visualizing a player's hands. With the presented system we aim to obtain an in-depth understanding of how MR can help players mitigate MPA by enabling them to practise while being confronted with stage fright.

In summary, our research focuses on the perception of three specific design aspects from a musician's point of view. The first aspect concerns hand visualizations in the Mixed Reality view of the user. In particular, we compare three different types of hand representations. Two are virtual hand models and differ in their appearances (serving as baselines), while the third is based on a camera that displays the real hands. The second design aspect concerns the virtual environments in which the user can practise. In this respect, PIANX includes three different environments. Each environment is designed and intended to provoke a certain stress level. The third design feature relates to feedback mechanisms. Our system incorporates a mechanism for real time feedback.

When comparing the three included settings (home, audition, concert), we found that audition and concert were perceived significantly more stressful than home. This indicates that environments involving some form of evaluation are specifically useful for MPA provocation. The vast majority of participants perceive the degree of realism to be a decisive criterion for the effectiveness of the virtual simulation and the immersion directly associated with it. Furthermore, shortening the distance as well as including familiarity between user and attendant, virtual people can increase the level of evoked stress. Concerning hand visualization, we found a clear preference of a real hand representation to the virtual hand models among the participants. Therefore, it is desirable to include the pianist's actual hands in the MPA piano training simulations.

Contribution Statement – Our contributions is twofold: 1) We present PIANX as a platform combining a real piano, hand tracking and Mixed Reality technology to alleviate music performance anxiety, and 2) we report on an online user study using video demonstrators to gain insights into the design of virtual MPA training platforms, showing that users prefer MR see-through hand representation and desire enhanced physiological feedback mechanisms.

2 BACKGROUND AND RELATED WORK

The following section will, first, briefly introduce Music Performance Anxiety (MPA) and summarize coping strategies. Afterwards, we will summarize prior work looking into how musicians can be supported using digital solutions. Finally, an overview will be provided on digital piano interfaces.

2.1 Music Performance Anxiety (MPA)

Anxiety by itself is an innate and natural human trait [9]. It only then becomes problematic when the affected person starts encountering unhealthy mental distress and negative effects on their functioning. Kenny defined Music Performance Anxiety (MPA) as the "experience of marked and persistent anxious apprehension related to musical performance that has arisen through specific anxiety conditioning experiences and which is manifested through combinations of affective, cognitive, somatic and behavioural symptoms" [19, 21]. MPA can occur in various types of performance settings. However, it is experienced most intensively in evaluative environments, such as recitals or auditions [19, 24, 37]. These scenarios involve a high ego investment and some form of judgement of the musical performance. MPA can result in an impairment of the musical performance and possibly cause permanent damages to mental health. Examples are depression, panic attacks, sleep disturbance, and side effects of medications used for MPA [9, 34].

2.2 Digital Training Solutions

As mentioned in the introduction, virtual simulations that offer a digital training method for playing piano in a stressful situation show great potential. There are multiple ways to create simulations in Virtual Reality (VR) or Mixed Reality (MR), for example by using a head-mounted display, a projection screen or a computer monitor.

According to Mandal, VR describes a fully "computer generated synthetic world that may be observed, moved through and manipulated by a user in realtime." [27]. VR can be assigned to the three dimensions immersion, presence, and interactivity [27, 43]. MR on the other hand indicates a partly computer-generated world [31]. In an MR environment, both real world and virtual world elements are merged and/or co-exist in one instance within a single display.

In the context of MPA, it is particularly important to focus on the level of immersion, for it strongly influences the level of anxiety the pianist experiences [5]. Similarly, prior work showed that the level of perceived anxiety is closely linked to the perceived presence and vice versa [1, 23].

Bissonette et al. developed a VR Exposure Training (VRET), which is based on projection [5]. VRET is designed for the treatment of Music Performance Anxiety and its impact on music students was tested. VRET exposes the students to four virtual environments, three representing typical classical music audiences and one showing an empty concert hall. Unlike in the works of Aufegger et al. [3], where the simulation is projected onto one single screen in front of the performer, VRET displays the simulation on multiple screens arranged around the test person. The study results revealed that most participants experienced reduced psychological MPA levels.

2.3 Digital Piano Systems

To create a piano playing experience within a virtual simulation, it is essential to provide sufficient visual feedback on hand and individual finger movements. Therefore, VR pianos often utilise a motion tracking device that is able to compile information about the positions of hands and fingers. Using this information, the hands can accurately be mapped onto a virtual hand model in VR. In addition, position data can give insights into finger movement properties, such as finger dynamics in piano touch and tempo [14, 15]. One way of implementing a VR Piano is to create a piano model, which solely exists in the VR view of the head-mounted display [17].

In HMD settings, hand movements are often performed in mid-air. Other applications rely on hand interaction with planar objects, which function as a replacement for the real piano surface [25]. Depth sensors can also be used for monitoring finger movements. Oka and Hashimoto, for instance, proposed a concept based on depth information for automated piano lessons, in which the practice of fingering is possible [35]. Another option for tracking hand movements is by detecting hand gestures. Qiao et al. created a piano playing VR system that uses gesture detection with the Leap Motion technology [39]. A study showed that the virtual piano application has good performance. However, one noteworthy disadvantage is the lack of tactile feedback for the user. This becomes especially problematic when the user wants to play fast passages.

Desnoyers-Stewart, Gerhard and Smith developed a virtual piano keyboard with which they explored the integration of physical objects into a virtual environment and its effects on immersion and feeling of presence [11]. The pianist uses a VR headset. However, as the pianist still plays on a real world keyboard, the authors referred to their system as a "Mixed Reality piano keyboard". Using such a MR piano keyboard instead of a keyboard that only exists in VR, comes with the benefit of haptic feedback that is added to the experience. Multiple studies investigated the role of physical touch in VR experiences. As of yet, most VR applications primarily address our visual and auditory senses [8, 10]. However, there is great value in equipping virtual objects with physical qualities [16]. Such haptics provide the user with more cues about the environment, thus enhancing their sense of immersion and interactivity and stimulating their imagination [10, 32]. Other hand tracking options include marker based solutions, which can either be magnetic or reflective. However, hardly any research work follows this approach.

2.4 Summary

Music Performance Anxiety is a widespread problem among musicians of any age, gender or skill level. Therefore, training possibilities reducing the psychological distress caused by MPA are highly desired. One approach to improve MPA coping skills is to introduce virtual simulations in MPA training, e.g., projection [3, 5]. Using VR or MR simulations instead of projection can add new degrees of immersion, presence and interactivity to the experience. Especially the introduction of haptic feedback by adding real world objects to the virtual experience in MR systems is beneficial [11].

To the best of our knowledge no approach to alleviate MPA in piano playing exist, where users are able to experience a virtual, MPA-inducing scene while at the same time being able to play on a real keyboard and seeing their real hands. Additionally, an understanding of how users perceive an MR setting for MPA training is missing as of today. Providing multiple design options, the PIANX platform offers a first step in designing and developing just that.

3 THE PIANX PLATFORM

3.1 Concept & Requirements

To enable haptic feedback and a realistic hand representation, we use a MIDI [41] piano keyboard and an HTC Vive PRO VR headset. PIANX can display the user's real hands using the HTC Vive Pro headset's built-in see-through camera in a virtual environment. In addition, the platform supports the display of virtual hands (as is common in state-of-the-art projects). As hands are constantly in motion during piano playing, displaying virtual hand representations requires hand tracking technology. To this end, we added the LeapMotion hand tracking device to our setup.

Figure 1: The *audition* environment puts the player in a situation where four judges observe the performance.

Besides a suitable hand and piano representation in VR, conceptual requirements also include the recording and processing of MIDI data, implementing suitable virtual environments that evoke stress, and visualizing feedback in real time.

3.2 System Design

3.2.1 Virtual Environment. The PIANX platform involves three virtual environments, intended to evoke a certain level of stress. The environments differs in the number of listeners, their level of expectation and their familiarity with the environment. The first two are based on the works of Williamon et al. [48]. They tested the effectiveness of two virtual environments in successfully inducing feelings of stress in violin students. The environments were displayed on a two-dimensional screen. One environment consisted of a virtual audience. The other involved an audition with three virtual judges. Both scenarios are driven by the expectation to deliver a high quality performance in an unfamiliar setting with several listeners. Due to these attributes, they are expected to provoke a high level of stage fright. In PIANX, both scenes are re-created in VR. Top view perspectives and the views whilst inside the simulation are shown in Figures 1 (audition) and 2 (concert hall).

In the virtual setting the piano is placed inside a living room with a single other virtual person (Figure 3). The other person is working on an electronic device and does not pay attention to the pianist. Compared to the other scenarios, the third scene reduces the number of listeners to a minimum and demonstrates their indifference to the performance. The placement of the user in a living room is supposed to set a familiar and homely atmosphere, hence provoking a low level of stress.

3.2.2 Hand Visualization. To provide a suitable virtual hand visualization, we considered three tracking technologies: (a) an OptiTrack Motion Capture System, which relies on infrared cameras and reflective markers; (b) the HTC-Vive Pro Hand Tracking, which is an embedded feature of the VR headset; and (c) a Leap Motion Controller, which uses a camera for hand gesture detection. Desnoyers-Stewart et al. summarize the properties of different tracking solutions, specifically regarding accuracy, form factor, and portability[11]. We implemented tracking using the three proposed options, ultimately

Figure 2: The *concert hall* environment exposes the player to a setting with many listeners.

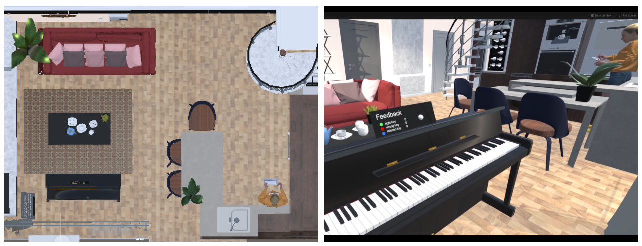


Figure 3: The *living room* environment was designed to create a rather relaxing atmosphere.

deciding on using the Leap Motion Controller for displaying two fully virtual hand representations, because of two reasons. The Optitrack augments the hands too much with markers to be able to freely interact with the system. Tests with the HTC-Vive Pro hand tracking showed that it is less precise and entails a larger latency of real to virtual hand tracking. Also the representations are based on prior work [11]. For the third option, i.e. the display of the user's real hands, we use the HTC Vive Pro see-through camera.

3.2.3 Feedback. PIANX accesses the MIDI data transmitted by the MIDI piano keyboard. From this data, the information which key was played *(keynote)*, the force with which it was pressed *(velocity)* and the timestamp when it pressed *(start time)* is extracted. This allows the *(duration)* for which a key is pressed to be calculated. For each key press, i.e. each MIDI event that occurs, PIANX saves the keynote, velocity, start time and duration, which is then used to determine whether a note was missed, played correctly or incorrectly *(status)*. Accordingly, meaningful feedback is provided in form of a small virtual interface window above the piano, that shows textual information (c.f. Figure 3, right).

3.3 Interaction Design

Our system includes different interaction possibilities that allow the piano player to receive feedback on their performance. The user can operate the system in two modes:

- *Base mode:* When this mode is activated, the most recent recording is saved as a MIDI file (referred to as "*comparison file*") and serves as a model for comparison with *practice files*.
- *Practice mode:* When this mode is activated, each recording is stored in a separate MIDI file (referred to as "*practice file*") and can be compared with the *comparison file*. This way, the pianist can receive feedback on the performance.

The user interacts with the system using the computer keyboard, which functions as user input controller. Once a user starts the application, they can give one of the following three commands:

(1) Switch between recording *base mode* or *practice mode* (by pressing "o")
(2) Start recording (by pressing "space")
(3) End and save a recording (by pressing "escape")

The three commands are available in both modes. An instruction panel inside the VR environment promotes the interactivity of the system. One elementary aspect of our interaction design is that PIANX lets pianists themselves create their own version of the performance without the VR headset, to which practice takes can be compared to. This decision originates on the awareness that each pianist has a different way of interpreting and performing a musical piece. After all, the aim is to compare, adapt and raise the performance quality of the VR performance to the quality of the pianist's individual version. This version can only be created in *base mode*. By giving the commands to start and end a recording, the system captures the performance and writes the MIDI data into one specific MIDI file. This file is defined as '*comparison file*'. The user can re-record the musical extract as often as they like. Once satisfied with the *comparison file*, users can switch to the second mode, the *practice mode*. In this mode, recording and saving a take will automatically create a practice MIDI file, which can be used for feedback and analysis afterwards. In contrast to the *base mode*, every saving creates a new file, allowing for multiple *practice files* to be created and stored.

3.4 Research Approach

The PIANX platform focuses on the design aspects of virtual environments, hand visualizations and feedback. We formulated three research questions, each referring to a different design aspect.

(1) *What are important and desired design features of virtual environments that effectively evoke Music Performance Anxiety?*
(2) *How do pianists perceive virtual compared to real hand representations for piano playing in a virtual simulation?*
(3) *What feedback variables do pianists desire when using an MR application that aims to alleviate Music Performance Anxiety?*

We had originally planned to invite casual piano players, teachers, and professionals to experience and explore the different features of the platform. To not put users at any risk, we decided to abort the study with the beginning of the Corona crisis, after we had demonstrated the platform to amateur piano players from within our institute.

After careful consideration we decided to conduct an online study, where instead of physically trying out the platform, participants had the opportunity to watch videos depicting the different aspects of the system. Afterwards they were asked to fill in a questionnaire, designed to answer the research question put forth.

4 SYSTEM

In the following the implementation is described – in particular the architecture, the implementation of the hand representation the different virtual environments a well as the feedback mechanism.

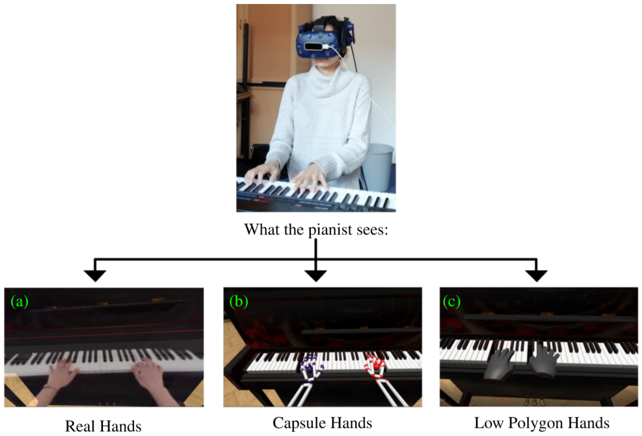


Figure 4: Visualization of the concept for testing MR and VR piano playing using different hand representations: *Real Hands* (a), *Capsule Hands* (b) and the *Low Polygon Hands* (c)

4.1 Architecture

The piano keyboard used is a Yamaha MIDI Master Keyboard with 88 keys. The hardware setup consists of a computer (HP Z VR Backpack G1 Workstation) running Windows 10 pro (32GB RAM, Intel Core i7-7820HQ, NVIDIA Quadro P5200) and the HTC-Vive Pro VR headset. The OUT port of the piano keyboard is connected to a tone generator, which in turn is connected to the computer via MIDI/USB interface as well as the loudspeakers. The tone generator is a device that plays the sound of the pressed key on the MIDI-Keyboard via the loudspeakers and transmits the MIDI data from the keyboard to the computer. The latter are used for the audio sound output. The program is written in C# and implemented using the Unity Game Engine (version v.2019.2.12f1). The computer is connected to both the tone generator and the VR headset, thus serving as the interface for all key hardware and software components.

4.2 Hand Tracking and Visualization

The PIANX platform offers three options for displaying the user's hand inside the VR environment. Figure 4 conveys the simplified concept idea. It shows the user's actions in the top picture. The three bottom pictures display the user's VR view for each of the three hand representations.

4.2.1 Virtual Hand Representation. In order to use the virtual hand models in PIANX, the Leap Motion Controller[1] with software Orion Beta is added to the setup. The device is attached to the VR headset using Velcro strips and connected via USB3.0 to the computer.

A study by Argelaguet et al. experimented with different degrees of realism of hand representations in VR [2]. They came to the conclusion that abstract and iconic hands lead to a better understanding of the virtual hands as their own. On the basis of this research, we selected two virtual hand model prefabs for our system. The first hand model type is the *Capsule Hand*, which consists of basic geometric forms. This prefab includes the display of left and right upper arms. The second type is the *Low Polygon Hand*.

[1]https://developer.leapmotion.com/ [Accessed: May 10, 2020]

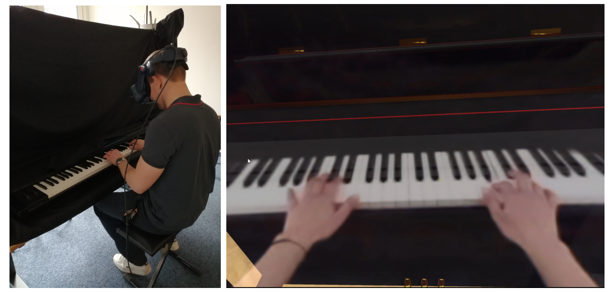


Figure 5: Real hand display system setup

Hand models of this type are black mesh hand models. They resemble a human hand more closely than the *Capsule Hand* model, as the mesh, similarly to human skin, covers the bones and single components. Figure 4 (b) shows the *Capsule Hands*, while 4 (c) illustrates the *Low Polygon Hands* on the right. A calibration program is implemented, that automatically adjusts the position of the real piano model. After executing the calibration, the relation between real hands and real keyboard is projected onto the relation between their virtual pendants.

4.2.2 Real Hand Representation. McGill et al. found evidence for drastic improvements in the performance while typing in VR as real world elements are included [29]. This suggests that seeing the real world hands and keys facilitate playing piano in VR, thereby causing less errors and increasing performance quality. Testing the representation with 4 people from the research group also hinted at this. Therefore, we implemented an additional option allowing the real hands to be seen. We enable the "see-through" feature of the VR headset's front-mounted camera. Figure 4 (a) shows the user's VR view using the HTC-Vive Pro see-through camera and turning on the see-through mode *transparent passthrough*. As a result, the person wearing the headset sees the virtual world transparently superimposed onto the real world's live camera image. No additional hardware is required. However, the see-through camera option cannot be limited to a certain area of the visual field of view. To limit the superimposition to the area of the real keyboards keys and the user's real hands, we use a black non-reflective blanket. The blanket is fixed in a way that it covers the real environment as much as needed to use the blue-screen-technique (see Figure 5). The piano keys are left uncovered and are, therefore, visible to the user in VR.

4.3 Virtual Environments

The human models and animations for the virtual environment are imported from mixamo.com[2].

Living Room. The living room 3D model was acquired from TurbosQuid.com[3] and imported into the Unity project. A few adjustments are made to the interior design, to create a more homely atmosphere and fit the virtual piano inside the room. One person (including animations) was added.

[2]https://www.mixamo.com/ [Accessed: May 10, 2020]
[3]https://www.turbosquid.com/3d-models/bedroom-bed-3d-model-1524240 [Accessed: May 10, 2020]

Audition. The audition scene contains only the piano and the four animated examiners sitting at a table. The user directly faces the judges. The background is black, a dramatic contrast to the white ground. As lighting plays an important role in evoking feelings of stress [30], a spotlight was placed directly above the scene.

Concert Hall. About 200 human models are placed inside the scene, with various looped sitting animations assigned to them. The model for the auditorium was purchased from cgtrader.com[4].

4.4 Feedback Mechanism

For providing realtime feedback, the recorded *comparison file* is used. It serves as a reference to which the realtime playing is compared. We implemented a method that carries out a realtime analysis of the current play when in *practice mode* and recording was developed. This happens by going through the *comparison file* sequentially: at every keystroke registered and transmitted as MIDI data, the played keynote value is immediately compared to the keynote value in the corresponding line of the *comparison file*. For this comparison we use the error metric suggested by Rogers et al. [40]. Therefore, three attributes are registered: missed notes, incorrectly played notes and correctly played notes. Incorrectly played notes can be identified as "pitch error" while correctly played notes are classified as "correct pitch" [12]. Each of the three error variables is appointed a number from 0 to 2. This value is compared for every played key and added to the MIDI file as *status*. To visualize the quantitative performance feedback, a panel is placed inside the scene. The panel displays the number of missed, correctly and incorrectly played notes and is updated with every keystroke. For an immediate and intuitive visual feedback, a circle is placed next to the three counters. Different colouring of the circle is used as a feedback tool. Red represents an incorrectly played note, green signals a correctly played note, and if the circle turns blue, the user missed a note. The display panel is placed right next to the piano, to the right of the user.

5 EVALUATION

We investigated what users consider important design features to evoke MPA (RQ1), how pianists perceive virtual compared to real hand representations (RQ2) and in which form they want to receive feedback while using an application to alleviate MPA (RQ3)[5].

5.1 Study Design

Participating in the survey took approximately 15–20 minutes. In the beginning, participants were briefed about the overall study's objective. To create a good understanding of how PIANX functions, we recorded seven videos from the user's VR view (a) in the three different setting; (b) using the three different hand representations; and (c) displaying the real time feedback mechanism. The videos were made available via YouTube.com[6]. In addition, several pictures showed the VR view for the corresponding questions.

5.2 Questionnaire

The online survey consisted of five parts:

1. The first part contains questions on the participants' demographics and their previous experiences in piano playing and VR.
2. In part two, participants are asked questions about previous experiences of stage fright and its effect on them. Questions related to MPA are adapted from *Kenny's Music Performance Anxiety Inventory* (K-MPAI) [22] and the Appendix of Sweeny's *Structured Interview Screening Questions and Selection Criteria* for Music Performance Anxiety [45].
3. Part three contains questions related to the designed virtual environments. They concerned the realism of simulations and experienced perception thereof. We derived the questions form Williamon et al. [48] and Kassab et al. [18].
4. The fourth part focused on the hand representations in our system. For questions about the perception of virtual hands, the questionnaire presented by Argelaguet et al. [2] served as a basis. They investigated the sense of body-ownership and the sense of agency of virtual hand representations when interacting with virtual environments. Selected questions were adapted to this context.
5. Questions related to feedback design are asked in part five.

Questions of part two to five are based on a 7-point Likert scale. Part three to five each address one research question. Additionally, part three to five include one question about the personal preference of the different conditions. The survey was completed by open questions regarding areas for improvement.

5.3 Recruiting

23 people with piano playing skills between 20 and 62 years took part. The number of years of piano playing experience ranges from 1 to 55 with an average of 16.5 years. The majority (56.5 percent) of the respondents practice the piano once a week or more often. 34.8 percent state to practice once a month to once a year. The remaining 8.7 percent reveal to have discontinued their practice. Most of the questioned musicians perform in public regularly, with 30.4 percent stating to do so every few months and 43.5 percent about once a year.

When asked about their familiarity with VR, 52.2 percent claim to have never experienced it before. 34.8 percent experience this technology once a month to once a year. The remaining 13.0 percent have interacted with it about one to four times in their lifetime.

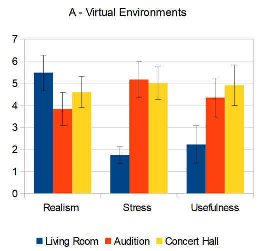
6 RESULTS

We present the results of the conducted online survey.

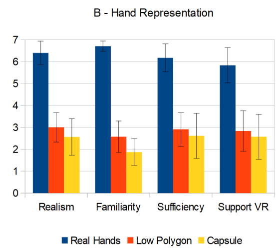
6.1 Music Performance Anxiety

Questions regarding Music Performance Anxiety were based on a 7-point Likert scale (1=not at all; 7=very much so). The majority of participants affirmed to play the piano better in private than in public (Mean=5.66, SD=1.36). According to most respondents, this happens even when thoroughly prepared to the best of their ability

[4]https://www.cgtrader.com/3d-models/interior/hall/auditorium-vr-ar-game-ready [Accessed: May 10, 2020]
[5]Note, that it was impossible to evaluate the platform with participants in the lab. Hence, the survey's main purpose was to trigger thought-provoking feedback.
[6]https://www.youtube.com/watch?v=JLJJfL99$_$-o;
https://www.youtube.com/watch?v=5w1TccMOhes;
https://www.youtube.com/watch?v=bb4IIyLoS8M;
https://www.youtube.com/watch?v=dVPhszF6-G0;
https://www.youtube.com/watch?v=9XHM2NQBiiQ;
https://www.youtube.com/watch?v=lAIpvjC8Y9w [Accessed: May 20, 2020]



(a) Likert scale results of the three virtual environments compared in the study.



(b) Likert scale results of visual feedback/support of VR illusion of hand representations.

Figure 6: Ratings for environment / hand respresentation.

(Mean=4.81, SD=1.78). Although the common opinion about the perception of stage fright itself as a problem is neutral (Mean=4.30, SD=2.14), participants are generally interested in using an application that helps coping with this anxiety (Mean=4.78, SD=1.78).

6.2 Virtual Environments

Figure 6a shows the ratings for the questions related to virtual environments. When directly comparing the preference of the presented virtual environments, a clear tendency towards the scenarios Concert Hall and Living Room becomes clear. 10 participants each choose the *Concert Hall* and the *Living Room* as their preferred practice environment, while 3 select *Audition*.

6.2.1 Realism. The latter environment is also perceived as the least *realistic* one (Mean=3.82, SD=1.50). The *Living Room* (Mean=5.48, SD=1.59) is perceived more realistic than the *Concert Hall* (Mean=4.61, SD=1.41). A Friedman test represents a statistically significant difference for the question about the degree of realism depending on the environment, $\chi^2(2) = 17.043$, $p < 0.001$. When applying the Wilcoxon test on the results of this question, solely the trial between the *Living Room* and the *Audition* is significantly different (Z=-3.672, p<0.001). Comparing the *Living Room* with the *Concert Hall* (Z=-2.244, p=0.025) and the *Concert Hall* with the *Audition* (Z=-1.894, p=0.058), no statistically significant differences are revealed.

6.2.2 Stress. Most participants expect the environment *Audition* to be most *stressful* (Mean=5.17, SD=1.61), closely followed by *Concert Hall* (Mean=5.00, SD=1.48). The *Living Room* received low scores in this matter (Mean=1.74, SD=0.75). A Friedman test shows a statistically significant difference in the perceived stress level depending on the environment, $\chi^2(2)=36.851$, $p<0.001$. Post hoc analysis with Wilcoxon signed-rank tests was carried out using a Bonferroni adjustment, that sets the significance level at $p < 0.017$. The tests reveal significant differences between the *Living Room* and the *Audition* environment trial (Z=-4.220, p<0.001) as well as the *Living Room* and the *Concert Hall* environment trial (Z=-4.224, p<0.001). However, the trial between the *Audition* and the *Concert Hall* shows no significant difference (Z=-0.202, p=0.840).

6.2.3 Evoking Stage Fright. The questionnaire reveals that the *Audition* (Mean=4.91, SD=1.83) scenario is expected to be most useful for *evoking stage fright*. The *Concert Hall* receives similar ratings (Mean=4.35, SD=1.77). The average rating for the *Living Room* (Mean=2.22, SD=1.70) can be found on the lower end of the Likert scale. A statistically significant difference in the responses for rating of the usefulness of the environments was revealed, $\chi^2(2) = 27.475$, $p < 0.001$. Based on the Wilcoxon test, there is a significant difference between the *Living Room* and *Audition* (Z=-3.362, p=0.001), as well as between the *Living Room* and the *Concert Hall* (Z=-3.454, p=0.001) trials. However, there is no significant difference between *Audition* and *Concert Hall* (Z=-2.012, p=0.044).

6.2.4 Suggestions for Improvements. The ranking in realism is complemented by additional feedback. Participants state the *audition* environment looking "too plain" (P1) and needing to be "more realistic" (P1,18,22). Two participants (P9,P20) suggest a repositioning of the jury as an audition "usually incorporates a jury able to observe the hands and the keyboard" (P9). One musician (P4) refers to their own experiences and hints that it can be "even more frightening when you feel like the jury does not really pay you their full attention", therefore proposing to add other animations to the examiners, like "whispering to one another, maybe even about your performance". Another suggestion for improvement of the audition environment is to reduce the distance between the player and the jury so that the player "sees the[ir] faces" (P22). For the *concert hall*, a spotlight (P21,P23) and background noises, such as the whispering of the audience, (P3,P4,P8,P21) are recommended.

General improvement ideas include adding a piano bench for more realism (P3) and the incorporation of people's real time reaction to one's performance (P22). An example could be to make the person in the living room "look up with a confused expression" (P22) during poor performance.

Participants contributed ideas for *new environments*. Four participants propose a scenario, where the musician must perform in a street (P1,P6,P17,P21). The sudden approach of attentive listeners is pointed out to cause increased stress (P1). Four participants suggest a classroom scenario (P3,P8,P12,P13), others deemed playing in front of a celebrity (P18), the piano teacher (P20) or family/friends (P10,P22) a suitable stage fright provoking scenario. Playing together with others or an orchestra (P9), as well as playing in a room without knowing who can hear the performance through the wall (P4) are also proposed virtual environments.

6.3 Hand Representation

Figure 6b contains the scores of participants on a 7-point Likert scale for questions related to hand representations. When comparing the views on the virtual hand types *Capsule Hands* and *Low Polygon Hands* with the real hands, 22 out of the 23 participants state to prefer seeing their real hands in the simulation. The remaining person prefers the Capsule Hand model. The existence of an arm representation additional to hands and fingers, as given with the *Real Hands* and the *Capsule Hands*, seems to be important to the musicians (Mean=5.30, SD=1.94).

6.3.1 Realism. Real Hands receive by far the highest score (Mean= 6.39, SD=1.08), compared to *Capsule Hands* (Mean=2.57, SD=1.67) and *Low Polygon Hands* (Mean=3.00, SD=1.35). Based on a Friedman test, a statistically significant difference between responses was found, $\chi^2(2) = 34.506$, $p < 0.001$. A post hoc analysis with Wilcoxon signed-rank tests was conducted. The results were validated against a Bonferroni correction, resulting in a significance level at $p < 0.017$. The analysis shows a statistically significant difference for realism when pairing *Real Hands* with *Low Polygon Hands* (Z=-4.226, p<0.001) or *Capsule Hands* (Z=-4.036, p<0.001).

6.3.2 Familiarity. Participants state the *Real Hands* to appear most familiar (Mean=6.70, SD=0.47) in contrast to the *Capsule Hands* (Mean=1.87, SD=1.22) and *Low Polygon Hands* (Mean=2.57, SD=1.44). There is a statistically significant difference for this question, $\chi^2(2) = 40.683$, $p < 0.001$. A recurrent Wilcoxon test for familiarity revealed statistically significant differences in all three cases when pairing *Capsule Hands* with *Low Polygon Hands* (Z=-2.684, p=0.007), *Capsule Hands* with *Real Hands* (Z=-4.241, p<0.001), and *Low Polygon Hands* with *Real Hands* (Z=-4.222, p<0.001).

6.3.3 Visual Feedback. The hands from the real world are also convincing in terms of sufficient visual feedback. A statistically significant difference between the responses for the sufficiency of visual feedback *Real Hands* (Mean=6.17, SD=1.27), *Capsule Hands* (Mean=2.61, SD=2.06), and *Low Polygon Hands* (Mean=2.91, SD=1.56) provide was shown, $\chi^2(2) = 30.400$, $p < 0.001$. Again, a statistical significance was found between the latter two options. However, there is a significant difference when comparing *Real Hands* with *Low Polygon Hands* (Z=-4.126, p<0.001) or *Capsule Hands* (Z=-3.889, p<0.001). The illusion of moving inside a virtual world is expected to be most supported by using *Real Hands* (Mean=5.83, SD=1.61) instead of *Capsule Hands* (Mean=2.57, SD=2.063) or *Low Polygon Hands* (Mean=1.85, SD=2.83). There is a statistically significant difference for the answers on immersion, $\chi^2(2) = 29.065$, $p < 0.001$. A Wilcoxon test reveals this difference to be valid for the trial between *Real Hands* with *Low Polygon Hands* (Z=-3.926, p<0.001) or *Capsule Hands* (Z=-3.844, p<0.001), yet not for the pair of *Capsule Hands* and *Low Polygon Hands* (Z=-0.846, p=0.387).

6.3.4 Further Comments. The considerable predilection for the real hand option is mainly due to it being the "most realistic" (P3,P10,P11,P12,P13,P14,P16,P21) and, therefore, also feel more "natural" (P17). According to participants, the real hands "make a transition from reality to virtuality much easier" (P1). The other two options "may be confusing while playing" (P18). While one person directly connects the feeling of presence in VR with the level of realism (P3), thereby arguing for MR, another (P4) remarks that playing with hands that seem "completely new" and look "technical" might be easier. Seeing that VR does not reach perfect realness, they would "rather get used to a new way of perceiving playing the piano which still does get the human movement right" (P4). This person chose the *Capsule Hands* option as favorable hand representation. Four participant reaffirm the importance of a representation of the arms (P1,P4,P9,P14). P22 comments that the level of realism was more important for the hands than for the environments.

6.4 Feedback Design

Concerning realtime feedback, the general opinion is that it is not as important for the improvement of stage fright coping skills (Mean=3.65, SD=2.31) as for performance skills (Mean=4.91, SD=2.31). A tendency towards the belief that realtime feedback might in fact be distracting (Mean=4.35, SD=1.82) can be seen. In the open questions, participants propose new feedback variables, such as an "indirect feedback through reactions" (P22) of the involved virtual people or checking the correctness of the volume of the played notes and the quality of sound dynamics (P3,P20,P23). Some participants desire feedback on playing speed deviations and timing errors (P3,P6,P7), as well as the accuracy of pedal usage (P23). Additional information can also be gained by applying eye tracking sensors to the system, to see where the focus lies during a performance (P2). Two musicians expressed skepticism towards the used feedback variable of correctness of played notes, particularly for stage fright evaluation (P9,P11). A participant notes that to them the "musical arc of suspense which frequently is disrupted when suffering from stage fright" (P9) seems to be most affected by stage fright. Therefore, performance accuracy measurements are not necessarily the most suitable variable. Another musicians underlines this impression, by emphasising the "artistic freedom" (P11) also having an influence on the correctness of played notes.

7 DISCUSSION

The goal of PIANX is to explore possibilities for a VR or MR application that helps pianists cope with stage fright. An online survey about the developed prototype was conducted. Most survey participants show a high willingness to try the application and state to be interested in using the system at home. The interest of musicians for MPA training application is supported by the research work of Matei and Ginsborg [28] and the study results of Studer et al. [44].

7.1 Design of the Environment

The first research question addresses the design of virtual environments to effectively evoke MPA. One aspect all participants commonly agree upon, is that a key feature of a stress provoking environment is the high degree of realism. As proposed in [42] and reaffirmed by one of the participants, the realism of an environment is closely connected to the feeling of presence. Suggestions, such as adding a piano bench or spotlights emphasise the importance of a convincing design. Concerning MPA, we expected the *Living Room* to provoke a rather low stress level, as the number of listeners was limited to one. The *Living Room* did indeed receive lower ratings for stress. However, apparently the number of listeners is not necessarily a decisive factor for anxiety. In fact, a shorter the distance between the pianist and the listener seems to be just as crucial in this matter, as multiple participants suggested to decrease the distance, even enabling the listener to see the pianist's fingers.

Furthermore, significantly more listeners (e.g. a live broadcast of the performance) might lead to different result. This could be investigated in the future. Apart from the number of listeners and distance, the responses indicate that a certain familiarity towards the listener seems to play a major role for evoking stage fright. Multiple participants individually propose an environment that involves performing in front of friends and family, or role models such as celebrities or a piano teacher. The high motivation to impress is the common leitmotif here. In her definition of MPA, Kenny hints towards the threat of social evaluation leading to higher MPA [19]. Other research work affirmed that the MPA level is higher for people, who are more motivated by the desire to impress the audience than to express something [47]. Contrary to our expectations, the audition environment seems to have a similarly high stress provoking character as the concert hall. Hence, evaluative environments should be included in future MPA training simulations.

7.2 Hand Visualization

As for hand visualization, we expected the display of real hands to be a preferable solution to the virtual hands. Previous lab tests revealed that playing in MR felt most intuitive and by far easiest with *Real Hand* representation. Indeed, apart from one person, all survey participants preferred this representation to the others. Nonetheless, we imagined the realism of the hand to possibly confound the illusion of moving inside a virtual world. Hence, an interest in a completely virtual constructed world was expected to some extent. Results show that participant did not feel this way about the implementation. Compared to both virtual hands, most participants feel that the *Real Hand* option in fact supports the immersion inside VR even more. The common consensus of the participants is that the degree of realism is a more determining factor for immersion and acceptance. Hence, a deeper investigation of incorporating real hands in MR piano systems is desirable.

The accuracy of the played notes was expected to be one of the most important feedback variables. This hypothesis is based on [40], who included accuracy measurements of missed notes and correctly/incorrectly played notes into their error metrics. Participants indeed view this as crucial information for the improvement of playing skills. For improvement of stage fright coping skills, however, some participants doubt the usefulness of this variable. Two point out that accuracy might be influenced by other factors, such as individual interpretation. Instead, the focus should be on aspects directly related to stage fright. These include, on one hand, physical variables such as heart rate and sweat measurements. On the other hand, psychological signs of stress such as the frequency of interruptions are suggested. The variable speed as additional feedback was also mentioned remarkably often. Möller et al. confirm that anxiety and excitement can have a physical influence on the muscle tonus, possibly causing tight muscles and tremor [33]. This can lead to a restriction of fine motor skills and thus, also of speed. Therefore, anxiety can be an influential factor for tempo and feedback and should be included in MPA training apps.

8 CONCLUSION

The PIANX platform investigates different ways of implementing and designing suitable applications for a piano playing experience in MR. The goal is to help pianists cope with their Musical Performance Anxiety by using stage fright evoking simulations. A survey among pianists of different skill levels revealed their views on design aspects of the proposed MPA training application.

Participants felt the degree of realism to be a decisive criterion for immersion and the effectiveness directly associated with it. For MPA evoking scenarios, environments familiar to the pianist are particularly suitable. Furthermore, the level of perceived stress might directly dependent on the distance of the pianist to the listeners.

Concerning hand representations, the online survey suggests that pianists prefer a real hand representation to a virtual one. Therefore, MR solutions including pianists' actual hands in the simulation seem to be more suitable than VR approaches.

Finally, the study revealed participants' desired feedback variables to improve their MPA coping skills. They favor feedback on physiological reactions, such as heart rate, timing or speed.

Experiencing Music Performance Anxiety before and during a musical performance affects a vast amount of musicians. Nonetheless, there are still many open questions as to how this phenomenon can be dealt with and be prevented [26]. VR and MR technologies are promising in this regard. We took a first step by presenting a platform to practice in stage fright provoking VR and MR scenarios and provide insights into how the use of MR, haptic feedback, and the representation of the players' hands are perceived by potential users. Future directions include approaching our main limitations, i.e., to conduct studies under controlled experimental conditions in the lab, to assess effects between different hand representations and virtual environments, and to utilise physiological sensors to more accurately measure user's stress and anxiety levels.

REFERENCES

[1] Ivan Alsina-Jurnet and José Gutiérrez-Maldonado. 2010. Influence of personality and individual abilities on the sense of presence experienced in anxiety triggering virtual environments. *International journal of human-computer studies* 68, 10 (2010), 788–801.

[2] Ferran Argelaguet, Ludovic Hoyet, Michael Trico, and Anatole Lecuyer. 2016. The role of interaction in virtual embodiment: Effects of the virtual hand representation. In *2016 IEEE Virtual Reality Conference (VR): Greenville, South Carolina, USA, 19-23 March 2016 : proceedings*. IEEE, Piscataway, NJ, 3–10. https://doi.org/10.1109/VR.2016.7504682

[3] Lisa Aufegger, Rosie Perkins, David Wasley, and Aaron Williamon. 2017. Musicians' perceptions and experiences of using simulation training to develop performance skills. *Psychology of Music* 45, 3 (2017), 417–431. https://doi.org/10.1177/0305735616666940

[4] Josiane Bissonnette, Francis Dubé, Martin D. Provencher, and Maria T. Moreno Sala. 2015. Virtual Reality Exposure Training for Musicians: Its Effect on Performance Anxiety and Quality. *Medical Problems of Performing Artists* 30, 3 (2015), 169–177. https://doi.org/10.21091/mppa.2015.3032

[5] Josiane Bissonnette, Francis Dubé, Martin D. Provencher, and Maria T. Moreno Sala. 2016. Evolution of music performance anxiety and quality of performance during virtual reality exposure training. *Virtual Reality* 20, 1 (2016), 71–81. https://doi.org/10.1007/s10055-016-0283-y

[6] Eleanor Blau. 1998. CLASSICAL MUSIC; Taking Arms Against Stage Fright. *The New York Times* (1998), 33. https://www.nytimes.com/1998/09/20/arts/classical-music-taking-arms-against-stage-fright.html

[7] Ariadna Brugues. 2009. Music performance anxiety : a review of the literature . URN: urn:nbn:de:bsz:25-opus-66035. (2009).

[8] Grigore Burdea. 1999. Haptic Feedback for Virtual Reality. *Virtual Reality and Prototyping Workshop* 2 (1999), 17–29.

[9] A. Beatriz Burin and Flávia L. Osório. 2017. Music performance anxiety: a critical review of etiological aspects, perceived causes, coping strategies and treatment. *Archives of Clinical Psychiatry (São Paulo)* 44, 5 (2017), 127–133. https://doi.org/10.1590/0101-60830000000136

[10] WANG Dangxiao, G. U.O. Yuan, L. I.U. Shiyi, ZHANG Yuru, X. U. Weiliang, and XIAO Jing. 2019. Haptic display for virtual reality: progress and challenges. *Virtual Reality & Intelligent Hardware* 1, 2 (2019), 136. https://doi.org/10.3724/SP.J.2096-5796.2019.0008

[11] John Desnoyers-Stewart, David Gerhard, and Megan Smith. [n.d.]. Mixed Reality MIDI Keyboard. In *Proceedings of the 13th International Symposium on CMMR*. 376–386.

[12] Carolyn Drake and Caroline Palmer. 2000. Skill acquisition in music performance: relations between planning and temporal control. *Cognition* 74, 1 (2000), 1–32. https://doi.org/10.1016/S0010-0277(99)00061-X

[13] M. Fishbein, S. E. Middlestadt, V. Ottati, S. Straus, and A. Ellis. 1988. Medical Problems Among ICSOM Musicians: Overview of a National Surve. *Medical Problems of Performing Artists* (1988), 1–8.

[14] Werner Goebl. 2017. Movement and Touch in Piano Performance. In *Handbook of Human Motion*, Bertram Müller, Sebastian I. Wolf, Gert-Peter Brueggemann, Zhigang Deng, Andrew McIntosh, Freeman Miller, and William Scott Selbie (Eds.). Vol. 1252. Springer International Publishing, Cham, 1–18. https://doi.org/10.1007/978-3-319-30808-1{_}109-1

[15] Werner Goebl and Caroline Palmer. 2009. Finger motion in piano performance: Touch and tempo. *Proceedings of the International Symposium on Performance Science* Auckland (2009).

[16] H. G. Hoffman. 14-18 March 1998. Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments. In *Proceedings. IEEE 1998 Virtual Reality Annual International Symposium (Cat. No.98CB36180)*. IEEE Comput. Soc, 59–63. https://doi.org/10.1109/VRAIS.1998.658423

[17] Inwook Hwang, Hyungki Son, and Jin Ryong Kim. 06/06/2017 - 09/06/2017. AirPiano: Enhancing music playing experience in virtual reality with mid-air haptic feedback. In *2017 IEEE World Haptics Conference (WHC)*. IEEE, 213–218. https://doi.org/10.1109/WHC.2017.7989903

[18] Eva Kassab, Jimmy Kyaw Tun, Sonal Arora, Dominic King, Kamran Ahmed, Danilo Miskovic, Alexandra Cope, Bhamini Vadhwana, Fernando Bello, Nick Sevdalis, and Roger Kneebone. 2011. "Blowing up the barriers" in surgical training: exploring and validating the concept of distributed simulation. *Annals of surgery* 254, 6 (2011), 1059–1065. https://doi.org/10.1097/SLA.0b013e318228944a

[19] Dianna T. Kenny. [n.d.]. Negative emotions in music making: performance anxiety. In *Handbook of music and emotion: Theory, research, applications*. 425–452.

[20] Dianna T. Kenny. 2006. Music performance anxiety: Origins, phenomenology, assessment and treatment. *Context: A Journal of Music Research* 31 (2006), 51–64.

[21] Dianna T. Kenny. 2011. *The psychology of music performance anxiety*. Oxford University Press, Oxford. http://www.loc.gov/catdir/enhancements/fy1117/2011924234-b.html

[22] Dianna T. Kenny, Pamela Davis, and Jenni Oates. 2004. Music performance anxiety and occupational stress amongst opera chorus artists and their relationship with state and trait anxiety and perfectionism. *Journal of anxiety disorders* 18, 6 (2004), 757–777. https://doi.org/10.1016/j.janxdis.2003.09.004

[23] Joung Huem Kwon, John Powell, and Alan Chalmers. 2013. How level of realism influences anxiety in virtual reality environments for a job interview. *International journal of human-computer studies* 71, 10 (2013), 978–987.

[24] Albert LeBlanc, Young Chang Jin, Mary Obert, and Carolyn Siivola. 1997. Effect of Audience on Music Performance Anxiety. *Journal of Research in Music Education* 45, 3 (1997), 480–496. https://doi.org/10.2307/3345541

[25] Hui Liang, Jin Wang, Qian Sun, Yong-Jin Liu, Junsong Yuan, Jun Luo, and Ying He. 2016. Barehanded music. In *Proceedings of the 20th ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games - I3D '16*, Chris Wyman and Cem Yuksel (Eds.). ACM Press, New York, New York, USA, 87–94. https://doi.org/10.1145/2856400.2856411

[26] Peggy Liebelt. 2000. Differentialpsychologische Untersuchungen zur Phänomenologie, Genese sowie psychologischen Behandlung von Podiumsangst bei Bühnenkünstlern - Dissertation Universität Leipzig. (2000).

[27] Sharmistha Mandal. 2013. Brief Introduction of Virtual Reality & its Challenges. *International Journal of Scientific & Engineering Research* 4, 4 (2013), 304–309.

[28] Raluca Matei and Jane Ginsborg. 2017. Music performance anxiety in classical musicians - what we know about what works. *BJPsych international* 14, 2 (2017), 33–35. https://doi.org/10.1192/s2056474000001744

[29] Mark McGill, Daniel Boland, Roderick Murray-Smith, and Stephen Brewster. 2015. A Dose of Reality. In *CHI 2015 crossings: CHI 2015 ; proceedings of the 33rd Annual CHI Conference on Human Factors in Computing Systems ; April 18 - 23, 2015, Seoul, Republic of Korea*, Jinwoo Kim (Ed.). ACM, New York, NY, 2143–2152. https://doi.org/10.1145/2702123.2702382

[30] Michael Meehan, Brent Insko, Mary Whitton, and Frederick P. Brooks. 2002. Physiological measures of presence in stressful virtual environments. In *Proceedings of the 29th annual conference on Computer graphics and interactive techniques - SIGGRAPH '02*, Tom Appolloni (Ed.). ACM Press, New York, New York, USA, 645. https://doi.org/10.1145/566570.566630

[31] Paul Milgram and Fumio Kishino. 1994. A Taxonomy of Mixed Reality Visual Displays. *IEICE Trans. Information Systems* E77-D, 12 (1994), 1321–1329.

[32] Mark Mine. 1995. Virtual Environment Interaction Techniques. *UNC Chapel Hill CS Dept., Technical Report* (1995).

[33] H. Möller and S. Castringius. 2005. Aufführungsangst ein gesundheitliches Risiko bei Musikern - Ursachen, Therapie und Prävention. *Musikphysiologie und Musikermedizin* 12, 3 (2005), 139–154.

[34] D. Riley Nicholson, Meghan W. Cody, and J. Gayle Beck. 2015. Anxiety in musicians: On and off stage. *Psychology of Music* 43, 3 (2015), 438–449. https://doi.org/10.1177/0305735614540018

[35] Akiya Oka and Manabu Hashimoto. 30/01/2013 - 01/02/2013. Marker-less piano fingering recognition using sequential depth images. In *The 19th Korea-Japan Joint Workshop on Frontiers of Computer Vision*. IEEE, 1–4. https://doi.org/10.1109/FCV.2013.6485449

[36] Evelyn K. Orman. 2003. Effect of Virtual Reality Graded Exposure on Heart Rate and Self-Reported Anxiety Levels of Performing Saxophonists. *Journal of Research in Music Education* 51, 4 (2003), 302–315. https://doi.org/10.2307/3345657

[37] Margaret S. Osborne and John Franklin. 2002. Cognitive processes in music performance anxiety. *Australian Journal of Psychology* 54, 2 (2002), 86–93. https://doi.org/10.1080/00049530210001706543

[38] Eric A. Plaut. 1988. Psychotherapy of Performance Anxiety. *Medical Problems of Performing Artists 3* 3 (1988), 113–118. https://www.sciandmed.com/mppa/journalviewer.aspx?issue=1137&article=1385&action=1

[39] Wei Qiao, Rui Wei, Sanyuan Zhao, Da Huo, and Fengxia Li. 22/08/2017 - 25/08/2017. A real-time virtual piano based on gesture capture data. In *2017 12th International Conference on Computer Science and Education (ICCSE)*. IEEE, 740–743. https://doi.org/10.1109/ICCSE.2017.8085592

[40] Katja Rogers, Michael Weber, Amrei Röhlig, Matthias Weing, Jan Gugenheimer, Bastian Könings, Melina Klepsch, Florian Schaub, Enrico Rukzio, and Tina Seufert. 2014. P.I.A.N.O. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces - ITS '14*, Raimund Dachselt, Nicholas Graham, Kasper Hornbæk, and Miguel Nacenta (Eds.). ACM Press, New York, New York, USA, 149–158. https://doi.org/10.1145/2669485.2669514

[41] Joseph Rothstein. 1995. *MIDI: A comprehensive introduction / Joseph Rothstein* (2nd ed. ed.). The computer music and digital audio series, Vol. v.7. A-R Editions, Madison, Wis.

[42] Maria V. Sanchez-Vives and Mel Slater. 2005. From presence to consciousness through virtual reality. *Nature reviews. Neuroscience* 6, 4 (2005), 332–339. https://doi.org/10.1038/nrn1651

[43] Jonathan Steuer. 1992. Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication* 42, 4 (1992), 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x

[44] Regina Studer, Patrick Gomez, Horst Hildebrandt, Marc Arial, and Brigitta Danuser. 2011. Stage fright: its experience as a problem and coping with it. *International archives of occupational and environmental health* 84, 7 (2011), 761–771. https://doi.org/10.1007/s00420-010-0608-1

[45] Gladys A. Sweeney and John J. Horan. 1982. Separate and combined effects of cue-controlled relaxation and cognitive restructuring in the treatment of musical performance anxiety. *Journal of Counseling Psychology* 29, 5 (1982), 486–497. https://doi.org/10.1037/0022-0167.29.5.486

[46] Robert Tamborrino. 2001. An examination of performance anxiety associated with solo performance of college-level music majors. *Dissertation Abstracts International Section A: Humanities & Social Sciences* 62 (2001).

[47] Benjamin Whitcomb. 2008. Overcoming Performance Anxiety. *American String Teacher* 58, 4 (2008), 36–39. https://doi.org/10.1177/000313130805800406

[48] Aaron Williamon, Lisa Aufegger, and Hubert Eiholzer. 2014. Simulating and stimulating performance: introducing distributed simulation to enhance musical learning and performance. *Frontiers in psychology* 5 (2014), 25. https://doi.org/10.3389/fpsyg.2014.00025

[49] Michiko Yoshie, Kazuo Shigemasu, Kazutoshi Kudo, and Tatsuyuki Ohtsuki. 2009. Effects of State Anxiety on Music Performance: Relationship between the Revised Competitive State Anxiety Inventory-2 Subscales and Piano Performance. *Musicae Scientiae* 13, 1 (2009), 55–84. https://doi.org/10.1177/1029864909013001003