The Effectiveness of VR Applications for Piano Learning: The Impact of Self-Discipline and Time Management

A Eficácia das Aplicações de Realidade Virtual no Aprendizado de Piano: O Impacto da Autodisciplina e da Gestão do Tempo

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Abstract: This study aims to compare the effects of distinct learning modalities on the extent to which pianists can improve during practice and to determine the predictive roles of self-discipline and time management abilities. Here, a total of 216 piano students from the city of Beijing were randomly assigned to learning with two VR apps and to conventional learning. Piano skills were measured using the Practical Piano Grades system at the pre- and post-intervention stages. Self-discipline and time management skills were assessed using the Brief Self-Control Scale and the Time Management Behavior Scale. After eight weeks of training, VR-assisted learners achieved statistically significant improvements in skill compared with those using traditional learning methods. The most significant effect was observed in the VRtuos group, whereas the use of the Grand Reality app yielded more moderate results. Self-discipline and time management were significant positive predictors of improvement across modalities. These findings indicate that the effectiveness of VR-assisted piano learning depends on the structural features of the virtual environment and a pianist's regulatory characteristics, rather than just the degree of immersion. This study identifies important practical implications for integrating VR technology into music education.

Keywords: music education; performance skills; piano lessons; self-discipline; time management; virtual reality

Resumo: Este estudo tem como objetivo comparar os efeitos de distintas modalidades de aprendizagem sobre o quanto pianistas podem evoluir durante a prática e determinar o papel preditivo da autodisciplina e das habilidades de gestão do tempo. Foram incluídos 216 estudantes de piano de Pequim, distribuídos aleatoriamente entre dois aplicativos de realidade virtual e métodos de aprendizagem convencionais. As habilidades de piano foram avaliadas por meio do sistema Practical Piano Grades nas fases pré- e pós-intervenção. A autodisciplina e a gestão do tempo foram medidas por meio da Brief Self-Control Scale e da Time Management Behavior Scale. Após oito semanas de treinamento, os aprendizes assistidos por VR apresentaram melhorias estatisticamente significativas em suas habilidades em comparação com os que utilizaram métodos tradicionais de aprendizagem. O efeito mais expressivo foi observado no grupo VRtuos, enquanto o uso do aplicativo Grand Reality apresentou resultados mais moderados. A autodisciplina e a gestão do tempo mostraram-se preditoras positivas significativas de melhora, independentemente da modalidade utilizada. Esses achados indicam que a eficácia do aprendizado de piano com realidade virtual depende das características estruturais do ambiente virtual e das características regulatórias do pianista, e não apenas do grau de imersão. Este estudo apresenta importantes implicações práticas para a integração da tecnologia de VR na educação musical.

Palavras-chave: educação musical; habilidades de performance; aulas de piano; autodisciplina; gestão do tempo; realidade virtual

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Introduction

In recent years, virtual reality (VR) has become one of the most promising areas for the development of digital educational technologies, including those designed for application in music education (Peng, 2024; Zhang, 2025). Researchers have shown a growing interest in deploying VR to support individual practice, improve motor coordination, boost engagement, and enhance self-regulation in the teaching of musical instruments (such as the piano). This vector opens new prospects for creating immersive learning environments, visualizing music, and increasing student engagement (Wijaya et al., 2020; Yu et al., 2023). VR creates a controlled learning space that reduces the impact of external stimuli, helping learners focus on what they are doing and in what order. This feature is particularly important for technical proficiency (Li, 2025; Pesek et al., 2024). VR thus facilitates the development of more comprehensive skills by integrating the cognitive, motor, and perceptual aspects of musical activity within a unified environment (Han et al., 2025; Yu et al., 2023).

Today, modern music education is increasingly challenged by declining student motivation, low self-discipline, and ineffective time management (Gorbunovs et al., 2016; Wolters and Brady, 2021). Self-discipline primarily refers to the ability to engage in regular practice, concentrate on the task, and organize the learning process. In self-directed learning, a significant portion of control over the learning process is transferred to the student (Hagger and Hamilton, 2019; Shi and Qu, 2022). Despite the growing adoption of VR in education, existing research primarily focuses on technical aspects and the overall impact of VR on motivation and student performance (Wang, 2024; Wu and Tao, 2022). Meanwhile, the psychological parameters that influence the effectiveness of VR-based learning remain superficially explored (Peng, 2024). In particular, individual skills such as self-discipline and time management are rarely considered as independent factors of successful VR-assisted piano learning (Gorbunovs et al., 2016; Shi and Qu, 2022).

The practical significance of this study lies in the implications it offers for the development of VR apps for music education. The present findings can inform the design of curriculum programs for music college and art school students. They may be useful to piano teachers, instructional designers, and experts in music pedagogy. This study's contribution lies in its ability to expand theoretical understanding of the role of self-regulation in digital learning and to create an interdisciplinary approach to piano education at the intersection of music pedagogy, educational psychology, and VR technology.

Literature Review

The contemporary research exploring the use of digital technologies in music education highlights a growing interest in immersive and interactive learning environments (Han et al., 2025; Wang, 2024; Zhang, 2025). VR is viewed as a tool for expanding standard pedagogical approaches through the use of visualization and multi-channel feedback in a controlled learning space (Kamp, 2025; Li, 2025; Lu, 2023). In the context of piano education, VR apps are most often studied for their impact on student engagement, movement accuracy, and independent practice (Ishida and Inutsuka, 2024; Wijaya et al., 2020; Yu et al., 2023).

This study draws on the theory of deliberate practice, which posits that the development of expertise requires a learner to engage in purposeful, structured practice on a regular basis and systematically adjust the outcome (Hatfield et al., 2017). In this model, the central mechanism of improvement is the learner's ability to maintain long-term, organized, and intellectually focused practice, which is closely linked to self-discipline and self-regulation (Gorbunovs et al., 2016; Hagger and Hamilton, 2019; Jung et al., 2017). From this perspective, the current study examines the effectiveness of VR-based learning as a result of the interaction between the digital environment and an individual's regulatory mechanisms, rather than as an autonomous effect of the technology, with self-discipline and time management as the primary factors influencing it.

A number of empirical studies emphasize the positive effects of VR and related technologies (e.g., augmented reality (AR), mixed reality, and interactive simulations) on subjective motivation and concentration (Molero et al., 2021; Sai, 2024; Wang, 2024). Virtual environments have the potential to reduce the sense of mundanity that often accompanies the learning process and to offer pianists a richer, more diverse learning experience (Kamp, 2025; Pesek et al., 2024). Beginning musicians and those who struggle to maintain a regular practice may benefit the most from VR integration (Ishida and Inutsuka, 2024; Yin, 2023). The short-term nature of these studies, however, and their reliance on self-reported data limit the possibility of in-depth analysis (Doganyigit and Islim, 2021; Wang, 2024).

Another research focus is the effectiveness of digital platforms and apps that support structured learning (Peng, 2024). Scholars emphasize the importance of a systematic approach, workload management, and progress visualization (Li, 2025; Yin, 2023). Tools that provide learners with information on study time, repetitions, and mistakes made can help promote a more conscious approach to learning (Lu, 2023; Sai, 2024). In most cases, however, the results are attributed solely to the software's functional characteristics, while students' individual characteristics are ignored (Peng, 2024; Zhang, 2025).

A significant body of research in educational psychology is devoted to self-regulation, self-discipline, and time management as key factors of academic success (Hagger and Hamilton, 2019; Jung et al., 2017; Shi and Qu, 2022). The ability to plan your studies rationally and stay on track was reported to be one of the most important predictors of academic achievement (Herron, 2023; Wolters and Brady, 2021). These variables are particularly important in the context of music education, as progress in mastering an instrument depends directly on the consistency and frequency of engagement in learning activities (Hatfield et al., 2017; Jääskeläinen et al., 2023). However, most studies do not address the relationship between self-regulation and the use of digital or immersive technologies (Gorbunovs et al., 2016; Shi and Qu, 2022).

A gap exists between research on the technological aspects of VR learning and the psychological analysis of learning progress (Peng, 2024; Wang, 2024). The former often treats VR as a universal tool for boosting performance, whereas differences between learner groups and their individual characteristics are largely ignored (Li, 2025; Zhang, 2025). The latter emphasizes skills such as self-discipline and time management, but rarely examines them in the context of technology-enhanced learning (Gorbunovs et al., 2016; Wolters and Brady, 2021).

Available studies offer an insufficient exploration of mediating and moderating mechanisms. Most often, researchers document the overall effect of VR or examine individual psychological variables in isolation (Peng, 2024; Yu et al., 2023). It remains unclear whether VR enhances skills such as self-discipline and time management, whether it can compensate for their absence, or whether it requires a high level of self-regulation (Shi and Qu, 2022; Wolters and Brady, 2021). Little is known about how the interaction between digital technologies and individual learners' characteristics influences the long-term outcomes of learning (Hagger and Hamilton, 2019; Jung et al., 2017).

A literature review suggests the need for a more comprehensive approach to evaluating the effectiveness of VR-powered piano apps. Even though existing research lays the theoretical and empirical foundation for further development, we do not fully understand the mechanisms by which the positive effects of immersive technologies are realized (Han et al., 2025; Wang, 2024). This highlights the importance of examining the roles of self-discipline and time management in successful VR-assisted piano learning. This study seeks to accomplish this task by empirically comparing the effectiveness of immersive piano instruction, with concrete psychological factors influencing it. Within the framework of the present study, an integrative research model is proposed that combines technological and individual psychological factors of learning. It is assumed that the use of virtual reality in piano instruction influences the development of performance skills not directly, but through the organization of the learning process and the learner's interaction with the digital environment. In this context, individual characteristics of self-regulation—particularly self-discipline and time management skills—play a central role, acting as significant predictors of learning effectiveness. Accordingly, the proposed model assumes an interaction between the instructional format (VR or traditional) and learners' self-regulation, jointly determining the extent of progress in the development of performance skills.

Problem Statement

This study examines factors affecting the effectiveness of VR-based apps in piano education, focusing on performance. Despite the increasingly more intense integration of immersive technologies in music education, empirical data on the psychological conditions under which VR can effectively improve piano performance is scarce. Among the understudied topics is the relationship between individual self-regulation abilities of a pianist, such as self-discipline and time management, their piano playing performance, and VR-user interaction.

Building on this research gap, the present study conceptualizes VR-assisted piano learning as an interaction between the structural characteristics of the learning environment and the learner's self-regulatory capacities. In this framework, the mode of instruction (VR-based vs. conventional) is treated as a contextual factor that shapes the organization, feedback, and pacing of practice, while self-discipline and time management are viewed as individual mechanisms that determine how effectively these affordances are utilized. Accordingly, self-regulatory skills are expected not only to directly contribute to performance improvement but also to condition the extent to which VR-based environments enhance learning outcomes.

This study aims to evaluate the effectiveness of VR-powered piano learning apps against conventional practice and to examine how individual self-regulatory skills (i.e., self-discipline and time management) affect piano performance. The objectives of the study are (1) to investigate changes in performance after exposure to different modes of learning; (2) to compare the extent to which the skill has progressed following the VR-assisted and traditional learning routines; (3) to analyze how self-discipline and time management skills affect the extent of improvement in the piano playing skill; and (4) to determine whether self-discipline and time management skills moderate the relationship between mode of learning and performance quality.

Materials and Methods

Here, performance skills were assessed through graded piano exams administered by the Associated Board of the Royal Schools of Music (Tang, 2024). Participants took identical practical exams before and after the intervention. To ensure the task difficulty level is appropriate and prevent a ceiling effect, the repertoire program was set for Grades 4 to 6. It encompasses pieces from the ABRSM Piano Syllabus for 2025 and 2026, including:

- Grade 4: ***Menuet and Trio*** from **Sonata** in **C** (Hob. XVI:1) by Joseph Haydn, **Sonata** in **G**, C. 34) by Domenico Cimarosa, ***Allegro assai*** from **Sonatina** in **F** (Anh. 5 No. 2) by Ludwig van Beethoven, and ***Allegro*** from **Sonatina** in **C** (Op. 3 No. 7) by George Berg.

- Grade 5: ***La tarantelle*** from **25 Études Faciles Et Progressives** (Op.100) by Friedrich Burgmüller, ***Spiritoso*** from **Sonatina** in **C** (Op. 36 No. 3) by Muzio Clementi, **Invention No. 8** in **F** (BWV 779) by Johann Sebastian Bach, and **Waltz** in **B minor** (D. 145 No. 6) by Franz Schubert.
- Grade 6: **Invention No. 14** in **B-flat** (BWV 785) by Johann Sebastian Bach, **Sonata alla Scarlatti** by Germaine Tailleferre, **Solfeggietto** in **C minor** (Wq. 117/2) by Carl Phillip Emanuel Bach, and ***Moment Musical*** in ***F minor*** from **Moments musicaux** (D. 780) by Franz Schubert.

The pieces were performed individually in the classroom setting under ABRSM exam conditions, which include an acoustic piano with a full-size keyboard and weighted keys.

The maximum score for an individual Practical exam is 150 (Tang, 2024). To get this score, a pianist must get a perfect score on each of the following segments: performance of the 3 prepared examination pieces, each worth a maximum of 30 points (90 points in total), scales and arpeggios (21 points), sight-reading (21 points), and aural tests (18 points). Higher scores indicate greater proficiency at playing the piano (Tang, 2024).

Self-discipline was assessed using the Chinese version of the Brief Self-Control Scale (BSCS), which has demonstrated reliability in research with Chinese students (Fung et al., 2020). The internal consistency of the BSCS is high ($\alpha = 0.83$), indicating its psychometric reliability and validity.

The time management behavior was evaluated using the Chinese version of the Time Management Behavior Scale (TMBS). This scale has shown high internal consistency (Cronbach's $\alpha = 0.84$) in empirical studies with student samples (Chen et al., 2017).

The VR apps chosen for piano practice are VRtuos and Grand Reality. These apps employ distinct approaches to teaching. More specifically, VRtuos emphasizes step-by-step visualization of motor positions and precise synchronization of rhythm and time, while Grand Reality strives to create a full-fledged performance environment with deep spatial and contextual integration. VRtuos gamifies learning through the following pathways: step-by-step visualization, immediate feedback, progressively more challenging tasks, and motivational game elements. In contrast, Grand Reality facilitates spatial immersion and makes virtual performances as close to reality as possible.

VRtuos

VRtuos is a virtual piano learning app for standalone VR headsets. In this study, it was leveraged to deliver instructional materials within the immersive learning environment. VRtuos lets users follow a sequence of individual notes that fall directly onto their piano's keyboard. Before starting the lesson, pianists were asked to calibrate the physical instrument with the app to ensure that visual cues align precisely with their keyboard layout. Once the keyboard is calibrated, users can follow the piece's visual flow (see Figure 1).

Figure 1 - A pianist playing the piano while receiving visual guidance from VRtuos

Source: Photo by the author.

The notation format of VRtuos (visual objects that fall on a keyboard) allows users to easily navigate the keystroke sequence, rhythm, and tempo of a piece without the need for traditional, paper-based music sheets. The display of visual cues was synced with the piece's temporal structure to ensure that the time intervals and pitch of individual keystrokes could be instantly compared to a perfect performance model.

Grand Reality

Grand Reality is a VR-powered piano simulator that lets users practice the piano in a fully immersive virtual environment. In this study, pianists were offered Grand Reality as an alternative to VRtuos (Figure 2).

Figure 2 - A pianist playing the piano while receiving visual guidance from Grand Reality

Source: Photo by the author.

This app creates a 3D environment featuring a realistic concert grand piano. A visualized model of a piano's keyboard and frame serves as a bolster for motor skill practice. All lessons were conducted without augmented or mixed reality technologies. This approach eliminated any interference by external factors and allowed focusing solely on the virtual scene.

The Grand Reality app lets users hone their spatial coordination and hand synchronization through real-time display of hand movements. The hand tracking feature allows pianists to focus on the precision and timing of their motor actions.

To help pianists gain control over their piano playing, the Grand Reality app integrates a virtual instrument model with a range of sensorimotor parameters. The system detects and tracks a pianist's hands and fingers, as well as the timing patterns of individual keystrokes, and compares them to the reference model to identify pitch (wrong keys), timing (lost rhythm), and phrasing issues. The feedback format of Grand Reality excludes direct instructional prompts but supports the display of contextual cues, including sections that require more work, tempo variations, and performance quality indicators.

Equipment

Students engaged in virtual piano practice received standalone VR headsets for immersive learning experiences: Oculus Quest 2. In terms of hardware, the Oculus Quest 2 features a built-in high-resolution display, head-tracking sensors, and a spatial tracking system, all without the need for a separate computer.

Each device supports inside-out tracking with six degrees of freedom (6DoF). The VR scene does not change after the pianist switches to a different posture or direction of gaze. The technical specifications, such as resolution and refresh rate, were maintained across all devices used in the intervention.

The Quest 2's hand-tracking software allows users to track the position of their hands and their movement. Visualizing hand motions as virtual models eliminates the need for hand controllers or additional equipment. For this study, two apps—VRtuos and Grand Reality—were installed on Oculus Quest 2 devices. Both software products ran in full-immersion mode, creating an isolated virtual environment and blocking external visual stimuli. The graphics, tracking, and interaction settings were maintained across all participants.

Before proceeding to the main portion of the experiment, each device underwent a technical check-up. The calibration process involved testing the accuracy of the head- and hand-tracking systems, assessing display stability, and eliminating software glitches. The equipment's default settings were maintained throughout the study; software updates were avoided to minimize the impact of technical factors.

Study Design

This study is a randomized controlled trial with parallel groups and a pre-test/post-test design. Participants were assigned to one of three groups (i.e., VRtuos, Grand Reality, and conventional piano practice) using a Mersenne Twister. The randomization sequence was generated prior to the start of the intervention using a computerized algorithm, ensuring equal probability of assignment to each group. Group allocation was performed by a researcher not involved in outcome assessment, and the assessors were blinded to participants' group membership. After signing an informed consent, participants completed baseline assessments and enrolled in the training intervention, followed by post-intervention tests.

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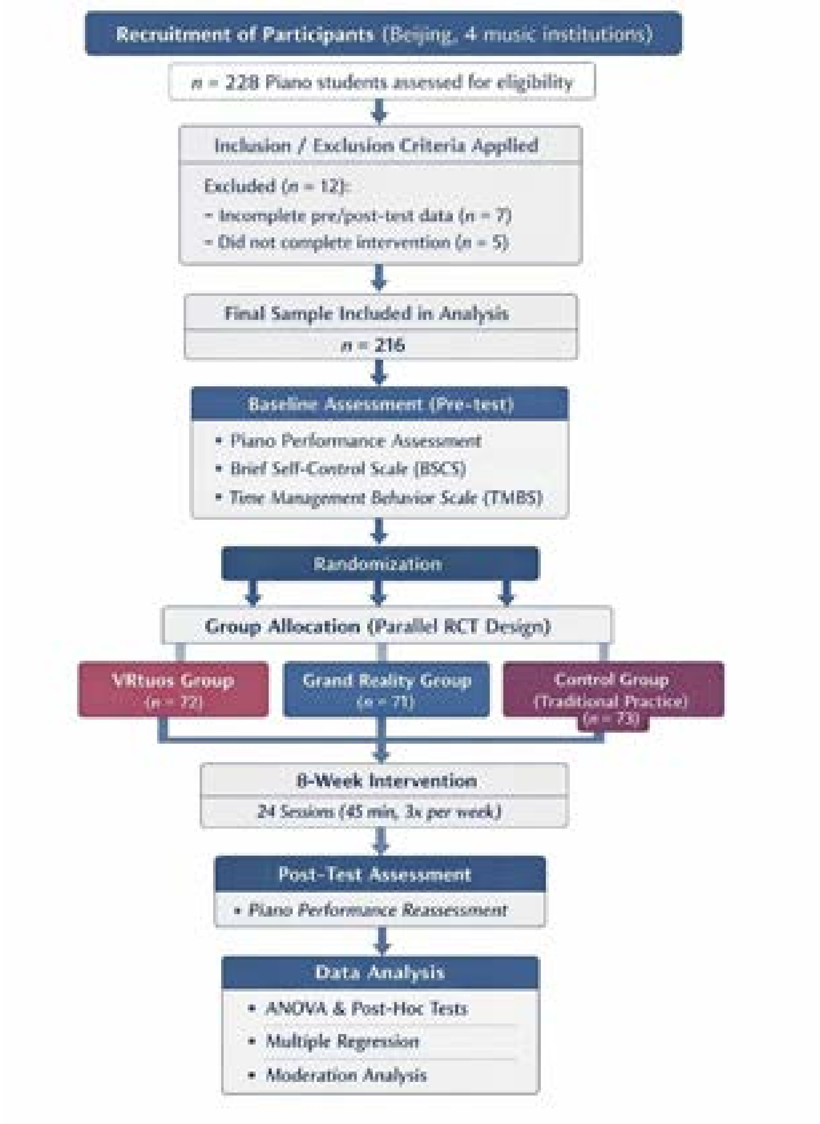
Psychometric pretests assessed a pianist's self-discipline and time management. The questionnaires were administered in written format in the classroom setting under the supervision of a researcher. Participants were instructed that there were no "right" or "wrong" answers; no time limit was set. The questionnaires took approximately 15-20 minutes to complete. The survey data were used as baseline predictors of performance improvement.

Piano skills were evaluated from an audio or video recording against the assessment criteria detailed in ABRSM's Piano Syllabus for 2025 and 2026 by two piano teachers with at least 10 years of experience preparing students for their ABRSM exams. The assessments were conducted before and after the intervention. The raters were not involved in the training process and were unaware of the group assignments. The final score was calculated as an average across the two raters. To ensure the reliability of expert evaluations, inter-rater agreement was assessed using the intraclass correlation coefficient (ICC). The analysis demonstrated a high level of agreement between raters (e.g., ICC = 0.87), indicating strong consistency in performance assessment. Once the pre-test was completed, participants were randomly assigned to one of three modalities: VRtuos, Grand Reality, and conventional piano practice (control group). This study's design is depicted in Figure 3.

Figure 3 - Flowchart of the empirical research on VR-based piano learning

Source: Prepared by the author.



Sample Size

The sample size necessary to achieve sufficient statistical power was determined in advance. The following hypotheses were set forth: improvements in the piano-playing skill differ between learning modalities (H1), whereas self-discipline (H2) and time management (H3) abilities predict the extent of improvement. The primary outcome measure is the change in performance quality, calculated as the difference between post-intervention and baseline values (Δ = post − baseline).

To test the first hypothesis (H1), the three groups (VRtuos, GR, and Control) were compared against each other in terms of piano skill improvement (as expressed by Δ units) through a one-way analysis of variance (ANOVA). To be able to pick up a moderately sized difference between the three modalities ($f = 0.25$), with $1 - \beta = 0.80$ and $\alpha = 0.05$ (two-tailed), the analysis requires at least 53 pianists in each group (158 pianists in total).

The remaining two hypotheses (H2 and H3) were tested using multiple linear regression, with piano skill improvement (Δ) as the dependent variable and self-discipline and time management as independent variables. The regression analysis requires at least 68 pianists to identify the combined effect of these predictors (with $1 - \beta = 0.80$ and $\alpha = 0.05$), a significantly smaller sample than needed for a between-group comparison; the desired effect size in this case is $f^2 = 0.15$.

Participant Selection Criteria

Piano students were deemed eligible for participation in the study if they were 18 to 25 years old, had basic piano skills (at least two years of training), were able to stay in the city of Beijing for the duration of the study, and engaged in independent piano practice. All participants were required to have normal or corrected-to-normal vision and hearing to ensure adequate perception of visual and auditory information. Professional pianists, those experienced in learning music through VR, and individuals with neurological, mental, or musculoskeletal disorders that could impact piano learning or interaction with VR were excluded from the analysis.

Participants

The study involved 228 piano students from four different music colleges and universities in Beijing. The preliminary number of recruited participants went beyond the minimum required sample size to compensate for potential data loss. Students with incomplete pre- and post-test data and those who did not complete the intervention were excluded from the analysis. The final sample consists of 216 participants. Pianists were equally distributed across groups by gender, age, and learning experience (for more details, see Table 1).

Table 1 - Distribution of piano student participants according to their profile

Variables	**Description**
Age	18–25 years (M = 21.1; SD = 1.8)
Sex	Female – *n = 131* (60.6%); Male – *n = 85* (39.4%)
Experience	M = 6.6 years (SD = 2.2)
Recruited from:	4 educational institutions
Distribution	Conservatory A — *n = 62*; Music University B — *n = 54*; College of Arts C — *n = 51*; Music Institute D — *n = 49*
Vrtuos Group	*n = 72*
Grand Reality (GR) Group	*n = 71*
Control Group	*n = 73*

Intervention

Students participated in an eight-week piano learning intervention. Lessons were held three times a week (24 lessons in total); each lasted 45 minutes (18 hours of practice in total). All lessons followed a preconceived plan that outlined the lesson structure, assignments, deadlines, exercise sequence, and instructions.

Each lesson consists of three stages: *technical practice* (scales, arpeggios, finger coordination, and rhythmic exercises), which lasts 10 minutes; the *study* of 15-to 30-second sections from Grades 4–6 piano pieces, which takes 25 minutes; and *self-correction*, which lasts 10 minutes. The repertoire was updated weekly to ensure a uniform level of difficulty and remove preference bias. In the self-correction stage, students practiced the most challenging sections they had encountered in previous lessons to correct errors and integrate the newly learned elements. This lesson structure was maintained throughout the intervention, but the approved repertoire plan varied in content. Participants were not allowed to independently change the assigned pieces, add new elements, skip lesson stages, or shorten the allotted learning time. They were also prohibited from practicing pre-test and post-test compositions to avoid rote memorization and to ensure that improvements were due to the acquisition of piano-playing skills rather than the repetition of pre-memorized repertoire.

Students were instructed to practice each section of a piano piece at least twice in a row; if any mistakes were made, the section was to be repeated. Students were told to transition to the next section after a set amount of time; their subjective sense of success was irrelevant. All tasks were completed individually, without teacher feedback.

Pianists in the VRtuos group received a gamified learning experience. The app automatically generates a layout for training exercises, sets the tempo, time intervals, and repetition cycles, identifies errors, and initiates the return to problematic sections. Pianists in the GR group gained experience playing the grand piano. The app identifies errors by comparing the outcome (pitch, rhythm, and note sequence) to the reference model and provides visual feedback.

The control group followed the same plan for developing technical skills but practiced them traditionally on an acoustic piano. In this group, all materials were paper-based. Digitally, performance errors were not recorded, nor did students in this group receive digital feedback.

Data Analysis

The data were analyzed using SPSS version 22. The first step was to determine whether skill improvement scores follow a normal distribution (Shapiro-Wilk test) and to uncover visual cues regarding skewness and kurtosis (Q-Q plots). The homogeneity of variances across groups was tested using Levene's test.

Differences in improvement across groups were assessed using a one-way ANOVA with learning modality as the factor. A significant ANOVA was followed by post-hoc tests. η^2 and Cohen's d were used to estimate the effect size.

The contribution of individual self-regulation abilities to piano skill development was analyzed through multiple linear regression. The change score for piano performance (Δ) is the dependent variable, whereas the baseline levels of self-discipline and time management, as measured by the BSCS and TMBS, are the independent variables. The results of the regression analysis are presented as standardized regression coefficients (β), coefficients of determination (R^2), and effect size values (f^2).

To assess multicollinearity among the predictors (learning modality, self-discipline, and time management), the Variance Inflation Factor (VIF) and Tolerance were calculated. The VIF values were below the recommended threshold of 5.0, indicating the absence of problematic multicollinearity, whereas the Tolerance indices exceeded 0.20, denoting acceptable independence among predictors. The moderating effects of a pianist's self-discipline and time management abilities on their success in the VR learning setting were examined. The analysis investigated the main effects of both the predictor (learning modality) and two moderators (i.e., self-discipline and time management ability) on the outcome variable, followed by the interaction effects of VR × self-discipline and VR × time management.

Ethical Considerations

The study follows the principles stipulated in the Declaration of Helsinki and ethical standards for research involving human subjects. The research protocol was approved by the Ethics Committee of Northeastern University (Approval No.: EC-2025-017; approval date: February 12, 2025). All participants were informed about the study, including its objectives, procedures, and conditions, and provided oral consent. All students who participated in the study did so voluntary and had the right to discontinue participation at any stage of the study without negative consequences. Personal information was anonymized and used exclusively for research purposes.

Limitations

This study has several limitations that should be considered when analyzing and interpreting its results. (1) The sample included piano students of a similar relative age and similar levels of training, which limits generalizability of the findings to other age groups and levels of musical education. (2) The intervention lasted only eight weeks, making it difficult to assess long-term effects. (3) Despite standardization of the lesson process, differences in the learning environment (gamification vs simulation) may have influenced the level of user engagement and subjective perceptions of the learning experience, which can be reflected in the findings. (4) The study focused primarily on the role of self-regulation skills, such as self-discipline and time management, without considering a broader range of psychological and cognitive characteristics. Finally, because the present findings were obtained under strictly controlled experimental conditions, one must exercise caution when transferring them to real-world educational contexts.

Results

Table 2 presents baseline data for the VRtuos, GR, and control groups. The mean scores on a practical piano exam showed that there were virtually no differences among groups before the intervention (p = 0.84). Similarly, the BSCS and TMBS total scores on the pre-test showed no statistically significant differences between groups (p = 0.62 and p = 0.71, respectively). A can be seen, the three groups had comparable piano-playing and self-regulation skills before the training began. The subsequent differences in improvement scores can thus be interpreted as resulting from the intervention.

Table 2 - Baseline scores for piano skill, self-discipline and time management

Domains	VRtuos	Grand Reality	Control	p-value
Performance (Pre-test)	101.79 ± 5.90	100.83 ± 6.21	101.16 ± 5.82	0.84
Self-discipline (BSCS)	45.78 ± 5.53	45.12 ± 5.78	44.74 ± 4.09	0.62
Time management (TMBS)	118.92 ± 17.76	117.87 ± 19.35	116.36 ± 15.76	0.71

Table 3 shows the means and standard deviations of the pre-intervention and post-intervention practical piano exams. Following the intervention, the mean exam score of the VRtuos group increased from 101.8 ± 5.9 to 111.1 ± 6.6, a change of 9.30 points. The mean exam score of the GR group increased from 100.8 ± 6.2 to 107.0 ± 7.0, up 6.20 points. The control group showed the smallest change (3.30 points), which was an increase in the mean exam score from 101.2 ± 5.8 to 104.5 ± 6.2

Table 3 - Mean scores on practical piano exam before and after the intervention

Variables	VRtuos	Grand Reality	Control
Practical Music Grades (Pre-test)	101.8 ± 5.9	100.8 ± 6.2	101.2 ± 5.8
Practical Music Grades (Post-test)	111.1 ± 6.6	107.0 ± 7.0	104.5 ± 6.2
Mean Δ (Post − Pre)	9.30	6.20	3.30

The choice of the learning modality had a statistically significant effect on the extent of improvement, as determined by ANOVA ($F(2, 213) = 15.68$, $p < 0.001$). The effect size (η^2) was 0.13, indicating a significant contribution of the learning environment to the variability in change scores.

Table 4 - One-way ANOVA and post-hoc comparisons for improvement in piano performance (Δ)

Comparison	Mean difference in Δ	p-value	Cohen's d
VRtuos vs Grand Reality	3.10	0.105	0.27
VRtuos vs Control	6.00	< 0.001	0.89
Grand Reality vs Control	2.90	< 0.001	0.66

Note: Δ = post-test minus pre-test. $\eta^2 = 0.13$ (medium–large effect)

The post-hoc test revealed that the VRtuos group has achieved significantly greater improvement in piano proficiency than the control group ($d = 0.89$). The difference between the VRtuos and GR groups failed to reach statistical significance ($d = 0.27$). Still, the GR group demonstrated significantly higher growth than the control group ($d = 0.66$). The estimated effect sizes suggest that VR-assisted pianists can achieve a more pronounced improvement in piano skill than their traditionally taught counterparts, with the best results obtainable with VRtuos (Table 4).

Figure 4 - Mean scores for piano skill improvement across groups (Δ units)

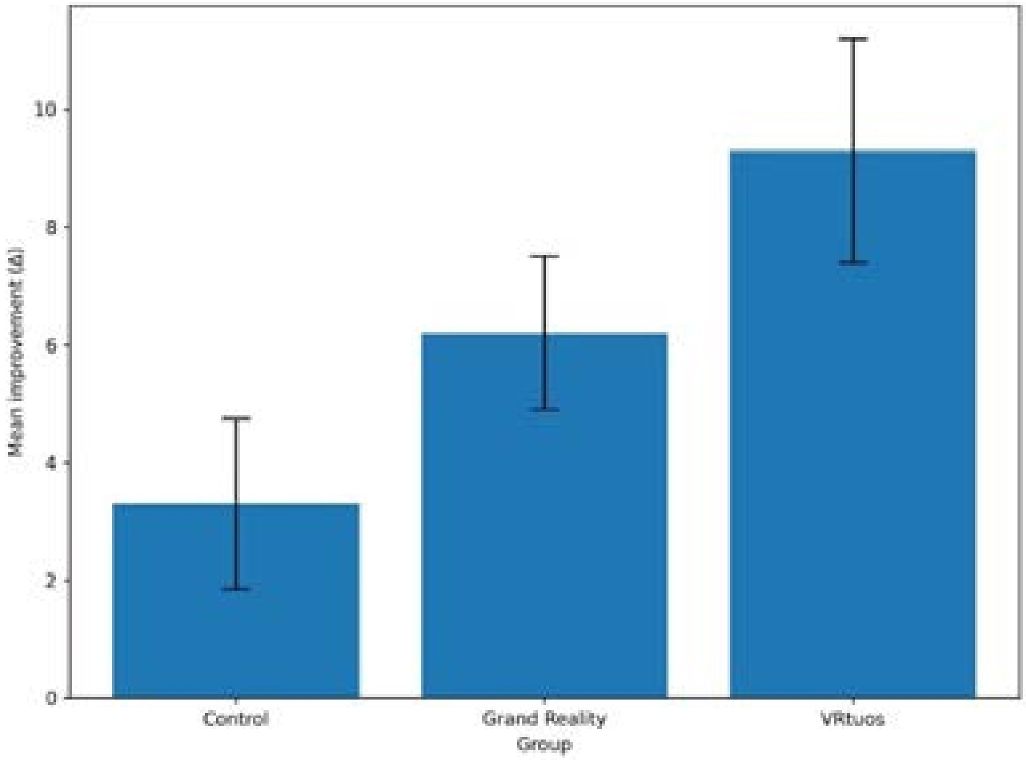


Figure 4 shows the average improvement in piano-playing skill across groups. The bars represent the mean Δ values, whereas the vertical lines represent the 95% confidence intervals. The control group showed a small improvement of 3.30 points, with a 95% confidence interval of [1.86; 4.74]. The GR group exhibited a moderate improvement of 6.20 points, with a 95% confidence interval of [4.64; 7.76]. The VRtuos group demonstrated the greatest improvement, with a 9.30-point gain and a 95% confidence interval of [7.36; 11.24]. Non-overlapping or minimally overlapping confidence intervals visually confirm the presence of significant differences in the extent of improvement between the VR groups and the control group.

Table 5 presents the correlation matrix of the studied variables. Improvement in piano-playing skill, as measured by the difference between pre-test and post-test scores, demonstrates a moderately significant positive relationship with self-discipline (r = 0.56) and a weaker, albeit still positive, relationship with time management (r = 0.38). This finding ties higher self-discipline and effective time management to greater professional growth in pianists. A moderate positive correlation (r = 0.44) was found between self-discipline and time management, reflecting their conceptual connection as regulatory characteristics of behavior. At the same time, the magnitude of this correlation does not indicate excessive interdependence between the two variables. Taken together, the correlation indices support integrating self-discipline and time management into the subsequent regression analysis as independent predictors of skill improvement.

Table 5 - Correlation between the extent of skill improvement, self-discipline and time management

Variables	**Δ Performance**	**Self-discipline (BSCS)**	**Time management (TMBS)**
Δ Performance	—	0.56	0.38
Self-discipline (BSCS)	0.56	—	0.44
Time management (TMBS)	0.38	0.44	—

To test whether self-discipline and time management abilities can predict the extent of skill improvement (Δ = post-test − pre-test) in pianists, a multiple linear regression was conducted. The group assignment was entered into the model as a dummy variable to control for the intervention effect. Results are presented in Table 6 below.

Table 6 - Multiple regression statistics for the prediction of skill progress (Δ)

Predictor	**β**	**SE**	**95% CI**	**p-value**
Self-discipline (BSCS)	0.48	0.38	[0.40, 0.56]	< 0.001
Time management skills (TMBS)	0.21	0.41	[0.13, 0.29]	< 0.001
Group (Grand Reality vs control)	0.29	0.45	[0.20, 0.38]	< 0.001
Group (VRtuos vs control)	0.41	0.47	[0.32, 0.50]	< 0.001

Model fit indices: R^2 = 0.385; f^2 = 0.63.
Note: β values are standardized coefficients. Group variables were dummy coded with the control group as the reference category; Δ = post-test minus pre-test.

The regression analysis showed that both abilities contributed significantly to the variance in change scores. Self-discipline exhibited the highest predictive value ($\beta = 0.48$, $p < 0.001$), indicating that greater self-control is associated with greater skill improvement. The time management ability was found to be a significant positive predictor of improvement ($\beta = 0.21$, $p < 0.001$), even though its contribution was less pronounced as compared to that of self-discipline.

Exposure to VR was associated with a greater change in training effectiveness. This link is consistent with ANOVA results. The coefficient of determination (R^2) was 0.39, indicating that approximately 39% of the variance in the extent of skill improvement can be explained by the combined effects of individual self-regulation abilities and learning modality. This relatively high level of explained variance appears reasonable given the use of the growth factor (Δ) and the inclusion of relevant and empirically validated predictors. The model's effect size was $f^2 = 0.63$, indicating a large effect. The results of the regression analysis support the second and third hypotheses of the study, highlighting the significant roles of self-discipline and time management in predicting effective piano learning in the VR setting.

Figure 5 depicts the relationship between the level of self-discipline and the extent of skill improvement. Each point represents an individual participant, whereas the solid line represents the linear regression relationship among variables. A consistent, positive linear trend is evident: pianists who scored higher on the BSCS improved their piano skills to a greater extent than those with lower self-discipline. The distribution of BSCS scores indicates inter-individual variability, but the absence of significant nonlinearities or clusters confirms that the linear regression model is valid.

Figure 5 - Relationship between the level of self-discipline (BSCS) and the extent of piano skill improvement (Δ)

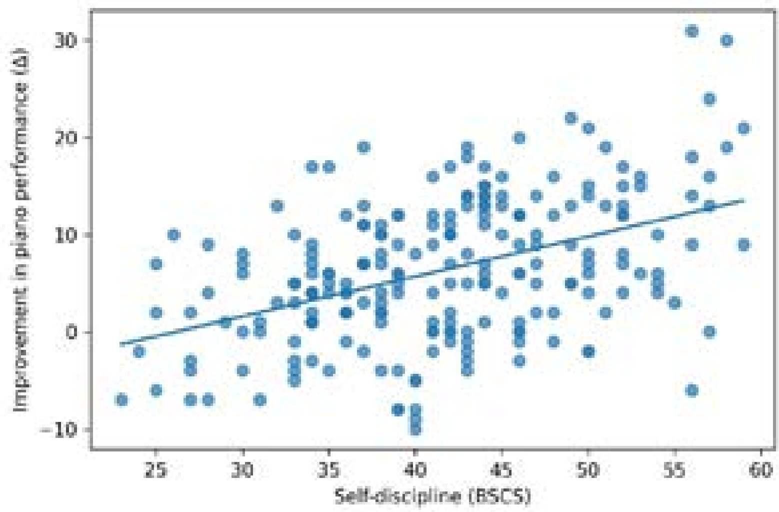
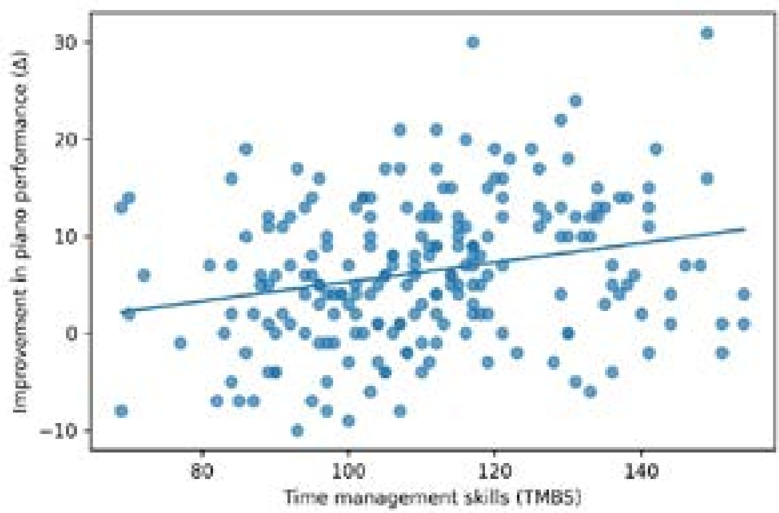


Figure 6 shows the distribution of change scores according to the pianist's capacity to plan and organize tasks before going into practice. The abscissa represents the total TMBS scores, and the ordinate represents the extent of the piano skill improvement (Δ). The trend line illustrates the general direction of the relationship between the two variables.

Figure 6 - Relationship between the level of time management (TMBS) and the extent of piano skill improvement (Δ)



As can be seen, higher TMBS scores are associated with greater improvements in piano-playing skills. However, the data distribution indicates significant variability in individual progress trajectories. Specifically, pianists with similar levels of time management skill improved to different extents. This finding highlights the complex nature of the factors that influence the effectiveness of piano training. At the same time, the generally upward slope of the regression line indicates a positive contribution of time management to piano mastery.

The moderation analysis revealed a significant interaction effect of the learning modality and self-discipline ($\beta = 0.19$, $SE = 0.07$, $p = 0.006$). This finding suggests that the impact of VR integration on piano training effectiveness is likely stronger when self-discipline is higher. Simply put, the effect of VR-based training on participants with high self-discipline (+1 SD) was significantly greater than that of traditional training. For participants with low levels of self-discipline (+/−1 SD), the difference between the learning modalities was smoothen out.

The interaction between learning modality and time management was also significant, albeit smaller ($\beta = 0.12$, $SE = 0.06$, $p = 0.041$). This finding suggests that an effective use of practice time moderately impacts the effectiveness of VR-assisted learning. However, their moderation effect is weaker than the moderation effect of self-discipline. The addition of interaction terms increased the model's explained variance ($\Delta R^2 = 0.04$), confirming that regulatory psychological factors contribute to variability in the effectiveness of VR-assisted piano learning.

Discussion

The present findings suggest that using immersive VR apps to learn the piano leads to significantly greater growth than traditional practice. The most significant gains were observed among VRtuos users. Learning with Grand Reality yielded smaller, albeit still significant, improvements in the piano-laying skill. These findings are consistent with previous research on the benefits of VR in musical and motor learning (Mangalam et al., 2024; Molero et al., 2021; Pesek et al., 2024). The VR's potential to boost engagement, concentration, and the effectiveness of repetitive practice has been previously reported (Brucker et al., 2024; Kamp, 2025; Sai, 2024).

The likely reason VRtuos was more effective than Grand Reality lies in the differences in how the learning environment is designed and how instructions are delivered. VRtuos employs a gamified training method that involves a strictly structured learning process, segmentation, and an AI-driven pace of learning, with a clear sequence of actions and frequent repetition. This approach is consistent with the theory of deliberative practice (Gorbunovs et al., 2016; Hatfield et al., 2017). In contrast, Grand Reality simulates an environment that resembles real-life circumstances, thereby giving users greater freedom to organize their practice (Hagger and Hamilton, 2019; Jung et al., 2017). The VRtuos's advantage thus lies in gamification, which not only motivates but also acts as an external regulator of learning activity. It partially compensates for the lack of self-discipline and time management skills (Lu, 2023; Wolters and Brady, 2021).

The results are consistent with existing data, which show that immersive technology-based activities promote accelerated skill development by improving the structure of the learning process and reducing distractions (Li, 2025; Yin, 2023). However, some studies have argued that the impact of VR may be limited or unstable, especially in the absence of clear goals or self-regulation mechanisms (Doganyigit and Islim, 2021; Peng, 2024; Wang, 2024). The differences between the two VR apps tested in this study highlight that the effectiveness of a virtual learning environment depends on how users interact with the learning content, not just on the level of immersion (Kamp, 2025; Lu, 2023; Sai, 2024).

The results of this study cast light on the role of individual factors that can influence academic success. Self-discipline and time management were shown to be important for improving piano playing, regardless of the chosen training format (Hagger and Hamilton, 2019; Herron, 2023; Jung et al., 2017; Shi and Qu, 2022). This suggests that even with technologically advanced and well-organized learning platforms, a pianist's self-regulatory behavior remains key (Gorbunovs et al., 2016; Wolters and Brady, 2021). These findings complement the existing body of research by focusing on the behavioral and organizational aspects of learning, rather than VR's motivational or cognitive effects (Edgar, 2019; Hatfield et al., 2017).

Unlike some studies that view VR as a universal means of enhancing learning outcomes, this study offers a more detailed assessment of its impact (Peng, 2024; Zhang, 2025). The observed positive effect was more pronounced among students with stronger self-regulation skills. This finding supports the theory of self-directed learning and emphasizes the need to consider individual differences when integrating digital technologies into the educational context (Hatfield et al., 2017; Jung et al., 2017; Wolters and Brady, 2021;). Note that VR technologies do not replace standard teaching methods; rather, they serve as a tool to enhance existing strategies and approaches.

Based on the results of the moderation analysis, the effectiveness of VR in teaching piano skills depends on a user's self-regulatory behavior, not just the teaching format. The significant interaction effect between learning modality and self-discipline suggests that VR is most effective when a pianist using it has a strong capacity for self-regulation and approaches tasks systematically. This finding is consistent with the theory of deliberate practice, which emphasizes the importance of concentration, regularity, and self-correction in developing mastery. In addition, self-discipline was identified as a key factor in success by researchers investigating digital and offline learning environments (Gorbunovs et al., 2016; Hatfield et al., 2017; Jung et al., 2017).

Time management also exerted a significant, albeit less pronounced, effect on the development of piano mastery. This underscores its supporting role in organizing effective VR practice. These findings confirm that the rational allocation of time and cognitive resources facilitates learning, but the stability of self-control over time and the ability to maintain concentration are also crucial (Hagger and Hamilton, 2019). Taken together, the present findings indicate that VR-assisted training is not a universal solution, but rather an element in the system of deliberate practice. The effectiveness of VR-assisted learning is determined by an interaction between the design of the digital environment and the learner's self-regulation skills.

Conclusion

The study comprehensively assessed the effectiveness of practicing the piano with two VR-powered apps (i.e., VRtuos and Grand Reality), focusing on the role of self-discipline and time management skills in professional growth. The results revealed that VR led to a greater improvement in skill than conventional piano-learning methods. The greatest effect was observed with VRtuos, which led to greater gains in piano skill than with traditional learning and Grand Reality. The use of the Grand Reality app was associated with a statistically significant improvement as well, but this change was less pronounced.

One of the main contributions of the current study is the confirmation of the roles that self-discipline and time management play in improving piano-playing skill. Higher levels of self-discipline and time management are associated with greater skill improvements, regardless of the learning modality. This observation suggests that the effectiveness of VR-assisted piano training depends not only on the technological features of the learning environment but also on the pianist's self-regulation abilities.

The study's practical significance lies in the potential of VR apps for music education. Based on the present findings, VRtuos can serve as an effective tool for piano learners in educational institutions. The results can inform the design of piano programs, digital courses, training modules aimed at fostering performance skills, and blended learning models that combine VR technology and self-regulated skill acquisition.

The scientific value of the study lies in expanding the current understanding of how VR influences skill development in performance, including behavioral predictors of learning effectiveness. This study shows that differences in VR learning outcomes depend not only on the degree of immersion but also on the structure of the learning environment and a pianist's individual characteristics.

Future research can focus on analyzing the long-term effects of VR-assisted learning, exploring changes in self-discipline and time management, and expanding the research approach by incorporating motivational, emotional, and cognitive factors. In addition, researchers should compare distinct pedagogical models embedded in the design of different VR environments, focusing on their impact on the sustainability of acquired piano skills.

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