Training and Assessing Teamwork in Interprofessional Virtual Reality-based Simulation using the TeamSTEPPS framework – Protocol for a Randomized Pre-post Intervention Study

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Submitted to: JMIR Research Protocols
on: November 12, 2024

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Abstract

Background: Interprofessional teamwork is essential for patient outcomes in emergency medicine, yet effective training in this area is scarce. Virtual reality (VR) offers a promising, resource-efficient solution for simulating emergency scenarios, but tools for assessing teamwork in VR environments are lacking.

Objective: This study aims to adapt and validate the TeamSTEPPS framework to assess teamwork in VR-based training, with the goal of improving both team collaboration and medical performance.

Methods: This prospective pre-post study involves nursing and medical students working in randomized interprofessional teams. On three time points (day 1, day 8, day 15), participants engage in a VR scenario simulating one out of three different emergency medical conditions. As intervention, a training video on successful teamwork is shown on day 8 immediately before the second VR-scenario. Teamwork is assessed objectively with the Team Performance Observation Tool (TPOT) which will be adapted and validated for application in VR settings and subjectively with the Teamwork Perceptions Questionnaire (T-TPQ). Medical performance will be recorded automatically by the VR software based on the medical measures conducted by the team.

Results: As of May 2024, 15 interprofessional teams have been enrolled. Data analysis will begin in late 2025.

Conclusions: This study addresses the challenge of adapting teamwork assessment tools to VR environments and may provide insights into the potential of VR-based training for improving interprofessional collaboration in medical education. Future research could include a control group to measure the effects of team training more rigorously or use more enhanced technologies (e.g. natural language processing) to capture a broader range of teamwork behavior.

(JMIR Preprints 12/11/2024:68705)
DOI: https://doi.org/10.2196/preprints.68705

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Background/Objective: Interprofessional teamwork is essential for patient outcomes in emergency medicine, yet effective training in this area is scarce. Virtual reality (VR) offers a promising, resource-efficient solution for simulating emergency scenarios, but tools for assessing teamwork in VR environments are lacking. This study aims to adapt and validate the TeamSTEPPS framework to assess teamwork in VR-based training, with the goal of improving both team collaboration and medical performance.
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Discussion: This study addresses the challenge of adapting teamwork assessment tools to VR environments and may provide insights into the potential of VR-based training for improving interprofessional collaboration in medical education. Future research could include a control group to measure the effects of team training more rigorously or use more enhanced technologies (e.g. natural language processing) to capture the full range of teamwork behavior.

Introduction:

Interprofessional teamwork plays a crucial role affecting patient outcomes in emergency medical contexts [1,2]. However, interprofessional team trainings are uncommon both in undergraduate medical education and in professional practice [3,4]. This is particularly due to the high personnel and resource requirements for effective team training [5,6]. VR-based training environments are playing an increasing role in emergency medicine, facilitating the widespread and effective learning of medical content, and may also enable interprofessional team collaboration training in the future [7]. The improvement in medical performance through such training is measured using various parameters such as checklists or “time to action” [8–11]. Some VR programs already allow for automated result recording [10], which could support examiners in complex practical exam settings

in the future.

In contrast to capturing medical knowledge or performance, there are currently no validated tools for measuring (interprofessional) team collaboration in VR-based environments. For conventional physical simulation-based training, numerous tools exist to objectively capture various aspects of teamwork [12,13]. These are often based on Crew Resource Management (CRM) or similar principles. However, these evaluation criteria cannot be fully transferred to VR scenarios for several reasons: Currently, team-capable VR training environments vary significantly in their level of functionality. For instance, considerable differences exist in how verbal interaction with virtual patients is represented (either through menu-based options or speech recognition [14]) and how haptic measures are depicted (solely via VR controllers [15,16] or additional haptic devices [8]). The ways teamwork is represented in VR environments (verbal communication, handing over objects, briefing/debriefing) also may differ and non-verbal communication skills such as facial expressions and nuanced gestures are largely missing among current VR-based avatars. Lastly, it is crucial to provide evaluators with a sufficient view on the actions and verbal communication in the VR scenario—whether as participants wearing a VR headset or through visualizing the participants' perspectives on a computer screen. These challenges may explain why the quality of teamwork in VR-based environments has barely been measured so far. While technical hurdles are increasingly being overcome through advances in hardware and software, assessment tools for team collaboration in virtual settings still need to be adapted and validated.

A well-validated framework that includes educational content and both subjective and objective tools for assessing teamwork in physical simulations is the TeamSTEPPS framework [17]. In its current version (3.0), it covers five dimensions: team structure, communication, leadership, situation monitoring, and mutual support, and provides both subjective and objective evaluation metrics. The objective metric, the Team Performance Observation Tool (TPOT), has been significantly enhanced in terms of test-retest and interrater reliability through the inclusion of behavioral anchors compared to the original version [18]. In a recently published comparison of the most promising team performance assessment tools for evaluating longitudinal training, the TPOT was rated the most comprehensive tool and showed the second-best interrater reliability [19]. The associated questionnaire for subjective team member perceptions, the Teamwork Perceptions Questionnaire (T-TPQ), is also well researched and validated [20]. While other assessment tools may outperform in specific criteria [12], the TeamSTEPPS concept is well suited for studies assessing comprehensive learning outcomes in simulations due to its alignment between teaching and assessment tools.

This study aims to adapt and validate objective and subjective assessment tools for the facets of teamwork that meet the requirements of VR-based environments, using the TeamSTEPPS measurement instruments. In the planned prospective study, these assessment tools will be used to

measure the objective quality and the subjective perceptions of teamwork longitudinally (before, immediately after, and one week after completing a VR-based team training). Additionally, medical performance of the teams will be assessed based on the medical actions taken. The hypotheses derived from this are as follows:

H1: A VR-adapted TPOT (vTPOT) supplemented with behavioral anchors demonstrates good item characteristics (concurrent validity, interrater reliability, internal consistency) for the various facets of teamwork compared to the original version.

H2: VR-based team training leads to a sustainable objective improvement in all facets of teamwork performance in interprofessional teams (as measured with the vTPOT).

H3: VR-based team training leads to sustainable subjective improvement in all facets of teamwork perceptions in interprofessional teams (as measured with an adapted T-TPQ).

H4: The increasing quality of teamwork is associated with an improvement in treatment quality, represented by the automatically recorded percentage of correctly performed medical actions.

Methods:

Apparatus

STEP-VR (version 1.0) will be used as the VR simulation of complex emergencies, co-developed with ThreeDee GmbH (Munich, Germany). The version includes multi-user functionality, allowing the selection of an avatar with typical nursing or medical attire and multiple stylized faces (Figure 1).

The VR hardware setup for this study includes two OMEN by HP 17-ck0075ng Laptops (chipset: Intel® Core™ i7-11800H; graphics adapter: NVIDIA® GeForce RTX™ 3070 Laptop GPU (8 GB GDDR6 dedicated)) and two Oculus Quest III VR head-mounted displays (HMD). The equipment enables STEP-VR to run at a constant framerate of over 60 frames per second on “high quality” display settings of the HMD.

Figure 1: Top left: Participants with VR-HMD and image transmission to a monitor (background) for the study staff. Top right: Interaction of stylized avatars in the first-person perspective. Bottom left: Final evaluation after the simulation with assessment of medical performance. Bottom right: Overview showing stylized avatars and a virtual patient.

Study Design:

A prospective pre/post-intervention study will be conducted between May 2024 and June 2025. Teams consisting of one nursing and one medical student will complete three different interprofessional VR-based scenarios on three dates. These teams will be newly randomized for each session.

Three scenarios, each lasting about 30 minutes, will be completed by all participants in random order on different dates: 1) Esophageal variceal bleeding due to ethyl-toxic liver cirrhosis (EVB), 2) exacerbated chronic obstructive pulmonary disease (COPD), and 3) tachycardic atrial fibrillation due to complicated urinary tract infection (AF-UTI). The contents of the scenarios and indicated medical actions are listed in Supplement Table 1 and were already described in detail elsewhere [16,21]. Participants can communicate via voice-over IP and interact with each other through avatars during the scenarios (e.g., handing over equipment or demonstrating findings on a screen). The type and order of medical actions and teamwork elements is not predetermined and can be independently structured by the team members (e.g., briefing, mid-discussion). After the scenario, a detailed guideline-based evaluation of the medical actions and an overview of the physiological course of the

disease can serve as the basis for debriefing.

On the first date (day 1), informed consent will be obtained. A tutorial will follow to familiarize participants with VR hardware and software. The first scenario will be completed without specific prior team training (pre-test). On the second date (day 8), a training video on successful teamwork including practical recommendations will be shown (approx. 30 minutes). The content of the training video is based on the official TeamSTEPPS guidelines [17] and has been adapted by the authors of the study to fit the specific context (limited time, VR setting). Additionally, video examples were shown to demonstrate how certain team interactions (particularly for performing “Check-Backs”, “Huddles”, giving feedback and applying the “Two-Challenge Rule”) can be implemented in VR. Then, the second scenario will be completed (post-test). Seven days later (day 15), without additional training, the third and final scenario will be completed (retention-test). Figure 2 provides an overview of the study design and data collection.

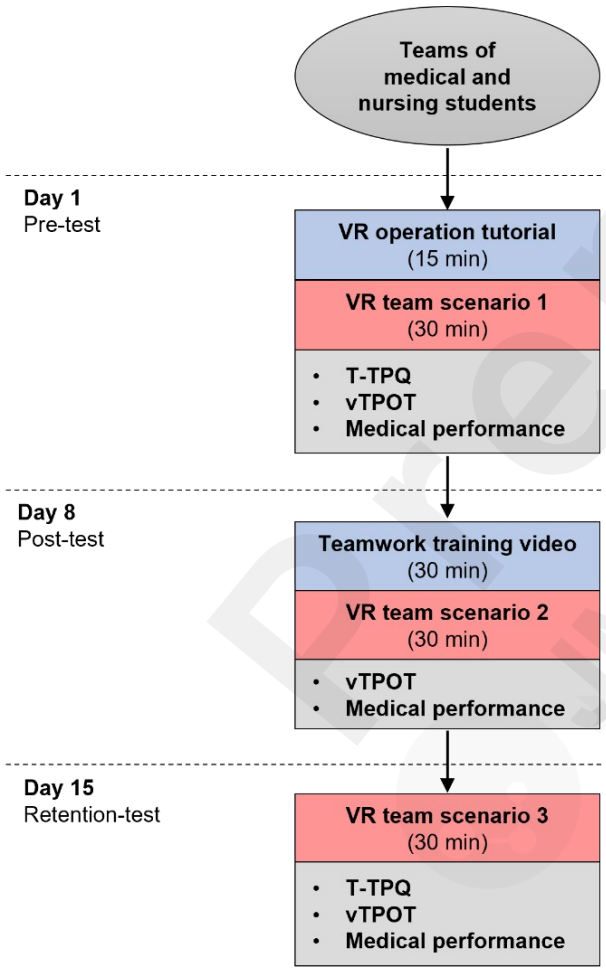

Figure 2: Overview of the data collection process. vTPOT: Team performance observation tool adapted for virtual reality scenarios. T-TPQ: TeamSTEPPS teamwork perceptions questionnaire.

Participants:

All regularly enrolled nursing students in their 2nd-3rd year of training and all medical students in their 8th-10th semester at the University Hospital of Würzburg are eligible to participate. Participants

of the study will provide written informed consent after being detailed on the study conditions.

Inclusion Criteria:

- Regularly enrolled nursing students in their 2nd or 3rd year of training or medical students in their 8th to 10th semester
- Signed informed consent provided
- 18 years of age

Exclusion Criteria:

- Known epilepsy
- Known severe motion sickness

Sample size calculation:

Since the team tandems are reassembled in a new, randomized form at each session a sample size estimation for three repeated measures time points could not be computed. Instead, we had to assume three independent groups. A between-groups ANOVA with an alpha level of 5%, a power of 80%, and assuming a large effect size, indicated that approximately 65 team tandems would be required, resulting in a total of 130 participants.

Measurement Instruments:

Adaptation and Validation of the TPOT for Virtual Reality-Based Scenarios

The original version of the TPOT includes 25 items to assess 5 facets of teamwork: team structure, communication, leadership, situational awareness, and mutual support. Compared to traditional, in-person team trainings, the novel context of VR-based interactions, as well as the small team size of two people, make adjustments necessary. To ensure content validity, respective changes will be proposed by four experts – a certified TeamSTEPPS expert (HP), a specialist in internal medicine and medical education (TM), an intensive care nurse with additional specialization in medical education (JM) and the study coordinator (ML, a skills lab tutor with special training and two years of experience in undergraduate medical education) – independently and implemented after thorough joint discussion.

To investigate the concurrent validity between the original TPOT and vTPOT, subsequently, six video recordings of teamwork in virtual reality scenarios will be evaluated by multiple raters using both instruments, and the correlation will be calculated overall and for each facet of teamwork. The interrater reliability for the vTPOT, as well as the internal consistency, will also be calculated from this analysis.

In the case of a future multicentric roll-out, it would also be possible to apply an additional modified Delphi method with the available number of experts. External partners will be asked to rate the appropriateness and applicability of items within the novel context of VR-based interactions [22].

Adaptation and Validation of the T-TPQ for Virtual Reality-Based Scenarios

The 35-item self-report tool T-TPQ developed by TeamSTEPPS, uses 5-point Likert scales to measure staff perceptions of Team Structure, Team Leadership, Situation Monitoring, Mutual Support and Communication. These five facets of teamwork correspond to those described in the above-mentioned TPO-T. The 5-point Likert scale ranges from 5 = “strongly agree” to 1 = “strongly disagree”. All items of the T-TPQ were translated into German.

Adaptation of the T-TPQ: For identification of inappropriate items of the T-TPQ, quantitative and qualitative methods will be applied. In the first step, as part of a pilot study, all participants initially answer the 35 items of the original T-TPQ. Following this, internal consistency is calculated, and items that strongly deviated from the responses to other items will be identified.

In the second step, an additional response option, 'not applicable,' will be integrated into the T-TPQ for all items. Also, within the pilot study, participants will be asked to explain why they had rated an item as 'not applicable.' Exclusion of inappropriate items will be made based on these analyses.

Validation of the automatically recorded medical performance score

After each scenario, both team members can view and discuss the final evaluation together. All medical tasks specific for each scenario are assessed, and it is recorded whether they were fully completed, partially completed, or not completed at all. The checklists for each scenario had been previously established by the authors based on guidelines from professional societies [23–25]. It was already ensured as part of a pilot study, that the automated final evaluation - in comparison with a manual checklist - accurately recorded all measures [10]. Importantly, when recording the tasks, the VR software does not differ whether they were carried out by medical or nursing staff. Based on that, a percentage score of medical performance for each team is generated.

Ethical considerations

Human subject ethics review approval: The local institutional review and ethics board judged the project as not representing medical or epidemiological research on human subjects and as such adopted a simplified assessment protocol. The project was approved without any reservation under the proposal number 20240422-01.

Informed consent: Students will be informed about the study, and their participation is voluntary. Written informed consent is obtained in printed form from all participants, who are also provided with information on data processing for the analysis and the publication of results. Contact details are supplied for participants wishing to withdraw their consent to data processing. The decision to participate or not has no consequences on the students’ academic progress.

Privacy and confidentiality: Survey data from the questionnaires are collected anonymously using the EvaSys® platform (Lüneburg, Germany). Data are processed and stored in accordance with local data protection laws.

Compensation details: A 30-euro book voucher will be handed to the participants upon completion of day 3.

Statistical analysis

Test quality criteria of vTPOT will be assessed as follows: For concurrent validity, Pearson's correlations will be calculated. Inter-rater reliability of the vTPOT will be calculated using Cohen's Kappa to quantify the agreement between the assessments of the independent reviewers. Internal consistency of the vTPOT will be assessed by employing Cronbach's alpha (α). A value exceeding 0.7 will be considered as acceptable, greater than 0.8 as good.

Considering the results of objective team performance, subjective teamwork perceptions and medical performance scores, descriptive statistics including mean and standard deviation (SD) will be calculated and presented in the format of mean ± SD. Pearson's correlations will be calculated to capture relationships between the results of different measurement instruments. Shapiro-Wilk test is used to check for normal distribution. In case of a violation of the normality assumption, non-parametric tests (Wilcoxon rank test for group differences and Spearman's test for correlations) are used. The calculations and generation of figures will be performed using GraphPad Prism (Version 10.1.2).

Results

This study received ethics approval in April 2024. As of May 2024, the enrolment of participants is ongoing and currently has 12 enrolled interprofessional teams. Data collection and analysis will be complete in 2025.

Discussion

Strengths and Limitations

This study leverages advanced VR technology to enhance interprofessional team training in medical education, allowing participants to engage in immersive, high-fidelity scenarios that closely mimic real-life emergency situations. A key strength lies in the utilization of an established VR-based training program (STEP-VR) that has been implemented in curricular teaching at several locations in Germany since 2020 and has already been evaluated in various teaching and examination settings. In terms of teamwork, the well-researched and validated measurement instruments of the TeamSTEPPS framework are used as a foundation, which is optimally aligned with teamwork training. The adaptation and validation are carried out in a rigorous selection process together with experts from all involved professions. Thus, results which will provide both objective and subjective insights into the improvement of teamwork skills. Additionally, the study's relatively large sample size and inclusion of participants from different cohorts within nursing and medical programs offer a

comprehensive view of the potential impact of VR-based training on interprofessional teams.

Despite these strengths, there are several limitations to consider. First, the absence of a control group limits our ability to definitively attribute improvements in teamwork to the VR-based training intervention alone. The pre-post design allows for intra-group comparisons, but the lack of a parallel group experiencing conventional training or no training reduces the robustness of our findings. The intervention (the training video on successful teamwork) is significantly shorter than typical training sessions from the TeamSTEPPS framework and may not achieve a sufficient effect. However, it was very important to us to find a training concept that could be applied both in academic studies and within the tightly scheduled clinical routine. Additionally, the study is conducted at a single institution, which may restrict the generalizability of the results to other educational contexts or healthcare systems. Lastly, another limitation stems from the voluntary nature of participant enrollment. It is possible that those opting to participate may already have a positive attitude towards teamwork or technology, potentially introducing a selection bias.

Challenges

One of the main challenges in this study is the adaptation of the TPOT and T-TPQ to VR environments. VR scenarios differ from traditional simulation in their representation of communication and interaction, as some elements (e.g. natural communication with patients and their relatives) may be missing and others (e.g. non-verbal cues and nuanced interpersonal behaviors) are often not as effectively captured in virtual environments. To address this, the VR-adapted TPOT (vTPOT) has been developed, but further validation will be necessary to confirm its reliability and validity in virtual settings. Additionally, the need for evaluators to accurately observe and assess participant actions in a VR scenario poses a challenge. Ensuring a clear and comprehensive view of participant behaviors, both in real-time and via recordings, will be crucial for the consistent and objective application of the vTPOT. Lastly, recruiting participants could prove challenging, as the curricula of the different study programs vary significantly and include shift work during practical placements.

Future Implications

To address some of the study's limitations, future research could incorporate a control group receiving traditional team training or no intervention, allowing for a more rigorous comparison of the effectiveness of VR-based training. A multi-center approach could also increase the generalizability of the findings by including participants from different educational institutions and healthcare settings.

Moreover, future studies could explore the integration of more sophisticated haptic devices and natural language processing to enhance the realism of the VR environment and better capture the full range of teamwork behaviors. As VR technology continues to advance, it will be essential to continuously refine the tools used for teamwork assessment to ensure they remain aligned with the

evolving capabilities of the technology.

Funding

No funding was received for this study.

Data Availability

The datasets generated during and analysed during this study will be available from the corresponding author on reasonable request.

Conflict of Interest

TM was involved in the software development process of STEP-VR. All other authors report no conflict of interest.

Author contributions

ML contributed to the conceptualization, will conduct the investigation and data curation. JM contributed to the conceptualization of the study and is involved in the recruitment of nursing participants. HP serves as the TeamSTEPPS expert, responsible for the adaptation of the questionnaires and the training of additional study personnel as raters. JB assisted in conceptualization of the study and will perform statistical analysis. SK also contributed to the conceptualization and participated in writing, review, and editing of the manuscript. TM was responsible for the conceptualization of the study, acquired funding, will supervise the execution and data analysis, and wrote the original draft for this research protocol.

Generative AI disclosure

No generative AI was used in the writing of this manuscript.

Supplement:

Medical Actions: Scenario 1 – EVB
Indication for gastroscopy
Successful hemodynamic stabilization (mean arterial pressure > 65 mmHg)
Collection of emergency laboratory tests (hemoglobin, coagulation, lactate)
Transfusion of packed red blood cells
Volume replacement with crystalloids
Administration of a prokinetic agent (IV erythromycin)
Administration of proton pump inhibitors in case of initially unclear bleeding source
Acute reduction of portal vein pressure (via vasoconstrictor)
Intravenous antibiotic therapy (covering gram-negative spectrum)
Medical Actions: Scenario 2 – COPD
Performance of blood gas analysis
Suctioning of purulent sputum
Administration of broad-spectrum antibiotic therapy
Performance of microbiological diagnostics including sputum sample
Performance of a 12-lead ECG for differential diagnosis of cardiac origin
Indication for non-invasive ventilation in hypercapnic failure
Ordering of a chest X-ray examination
Symptomatic relief of dyspnea with morphine administration
Administration of bronchodilator therapy with ß2-mimetics/anticholinergics
Administration of anti-inflammatory therapy with prednisolone
Medical Actions: Scenario 3 – AF-UTI
Administration of effective anticoagulant drugs
Successful pharmacological control of heart rate
Treatment of urinary retention by insertion of bladder catheter
Administration of appropriate empirical antibiotics
Cardioversion only after exclusion of thrombi
Performance of microbiological diagnostics, including urinary samples
Ultrasound examination of the urinary tract
Administration of fluids (after treatment of urinary obstruction)
Recording of a 12-lead ECG
Request for a urological consultation

Supplement Table 1: Medical actions to be performed during the VR scenarios. AF-UTI: atrial fibrillation due to complicated urinary tract infection, COPD: chronic obstructive pulmonary disease, ECG: electrocardiogram, EVB: esophageal variceal bleeding, IV: intravenous

References

1. Hall P, Weaver L. Interdisciplinary education and teamwork: a long and winding road. Med Educ 2001;35(9):867-875. PMID:11555225
2. Rosen MA, DiazGranados D, Dietz AS, Benishek LE, Thompson D, Pronovost PJ, Weaver SJ. Teamwork in healthcare: Key discoveries enabling safer, high-quality care. Am Psychol 2018;73(4):433-450. PMID:29792459
3. Gross B, Rusin L, Kiesewetter J, Zottmann JM, Fischer MR, Prückner S, Zech A. Crew resource management training in healthcare: a systematic review of intervention design, training conditions and evaluation. BMJ Open 2019;9(2):e025247. PMID:30826798
4. Weaver SJ, Lyons R, DiazGranados D, Rosen MA, Salas E, Oglesby J, Augenstein JS, Birnbach DJ, Robinson D, King HB. The anatomy of health care team training and the state of practice: a critical review. Acad Med 2010;85(11):1746-1760. PMID:20841989
5. van de Ven J, van Baaren GJ, Fransen AF, van Runnard Heimel PJ, Mol BW, Oei SG. Cost-effectiveness of simulation-based team training in obstetric emergencies (TOSTI study). Eur J Obstet Gynecol Reprod Biol 2017;216:130-137. PMID:28763738
6. Block L, Lalley A, LaVine NA, Coletti DJ, Conigliaro J, Achuonjei J, Block AE. The Financial Cost of Interprofessional Ambulatory Training: What's the Bottom Line? Journal of Graduate Medical Education 2021;13(1):108-112. PMID:33680309
7. Abbas JR, Chu MM, Jeyarajah C, Isba R, Payton A, McGrath B, Tolley N, Bruce I. Virtual reality in simulation-based emergency skills training: A systematic review with a narrative synthesis. Resuscitation Plus 2023;16:100484. doi:10.1016/j.resplu.2023.100484
8. Moll-Khosrawi P, Falb A, Pinnschmidt H, Zöllner C, Issleib M. Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students during COVID-19 pandemic: a randomised controlled trial. BMC Med Educ 2022;22(1):483. PMID:35733135
9. Mühling T, Schreiner V, Appel M, Leutritz T, König S. Clinical Competency Assessments: A Comparative Study of Virtual-Reality-Based and Traditional Physical OSCE Stations (Preprint); 2023.
10. Keicher F, Backhaus J, König S, Mühling T. Virtual Reality for Assessing Emergency Medical Competencies in Junior Doctors – A Pilot Study; 2024.
11. Chang TP, Hollinger T, Dolby T, Sherman JM. Development and Considerations for Virtual Reality Simulations for Resuscitation Training and Stress Inoculation. Simul Healthc 2021;16(6):e219-e226. PMID:33273419
12. Shannon Marlow, Tiffany Bisbey, Christina Lacerenza, and Eduardo Salas. Performance Measures for Health Care Teams: A Review 2018.
13. Boet S, Etherington C, Larrigan S, Yin L, Khan H, Sullivan K, Jung JJ, Grantcharov TP. Measuring the teamwork performance of teams in crisis situations: a systematic review of assessment tools and their

measurement properties. BMJ Qual Saf 2019;28(4):327-337. PMID:30309910

14. Moore N, Ahmadpour N, Brown M, Poronnik P, Davids J. Designing Virtual Reality-Based Conversational Agents to Train Clinicians in Verbal De-escalation Skills: Exploratory Usability Study. JMIR Serious Games 2022;10(3):e38669. PMID:35793129
15. Mahling M, Wunderlich R, Steiner D, Gorgati E, Festl-Wietek T, Herrmann-Werner A. Virtual Reality for Emergency Medicine Training in Medical School: Prospective, Large-Cohort Implementation Study. J Med Internet Res 2023;25:e43649. PMID:36867440
16. Mühling T, Späth I, Backhaus J, Milke N, Oberdörfer S, Meining A, Latoschik ME, König S. Virtual reality in medical emergencies training: benefits, perceived stress, and learning success. Multimedia Systems 2023;29(4):2239-2252. doi:10.1007/s00530-023-01102-0
17. King HB, Battles J, Baker DP, Alonso A, Salas E, Webster J, Toomey L, Salisbury M. Advances in Patient Safety: New Directions and Alternative Approaches (Vol. 3: Performance and Tools): TeamSTEPPS™: Team Strategies and Tools to Enhance Performance and Patient Safety. Rockville (MD); 2008.
18. Zhang C, Miller C, Volkman K, Meza J, Jones K. Evaluation of the team performance observation tool with targeted behavioral markers in simulation-based interprofessional education. J Interprof Care 2015;29(3):202-208. PMID:25421454
19. Soghikian S, Chipman M, Holmes J, Calhoun AW, Mallory LA. Assessing Team Performance in a Longitudinal Neonatal Resuscitation Simulation Training Program: Comparing Validity Evidence to Select the Best Tool. Cureus 2024. doi:10.7759/cureus.68810
20. Peltonen J, Leino-Kilpi H, Heikkilä H, Rautava P, Tuomela K, Siekkinen M, Sulosaari V, Stolt M. Instruments measuring interprofessional collaboration in healthcare - a scoping review. J Interprof Care 2020;34(2):147-161. PMID:31331216
21. Rickenbacher-Frey S, Adam S, Exadaktylos AK, Müller M, Sauter TC, Birrenbach T. Development and evaluation of a virtual reality training for emergency treatment of shortness of breath based on frameworks for serious games. GMS J Med Educ 2023;40(2):Doc16. PMID:37361243
22. Nasa P, Jain R, Juneja D. Delphi methodology in healthcare research: How to decide its appropriateness. World J Methodol 2021;11(4):116-129. PMID:34322364
23. Götz M, Anders M, Biecker E, Bojarski C, Braun G, Brechmann T, Dechêne A, Dollinger M, Gawaz M, Kiesslich R, Schilling D, Tacke F, Zipprich A, Trebicka J. S2k-Leitlinie Gastrointestinale Blutung. [S2k Guideline Gastrointestinal Bleeding - Guideline of the German Society of Gastroenterology DGVS]. Z Gastroenterol 2017;55(9):883-936. PMID:29186643
24. Vogelmeier C, Buhl R, Burghuber O, Criée C-P, Ewig S, Godnic-Cvar J, Hartl S, Herth F, Kardos P, Kenn K, Nowak D, Rabe K, Studnicka M, Watz H, Welte T, Windisch W, Worth H. Leitlinie zur Diagnostik und Therapie von Patienten mit chronisch obstruktiver Bronchitis und Lungenemphysem (COPD). [Guideline for the Diagnosis and Treatment of COPD Patients - Issued by the German Respiratory Society and the German Atemwegsliga in Cooperation with the Austrian Society of Pneumology]. Pneumologie

2018;72(04):253-308. PMID:29523017

25. Hindricks G, Potpara T, Dagres N, Arbelo E, Bax JJ, Blomström-Lundqvist C, Boriani G, Castella M, Dan G-A, Dilaveris PE, Fauchier L, Filippatos G, Kalman JM, La Meir M, Lane DA, Lebeau J-P, Lettino M, Lip GYH, Pinto FJ, Thomas GN, Valgimigli M, van Gelder IC, van Putte BP, Watkins CL. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS): The Task Force for the diagnosis and management of atrial fibrillation of the European Society of Cardiology (ESC) Developed with the special contribution of the European Heart Rhythm Association (EHRA) of the ESC. Eur Heart J 2021;42(5):373-498. PMID:32860505

Supplementary Files

Figures

Top left: Participants with VR-HMD and image transmission to a monitor (background) for the study staff. Top right: Interaction of stylized avatars in the first-person perspective. Bottom left: Final evaluation after the simulation with assessment of medical performance. Bottom right: Overview showing stylized avatars and a virtual patient.

Overview of the data collection process. vTPOT: Team performance observation tool adapted for virtual reality scenarios. T-TPQ: TeamSTEPPS teamwork perceptions questionnaire.