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Virtual reality simulation in non-technical skills training for healthcare professionals:

a systematic review

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Summary statement

This systematic review, conducted in accordance with PRISMA guidelines, is aimed to review current research in virtual reality for healthcare training, specifically pertaining to non-technical skills. PsycInfo and Medline databases were queried for relevant articles published through December 2017. Of the 1377 publications identified, 80 were assessed for eligibility and 26 were finally included in the qualitative synthesis. Overall, the use of virtual training for non-technical skills is recent in healthcare education, and has increased since 2010. Screen-based VR simulators or virtual worlds are the most frequently used systems. The non-technical skills addressed in VR simulation include mainly teamwork, communication and situation awareness. The majority of studies evaluate the usability and acceptability of VR simulation, and few studies have measured the effects of VR simulation on non-technical skills development.

Keywords: virtual reality simulation; non-technical skills; healthcare training; medical education; systematic review.
Virtual reality simulation in non-technical skills training for healthcare professionals: a systematic review

Introduction

With the publication of To Err is Human in 1999(1) and Safety at the Sharp End(2), attention was drawn to the importance of human factors in operational teams, identifying skills that were first described for crew resource management in aviation and other high-risk industries. Flin described these non-technical skills (NTS) as “the cognitive, social and personal resource skills that complement technical skills, and contribute to safe and efficient task performance”(2). In Flin’s taxonomy, NTS included individual cognitive skills (e.g., situation awareness, decision-making, coping with stress and management of fatigue) and interprofessional social skills (e.g., cooperation and teamwork, conflict resolution, leadership).

Evidence that human factors have an impact on surgical performance(3) led to the development of training programs focusing on NTS to improve patient safety(4). Using Flin’s taxonomy, several tools (i.e. ANTS, NOTSS, SPLINTS) have been designed to provide surgical teams with a common language to discuss and develop the human factors that are critical for patient safety(5).

Several studies have demonstrated the efficiency of simulation for knowledge acquisition and for technical(6–8) and non-technical(9,10) skills training in healthcare. Training healthcare professionals to manage rare or critical events in a standardized manner and without risk for the patient has become a major challenge(11). Although the benefits of simulation have been well documented, the human resources required for mannequin or standardized patient-based simulation and the availability of human resources in simulation centers remain scarce. However, various simulation methods have recently been developed using real actors, mannequins, standardized patients, computer simulators or serious games.
With the development of technology and the “laparoscopic surgery revolution”\(^{(12)}\), Virtual Reality (VR) simulators are being used more widely in both professional practice and education programs\(^{(13,14)}\). VR is a broad concept that encompasses three categories of simulators: screen-based VR simulators, virtual worlds, and immersive virtual reality environments. First, screen-based VR simulators have been used since the nineties to develop psychomotor skills for endoscopic surgery\(^{(15)}\). They consist of an interface comprising a computer and monitors coupled to mechanical devices or haptic units\(^{(16)}\). This kind of simulator requires very little set-up time and can be used repeatedly by learners for practice in different pathologies and with a number of anatomical variations\(^{(17)}\). Second, virtual worlds are three-dimensional virtual environments based on multiplayer online gaming, allowing users to free themselves from geographical proximity or time constraints (individual connection and full time access)\(^{(18–20)}\). For health professionals, medical furniture, instruments, devices, tools and characters are added to create dedicated medical virtual worlds\(^{(21)}\). Lastly, immersive virtual reality environments combine three-dimensional imaging, interactions with the environment, possible haptic feedback and head-mounted displays (HMD) or cave automatic virtual environments (CAVE, room-sized cube VR environments) to immerse the user and occlude the real world in order to provide a feeling of presence\(^{(13,22)}\).

The effects of VR-based training on healthcare professionals have mostly been studied in relation to the development of technical skills, either surgical (e.g., procedure, planning, knowledge of instruments) or psychomotor (e.g., dexterity, accuracy, speed)\(^{(23,24)}\). The use of VR simulation-based training for the development of NTS seems to be less common. In view of the recent developments described above, a systematic review of how VR has been used for NTS skills training and assessment could provide powerful new insights into the value and efficiency of this technique. This paper provides such a review, focusing on the use of virtual
reality in the evaluation and development of a predefined set of cognitive and interprofessional social skills required by healthcare professionals.

METHODS

**Data source and search strategy**

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)\(^{(25)}\). The PICOS worksheet and search strategy\(^{(26)}\) were used to organize our research topics and terms, combining five concepts: Population, Intervention, Comparison, Outcome and Settings. Based on this framework, we produced a comprehensive research equation: “(nurs* OR scrub nurse OR surgeon* OR medical student OR nursing student OR health* OR clinical) AND (virtual reality OR virtual*) AND (virtual gaming simulation OR immers* OR serious game) AND (skills training OR training OR medical education) AND (non-technical skill* OR cognitive skill* OR team* OR leadership OR communicat* OR decision making OR task management)”. We searched two main databases, Psycinfo and Medline, because they both cover our fields of interest (healthcare, VR and NTS) and because their query forms are very similar, allowing us to use the same research equation. The search was conducted in May 2017 with a final extraction for screening on 11th December 2017.

**Selection criteria**

Inclusion of articles was based on the following criteria: 1) Focus on healthcare professionals working in teams; 2) Focus on Virtual Reality used in an educational or training context that includes outcomes data; 3) Focus on NTS in line with Flin’s pre-defined set of NTS referring to cognitive skills (situation awareness, decision-making, stress and management fatigue) and interprofessional social skills (cooperation and teamwork, conflict resolution, leadership). To get the most reliable source of scientific information, only publications in peer-reviewed journals were considered. Since VR is a relatively new technology, the period chosen
for study selection was between 2007 and 2017. Finally, to have an international overview, only articles written in English have been retained.

**Study selection and eligibility criteria**

We extracted 1373 references, 460 on Psycinfo and 913 on Medline. Four others found on Google Scholar while reading on the subject were added, thus making a total of 1377 references. We removed 188 abstracts in duplicate, resulting in 1189 titles and abstracts to read for selection. At this stage of the process, 1109 references were excluded.

In accordance with the first selection criterion, study populations that did not involve health professionals (e.g. pedestrians, cyclists, students, athletes or patients) were removed, as well as those working in smaller teams or solo (e.g. dentists, pharmacists and vets).

Following the second selection criterion, articles dealing with learning methods that were not the focus of this study were deleted (e.g., e-learning, e-classroom, web-based learning, telemedicine, mobile applications, social networks). According to the same criterion, some references were also excluded because the term “virtual” was used without referring to virtual reality (e.g., virtual teams, virtual communities, virtual classroom, virtual consultations and virtual patients). There is a vast literature on the “Virtual Patient”, focusing on the interpersonal social skills of healthcare professionals required to facilitate accurate diagnosis, give appropriate advice, and instruct patients about treatment. As these skills do not come within the scope of our predefined set, these references were not included in the present review.

Finally, according to the third criterion, articles that did not address NTS were excluded: knowledge representation (anatomy, physiology, histology, 3D planning for radiotherapy), technical skills, interpersonal patient-physician relationship (diagnosis, notification of critical results or pathology), psychiatric disorders (dementia, post-traumatic stress disorder), or remediation (cognitive behavioral therapy, rehabilitation) that also use VR technologies but are out of the scope of this review.
This initial selection included 80 articles with abstracts that were insufficiently clear to
decide whether or not they were eligible, and these were uploaded in order to read the full text.
However, five remained unavailable even after their main authors were contacted by e-mail,
which reduced the number of articles to read to 75.

After the full-text analysis, 49 articles were excluded for four reasons: 1) they did not
involve NTS (n= 31), 2) they did not use virtual reality (n= 15), 3) they did not involve health
professionals (n= 2), or 4) it was a review article with no experiment (n=1).

Selection bias (interrater reliability)

To check the validity of the study, a sample of the articles (30%) was independently
coded by the second author. Based on the eligibility criteria, the second coder decided whether
or not to examine an article in depth. After reviewing the abstract and full text, the two coders,
meaning the first and second authors, agreed on 26 articles, 11 that should be selected and 15
rejected. Their opinions only diverged on the implementation of NTS in one article (3.7%),
which was eventually excluded (Cohen Kappa = .92). The selection process is summarized in
the flowchart (see Figure 1).

INSERT FIGURE 1 HERE

To obtain a descriptive analysis of the results of this review, we drew up a comparative table,
fasically focusing on medical specialties, VR simulator typologies, study populations, and assessed NTS.
For the latter, when assessment tools were mentioned, presence or absence of their validity
evidence in the virtual environment was also examined. Another criterion for the analysis was
outcomes, according to Kirkpatrick’s levels (see Table 1, Supplemental Digital Content 1,
which shows the characteristics of the studies included in the review). This framework was
chosen because the Kirkpatrick Model(27) is frequently used to evaluate training programs; for
example, it was recently used to evaluate serious games for training healthcare professionals(28).
This model has four levels: 1) affective reactions after the training program, 2) improvement of
knowledge and skills, 3) change of behavior and transfer of skills in professional contexts, 4) increased patient care quality and reduced costs.

RESULTS

Study characteristics

VR is a recent technology and, as expected, the number of articles published per year over the last decade on this subject is rather low although it has been increasing, with a peak of seven articles in 2015. The median number of articles published per year is two (interquartile range [IQR] = 3-1, min = 0, max = 7).

Regarding sample size, the average number of participants was 39.69 (min = 10, max = 148, SD= 37.33). Looking more closely at their study design, 17 studies used an experimental design (pre-test/post-test, group comparisons or control/test group comparisons)\(^{(29–44)}\), nine were observational studies\(^{(18–20,45–50)}\), and one was based on qualitative interviews\(^{(51)}\).

Medical specialties

Emergency medicine\(^{(18,19,32,44,47)}\) and health education\(^{(20,37,41,50,51)}\) stand out from the rest with five articles each, but the latter includes issues that potentially concern all specialties or health professionals in different sectors. Next are urology\(^{(29,30,40,48)}\) and gastroenterology\(^{(33,34,45,46)}\) with four articles each. A further eight articles dealt with interprofessionality\(^{(18,32,37,41,47–50)}\).

Study populations

Most of the studies include a range of professions: nurses feature in eight articles\(^{(19,20,32,37,38,40,48,49)}\), surgeons\(^{(33,35,38,39,43,45,46)}\) in seven, and five articles mention other professionals\(^{(18,19,32,37,38)}\). With regard to students, 12 articles involve residents or postgraduate trainees\(^{(18,33,35,36,38–40,42,44–46,48)}\), ten concern health students regardless of their level or specialty\(^{(30,31,39,41,44–47,50,51)}\), and three articles mention trainees\(^{(29,34,38)}\).
In the studies selected for review, two technologies are equally represented: Screen-based VR simulators in 12 studies\(^\text{29,30,33,34,36,38–40,42,43,48,49}\) and virtual worlds in 12 articles\(^\text{18–20,31,32,35,37,41,44,47,50,51}\). Immersive virtual worlds are less common, as they are found in only three studies\(^\text{39,45,46}\).

### NTS and assessment metrics

Among the 26 studies, the most frequently investigated NTS is teamwork, which is mentioned in 19 articles\(^\text{18,19,29–32,34,35,37,38,40–42,45,47–51}\). After that is communication\(^\text{(15/26)}\)\(^\text{18,29,30,32–34,37,38,40–42,47–50}\), followed by situation awareness\(^\text{(10/26)}\)\(^\text{18,20,29–31,34,42,46,48,51}\), decision-making\(^\text{(8/26)}\)\(^\text{18,20,29,30,32,34,40,42}\), leadership\(^\text{(8/26)}\)\(^\text{18,29,30,34,37,41,42,44}\), and stress management\(^\text{(6/26)}\)\(^\text{18,36,39,43,44,46}\). Most studies measured more than one NTS construct, with the exception of three articles focusing specifically on stress management\(^\text{(36,39,43)}\), three others on teamwork\(^\text{(19,35,45)}\), and one on communication\(^\text{(33)}\).

Specific metrics for NTS assessment are mentioned or described in detail in 16 articles\(^\text{18,20,29–37,41–44,49}\), ten of which\(^\text{18,29,30,33,34,37,41–44}\) mention and use specific validated assessment tools for NTS in the operating room or in a clinical environment (i.e. NOTECHS, NOTSS, T-NOTECHS, CGRS, M-OSANTS, TOSCE, T-TAQ, SURG-TLX, EMCRM). These assessment tools are presented as validated for simulation\(^\text{(52,53)}\), but none of them mention their validation in the very specific context of VR simulation. Four articles\(^\text{31,34,36,42}\) use scales designed for a specific NTS, but are not specific to the operating room or to health professionals (i.e. situation awareness, self-efficacy, anxiety). Six articles\(^\text{18,20,32,35,43,49}\) use their own tools or checklists, or open-ended questions rather than a questionnaire. Again, none of these tools or checklists take into consideration the specificity of VR simulation, but are simply transferred from real life or traditional simulation contexts.

### Outcome measures
The levels of assessment of the simulators or scenarios used in the studies reach Kirkpatrick’s level 1 (affective reactions) in 19 articles (18–20,29,30,32,37–48,51) and level 2 (learning: attitude, knowledge) in 18 (18–20,29–37,39,41–44,49,50). Level 3 (behavior) is only reached in two articles (33,34) that describe a test of skills transfer to the clinical environment in order to evaluate behavioral changes among trainees. No studies were found that reached level 4 (results) evaluating the effect of simulation on patient care quality and cost.

Overall, this review demonstrates that few medical specialties use virtual reality for NTS training. The most frequently used systems are screen-based VR simulators or virtual worlds, while immersive virtual worlds are rarely used. The most frequently studied NTS are the interpersonal and interprofessional social skills needed for effective medical teams, including teamwork and communication, together with situation awareness, which is a crucial cognitive ability.

**Objectives and findings of the studies**

Two main categories of study objectives emerged from our review (see Table 2, Supplemental Digital Content 2, which shows the objectives, measures and main findings of the studies). The majority of studies are simulator or scenario centered, with a clear goal of establishing the acceptability of the technology for NTS training. This is the goal of 20 articles (18–20,29,31,35–39,41–49,51). As VR has only been introduced in healthcare training recently, it seems logical to assess this first. The general conclusion of these studies is that VR simulators offer promising opportunities for NTS training of health professionals. Their acceptability as an NTS training tool is validated either directly (37,41) or through one or more of its predictors as defined by Nielsen’s model of system acceptability (54): validity or fidelity (18,29,38,39,42,45,46), usefulness or utility (41,42,44,46), efficiency, effectiveness or efficacy (19,35,47,48), and usability (20,43,47). The acceptability of VR simulators is not assessed alone but together with teamwork (19,35,37,38,41,45,47,48,51), situation awareness (20,31,46), stress management (39,43,46), self
efficacy\textsuperscript{(36)}, and leadership\textsuperscript{(44)}, or with several NTS using a dedicated assessment tool such as NOTECHS or NOTSS\textsuperscript{(18,29,42)}.

The purpose of the six remaining articles, among the most recent ones of this review, is to propose different uses of VR simulation. One includes a virtual reality program that focuses on communication tools as an initial introduction to team communication strategies\textsuperscript{(50)}. The other five are curriculum centered, their objectives being to incorporate NTS training modules using VR simulators in the medical curriculum: four of them describe distributed simulation\textsuperscript{(30,33,34,40)}, in other words, the use of VR simulators initially designed for teaching technical skills in wider settings or scenarios\textsuperscript{(29)}, and the fifth\textsuperscript{(32)} addresses emergency preparedness using a virtual world.

DISCUSSION

There are few medical specialties that use virtual reality simulation for NTS and their goals vary. First, virtual worlds are used in healthcare education and in emergency medicine to provide practice opportunities for rare events or extreme situations that are difficult to set up in real life. Second, screen-based VR simulators are used for technical skills training in domains involving laparoscopic surgery or robotic-assisted surgery, such as gastroenterology\textsuperscript{(33,34)} and urology\textsuperscript{(30,40)} curricula. In the latter, NTS are introduced progressively in VR simulation scenarios as trainees develop their technical skills\textsuperscript{(55)}. This is congruent with the conclusions of Shamim-Khan et al. (2013)\textsuperscript{(40)} and Rudarakanchana et al. (2014)\textsuperscript{(38)} who observed that junior trainees focus more on technical skills and feel that the introduction of NTS adds stress and anxiety due to the need to multitask. It also follows the hierarchy of core, procedural and team skills proposed by Windsor (2009), who illustrates it with a musical analogy of note, melody and harmony: just like musicians begin to learn playing a note before trying to play a melody and then join an orchestra, core skills such as knot tying, dissecting or suturing, for example,
should be trained before procedural skills (i.e. how to dissect out a pathology). Then, team skills can be trained\(^{(12)}\). Nevertheless, this progression does not enjoy consensus and must be considered for each set of NTS. For example, the addition of cognitive skills likely to help error-detection to technical skills training can result in more effective learning\(^{(56)}\).

Screen-based VR simulators or virtual worlds are thus the most frequently used systems. Immersive virtual worlds are less commonly used and are mentioned in only three articles\(^{(39,45,46)}\), two of them using head-mounted displays\(^{(39,46)}\). They were published between 2015 and 2016, which corresponds to the time when HMD such as Oculus Rift or HTC Vive became mainstream, even though immersive VR simulation is not a new technology in healthcare as it has been used since the early 2000s\(^{(57)}\). It will be interesting to see how these devices will be used in the future as their comfort and fields of view improve, and how they can be integrated into new surgical training modules.

One of the major interests of VR is its realism, which is stressed in several studies\(^{(29,38,39,42,45,46)}\). Even though avatars may sometimes behave awkwardly, and haptic feedback may be approximate or missing, participants still recognise the main features of their environments or work organizations. This contributes to the feeling of immersion mentioned in two articles\(^{(19,39)}\). These two notions are of particular interest in that they help trainees gain confidence\(^{(19,29,37,42)}\) by providing them with new learning opportunities, such as discovering an emergency room without stress\(^{(47)}\), or being able to develop the skills needed to react to disasters when training in an unfamiliar environment\(^{(32)}\). However, the degree of realism expected in a VR simulator has to be questioned for each scenario: if more haptic feedback, such as somatosensations or kinematic interactions, is expected with a high degree of fidelity, too much realism for an avatar in virtual worlds can lead to anxiety and rejection, due to the uncanny valley phenomenon. According to this theory, participants react favorably to environments that
are very similar or very dissimilar to reality, but are uncomfortable with intermediate realism\textsuperscript{(58,59)}.

The affective component of learning has been described as one of the four key criteria for simulation-based learning, which is centered on the learners’ needs and for which motivation and self-efficacy are key concepts\textsuperscript{(60)}. With this in mind, many VR simulators allow participants to replay their session, helping them recognize and analyze both their interactions and their emotions\textsuperscript{(61)}. The emotional impact of VR simulation on self-efficacy is emphasized and appreciated by trainees\textsuperscript{(44)}, as well as the opportunity provided by some scenarios to communicate with other disciplines before any clinical practice\textsuperscript{(47)} or to experience human interactions in problematic environments\textsuperscript{(51)}. In terms of motivation, VR simulation seems to be of particular interest as it is described as a highly rated learning experience\textsuperscript{(37)}, preferred to standard didactic lectures\textsuperscript{(46)}, and seen as excellent preparation for clinical situations\textsuperscript{(47)}.

Another interest of VR simulation is data generation because VR simulators can track and record every action. The data are used to give learners feedback on their performance and progress over time through their profile, allowing them to verify their skills acquisition and become proactive in their learning. But they also help educators better understand their students’ learning processes, allowing them to adjust their inputs and complement their traditional teaching methods with appropriate simulations\textsuperscript{(50)}. In addition, as most VR simulators and scenarios can be used in different cultural and geographic environments, the collected data could also be used for further intercultural studies of NTS\textsuperscript{(50)}.

The most frequently studied NTS are interpersonal and social skills, such as teamwork and communication. As a cognitive skill, situation awareness also features frequently, as it is a crucial personal skill, especially in dynamic environments such as medical settings where it can impact decision-making and communication\textsuperscript{(62)}. While the capacity of VR environments to recreate realistic situations makes it suitable for stress management training, none of the articles
selected for this review discuss fatigue management. Even though VR is used to that end for patient-focused psychological therapy, healthcare professionals may not perceive fatigue and stress management as an issue warranting the use of simulation scenarios.

Most studies are set up to assess a simulator or scenario, reaching Kirkpatrick’s level 1 (affective reaction) or 2 (learning). According to these articles, VR simulators offer NTS training opportunities for healthcare students, as their feasibility, usability, validity, acceptability or effectiveness have been validated in different situations. However, their conclusions recommend further studies. The impact of VR simulation on NTS training still requires more systematic assessment in routine clinical practice in order to validate a possible transfer of skills for health professionals and to determine whether it achieves its ultimate goal of improving patient safety (Kirkpatrick’s level 4). This is challenging because patient safety is multifactorial, and because, as this review shows, validated tools to assess NTS are not systematically used, making large-scale comparisons difficult. Furthermore, few studies mention the inclusion of NTS training using VR simulators in the curriculum as a way of helping students progress.

To continue the development of VR systems for NTS training, four lines of research are required. First, studies are needed regarding the validation of specific NTS assessment tools for VR simulation. So far, these tools have not been validated, which may impact their evaluation in these specific environments. Second, studies are needed to estimate the different technical possibilities offered by VR technologies for NTS training, such as mixed and augmented reality. Third, debriefing is considered a key element for skills transfer in simulation-based training\(^{63}\). While this has been studied in different simulation contexts\(^{64}\) and with different frameworks\(^{65}\), specific debriefing methods for VR simulation are scarce. Avatar-based debriefing\(^{66}\), for example, could be developed for health education. Fourth, future studies should evaluate the effects of these training methods at different levels of learning: attitudes,
skills, transfer of skills, and cost-benefit ratio. In particular, more studies are needed in the near future to investigate the transfer of skills to the operating room (Kirkpatrick’s level 3) and to validate VR simulation as an efficient training tool for NTS. But what is really missing is the impact of these tools on the quality of care for patients and on the overall cost of care (Kirkpatrick’s level 4), which has not yet been established.

Limitations

As our search was limited to 2 databases, there is a risk that some relevant articles were missed. The decision to select only articles written in English also excludes studies published in other languages. Our search may also have been limited by the definitions of VR and NTS, as the keywords may not have used a very specific terminology, such as avatar, 3-dimensional, HMD, mixed or augmented reality. Augmented reality, the integration of digital information into the physical world in real time, or mixed reality, the use of real objects to enhance simulations, are related to virtual environments or VR settings. Thus, some studies may use simulators based on VR technology but not specify it in their keywords. However, in order to be as comprehensive as possible for this review, the search request was replicated, replacing virtual reality with augmented and mixed reality: 58 articles were found but none of them dealt with NTS training.

Another limitation of this review is that NTS are not always defined and explicitly operationalized in studies and are sometimes concealed behind technical skills on which they are highly dependent. Finally, a limitation concerns Virtual Patient simulation, focusing on the interpersonal social skills of healthcare professionals with their patient. It was decided that this did not come within the set of skills defined for this review. However, there is a vast literature on Virtual Patients, which are frequently used in virtual worlds and virtual immersive environments. A systematic literature review concerning the development of interpersonal social skills and communication with patients via VR could thus be examined in another paper.
Conclusion

In conclusion, VR simulation systems are a recent development in health education. The use of VR simulators has increased for technical skills training, but to a lesser extent for NTS (i.e. cognitive and interprofessional social skills). This systematic review of articles published from 2007 to 2017 shows that screen-based VR simulators or virtual worlds are the most frequently used systems, and teamwork, communication or situation awareness are the most frequently addressed NTS. The evaluation of VR systems as training tools is essential, but there has, so far, been little systematic research. The majority of studies evaluate the usability and acceptability of VR simulation, and few studies have measured the effects of VR simulation on non-technical skills development.

Nevertheless, the development of VR technologies and the portability of VR systems offer a very promising outlook for the future training of healthcare professionals. The wide range of possible scenarios that can be simulated, especially for NTS training, will undoubtedly contribute to the “successful integration of simulation throughout the fabric of healthcare”\(^{(11)}\).
REFERENCES


Figure Legends

Figure 1. Flowchart of systematic review

Supplemental Digital Content 1. PDF, Table 1. Characteristics of studies included in the review

Supplemental Digital Content 2. PDF, Table 2. Objectives, measures and main findings of studies included in the review