Review

Can virtual reality improve orthopaedic surgical competence among orthopaedic residents and students? A systematic review

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Abstract

Virtual reality simulated experiences (VRSE) offer a promising alternative to traditional orthopaedic training methods, which are often costly and place a significant financial strain on hospitals. As the medical community faces increasing demands for cost-effective, scalable, and durable educational systems, VRSE has the potential to revolutionise surgical instruction and enhance trainee engagement. To assess its effectiveness, a systematic review was conducted using a comprehensive search strategy via the NICE Healthcare Databases Advanced Search. Six randomised controlled trials involving 130 participants were included in the review, which was registered prospectively with PROSPERO (CRD42023463827). The findings indicated that VRSE may improve procedural completion rates and enhance key surgical skills, such as time efficiency, motion control, instrument handling, and knowledge retention. Despite these positive outcomes, current evidence remains insufficient to conclude that VRSE is an effective alternative to traditional educational methods. Further research is necessary to establish its long-term value in orthopaedic training.

Keywords

Virtual reality; orthopaedics; residency; education; medical students

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Introduction

In 2020, musculoskeletal disorders were the second leading cause of non-fatal disability, affecting over 1.63 billion individuals worldwide.[1] The rising prevalence of these conditions is primarily driven by an aging population.[2] Global life expectancy is projected to increase by nearly five years by 2050, further contributing to the growing burden of orthopedic conditions and, consequently, an increased demand for surgical interventions.[3]

More specifically, the number of total knee arthroplasties (TKA) has been steadily increasing in Europe every year and is expected to increase dramatically in the United States by 2050 (143%).[4,5] This will lead to a growing demand for surgeons, particularly orthopaedic specialists.[6]

The existing orthopaedic training already imposes a substantial financial burden on hospitals.[7] Gaskill et al portray a negative yield in returns of orthopaedic training in adult arthroplasty and trauma when working hours are controlled.[7] This presents an opportune moment for the medical community to adapt to the changing needs and develop a more cost-effective and durable to time educational system.

Furthermore, the evolution of surgical techniques and the rapid changes in the healthcare system introduced by technological advancements uncover important limitations to the previous teaching models.[8,9] These limitations encompass and are not restricted to escalating costs, reduced surgical time, increased number of patients and inconsistent standardised training.[7,10,11] These can hinder a learner's experience and impact patient safety.[12]

While cadaveric models currently serve as the gold standard for simulations, they suffer from substantial drawbacks, including the risk of disease transmission, high expenses, and lengthy preparation periods, thus limiting their accessibility in educational institutions.[13-17] Virtual reality simulated experiences (VRSE) emerge as a highly promising alternative, capable of revolutionising the prevailing methods of instruction.[18]

The adoption of VRSE within the orthopaedic field is steadily increasing.[19] Nevertheless, the question whether VRSE stands as an effective alternative compared to traditional educational options remains. Previous studies with small cohort sizes managed to present subtle benefits. We aimed to distinguish the most frequently utilised VRSE software and present its advantages and disadvantages in training the future orthopaedic surgeons.

Methods

Inclusion Criteria

Articles were screened to check if they met the following criteria: they involved participants that are surgical trainees/residents or medical students, they reported outcomes related to surgical skill improvement, knowledge acquisition, or performance metrics, they were published after 2013, they were randomised control trials and they were written in the English language. Our search was further narrowed to studies using a single virtual reality (VR) software, to minimise bias. During our search the software with the biggest cohort size appeared to be Osso VR which was therefore used as an inclusion criterion. (Table 1)

Search Strategy

A comprehensive search strategy was carried out using the NICE Healthcare Databases Advanced Search (National Institute of Health and Clinical Excellence) of two databases between January 2013 and December 2024: Embase and PubMed. (Figure 1) The following search strategy was used; ("orthopedic surgery" OR "orthopaedic surgery" OR "orthopaedic training" OR "orthopedic training" OR "orthopaedic residency" OR "orthopedic residency" OR "orthopaedic resident" OR "orthopedic resident" OR "medical student" OR "medstudent") AND ("virtual reality" OR "VR" OR "augmented reality"). The bibliography of the relevant articles was further screened by the first three authors, and all potentially relevant articles were reviewed again by the first three authors to ascertain whether the inclusion criteria had been met. If there was disagreement between the first two authors regarding whether a study should be included, the matter was referred to the most senior author for a decision. The final six articles

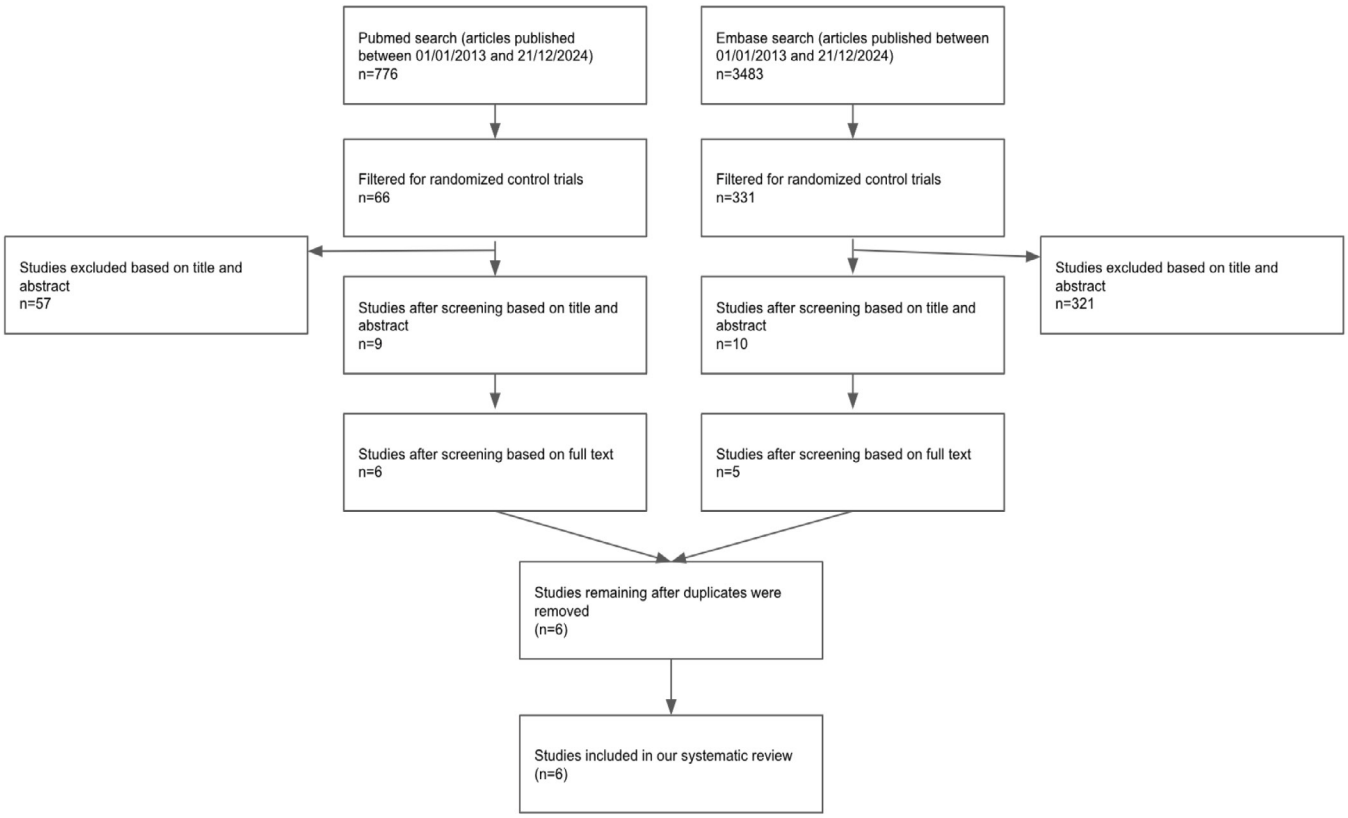

Figure 1: *Study selection process*

encompassed 130 participants. The systematic review was prospectively registered with PROSPERO (CRD42023463827) and was performed in accordance with the PRISMA guidelines.

Data Extraction

Once the studies were selected, the first three authors reviewed the manuscripts independently. Because of the heterogeneous nature of the data of the selected articles, statistical analysis was not possible. Instead, a narrative analysis was performed. The data that was extracted from each study included: setting and country, purpose of study, intervention/simulated tasks, assessment method, participants, educational background, outcome and findings.

Quality and Bias assessment

The six final articles were methodically assessed for validity and bias by the first two authors independently using the Cochrane Risk of Bias tool. The bias domains that were assessed were: Random sequence generation, Allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data and selective reporting.[20]

Results

Study characteristics

After screening 397 studies based on title and abstract and consequently ten studies based on full text, six were found to meet the inclusion criteria consisting of 130 participants. The participants consisted of medical students (n=66) and orthopaedic residents (n=64). All of the studies included were conducted in institutions in the USA and all of them used software developed by the same company. (Table 2)

The primary objective of the studies was to assess the effectiveness of VR as an instructional tool in orthopaedics and to compare its efficacy with conventional educational methods employed in or-

Table 1: Population Intervention Control Outcome (PICO)	
Population	Medical students and Orthopaedic residents/trainees
Intervention	Training on an orthopaedic task with VR simulation
Control	Standard training
Outcome	Outcomes relevant to surgical competence such as time to complete, surgical skills, and correct steps performed.

thopaedic surgery education. This evaluation was conducted through comparative analyses involving two or more distinct groups of participants. Interestingly, all six studies focused on simulating lower limb procedures.

More precisely, two of these studies centred on the simulation of intramedullary nailing (IMN) procedure for the tibial bone.[21,22] Additionally, two studies involved simulation of procedures related to slipped capital femoral epiphysis (SCFE) screw fixation.[23,24] The remaining two studies focused on simulating unicompartmental knee arthroplasty.[25,26]

The composition of control groups varied across some of the studies. Specifically, Blumstein et al., Cevallos et al., and McKinney et al. compared their VR groups with a single alternative group, utilising standard guides as the only training resource.[21,24,25] Zaid et al. compared the VR group with another "guide" group, providing access to the manufacturer's technique guide and surgical videos.[26]

Furthermore, two studies incorporated three distinct groups within their analyses. Margalit et al. compared their VR group with a control group that used reading materials and videos, as well as a group engaged in physical simulations using a sawbones model.[23] Lastly, Orland et al. conducted comparisons among the VR group, a group using technique guides exclusively, and a group combining VR and technique guides in their educational approach.[22]

Assessment methods and Outcome measures

Following the completion of their designated training methods, all participants across the studies (n=130) were required to execute the respective procedures on sawbones models. Subsequently, their performance was subjected to evaluation by assessors who were blinded to the participants' identities.

In Blumstein et al.'s study, the evaluation involved the use of a procedure-specific checklist. The checklist assessed whether participants correctly performed key criteria, including guidewire insertion, entry reamer selection, nail assembly, nail insertion depth, proxima interlock guides, and proximal interlock screw placement. Additionally, a 5-point global assessment scale was utilised, allowing for a more comprehensive evaluation of the participants' overall performance. This scale includes assessment of time and motion, instrument handling, knowledge of instruments, flow of operation & forward planning and knowledge of the specific procedure.[21]

The participants in the study of Cevallos et al underwent a multifaceted assessment. Their performance was evaluated based on similar criteria, including the time taken to complete the procedure, the number of pin insertions and removals, the penetration of the articular surface, the angle between the pin and the physis, the distance from the pin tip to the subchondral bone, and the distance from the center-center point of the epiphysis. These metrics provided a detailed evaluation of participants' technical skills and precision during the procedure.[24]

Margalit et al used the Global Rating Scale (GRS), similarly to Blumstein et al. Their outcomes evaluated the score of the GRS,the amount of fluoroscopy used, radiographic screw position, physical screw accuracy, the presence of breeching of the articular surface or femoral neck, and an overall platform rating on a scale of 0 to 10.[23]

A procedure-specific checklist was also used by McKinney et al. Additionally, an adapted Global Assessment 5-point Rating Scale was employed to evaluate participants' performance.[25]

The outcome measures in Orland et al.'s study

Table 2: Study characteristics

Study	Country and setting	Purpose	Study design	VR simulated task / intervention	(control) groups	Assessment	Outcome measures	Participants	Findings
Blumstein et al[21]	Single institution in the USA, name was not mentioned	Evaluate the efficacy of VR training in teaching orthopaedic surgical techniques compared to standard surgical guide training by evaluating the performance of novice medical students performing a SawBones tibial shaft IMN procedure.	Blinded, randomized prospective study	Simulation of intramedullary nailing (IMN) of the tibial bone	VR group vs standard guid group	Perform tibia IMN procedure using Saw-Bones.	Evaluated by a blinded attending surgeon using procedure-specific checklist and 5-point global assessment scale.	20 first and second-year medical students without prior experience of procedure	When participants were evaluated using objective structured assessment of technical skills using the Global Assessment 5-point rating scale, those who received VR training prior to the procedure performed significantly better in all categories than participants who were provided with a printed standard guide.
Cevallos et al[24]	Orthopedic Institute for Children, Los Angeles, CA.	To examine the efficacy of virtual reality (VR) to prepare surgical trainees for a paediatric orthopaedic surgery procedure: pinning of a slipped capital femoral epiphysis (SCFE).	Randomised trial	Simulation of slipped capital femoral epiphysis (SCFE) screw fixation	Study guide (SG) group vs VR training group	A SCFE guidewire placement on a Saw-Bones model embedded in a soft-tissue envelope	Participants were evaluated on: >Time >Number of pin "in-and outs" >penetration of the articular surface >Angle between the pin and the physis >Distance from pin tip to subchondral bone >Distance from the center-center point of the epiphysis	20 fourth-year medical students, first- and second-year orthopaedic residents without experience with the SCFE procedure.	VR training trended toward improved skill acquisition and application in preparation for SCFE pinning, with implications for improved acquisition of general orthopaedic skills (i.e., use of fluoroscopy, spatial awareness).

Margalit et al[23]	Single institution in the USA, name was not mentioned	Compare outcomes between orthopaedic trainees using various preoperative training platforms (physical simulation [PS], virtual reality [VR], and reading/ videos) in a slipped capital femoral epiphysis model.	Randomised control trial	Simulation of slipped capital femoral epiphysis (SCFE) screw fixation	Reading/ video (control group) vs VR group vs physical simulation group	To perform in situ pin fixation on the phantom limb model (saw-bones)	>Overall surgical time >Amount of fluoroscopy >Global Rating Scale score >Radiographic screw position >Physical screw accuracy >Presence of breeching of the articular surface or femoral neck >Overall platform rating (0 to 10)	21 orthopaedic trainees, consisting of nine junior orthopaedic residents and 12 senior medical students, were recruited from a single institution	Although practising with a physical SCFE model may be the most realistic method to train novice surgeons, VR training modules may yield similar radiographic accuracy and surgical technique performance while offering a more convenient to practice surgical skills.
McKinney et al[25]	Community Memorial Health System, a primary clinical care institution in Ventura, California	Evaluate the effectiveness of immersive virtual reality training in orthopaedic surgery education in comparison to the standard technique guide for fixed-bearing medial unicompartmental knee arthroplasty	Blinded, parallel, randomised study	Simulation of fixed-bearing medial unicompartmental knee arthroplasty (UKA)	Use of VR simulation only vs Use of technique guide only	Surgical performance of UKA on a SawBone model	>Assessed on the steps of the procedure using a procedure-specific checklist >Assessed using adapted Global Assessment 5-point Rating Scale focusing on (time and motion, instrument handling, knowledge of instruments, flow of operation and forward planning and knowledge of specific procedure)	22 orthopaedic surgery residents	Residents who used the VR training method executed significantly more steps correctly and completed the procedure in faster time.

Orland et al[22]	University of Illinois College of Medicine, Chicago	Does a virtual reality simulator with or without a standard technique guide result in (1) a higher proportion of participants who completed the insertion of an intramedullary tibial nail in a synthetic bones model and (2) greater procedural accuracy than does training with a technique guide alone?	Randomised control trial	Simulation of intramedullary tibial nail insertion	Use of technique guide only vs use of VR simulation only vs use of both	Insert an intramedullary nail into an intact, compact bone-model tibia that lacked surrounding soft tissue.	> Proportion of participants in each of the three study groups who were able to complete the task. > Proportion of incorrect steps in each group (defined as the number of incorrect steps compared with the number of steps performed) > Number of hints requested during the test > Mean time to completion of the task.	25 first- and second-year medical students without prior exposure to intramedullary tibial nail insertion.	Virtual reality increased both procedural accuracy and the completion proportion compared with a technique guide in medical students.
Zaid et al [26]	Conducted at a single, large academic orthopaedic surgery residency program in the USA. No further details mentioned	Determine whether VR improves surgical competence over traditional procedural preparation when performing a unicompartmental knee arthroplasty	Randomised Controlled Trial	Simulation of unicompartmental knee arthroplasty	"Guide" group (control) with access to manufacturer's technique guide and surgical video VS VR group	Surgical performance of UKA on a SawBone model	>Surgical Time >Objective Structured Assessment of Technical Skills (OSATS) validated rating system focusing on: time and motion, instrument handling, knowledge of instruments, flow of operation and knowledge of specific procedure	22 orthopaedic surgery trainees	VR training demonstrated equivalent Saw-Bones surgical competence compared with the use of traditional technique guides, as measured by surgical time and OSATS scores. Both groups also experienced similar improvement in trainee confidence to perform the surgery alone. In addition, most trainees found the VR technology beneficial and would use it if available.

included the proportion of participants in each of the three study groups who were able to complete the task successfully. Additionally, the assessment considered the proportion of incorrect steps in each group, defined as the number of incorrect steps compared to the total number of steps performed. The study also measured the number of hints requested during the test and the mean time taken to complete the task. These measures assessed participants' task completion abilities, accuracy, and efficiency.[22]

In Zaid et al.'s study, an Objective Structured Assessment of Technical Skills (OSATS) validated rating system was used. This rating system encompassed aspects similar to those of GRS.[26]

Findings

Orland et al. found that VR training significantly improved procedural completion rates, with a higher proportion of participants in the VR group (6 of 8) and the virtual reality and technique guide group (7 of 9) successfully completing intramedullary nail procedures compared to those in the technique guide-only group (2 of 8). Additionally, participants trained with VR made fewer errors during the procedure.[22]

Similarly, McKinney et al. reported positive outcomes with VR training. Residents who utilised VR training executed significantly more steps correctly and completed procedures in faster times than those in the technique guide group. Moreover, participants who underwent VR training scored significantly higher in 4 of the 5 global assessment categories, including: time and motion (3.64±0.67 vs 2.36±0.92, $p<0.01$), instrument handling (3.73±0.90 vs 2.82±1.08, $p=0.05$), knowledge of instruments (3.82±0.60 vs 2.45±1.13, $p<0.01$) and flow of operation and forward planning (3.45±0.52 vs 2.36±1.12, $p=0.01$).[25]

In contrast, Margalit et al. didn't find significant differences in most objective parameters,including screw accuracy, breaching of the femoral head or neck, surgical time, radiographic accuracy and surgical technique. However, participants expressed a preference for physical simulation, followed by VR, over conventional book/video materials. This suggests that VR training may offer similar performance in radiographic accuracy and surgical technique as physical simulation while providing greater convenience.[23]

Cevallos et al. observed that VR training trended toward improved skill acquisition for SCFE pinning, potentially benefiting general orthopaedic skills. Although limited by sample size, the current study suggests that VR training appears to be more effective than traditional preparatory methods in achieving a shorter procedure time, decreasing the number of "in-and-out" events, decreasing the number of violations of the joint space, and achieving a better overall pin placement, although most of the results were not statistically significant.[24]

Blumstein et al. found that VR training significantly enhanced performance across all five categories of the Global Assessment 5-point rating scale. Although not statistically significant, a higher number of students from the VR group performed each step correctly on a procedure-specific checklist. However, the VR group had a significantly higher aggregate number of steps performed correctly.[21]

Finally, Zaid et al. reported no statistically significant differences in surgical times or OSATS scores between the VR group and the technique guide and surgical video group during unicompartmental knee arthroplasty procedures.[26]

Risk of bias assessment

The Cochrane Risk of Bias tool was employed to evaluate the potential bias in the studies. (Table 3) Overall, the studies demonstrated a low risk of bias. Random allocation of participants and blinding of assessors were consistently implemented in all studies. However, due to the study's inherent nature, blinding of participants was not feasible.[20]

Discussion

The adoption of VRSE within the orthopaedic field is steadily increasing.[19] Our systematic review provides substantial evidence that the use of VR in the training of orthopaedic trainees and medical students can be beneficial in procedural completion rates in all five aspects of surgery. Faster time and motion, improved instrumental handling, and knowledge of instruments. The flow of operation

Table 3: Cochrane Risk of Bias Tool

Study	Bias domains							
	Random sequence generation	Allocation concealment	Blinding of participants	Blinding of personeel	Blinding of outcome assessors	Incomplete outcome data	Selective reporting	Other bias
Blumstein et al (2020)	+	+	?	+	+	?	?	?
Cevallos et al (2022)	+	?	?	+	+	+	+	+
Margalit et al (2022)	+	?	?	+	+	+	+	+
McKinney et al (2022)	+	+	?	+	+	+	?	?
Orland et al (2020)	+	+	?	+	+	+	?	+
Zaid et al (2022)	+	+	?	+	+	+	+	?

+ Low risk of bias ? Unclear risk of bias - High risk of bias

and forward planning as well as the knowledge of the specific procedure. Importantly two of these aspects can be vital for experienced surgeons as well. Knowledge of instruments and specific procedures is not linked to the experience of the surgeon in operation but rather in the experience of the surgeon using the specific equipment produced by a specific company.[27] VR can assist in the pre-operative training of surgeons and assistants to increase efficiency and confidence during the real operating time.

Additionally, while a panoramic view of the VR landscape in orthopaedics is necessary, our systematic review offers a concentrated insight into a single, popular tool. Clarke et al conducted a comprehensive review of different VR simulator softwares, offering a heterogeneous approach to assessing the potential of VR in orthopaedic training.[28] This wide-ranging analysis allowed the capture of a diverse spectrum of simulator types and applications, providing a holistic view of the field's capabilities and limitations. In contrast, our study focused exclusively on VR software produced by one manufacturer as a single comparison point in the effort to minimise the introduction of variables which could affect the consistency and compatibility of outcomes across the simulators. This narrowed lens allowed for a more controlled and homogeneous analysis, enabling us to delve deeply into the specifics and nuances of the efficacy in a single VR environment.

Current VR systems also face some limitations.[29] Haptic feedback for example, which lacks accurate emulation for many orthopaedic procedures as it is primarily geared towards arthroscopy-based tasks.[30] New softwares such as FundamentalVR offer such opportunities but large-scale procedures remain understudied, and the cost-effectiveness of these simulators is uncertain.[30] Despite these, VR's potential for efficient surgical learning is evident, especially if integrated with real-world tactile sensations.

Furthermore, endorsements from leading surgical boards emphasise the value of preparing medical students for surgical residencies with a focus on quality care and patient safety.[31] Implementing VR in surgical rotations can enhance a student's learning experience, addressing the current gap in instruction and feedback that many students perceive

during their training.[32] Additionally participants who trained with VR made fewer errors during the simulated operating procedure, indicating that by utilising VR as a repetitive, muscle memory training tool, competency can be improved while also enhancing patient safety.[22]

Limitations and strengths

The selected articles have adopted different methodological approaches in their respective analyses and reports and in some cases used different outcome measures. This heterogeneity introduces a potential source of variability, impacting the overall consistency of this review. Additionally, the amount of time spent training on VR software differed between studies making it harder to compare the findings. Another notable limitation is the absence of stratification based on gender or educational levels in the review, thereby precluding a nuanced analysis of potential disparities. Furthermore, the limited number of articles meeting the inclusion criteria for this review, totaling only six, and involving a relatively modest sample size of 130 participants, raises concerns about the generalizability of the conclusions drawn. Additionally, all the selected studies were conducted exclusively in the United States. This geographical restriction introduces another layer of uncertainty regarding the applicability of the findings, especially considering the variations in the structure of residency programs in Europe compared to the United States.

However, this review also has a number of strengths. Firstly, the included studies underwent a rigorous bias assessment conducted by the two first authors, lending greater credibility to the synthesised findings. Additionally, only articles using one specific VR software were included, in order to enhance the comparability of the results. Lastly, all the studies incorporated into this review have been peer-reviewed and have been sourced from high-impact academic databases.

Conclusion

While the initial findings on the use of VR software for training orthopaedic residents and medical students are promising, the question of whether VRSE serves as an effective alternative to traditional educational methods remains inconclusive, warranting further research. To address this gap, a new study should be conducted, preferably across multiple centres, including those in Europe, with a larger participant pool.

Conflict of Interest

The authors declared no conflicts of interest.

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