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# Collaborative team training in virtual reality is superior to individual learning for performing complex open surgery: a randomised controlled trial

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**CONFLICT OF INTEREST**:

T.C.E declares research funding from Johnson & Johnson, A.D.L declares research funding from the Royal College of Surgeons of England, J.P.C declares research funding and paid consultancy from Johnson & Johnson, Zimmer Biomet and JRI, he declares shares/stock in Embody Orthopaedic. K.L declares research funding from Johnson & Johnson, and the Royal College of Surgeons Royal College of Surgeons of England

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Ethical approval was granted prospectively by the Health Research Authority (REC reference: 18/HRA/2085, IRAS ID: 237607).

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**AUTHOR CONTRIBUTIONS:**

T.C.E: Conceived initial idea, designed study, data collection/analysis, drafted manuscript

D.S: Collected and analysed data, edited manuscript

S.G: Collected and analysed data, edited manuscript

S.K: Collected and analysed data, edited manuscript

A.Patel: Collected and analysed data, edited manuscript

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A.D.L: Data interpretation, wrote & edited manuscript,

J.P.C: Conceived initial idea, wrote & edited manuscript, supervision

K.L: Conceived initial idea, designed study, data analysis, wrote and edited manuscript

**RUNNING HEAD:** Surgical team training in virtual reality

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**STRUCTURED ABSTRACT**

**Objective:** To assess if multiplayer virtual reality (VR) training was superior to single player training for acquisition of both technical and non-technical skills in learning complex surgery.

**Summary Background Data:** Superior team-work in the operating room (OR) is associated with improved technical performance and clinical outcomes. VR can successfully train OR staff individually, however VR team training has yet to be investigated.

**Method:** Forty participants were randomised to individual or team VR training. Individually-trained participants practiced alongside virtual avatar counterparts, whilst teams trained live in pairs. Both groups underwent five VR training sessions over 6-weeks. Subsequently, they underwent a real-life assessment in which they performed Anterior Approach Total Hip Arthroplasty (AA-THA) surgery on a high-fidelity model with real equipment in a simulated OR. Teams performed together and individually-trained participants were randomly paired up. Videos were marked by two blinded assessors recording the NOTSS, NOTECHS II and SPLINTS scores. Secondary outcomes were procedure time and number of technical errors.

**Results:** Teams outperformed individually-trained participants for non-technical skills in the real-world assessment (NOTSS 13.1 ± 1.5 vs 10.6 ± 1.6, p =0.002, NOTECHS-II score 51.7 ± 5.5 vs 42.3 ± 5.6, p=0.001 and SPLINTS 10 ± 1.2 vs 7.9 ± 1.6, p = 0.004). They completed the assessment 28.1% faster (27.2 minutes ± 5.5 vs 41.8 ±8.9, p<0.001), and made fewer than half the number of technical errors (10.4 ± 6.1 vs 22.6 ± 5.4, p<0.001).


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**Conclusions:** Multiplayer training leads to faster surgery with fewer technical errors and the development of superior non-technical skills.

**Keywords:** Virtual Reality, Simulation, Interprofessional Education, Surgical Teams, Patient Safety

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## INTRODUCTION

Adverse events occur in around 1 in 10 admissions to hospital.[1-3] The most common place for these to happen is in the operating room (OR), with the majority of these surgical errors considered preventable.[1, 4-6] To improve patient safety, a number of measures have been suggested to reduce the incidence of error, focussing on both individual roles and team performance.[7-9]

The surgical team is comprised of a surgeon, anesthesiologist, scrub technician, anaesthetic assistant and circulating staff. Superior team performance is strongly associated with a reduction in adverse events, complications and mortality and with improved patient outcomes.[10, 11] It also has an indirect effect on outcomes by promoting greater surgical efficiency and shorter operative times which in themselves result in a reduced chance of a serious complication occurring.[12] Therefore , highly performing surgical teams who deliver efficient operations reduce the likelihood of patients coming to harm.

Implementation of interventions which focus on team performance within surgery have resulted in both improvements in non-technical skills, and also reduced intraoperative technical error.[7] However, whilst these interventions, which are based on crew-resource management training within the aviation industry, are effective, they are often delivered in course format, requiring significant resources and time off work for participants.

Immersive Virtual Reality (iVR), is an easily accessible technology where participants from anywhere in the world can enter a virtual OR and perform surgery using a motion tracked

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headset and controllers.[13] It has proven effective in training junior surgeons to perform both endoscopic and complex open procedures.[13, 14] Similarly scrub technicians, who in many parts of the world have limited structured training, have been shown to benefit from a virtual reality curriculum in complex revision total knee arthroplasty surgery.[15] However, despite lending itself perfectly to collaborative learning in the virtual world, iVR has yet to be used for multidisciplinary team training in the OR.

The anterior approach (AA) for total hip arthroplasty (THA) is known to be technically challenging with a strenuous learning curve.[16] Complication rates of up to 20% have been reported for surgeons learning this operation, reducing to 7% once accomplished.[17] This study aimed to investigate whether an innovative collaborative team iVR module was superior when compared to conventional single player iVR training. As a technically difficult, multistep open operation, the AA-THA was chosen to test the hypothesis that this collaborative approach will be superior to individual learning.

## METHODS

### *Setting and participants*

The study protocol was registered (ISRCTN32225943) and ethical approval was granted prospectively by the Health Research Authority (REC reference: 18/HRA/2085, IRAS ID: 237607). This research was conducted in a specially designed virtual reality training facility, in the simulation laboratory at Imperial College London. Between April and October 2021 participants were recruited for one of two roles: Surgeon or scrub technician. Junior orthopedic surgical residents in their second to fifth year post-qualification (Foundation Year 2 to Specialist Trainee Year 3 in the UK terminology) were eligible to be recruited for the

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surgeon role. They were excluded if they had previously performed any supervised AA-THA operations, >10 THA operations by any approach, had previous participation in orthopaedic surgery iVR simulation or if they could not commit the required time to the study. Undergraduate nursing students, medical students and qualified scrub technicians or anaesthetic assistants, within their first year of training were eligible to be recruited for the scrub technician role. Participants were excluded if they had previous experience scrubbing for AA-THA procedures, > 1-year experience in an orthopaedic scrub role of any kind, prior training in THA instrumentation, previous orthopaedic iVR simulation experience or if they were unable to commit the required time to the study. All participants provided written informed consent to participate.

*Randomization*

Participants were randomized to one of two parallel groups using a block randomization protocol in a 1:1 allocation ratio using an online computer-generated random number sequence by a physician associate not involved in the trial. Participants were randomized to either solo iVR (with the individual training as either a surgeon or scrub technician) or team iVR (training with a co-participant surgeon or scrub technician). Group allocation was concealed until participants were fully enrolled in the study.

*Baseline visit*

At baseline all participants provided demographic information and underwent a short written, role-specific baseline knowledge assessment. This was developed to assess key skills and knowledge required to perform the operation in the real world. For surgeon participants this involved instrumentation terminology and application, procedural steps and understanding of the target orientation of components and technique (14 questions). Scrub technicians were assessed on knowledge of instrumentation, procedural sequence and a practical element asking them to assemble equipment (19 questions). A short introductory presentation was subsequently delivered to all participants to standardize baseline knowledge.

*iVR Training*

The software used in this study was a bespoke team training package created through augmentation of a pre-existing and validated AA-THA module (Pixelmolkerei, Chur, Switzerland).[18] This module, a previous AA-THA cognitive task analysis,[19] and intraoperative video footage, were interrogated to divide the choreography into key steps for surgeons and scrub technicians. Once created, the module was beta tested with iterative feedback from experienced scrub technicians, surgeons and lay representatives to further refine the system. Three modes were established; multiplayer (scrub technician and surgeon training live in pairs), solo scrub technician, and solo surgeon (training with a computer avatar playing the alternative role). In the solo mode, participants completed the steps for their role, once a step was fully complete the computer avatar would respond by moving on to perform the next task in their sequence. Solo participants were not able to verbally interact with the avatar. The training was otherwise identical between the multiplayer and solo modes, teaching them to perform an AA-THA in the supine position. It guides participants through their role-specific tasks with audio commentary, identifying the equipment needed at each stage and illustrating how to complete the key steps. This was delivered using an Oculus Rift S headset and two hand-held motion-tracked controllers (Meta Platforms, California, USA; figure 1). Each training session lasted approximately 90 minutes with 30 minutes for training followed by 60 minutes of assessment and was supervised by an iVR technician who provided technical support and ensured safety of the participants. In the assessment mode, participants were not guided; however automatic, computer-generated prompts were provided

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when progress wasn't made after 30 seconds. All participants underwent five iVR sessions over the six-week period. This timetable was chosen as previous studies have  indicated that the learning curve in virtual reality surgery training reaches a plateau after four iVR sessions.[20]

*Real-world Assessment*

Following the final iVR session, participants completed a real-world assessment on a high-fidelity model with silicone skin, subcutaneous fat, fascia, capsule and a validated saw bone femur and pelvis (Sawbones®, Pacific Research Laboratories, Vashon Island, USA). The assessment took place in a 360-degree distributed simulation operating theatre (figure 2). This set up has been previously validated as an appropriate medium to test both technical and non-technical skills.[21] Team-trained participants performed this assessment in their training pairs, solo participants were randomly paired, using a computer-generated random number sequence, with another solo participant of the opposite role. Participants performed the full procedure wearing a surgical gown, gloves and cap using real surgical instruments (figure 2). They were instructed to perform the procedure together exactly as they had been taught in iVR. Participants were assisted by three passive surgical assistants; two of whom held retractors as directed and a third who operated the traction table for manipulation of the femur. They were only prompted if they requested help or they were performing an unsafe action or one which may jeopardize the remainder of the assessment. The assessment was filmed using three cameras (GoPro HERO7, GoPro, San Mateo, California, USA) stationed around the operating theatre enabling assessment of the surgeon, the scrub technician and their teamwork.

*Video Assessment – Non-technical skills*

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Video recordings of assessments were analyzed independently by two assessors who were not involved in the iVR training and were blinded to participant group. One assessor was a senior hip arthroplasty fellow with over 10 years post graduate experience, the other was an orthopedic surgery trainee with 4 years post graduate experience. Both had specific training using three non-technical skills scores: 1. Non-Operative Technical Skills for Surgeons (NOTSS) (primary outcome measure) 2. The Non-TECHnical Skills II (NOTECHS II) score and 3. The Scrub Practitioners' List of Intraoperative Non-Technical Skills (SPLINTS) score. All three scores have been previously validated and have been demonstrated to be reliable and reproducible.[22-24] The mean scores were used and interobserver reliability calculated using the intraclass correlation coefficient (ICC). Details of the scoring methodology for each metric are published elsewhere.[22-24] In short, each score grades participants' performance in several well-established non-technical subdomains. These include: Situation awareness (SA), teamwork and communication (T&C), decision- making (DM), problem-solving (PS), leadership (L) and task management (TM). The NOTSS score focuses on the surgeon, grading each of four subdomains (SA, T&C, DM, L) out of 4. These scores are subsequently added together with the highest possible score (indicating the best nontechnical performance) being 16 and the lowest score being 4.[22] The SPLINTS score takes a similar approach focusing on the scrub technician, grading three subdomains (SA, T&C, TM) out of four, giving a maximum score of 12.[24] The NOTECHS II score examines non-technical performance of each surgical team participant individually (surgeon, scrub technician, anesthetist), before adding the scores together. The four subdomains (L, PS & DM, T&C, SA) are graded out of 8 providing a maximum score for each participant of 32. The maximum possible score for all three participants would be 96, however, this was adapted in the present study to include just the scrub technician and surgeon with the best possible score being 64.[23]

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*Video Assessment – Technical Skills*

Technical skills were assessed by the two blinded observers independently using the same assessment video footage. An 80-point task specific checklist (TSC) for the anterior approach THA (Supplementary Table 2, Supplemental Digital Content 1, http://links.lww.com/SLA/E852) was created from the previously expert derived and validated anterior approach total hip arthroplasty module (Pixelmolkerei, Chur, Switzerland).[13, 20] The steps from this checklist were used to assess the real-world assessment. Surgical teams were graded on the number of steps from the TSC they successfully completed. Procedural errors were calculated by subtracting the number of successfully completed steps from the maximum possible score of 80.

*Acetabular Component Orientation*

Accurate acetabular component orientation is a well-established surrogate of technical proficiency in hip arthroplasty, with mal-positioning being closely associated with complications such as dislocation, impingement, accelerated polyethylene wear, and revision surgery.[25-27] Furthermore, in AA-THA there is a greater propensity to place this component outside the target safe zone reported when compared to other approaches.[28] As such, surgeons were assessed for their acetabular component positioning using a digital goniometer (Wixey™, U.S.A). This was measured according to their error in degrees from the prescribed target of 20 degrees anteversion and 40 degrees of inclination, selected to be well within the widely accepted 'safe zone'.[27, 29, 30] Anteversion was measured in relation to the anterior pelvic plane, which was made parallel to the operating table for the assessment performed in the supine position. The digital goniometer was calibrated at zero degrees on the table and placed horizontally on the introducer. Acetabular inclination was measured in relation to the axial plane of the pelvis. To measure it, the pelvis was rotated through 90 degrees from the supine position and then the same process was repeated.

*Sample size*

An *a priori* calculation for sample size was made for the NOTSS score as the primary outcome measure. The minimum effect size was calculated from a comparable simulation study by Brunckhorst et al., who measured surgical trainees' NOTSS scores in a similar distributed simulation environment.[21] This article determined an effect size of 1.34 standard deviations between control and intervention groups (total NOTSS scores, mean ± SD: control: 9.1 ± 3.42, intervention: 13.1 ± 2.49). To achieve power of 80% with an alpha of 0.05, 40 participants (20 for each arm, giving 10 team and 10 solo pairs for the final real-world assessment) were required.

*Statistical Analysis*

Statistical analysis was performed using Stata (*Stata/IC 10.1, StataCorp LP, College Station, TX* ). Inter-observer reliability between the two video analysers was assessed using a two-way, intraclass correlation co-efficient (ICC), where a score above 0.75 generally indicates good agreement.[31] Data comparing group performances was tested for normality using the Shapiro-Wilk test alongside visualisation of the data through histograms. Variables with normal distribution were analysed utilising the independent-samples *t*-test. Non-parametric variables were analysed using Mann-Whitney U Test. A two-sided p- value of 0.05 or less was deemed statistically significant. All results are stated as mean ± standard deviation unless stated otherwise.

## RESULTS

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Forty-six participants were initially screened for eligibility, six declined to participate due to the time commitment. Forty subjects fully enrolled in the study as shown in the CONSORT flow diagram. The demographics of participants is shown in Tables 1 and 2. There were no significant differences between groups comparing baseline knowledge scores for surgeons (team 46.5% ± 11.9 vs 34.3% ± 17.1 , p=0.08) or scrub technicians (team 46.9% ± 28.4 vs 50.5% ± 27.9 , p=0.776)

*Non-technical performance*

Table 3 summarises the study's key findings. For non-technical performance, team trained participants outperformed the solo groups in all of the three non-technical elements. NOTSS (13.1 ± 1.5 vs 10.6 ± 1.6, p =0.002), NOTECHS II (51.7 ± 5.5 vs 42.3 ± 5.6, p=0.001) and SPLINTS (10 ± 1.2 vs 7.9 ± 1.6, p = 0.004) (figure 3).

*Technical performance*

Team-trained participants performed the procedure 28% faster when compared to the solo group (28.2 minutes ± 5.5 vs 41.8 ±8.9, p<0.001) and made fewer than half the number of procedural errors (10.4 ± 6.1 vs 22.6 ± 5.4, p=0.001) (figure 4). Supplementary Table 2, Supplemental Digital Content 1, http://links.lww.com/SLA/E852 demonstrates the detailed breakdown of errors made between team and solo participants. There were no significant differences in the accuracy of acetabular component orientation measurements between groups (table 3).

*Reliability*

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Interobserver reliability was excellent for all video measured metrics; NOTSS: 0.92 (95% Confidence Interval (CI): 0.79-0.97), NOTECHS II: 0.94 (95% CI: 0.84-0.98), SPLINTS: 0.92 (95% CI: 0.80-0.97), Technical errors: 0.99 (95% CI: 0.98-1.00); Supplementary Table 1, Supplemental Digital Content 1, http://links.lww.com/SLA/E852.

## DISCUSSION

The most important finding of this study was that those who trained in a team exhibited superior non-technical skills, performing the operations more efficiently, and with fewer technical errors when compared to those who trained alone. The use of iVR simulation to facilitate delivery of this training appears to be feasible and highly effective.

The association between good teamwork skills and improved patient safety is now well established.[10, 11, 32, 33] One of the key findings of the present study was that the superior non-technical skills exhibited by team-trained participants, were associated with a reduced number of procedural errors. Several other authors have supported these findings, linking superior non-technical performance to reduced surgical error, complications, mortality and improved outcomes.[10, 11, 33] Fecso et al. focused on technical adverse events in bariatric surgery, the authors noted superior non-technical performance for both scrub technicians and surgeons to be linked to a reduction in technical adverse events.[10] Similarly Mazzocco et al. in a study of 300 observed surgeries, suggested that mortality and significant complications were more likely when a paucity of good intraoperative teamwork behaviours were observed. The work of Catchpole et al. concours with the findings of the present study, examining technical errors and nontechnical skills for surgical teams performing two common general surgical procedures. The authors report that superior scores in both nursing and surgical

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domains of the NOTECHS II were correlated with a decreased chance of observing a technical error. They conclude that interventions designed to improve teamwork may be beneficial in terms of technical error and patient outcome. It is worth noting that these studies were conducted in the clinical environment, whereas the present study was assessed in a simulation. The advantage of our study is the reduction in potential bias through its randomized design. The similar conclusions drawn give support to the notion that the benefits seen through team training in the simulation may transfer to physical world. This has important patient safety implications through improving technical proficiency and error reduction, which are both linked to reduced complication rates and superior patient outcomes.[34]

A second benefit of the team training was increased efficiency, with a 28% reduction in overall procedure time recorded. This may also have a beneficial effect on patient safety; there is now a substantial body of evidence linking prolonged operation times to an increased risk of developing significant complications.[12, 35, 36] In a recent registry based study including 92,343 TKA operations, operation times >100 minutes were associated with almost double the risk of experiencing deep infection.[12] Similar findings have been demonstrated by other authors highlighting considerable reductions in complications with shorter, more efficient operating times.[35, 36] The presented evidence would suggest team training not only reduces error, but also improves efficiency. If these benefits translate into the physical world, utilizing this type of training in complex surgery could be an easily accessible and effective method of potentially reducing these complications.

One suggestion for superior non-technical skills being linked to reduced intraoperative error is to do with flattening hierarchical gradients, allowing all team members to communicate

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freely, making operations safer and less error-prone.[37] Steep hierarchical gradients are thought to lead to more junior team members not challenging questionable decisions made by senior team members.[37] In both aviation and healthcare this has been shown to be harmful.[37, 38] It has been suggested that nurses can feel subservient to doctors in the hierarchy.[37] Communication has been demonstrated to be more successful under flatter interprofessional hierarchies, leading to improved patient care.[39] Interprofessional learning and problem solving together could be an explanation for why the team trained participants performed more effectively. It is also interesting to note that although the team group in the present study outperformed the solo group in all subdomains of the three non-technical metrics, the difference was marginally more pronounced in the communication subdomains. This may suggest communication to be a pivotal factor in the improvement seen.

The concept of interprofessional education (IPE) has evolved recently to introduce this training at an early career stage. Multiple studies support this idea with data suggesting training medical students and technicians together leads to superior nontechnical skills development, better interprofessional relations and superior patient outcomes.[40, 41] Our study supports this, demonstrating that the virtual world is an ideal place for delivering IPE training without the significant resources and organization constraints associated with more conventional IPE teaching modalities.

Although there is a paucity of data using iVR in a collaborative approach, it has demonstrated success in training surgeons and scrub technicians individually. One of its advantages over other forms of high-fidelity simulation training is it doesn’t require significant resources or equipment. Virtual reality headsets can now be purchased for less than $500 and are easily transportable.[42] Furthermore, this training modality is highly efficacious for training both

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endoscopic and open operations.[43-45] In a study by Logishetty et al., 32 surgical residents were trained to perform total hip arthroplasty operations using an anterior approach [20]. Residents improved significantly over the 6-session curriculum reducing the number of assistive prompts received, errors and procedural times, reaching expert levels by the 4th session. A number of other studies have demonstrated a similar effect in training surgeons, further supporting this concept.[13, 45] More recently this technology has been applied to training scrub technicians. Edwards et al. demonstrated substantial improvement in real-world technical skills scores following a 4-week VR curriculum for scrub technicians learning revision total knee arthroplasty surgery.[15] The authors also show improvement in confidence and anxiety levels after the training. The present study appears to be the first to combine both roles and the benefits of doing so on teamwork. Future studies could examine adding other roles into the equation to expand this training to the rest of the surgical team.

There are several important factors to consider applying this data moving forward. The iVR training programme utilised in the present study delivered substantial benefit when used for team training, however was time intensive. In time-pressured healthcare systems, implementing a 5-session team iVR curriculum may not be practical, which questions whether these benefits can be obtained over a shorter time period. The authors feel the main reasons for the team groups superior performance, were related to familiarity, collective problem solving and ability to communicate freely without the barriers of work-based hierarchy. This allows teams to work better together and complete the sequence of steps with greater accuracy whilst being more efficient. However, individual role technical ability was not influenced by team training. There were no differences seen in component orientation (acetabular anteversion and inclination) between groups. This could be because there is little teamwork involved in the surgeon orientating the components. These aspects of the training could potentially be taught separately from a team training focussed intervention, in order to maximise efficiency.

Another important consideration is whether the benefits seen could be delivered in an alternative medium. The iVR team training allowed participants to gain teamwork skills organically through repetitive practice. However it may be possible to expedite the development of these skills using targeted teamwork interventions. Classroom or simulation-based team training has been utilised in a number of studies with encouraging results. Crew resource management (CRM) training, which originates in the aviation industry, focusses on improving non-technical skills. A study by McCulloch et al. demonstrated how a CRM training programme not only improved surgical team non-technical performance, but also improved technical performance and error in two commonly performed general surgery procedures.[46] Forse et al. found similar benefits investigating another targeted team training course (TeamSTEPPS). The authors suggested this training led to significant improvements in OR staff teamwork alongside benefits to patient safety with significantly improved mortality and morbidity rates.[47] It may be possible to expedite the development of teamwork skills with a targeted intervention, potentially delivered in an iVR environment. This method of delivery for targeted non-technical skills training, has yet to be investigated and forms an interesting area for future research.

This study has several limitations. First, although baseline scores were similar between groups, the novice scrub technician group were a diverse mix of student nurses, medical students, newly qualified scrub technicians and anaesthetic assistants. Although the primary outcome was related to overall team performance and not role specific, this may have introduced some bias and limit how these results can be generalised to the wider population

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of scrub technicians. Additionally, although randomised, when comparing team and solo surgeon groups, there were more CT2 participants in the team group. Whilst this was not statistically significant, this group also had higher baseline knowledge scores which could have biased the final assessment results. To mitigate a pre-existing knowledge discrepancy, the authors provided an introductory presentation to all participants, however we did not repeat the baseline assessment to ensure knowledge parity had been achieved. Second, the real-world assessment was conducted in a simulated setting on a high-fidelity model and focussing on one operation. This means we cannot comment on how this performance would translate into a real operating theatre or across different surgical disciplines. Third, whilst the iVR training modules were identical between solo and team trained groups, the solo participants were provided with a perfect avatar playing the counterpart role. This could have introduced some bias in their ability to retain information. Finally, as this was a simulated study, the true impact of this intervention on patient safety in the real operating theatre is as yet unknown, this could form an interesting area for future research

## CONCLUSION

Collaborative surgical team iVR training led to the development of superior non-technical skills alongside more efficient and less error prone surgery. This multidisciplinary approach using iVR technology could be easily implemented into operating theatres around the world and has potential to lead to safer and more efficient surgery.

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**Figure 1:** The virtual reality equipment set up for the multiplayer mode. The images in the top right and left demonstrate the view through the headsets for the surgeon (right) and scrub nurse (left). The image below shows the hardware (headset and motion tracked controllers) being used in a team training session

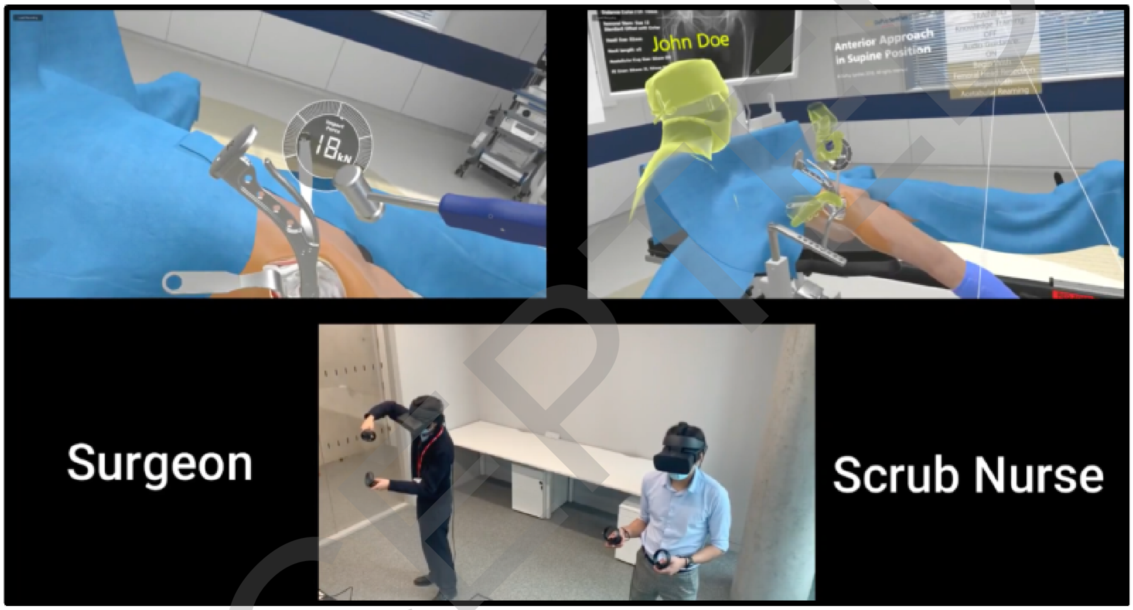


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**Figure 2:** The set up for the real-world assessment using the distributed simulation. Figure 3A demonstrates the overall set up with equipment, personnel and model. Figure 3B shows a participant broaching the femur during the simulated operation


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**Figure 3:** Column scatter plots demonstrating the non-technical performance in the real-world assessment for the three measured scores: (A) Non-Technical Skills for Surgeons (NOTSS) (B) Non-TECHnical Skills II (NOTECHS II) and (C) Scrub Practitioners' List of Intra-operative Non-Technical Skills (SPLINTS), for team (T) and solo (S) trained participants. The central horizontal line within the box shows the mean. The whiskers demonstrate the standard deviation. Significant p-values (<0.05) are indicated

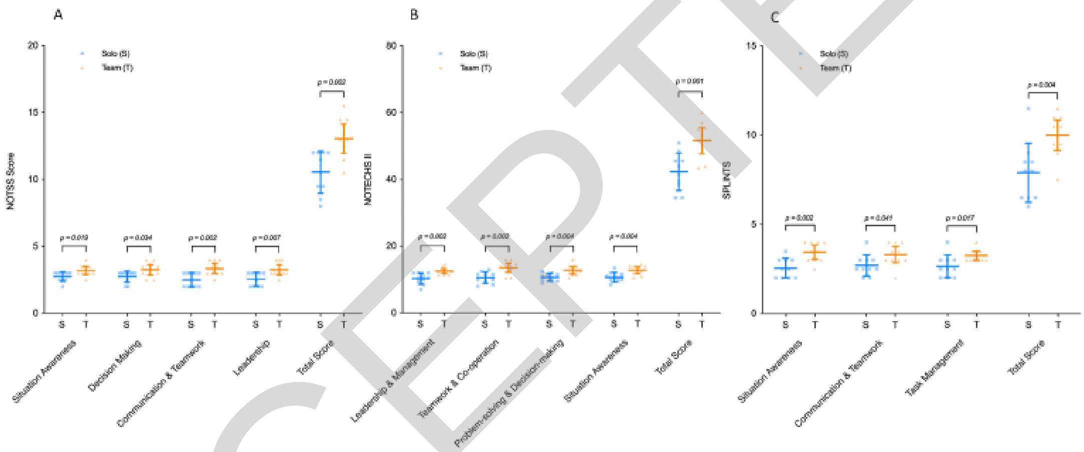


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**Figure 4:** Column scatter plots demonstrating the technical performance metrics in the real-world assessment: (A) Technical error count and (B) Procedure duration in minutes, for team (T) and solo (S) trained participants. The central horizontal line within the box shows the mean. The whiskers demonstrate the standard deviation. Significant p-values (<0.05) are indicated

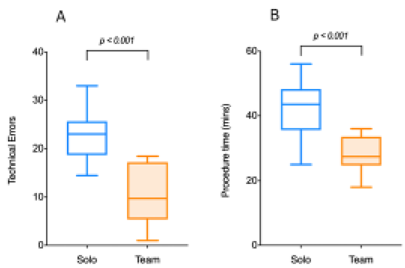


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**Table 1.** Summary of demographics for surgical residents

| Characteristic | Team Surgeons (n=10) | Solo Surgeons (n=10) | p-value |
|---|---|---|---|
| **Male:female (n)** | 7:3 | 10:0 | 0.211 |
| **Mean age (years ± SD)** | 29.2 ± 3.0 | 28.5 ± 2.1 | 0.552† |
| **Hand dominance (right:left)** | 9:1 | 10:0 | 1.00 |
| **Baseline knowledge score (% ± SD)** | 46.5 ± 11.9 | 34.3 ± 17.1 | 0.08† |
| **Level of training** | | | 0.243 |
| **FY2** | 1 | 0 | |
| **CT1** | 3 | 7 | |
| **CT2** | 5 | 2 | |
| **ST3** | 1 | 1 | |
| **Video game previous experience** | | | 0.103 |
| **Never** | 0 | 0 | |
| **Rarely** | 4 | 0 | |
| **Occasionally** | 4 | 4 | |
| **Frequently** | 2 | 5 | |
| **Very Frequently** | 0 | 1 | |
| **Virtual reality experience** | | | 0.591 |
| **Never** | 4 | 2 | |
| **Rarely** | 4 | 3 | |
| **Occasionally** | 2 | 3 | |
| **Frequently** | 0 | 2 | |
| **Very Frequently** | 0 | 0 | |

† Independent-samples students *t*-test, otherwise Fisher's exact test (categorical data)
SD, Standard Deviation; PGY, Postgraduate Year; FY2, Foundation Year 2; CT1, Core Trainee Year 1; CT2, Core Trainee Year 2; ST3, Specialist Trainee Year 3

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**Table 2.** Summary of demographics for scrub technicians

| Characteristic | Team Scrub (n=10) | Solo Scrub (n=10) | p-value* |
|---|---|---|---|
| **Gender** | | | 1.00 |
| **Male** | 3 | 3 | |
| **Female** | 6 | 7 | |
| **Non-binary** | 1 | 0 | |
| **Mean age (years ± SD)** | 24 ± 6.1 | 24.7 ± 6.3 | 0.803† |
| **Hand dominance (right:left)** | 10:0 | 9:1 | 1.00 |
| **Baseline Knowledge Score (% ± SD)** | 46.9 ± 28.4 | 50.5 ± 27.9 | 0.776† |
| **Role** | | | |
| **Nursing Student** | 2 | 3 | 1.00 |
| **Medical Student** | 6 | 6 | |
| **Junior Scrub Technician** | 1 | 1 | |
| **Anaesthetic Assistant** | 1 | 0 | |
| **Video game previous experience** | | | 0.039 |
| **Never** | 3 | 0 | |
| **Rarely** | 0 | 4 | |
| **Occasionally** | 6 | 4 | |
| **Frequently** | 1 | 1 | |
| **Very Frequently** | 0 | 1 | |
| **Virtual reality experience** | | | 0.656 |
| **Never** | 6 | 4 | |
| **Rarely** | 4 | 5 | |
| **Occasionally** | 0 | 0 | |
| **Frequently** | 0 | 1 | |
| **Very Frequently** | 0 | 0 | |

†Independent-samples students *t*-test, otherwise Fisher's exact test used (categorical data)
SD, Standard Deviatin

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**Table 3.** Summary of non-technical and technical outcomes in the real-world assessment

| Variable | Team (n=10) | Solo (n=10) | p-value |
|---|---|---|---|
| NOTSS | 13.1 ± 1.5 | 10.6 ± 1.6 | 0.002* |
| NOTECHS II | 51.7 ± 5.5 | 42.3 ± 5.6 | 0.001* |
| SPLINTS | 10 ± 1.2 | 7.9 ± 1.6 | 0.004* |
| Procedural errors | 10.4 ± 6.1 | 22.6 ± 5.4 | <0.001* |
| Anteversion error (°) | 5.9 ± 4.3 | 6.9 ± 4.8 | 0.606 |
| Inclination error (°) | 5.7 ± 4.5 | 4.9 ± 3.3 | 0.680 |
| Procedure time (mins) | 28.2 ± 5.5 | 41.8 ± 8.9 | <0.001* |

* statistically significant result

Data presented as mean ± standard deviation, means compared using the independent samples student's *t*-test

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