High-Fidelity simulation and its impact on non-technical skills development among healthcare professionals: A systematic review and meta-analysis

Ida Vangone[1], *Rosario Caruso*[2,3], *Arianna Magon*[3], *Carmelo Giamblanco*[4], *Gianluca Conte*[3], *Irene Baroni*[3], *Sara Russo*[1], *Silvia Belloni*[5], *Cristina Arrigoni*[6]

[1]Department of Biomedicine and Prevention, University of Rome Tor Vergata, Rome, Italy; [2]Department of Biomedical Sciences for Health, University of Milan, Milan, Italy; [3]Health Professions Research and Development Unit, IRCCS Policlinico San Donato, San Donato Milanese, Italy; [4]Department of General Medicine, Civil Hospital of Vigevano – ASST Pavia, Pavia, Italy; [5]Gastroenterology Unit, IRCCS Humanitas Research Hospital, Rozzano, Italy; [6]Department of Public Health, Experimental and Forensic Medicine, University of Pavia, Pavia, Italy

Abstract. *Background and aim*: High-Fidelity Simulation (HFS) has emerged as a pivotal educational strategy in healthcare, particularly for bridging the gap between theoretical knowledge and practical application. Non-technical skills, encompassing cognitive and interpersonal abilities that complement technical proficiency, play a crucial role in improving performance and reducing the likelihood of adverse events, thereby enhancing patient safety. This systematic review and meta-analysis aimed to investigate the efficacy of HFS in enhancing non-technical skills among healthcare professionals. *Methods*: The literature search was conducted in PubMed, Embase, Scopus, CINAHL, and Google Scholar, covering the period from February 2012 to August 2023. The inclusion criteria focused on randomized controlled trials (RCTs) and quasi-experimental studies that assessed the impact of HFS on measurable non-technical skills. Quality assessment was performed using RoB2 for RCTs and ROBINS-I for quasi-experimental studies. A random-effects meta-analysis, sensitivity analysis, and subgroup analyses were conducted. *Results*: Six studies met the inclusion criteria. The meta-analysis revealed a significant positive impact of HFS on non-technical skills, with an overall effect size (SMD) of 1.433, 95% CI [0.695, 2.172]. However, substantial heterogeneity was observed ($I^2 = 93.3\%$). Subgroup analyses indicated variations in effect sizes based on study design, specific non-technical skills domains, and geographic location. Notably, quasi-experimental studies showed a higher effect size compared to RCTs. *Conclusions*: HFS is an effective educational tool for improving non-technical skills among healthcare professionals, particularly in enhancing self-efficacy. However, the observed heterogeneity and variations in effect sizes emphasize the requirement for more standardized and rigorous research to enhance the utilization of HFS in various educational settings and geographical locations. Future studies should address the methodological limitations and explore the factors contributing to the variability in outcomes. (www.actabiomedica.it)

Key words: education, nursing, high-fidelity simulation, non-technical skills, systematic review

Introduction

In recent years, simulation-based learning has emerged as a pivotal educational strategy in healthcare, offering a secure and controlled environment for developing cognitive and psychomotor skills (1). This innovative approach aims to bridge the gap between theoretical knowledge and practical application (2). In this regard, evidence suggests that simulation-based learning may also enhance the quality of patient care (3).

Simulation modalities could be categorized based on their degree of fidelity, which refers to the extent to which a simulation mimics the real-world system it represents (4). These categories include low, medium, and high fidelity. The first type of fidelity, known as task trainers, are static models typically representing specific body parts. They assist students in acquiring specific procedural skills without the use of technology. The second type of fidelity offers greater realism than low fidelity; mannequins, for instance, feature palpable pulses, blood pressure, breath, bowel sounds, and fetal heart tones. However, they are not programmed to respond to interventions (5). The third type of fidelity pertains to simulation experiences characterized by exceptionally realistic scenarios, offering a high level of interactivity and realism for learners through the integration of technology (6). Among these, high-fidelity simulation (HFS) has garnered significant attention for a multitude of compelling reasons. First and foremost, HFS stands out as the most realistic form of simulation, employing advanced, full-scale computerized patient simulators or standardized patients to offer an authentic learning experience (7,8). The high-tech manikins used in HFS further enhance this unparalleled realism, which can intricately replicate human physiological parameters such as respiration, vocalization, and cardiac and pulmonary sounds.

The simulated clinical environment in HFS is realistic and highly interactive (9). This interactivity enables real-time decision-making and problem-solving, closely mimicking the pressures and demands healthcare professionals face in actual clinical settings (10). Moreover, HFS facilitates the comprehensive development of both technical skills (referring to specific procedural and clinical abilities) and non-technical skills (encompassing cognitive and interpersonal skills). Technical skills encompass clinical knowledge, manual dexterity, proficiency in using medical equipment, and the ability to carry out medical procedures with precision. Examples of technical skills include surgical techniques, administering medications, interpreting diagnostic tests, and conducting medical assessments. Non-technical skills, on the other hand, refer to a broader set of cognitive, interpersonal, and behavioral abilities that healthcare professionals need to work effectively in a healthcare environment. Non-technical skills also encompass critical thinking, problem-solving, situational awareness, leadership, and effective communication with patients, families, and colleagues. The high degree of realism in HFS provides a safe and controlled environment for healthcare professionals to make and learn from errors without compromising patient safety (11). This makes HFS an invaluable tool for risk-free, hands-on training, thereby contributing to the development of well-rounded healthcare professionals who are better equipped to ensure patient safety and deliver high-quality care.

Healthcare professionals, including nurses, are ethically and legally obligated to deliver high-quality care while ensuring patient safety (12). Achieving this mandate necessitates the mastery of both technical and non-technical skills. Non-technical skills encompass cognitive abilities like decision-making and situational awareness, as well as interpersonal competencies such as communication, teamwork, and leadership (13). In this regard, empirical evidence suggests that simulation-based training positively impacts various healthcare professional groups by enhancing non-technical and technical skills (14). This training modality is equally beneficial for both novice and experienced healthcare professionals (15).

While there is a growing body of literature that delves into various aspects of simulation-based learning in healthcare, it is worth noting that previous meta-analytic reviews have already addressed the impact of adopting HFS on technical skills (7,9). However, a notable gap remains in the form of a dearth of recent meta-analytic reviews specifically dedicated to evaluating the effects of HFS on non-technical skills (16). This gap is significant for several reasons. First, meta-analytic reviews provide a higher level of evidence by synthesizing findings from various studies, offering more robust conclusions than individual studies. Second, such reviews could quantitatively identify consistencies and discrepancies in the existing literature, providing a clearer picture of the current state of knowledge and highlighting areas for future research. Third, a meta-analytic review may offer valuable insights for individuals involved in healthcare educators, such as instructors, professors, clinical preceptors, and simulation educators, as well as policymakers. For these reasons, this study sought to critically examine the evidence regarding the effects of HFS on non-technical skills in healthcare professionals.

Methods

Design

We carried out a systematic review and meta-analysis in adherence to the guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (17). This rigorous approach was guided by the central research question: "Does HFS effectively enhance non-technical skills among healthcare professionals?" To ensure transparency and methodological rigor, the protocol for this review was prospectively registered with the Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42023450699.

Search strategy

The literature search strategy for this systematic review was independently executed by two authors (IV and CG). The search covered the period from February 2012 to August 2023, intentionally selected to incorporate the latest developments in this field following the publication of the most recent review on this topic in January 2012 (18). The search was developed by following the "Participants, Intervention, Comparison, Outcome, and Study Design" (PICOS) framework (19). This framework guided the development of our search query across four major databases: PubMed, Embase, Scopus, and CINAHL, as detailed in Supplementary File 1. The initial search was conducted on the PubMed database, utilizing both MeSH terms and free-text words, combined with appropriate Boolean operators. Subsequently, this search strategy was tailored to fit the syntax and requirements of each of the other databases. To supplement our database searches and ensure a thorough review, we also performed a manual search on Google Scholar.

Initially, no language restrictions were imposed to ensure a comprehensive global search, thereby allowing for the inclusion of studies from various geographical regions. However, it is important to note that while we aimed for linguistic inclusivity, practical limitations arose during the review process. Specifically, articles not written in English or Italian were only included if they were translatable: if articles were available solely in PDF format without an accompanying HTML version, making them untranslatable, they were excluded from the review. The exclusion of articles available solely in PDF format without an accompanying HTML version is mainly due to practical limitations in the translation process. PDF documents may present challenges for automated translation tools because they do not contain selectable text. In this study, we utilized Microsoft Translator as one of the automated translation tools for language translation tasks. As a result, the final set of included studies comprised articles published in either English or Italian.

Inclusion and exclusion criteria

In this systematic review and meta-analysis, studies were included based on a set of carefully defined criteria.

First, the study design had to be either a randomized controlled trial (RCT) or a quasi-experimental study, both of which are methodologies that focus on healthcare professionals. Importantly, including these specific study designs provides a robust and reliable assessment of the efficacy or effects of HFS in developing non-technical skills among healthcare professionals. It is important to clarify the distinction between efficacy and effects in this context. Efficacy refers to the extent to which an intervention produces a beneficial result under ideal conditions, often assessed through RCT. These designs are considered the gold standard for determining efficacy because they minimize bias through randomization and control groups, thereby providing the most reliable evidence of an intervention's intrinsic influence on the outcome over a control group. Conversely, effects is a broader term encompassing an intervention's real-world impact, including its efficacy, but also influenced by various external factors. In other words, efficacy can be considered a subset of effects, representing the intervention's impact in a controlled setting. While not as rigorous as RCTs, quasi-experimental designs are valuable for capturing these broader effects. They offer insights into the impact of HFS on non-technical skills among healthcare professionals in more diverse and less controlled environments.

Second, the study needed to involve the application of HFS. The rationale for this criterion is to isolate the impact of HFS on the development of non-technical skills, separate from other forms of simulation or educational methods. This criteria allows for a more precise evaluation of how HFS contributes to non-technical skill development, thereby strengthening the validity of the review's conclusions.

Third, the study must include measurable outcomes related to non-technical skills, such as teamwork, communication, situational awareness, decision-making, and leadership. This criterion serves a dual purpose: (a) to assess the impact of HFS on non-technical skills in healthcare settings and (b) to facilitate the meta-analysis component of the review, allowing for a quantitative synthesis of the data.

Study selection process

The database search results were downloaded and organized using Rayyan® online software, which was also employed to eliminate duplicate entries (20). Two authors (IV, CG) independently screened titles and abstracts to identify studies that met the inclusion and exclusion criteria. Subsequently, these authors independently reviewed the full texts of the shortlisted studies to finalize the selection. At the conclusion of each phase of the selection process, a consensus discussion was held to reconcile any differences in the authors' selections. In instances where a consensus could not be reached, a third author (RC) was consulted to facilitate agreement.

Initially, records were identified as follows: 128 from PubMed, 260 from Embase, 56 from Cinhal, and 10 from Scopus. An additional 6 records were identified through a manual search, bringing the total number of records to 460. Before the screening process commenced, 105 duplicate records were removed, leaving 349 records for screening. Before delving into the screening process, 105 duplicate records were identified and removed, leaving 349 records for screening. Two authors independently assessed the titles and abstracts of these records. Of the 349 records, 313 were excluded for various reasons: 95 had the wrong outcome, 166 pertained to the wrong population, and 52 had an inappropriate study design. Subsequently, 24 reports were retrieved for a full-text assessment. All 24 were successfully accessed and evaluated. However, 20 of these reports were later excluded: 10 due to the wrong outcome and another 10 because of the wrong study design. From the manual search, 6 reports were assessed for eligibility. Out of these, 4 were excluded for having an outcome not related to non-technical skills. In the end, 6 studies met all the inclusion criteria and were incorporated into the systematic review. The entire selection process, consistent with the PRISMA guidelines, is visually represented in Figure 1.

Data extraction

The data extraction process was executed utilizing a Microsoft Excel worksheet. Two reviewers (IV and RC) independently performed the extraction to ensure accuracy and reliability. Both reviewers were trained in the review topic, data analysis, and statistics, and a predefined protocol was in place for resolving any disagreements between them.

For each study meeting the inclusion criteria, a multi-faceted set of information was extracted. Basic identifiers such as the first author's name, year of publication, and country of the study were recorded to provide context and account for geographical variations. Methodological details were also captured, including research design, target population, and the setting, to offer a comprehensive understanding of each study's context and scope.

Quantitative metrics like sample size, broken down into experimental and control groups, were recorded. Outcome data were extracted from the last follow-up of each study and expressed in a standardized format, often as mean ± standard deviation (SD), to facilitate subsequent meta-analysis. This approach ensures that the most recent and comprehensive data are included, enhancing the quality and interpretability of the review. When outcome data were not readily available in the desired format of mean ± SD, various

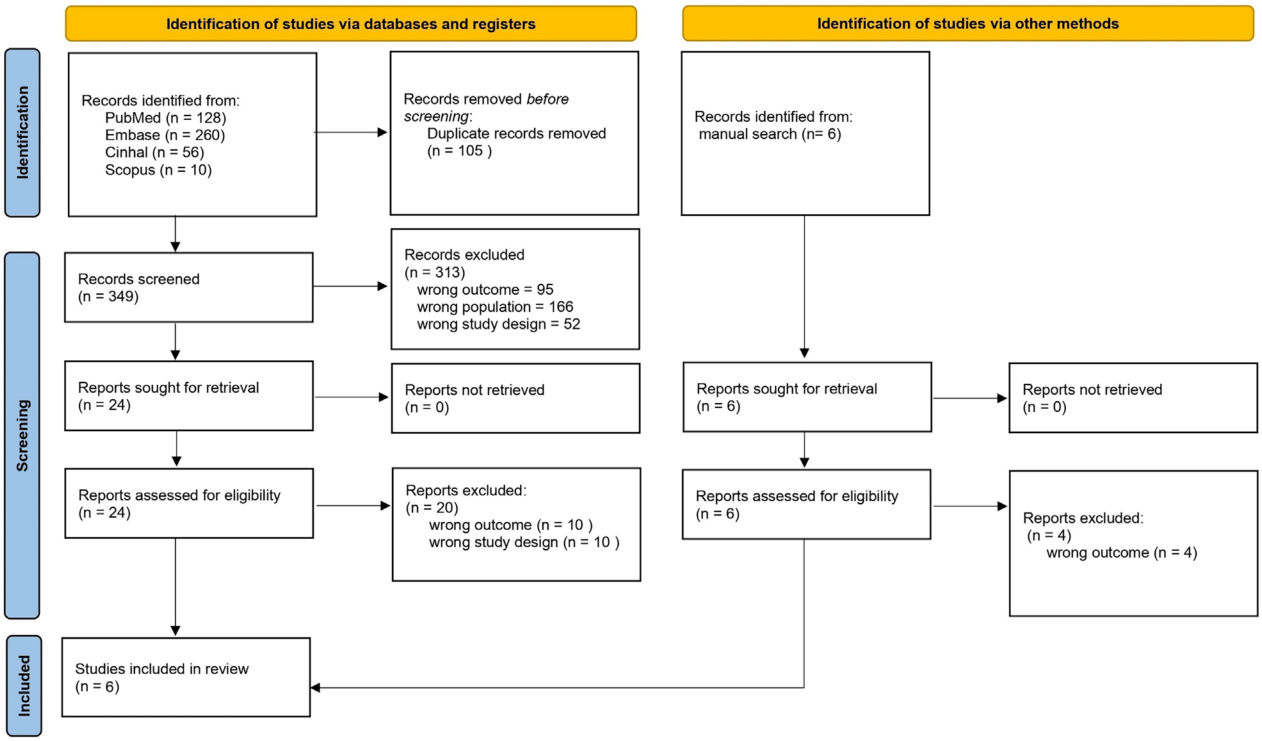

Figure 1. PRISMA 2020 flow diagram.

strategies were employed to transform and standardize the information. In cases where the data were presented in figures or graphs, Plot Digitizer (version 3) software was used to digitize the data points to obtain summary statistics in the form of mean and SD. For studies that reported outcomes using other statistical measures, such as median or confidence intervals, mathematical conversions were applied to approximate the mean and SD. These transformations were conducted in accordance with established statistical guidelines to ensure accuracy and comparability across studies (21).

A concise summary of each study's main findings was also included to encapsulate its contributions to the field.

Quality appraisal

The methodological quality of the included studies was assessed using two design-specific tools by two authors (IV and CG). For RCTs, the reviewers used Version 2 of the Cochrane Risk of Bias assessment tool (RoB 2.0) (22). This tool evaluates six criteria: the randomization process, deviations from intended interventions, measurement of the outcome, missing outcome data, selection of the reported result, and overall bias. Each criterion is classified into one of three categories: high risk, some concern, and low risk.

For quasi-experimental studies, the Risk Of Bias In Non-randomized Studies – of Interventions (ROBINS-I) assessment tool was employed (23). This tool assesses various domains, including pre-intervention, confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, and measurement of outcomes.

Disagreements between the two reviewers were resolved through discussion. If conflicts regarding study eligibility persisted, a third author (RC) would be consulted to reach a resolution.

Statistical analysis

In the statistical analysis, we employed random-effects inverse-variance models with the

DerSimonian-Laird estimate of tau^2 to assess the impact of HFS on the outcome "non-technical skills" (24). Given the multi-faceted nature of non-technical skills, which is considered a composite outcome and includes domains such as self-efficacy in various areas, clinical judgment, and teamwork, we anticipated a high degree of heterogeneity in the outcomes. We used the Standardized Mean Difference (SMD) with a 95% Confidence Interval (CI) as a more robust measure to account for the variability in how primary studies assessed outcomes that refer to non-technical skills. The orientation of the effect was set up so that a SMD above zero signified a positive result from the HFS in improving non-technical skills. To evaluate the overall effect size, we also employed the z-test. The z-test provides a measure of how far away our observed effect size is from the null hypothesis and helps us determine the p-value, which we used for hypothesis testing. A significant p (< .05) would indicate that the observed effect is statistically significant and not due to random chance (24). To assess heterogeneity, we planned to use Cochran's Q test and the I^2 statistic. Cochran's Q test provides a p-value to test the null hypothesis that all studies in the meta-analysis have the same effect size. A significant p-value would indicate that the effect sizes are heterogeneous. The I^2 statistic quantifies the proportion of total variation in the study estimates that is due to heterogeneity rather than chance. I^2 values can be categorized as low (25-49%), moderate (50-74%), and high (75-100%) heterogeneity, providing a more nuanced understanding of the extent of variability among the included studies (24).

To further validate the robustness of our meta-analysis on the composite outcome, we conducted a sensitivity analysis using the leave-one-out method. This approach helped us to determine the influence of each individual study on the overall meta-analysis results, thereby ensuring the reliability of our findings. Publication bias was assessed graphically, using a funnel plot, and quantitatively, using the trim-and-fill method. The funnel plot visually displayed the distribution of the studies, while the trim-and-fill method adjusted for any asymmetry in the plot, providing a more accurate estimate of the true effect size. In the case the adjusted estimate derived from the trim-and-fill method does not differ from the unadjusted estimate, the likelihood of publication bias is limited.

Additionally, we conducted planned subgroup analyses to delve deeper into the data. These analyses were based on geographic location, the specific domain of non-technical skills being assessed, the design of the primary studies, and the profession. The aim of these subgroup analyses was to identify any patterns or discrepancies that could further inform our understanding of the effects of HFS on non-technical skills. The statistical analyses for this study were performed using Stata 18 MP-Parallel Edition (StataCorp LLC, College Station, TX, USA). The 'metan.ado' file was utilized for the meta-analysis procedures.

Results

Study characteristics

In this systematic review, a total of six studies were included (2,25–29). The geographical distribution of these studies shows that two were conducted in Asia (33%) (26,27), two in the USA (33%) (28,29), and two in Europe (33%) (2,25). Regarding the methodology, two studies were RCTs (34%) (25,29), and the remaining three were quasi-experimental studies (66%) (2,26–28). Table 1 presents the summary of the study characteristics.

Luo et al. (2021) conducted a quasi-experimental study focusing on clinical judgment in Asia. The study found that nurses in the Virtual Simulation group reported better clinical judgment compared to other learning modalities. Wang et al. (2017) carried out an RCT in the USA centred on teamwork skills and found that high-fidelity hands-on training was more effective than computer-based training. Bragard et al. (2016) conducted another RCT in Europe, evaluating the total score of non-technical skills. Maenhout et al. (2021) performed a quasi-experimental study in Europe investigating self-efficacy and showed a positive effect on self-efficacy and self-perceived leadership abilities among nurses and midwives. Jung et al. (2023) conducted another quasi-experimental study in Asia,

Table 1. Study characteristics.

First Author, Year	Study Design	Country	Population	Content	Setting	Results	Notes
Luo, 2021	Quasi-Experimental	China	59 Nurses	3 Learning Modalities: HFS, VS, Case Study	Level A Hospital	VS group had better clinical judgment; the HFS group was more confident.	Participants randomized into HFS, VS, and Case Study groups. VS showed better clinical judgment, while HFS had higher confidence levels.
Wang, 2017	RCT	USA	40 Participants	HO vs CB Simulation for CR and TS	Radiology Dept.	HO group rated the training as more effective.	Compared HO with CB simulation. HO group showed significant improvements in CR and TS.
Bragard, 2019	RCT	Belgium	16 in 4 Teams	HFS vs Video for TS and NTS	Pediatric & Emergency	Positive impact on stress, satisfaction, and skills.	Focused on TS and NTS. HFS group with debriefing showed significant improvements.
Maenhout, 2021	Quasi-Experimental	Belgium	71 Nurses & Midwives	Impact of HFS on self-efficacy and leadership	NICU	Positive effect on self-efficacy and leadership.	Investigated effects of repeated HFS on self-perceived leadership in NICU. Positive impact on self-efficacy and leadership.
Jung, 2023	Quasi-Experimental	Korea	44 Nurses	HFS vs Standard Training for patient safety	ICU	The experimental group showed higher competency.	Compared HFS-based programs with standard training. The experimental group showed improvements in patient safety and communication self-efficacy.
Natarajan, 2023	Quasi-Experimental	USA	Various	Teamwork skills measured by CTS	NICU	Mixed results on teamwork scores.	Used HFS to assess NICU teamwork. Significant improvement in real-time teamwork during delivery, but not consistently overall.

Abbreviations: HFS: High-Fidelity Simulation; VS: Virtual Simulation; HO: Hands-On; CB: Computer-Based; CR: Contrast Reaction; TS: Technical Skills; NTS: Non-Technical Skills; NICU: Neonatal Intensive Care Unit; ICU: Intensive Care Unit; CTS: Clinical Teamwork Scale.

also focusing on self-efficacy, and found that the experimental group showed significantly higher patient safety competency and communication self-efficacy scores. Lastly, Natarajan et al. (2023) carried out a quasi-experimental study in the USA, examining teamwork skills, and observed a significant improvement in real-time teamwork scores during resuscitation in the delivery room.

Risk of bias

The risk of bias assessment using both RoB2 and ROBINS-I tools indicates a generally low risk of bias across the included studies. In the RoB2 assessment, two RCTs were evaluated. Bragard et al. (2019) demonstrated 'some concerns' related to the randomization process and received a 'some concerns' rating for overall bias. In contrast, Wang et al. (2017) received a 'low' risk rating in all domains, including overall bias.

For the ROBINS-I assessment, four quasi-experimental studies were evaluated. Luo et al. (2021), Maenhout et al. (2021), and Jung et al. (2023) had 'low' risk ratings in the domains of Confounding, Selection of Participants, Classification of Interventions, Deviations from Intended Interventions, and Measurement of Outcomes (D1 to D6). These studies had a 'moderate' risk in the domain of Selection of the Reported Result (D7). Natarajan et al. (2023) also had 'low' risk ratings in most domains but had a 'moderate' risk in the domains of Missing Data and Selection of the Reported Result (D7). Due to the presence of one 'moderate' risk in at least one domain of the quasi-experimental studies, the overall risk of bias for the ROBINS-I assessments was 'moderate'. Additional details are described in Figure 2.

Figure 2. A represents the RoB2 assessment, B is the ROBINS-I assessment.

Effects of HFS on non-technical skills

The overall effect size (SMD) in the meta-analysis was 1.433, 95% CI [0.695, 2.172], z = 3.804, p < .001, indicating a significant impact of High-Fidelity Simulation (HFS) on non-technical skills (Figure 3. Heterogeneity was significant, as evidenced by Cochran's $Q_{(9)}$ = 134.45, p < .001. The I^2 statistic was 93.3%, suggesting that a substantial proportion of the observed variance was due to between-study heterogeneity rather than chance. The heterogeneity variance (tau^2) was estimated to be 1.2295 using the DerSimonian-Laird method.

In the sensitivity analysis, the study by Jung et al.'s study (26) in relation to the outcome 'a', which stands for the data extraction related to self-efficacy, stands out for its notably lower effect size estimate of 0.912, 95% CI [0.364, 1.460], compared to the overall combined effect size of 1.433. Therefore, the study by Jung et al. (26) had results that suggest a smaller impact on the measured effect compared to the other studies, which had a more significant positive impact. As a result, the overall combined effect size is pulled down or reduced by the inclusion of Jung et al.'s findings. The other individual studies included in the analysis did not substantially impact changing the overall effect size estimate.

Subgroup analysis

In the subgroup analysis (Figure 4), we examined the impact of HFS on non-technical skills across study design, specific domains of non-technical skills, and geographic location.

For the study design, quasi-experimental studies (n=7 domain-specific extractions from the 3 included studies) showed a significant effect size (SMD = 1.886, 95% CI [0.939, 2.834], p < 0.001), whereas randomized controlled trials (RCTs, n = 3) did not show a significant effect (SMD = 0.419, 95% CI [-0.325, 1.162], p = 0.270). The test for group differences was significant (Q_b = 5.71, p = 0.017), indicating that the study design significantly influenced the effect size.

When examining specific outcomes, the self-efficacy domain (extracted 3 times) showed a notably significant effect size (SMD = 3.779, 95% CI [1.010,

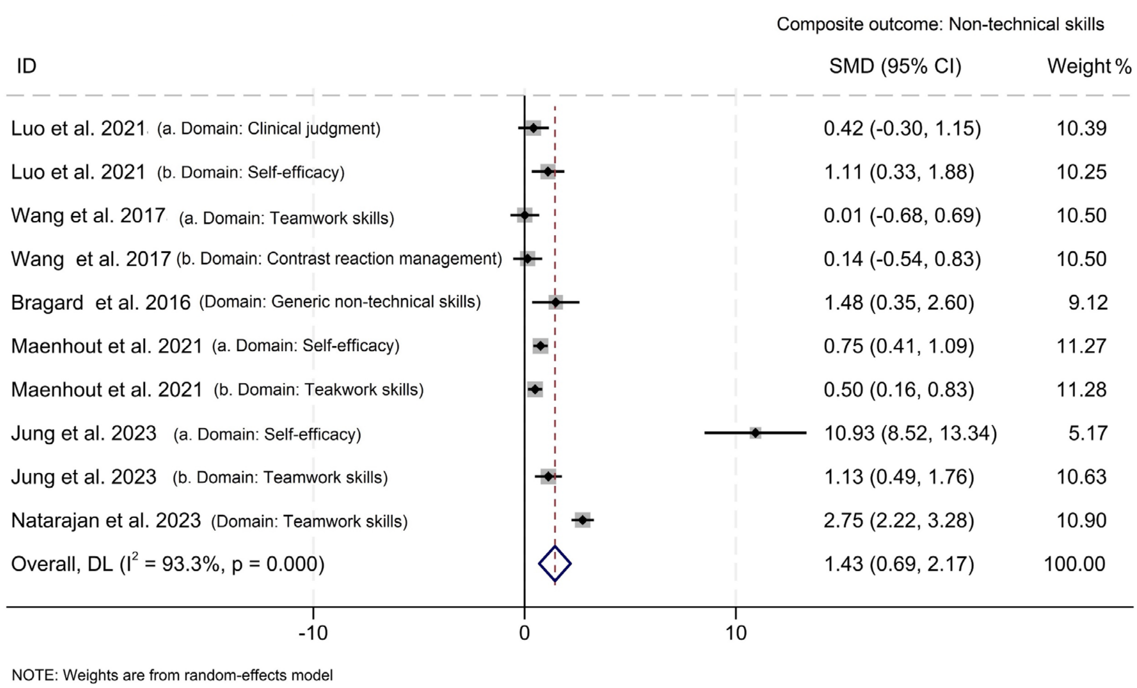

Figure 3. Meta analysis on the composite outcome "non-technical skills".

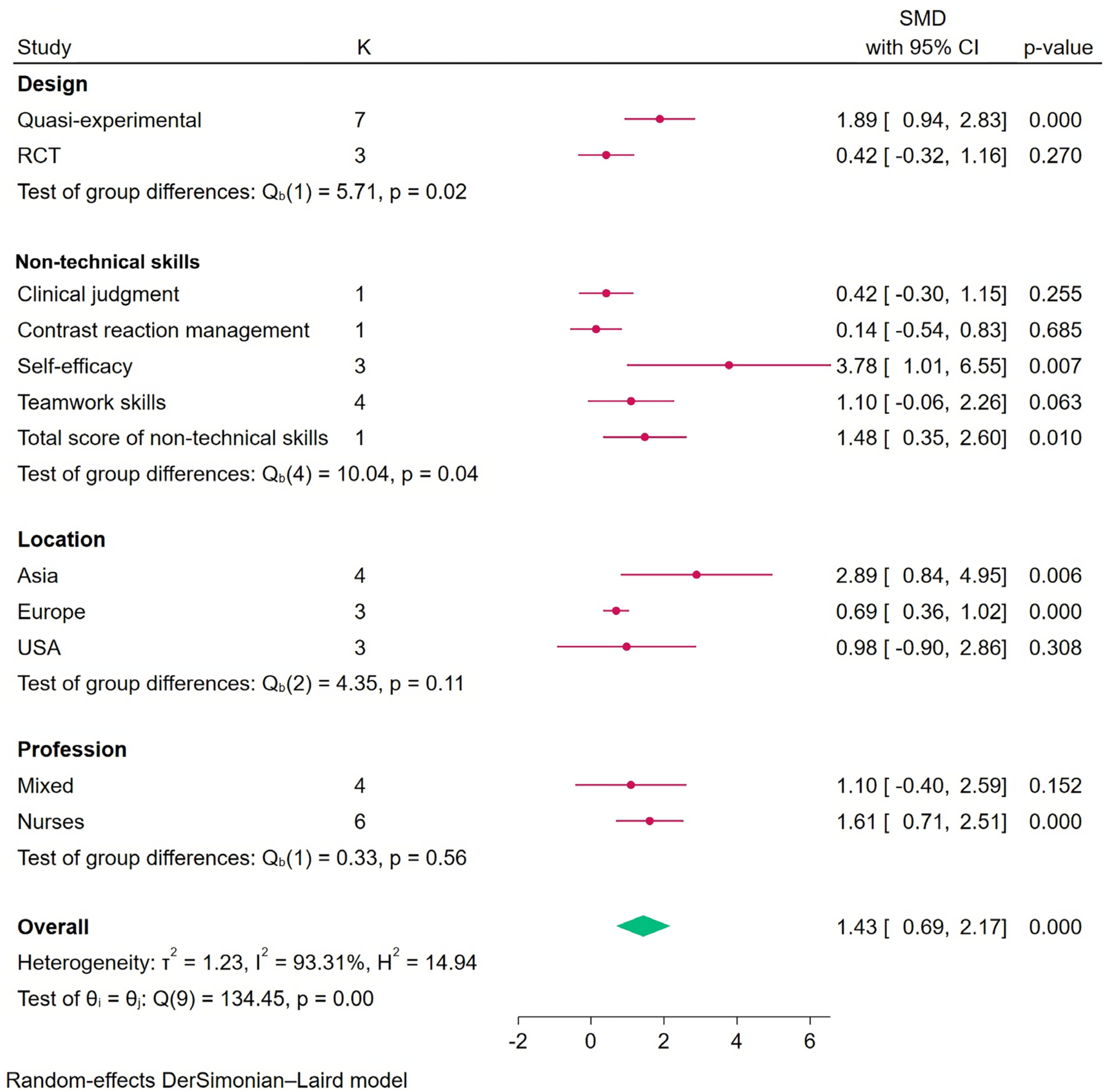

Figure 4. Subgroup analysis.

6.549], p = 0.007). Other outcomes like clinical judgment and teamwork skills did not show a significant effect. The test for group differences was also significant (Q_b = 10.04, p = 0.040), suggesting that the type of outcome assessed also had a significant impact on the effect size.

In terms of geographic location, studies conducted in Asia showed a significant effect size (SMD = 2.892, 95% CI [0.838, 4.946], p = 0.006), while those in Europe also showed a significant but smaller effect (SMD = 0.691, 95% CI [0.359, 1.024], p < 0.001). Studies from the USA did not show a significant effect. The test for group differences was not significant (Q_b = 4.35, p = 0.114), suggesting that location did not significantly influence the effect size.

We also examined the impact of the participants' professions on the effect size. Only the subgroup consisting of studies involving nurses showed a significant effect size (SMD = 1.610, 95% CI [0.708, 2.513], p < 0.001). In contrast, the subgroup of studies with mixed professions did not show a significant effect size (SMD = 1.095, 95% CI [-0.405, 2.595], p = 0.152). The test for group differences in the profession category was not significant (Q_b = 0.33, p = 0.564), suggesting that the profession of the participants did not significantly influence the overall effect size.

In the subgroup analysis, the subgroup of European studies exhibited notably lower heterogeneity than other subgroups, with an I^2 value of 38.48%. This result suggests that the studies conducted in Europe were more consistent in their findings, providing a more homogeneous evidence base for the impact of HFS on non-technical skills within this geographical context. This aspect contrasts with other subgroups, where I^2 values ranged up to 97.03%, indicating substantial variability.

Publication bias

In assessing publication bias, the nonparametric trim-and-fill analysis using a random-effects model with the DerSimonian–Laird method revealed no involved imputed studies (i.e., some missing or unreported studies), indicating that the observed effect size of 1.433 with a 95% CI [0.695, 2.172] remained unchanged even after accounting for potential missing studies. Additionally, the funnel plot depicted in Figure 5 showed low asymmetry, further supporting the absence of significant publication bias in the included studies.

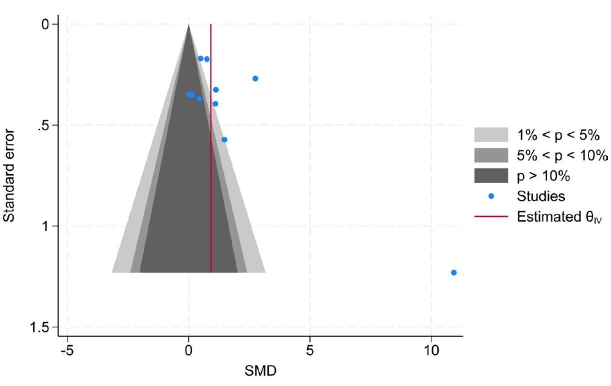

Figure 5. Countour-enhanced funnel plot.

Conclusion

The systematic review revealed a significant positive impact of HFS on non-technical skills, indicating that HFS could enhance self-efficacy, teamwork, and clinical judgment among healthcare professionals. This finding is particularly important because non-technical skills are often considered critical factors for patient safety and effective healthcare delivery (30,31). In a complex and fast-paced healthcare environment, communicating clearly, making sound clinical judgments, and working effectively as part of a team is indispensable (32).

One of the most compelling aspects of this review is how it bridges the gap between theoretical knowledge and practical application. While the importance of non-technical skills has long been recognized (10), the review provides empirical evidence supporting the use of HFS as an effective training tool for these skills. This study adds a layer of scientific rigor to what has often been an area guided by expert opinion or narrative synthesis (e.g., summarizing studies qualitatively and discussing their implications without employing analytical techniques). In other words, the review's findings could serve as a basis for promoting HFS training programs across healthcare institutions. With quantifiable benefits, healthcare educators and administrators may have additional evidence to sustain HFS and incorporate it into training curricula.

The specific domains of non-technical skills investigated in the results of this study, including self-efficacy, teamwork, communication, and clinical judgment, are often cited as critical for patient safety and effective healthcare delivery (33–35). Prior research has emphasized the role of these skills in reducing medical errors, improving patient satisfaction, and enhancing the overall quality of care (36). However, the emerged heterogeneity in terms of employed approaches and assessed outcomes suggests that additional research is required to sustain a higher standardization of HFS in the educational contexts and in the research field.

For instance, the study design played a pivotal role in the observed effect sizes in our systematic review, particularly differentiating between quasi-experimental studies RCTs. Quasi-experimental studies showed a significantly higher effect size (SMD = 1.886, 95% CI [0.939, 2.834], p < 0.001) compared to RCTs, which did not show a significant effect (SMD = 0.419, 95% CI [-0.325, 1.162], p = 0.270). This discrepancy is further underscored by the significant test for group differences, indicating that the study design itself significantly influenced the effect size. These findings have important implications for both research and practice. They suggest that the choice of study design could substantially impact the outcomes, potentially skewing our understanding of the effects of HFS in enhancing non-technical skills. In line with recent research, this result calls for a more nuanced approach to interpreting results across different study designs, which means that we should consider the intricacies and specific circumstances of different study designs when evaluating the findings. This emphasizes the need for further research to understand the underlying factors contributing to these differences and to make our interpretations more refined and context-sensitive (36,37).

The systematic review revealed a notably significant effect size in the domain of self-efficacy (SMD = 3.779, 95% CI [1.010, 6.549], p = 0.007), highlighting the potent influence of HFS on boosting self-efficacy among healthcare professionals. Interestingly, other outcomes, such as clinical judgment and teamwork skills, did not show a significant effect. This divergence in outcomes could be attributed to various factors, including the design of the simulation, the metrics used for evaluation, or the specific training needs of the participants (38). The significant test for group differences in outcomes further emphasizes that the type of outcome assessed significantly impacts the effect size, warranting a more tailored approach to HFS interventions based on the desired outcomes.

Geographically, the review found significant effect sizes in studies conducted in Asia (SMD = 2.892, 95% CI [0.838, 4.946], p = 0.006) and Europe (SMD = 0.691, 95% CI [0.359, 1.024], p < 0.001). However, studies from the USA did not show a significant effect. This geographical variation could be influenced by cultural factors, healthcare systems, or educational approaches that differ across regions (39). Despite these variations in each subgroup, the test for group differences based on location was not significant, indicating that geographical location did not significantly influence the overall effect size by considering the available power to perform these comparisons. This suggests that while regional differences may exist, they are not the primary determinants of the effects of HFS in enhancing non-technical skills.

The systematic review found a significant effect size in studies that focused on nurses (SMD = 1.610, 95% CI [0.708, 2.513], p < 0.001), suggesting that HFS is particularly effective in enhancing non-technical skills among this group of healthcare professionals. On the other hand, studies involving mixed professions did not show a significant effect size (SMD = 1.095, 95% CI [-0.405, 2.595], p = 0.152). This lack of significance in mixed-profession studies could be due to the diverse training needs and skill levels among different professions, which may dilute the overall impact of HFS. Interestingly, despite these variations based on the profession of the participants, the test for group differences in this category was not significant. Therefore, even if the results within each professional group are insightful, the between-studies comparisons require more power to detect significant differences, suggesting that more primary research is needed to clarify these variations. While targeted HFS interventions may be more effective for specific professions like nursing, the general applicability of HFS across various healthcare professions should not be discounted (40).

Overall, the observed heterogeneity in effect sizes and the influence of various factors such as study design, geographical location, and profession highlight the need for more rigorous and controlled research. Future studies should aim to produce more consistent evidence by controlling for possible confounders like training duration, participant experience, and simulation fidelity (41). This would enable a more nuanced understanding of how HFS could be tailored to maximize its educational impact across different settings and professional groups. Standardized methodologies and outcome measures could also contribute to a more cohesive body of evidence. Such advancements in research would be invaluable for informing educational practices and policies, ensuring that HFS is utilized to its fullest potential in enhancing the quality of healthcare education and, ultimately, patient care.

This study is not without limitations. First, the review included a relatively small number of studies, which may limit the generalizability of the findings. Second, the studies varied in their methodologies, including the use of different scales and outcome measures, which could contribute to the observed heterogeneity in effect sizes. Third, although the risk of bias was generally low or moderate across the included studies, some concerns were raised in specific domains, such as the randomization process in one of the RCTs and the overall risk of bias in the quasi-experimental studies. Fourth, the review did not account for potential confounders like the level of experience of the participants or the quality of the simulation equipment, which could influence the outcomes. Lastly, the review focused primarily on studies conducted in Asia, Europe, and the USA, potentially overlooking valuable research from more specific and precise geographical locations. These limitations should be considered when interpreting the results and should serve as areas for improvement in future research.

This systematic review provides compelling evidence that HFS has a significant positive impact on enhancing non-technical skills among healthcare professionals, particularly in the domain of self-efficacy. While the review reveals variations in effect sizes based on study design, geographical location, and profession, these factors did not significantly alter the overall positive impact of HFS. The findings underscore the importance of non-technical skills in healthcare and validate the use of HFS as an effective educational tool. However, the review also highlights the need for more rigorous, controlled research to produce consistent evidence that can be effectively translated into educational practice. Limitations such as a small number of studies and methodological heterogeneity should be addressed in future research. Overall, the review sets a foundation for the continued integration of HFS in healthcare education, aiming to improve patient care and safety.

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Authors Contribution: Conceptualization: IV, CA, and RC were instrumental in the initial conceptualization and design of the study. Methodology: IV, RC, AM, and GC played a key role in developing the methodology for the systematic review and meta-analysis. Formal Analysis: The formal analysis of the data was primarily conducted by RC, AM, and IV. Investigation: All authors were responsible for carrying out the investigation, including the literature search and data collection. Data Curation: All authors provided essential resources and materials necessary for the completion of the study. Writing - Original Draft Preparation: The original draft of the manuscript was prepared by IV, with significant contributions from RC and AM. Writing - Review & Editing: All authors were heavily involved in reviewing and editing the manuscript for intellectual content and clarity. Visualization: The creation of visual content, such as figures and tables, was overseen by RC and SB. Supervision: The overall supervision of the project was led by RC and CA.

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Correspondence:
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Ida Vangone, RN, MSN, PhD(s)
Department of Biomedicine and Prevention, University of Rome Tor Vergata, Rome (Italy)
E-mail: ida.vangone01@universitadipavia.it
ORCID ID: https://orcid.org/0000-0002-5037-6239

Appendix – Supplementary file

Supplementary file 1. Search Strategy

Search strategy

Question: *Does high-fidelity simulation enhance the non-technical skills of healthcare professionals?*

P Healthcare Professionals
I High fidelity simulation
C Any other strategies
O Non technical skills (team working, leadership, critical thinking, awareness, communication, decision making)

PubMed

Filters:

- Language: English, Italian
- Period of research from 2011/2/1 (data of the last article from precedent review)- 2023/6/01

PIO	#	Search string	# of results
P	1	"Health Personnel"[MeSH Terms] OR "health care provider" [Title/Abstract] OR "Health Care Professional*"[Title/Abstract] OR "nurs*"[Title/Abstract]	942,170
I	2	"High Fidelity Simulation Training"[MeSH Terms] OR "High fidelity simulation"[Title/Abstract] OR "High Fidelity Simulation Training"[MeSH Terms] OR "High fidelity simulation"[Title/Abstract] OR "HFS" [Title/Abstract]	4,212
C	NA	NA	NA
O	3	"team working"[Title/Abstract] OR "thinking"[MeSH Terms] OR "Critical thinking"[Title/Abstract] OR "thinking critical" [Title/Abstract] OR "clinical judgement" [Title/Abstract] OR "Awareness"[MeSH Terms] OR "Situational awareness"[All Fields] OR "Situation Awareness"[Title/Abstract] OR "awareness situation"[Title/Abstract] OR "Decision making"[MeSH Terms] OR "Decision making"[Title/Abstract] OR "leadership"[MeSH Terms] AND "leadership"[Title/Abstract] OR "Communication"[MeSH Terms] OR "Communication"[Title/Abstract] OR "non technical skill*"[Title/Abstract] OR "nontechnical skill*"[Title/Abstract]	343,767
	4	#1 AND #2 AND #3	**128**

Embase

Filters:

- Language: English, Italian
- Period of research from 2011/2/1 (data of the last article from precedent review)- 2023/6/01

PIO	#	Search string	# of results
P	1	'health care personnel':ab,ti OR nurs*:ab,ti	635,769
I	2	'high-fidelity simulation':ab,ti OR 'high fidelity simulation':ab,ti OR hfs:ab,ti	8,387
C	NA	NA	NA
O	3	'communication':ab,ti OR 'leadership':ab,ti OR 'teamwork':ab,ti OR 'decision making':ab,ti OR 'clinical thinking':ab,ti OR 'awareness':ab,ti OR 'non technical skill*':ab,ti	949,144
	4	#1 AND #2 AND #3	**260**

Cinhal

Filters:

- Language: English, Italian
- Period of research from 2011/2/1 (data of the last article from precedent review) - 2023/6/01

PIO	#	Search string	# of results
P	1	MH “Health Personnel+”	635,482
I	2	AB “high fidelity simulat*” OR hfs OR “high-fidelity simulat*”	1,670
C	NA	NA	NA
O	3	AB communication OR leadership OR “team working” OR “clinical thinking” OR “decision making” OR awareness OR “situation* awareness” OR “nontechnical skill*” OR “non technical skill*”	278,549
	4	#1 AND #2 AND #3	**56**

Scopus

Filters:

- Language: English, Italian
- Period of research from 2011/2/1 (data of the last article from precedent review)- 2023/6/01

PIO	#	Search string	# of results
P	1	TITLE-ABS-KEY (health AND professional* OR health AND personnel OR nurs*)	829,067
I	2	TITLE-ABS-KEY (high fidelity simulat* OR hfs)	27,819
C	NA	NA	NA
O	3	TITLE-ABS-KEY (communication OR leadership OR awareness OR team AND working OR decision AND making OR clinical AND thinking OR non AND technical AND skill* OR nontechnical AND skill*)	637
	4	#1 AND #2 AND #3	**10**