Virtual Reality Simulation in Nontechnical Skills Training for Healthcare Professionals

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

2   **a systematic review**

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18 **Conflict of Interest**

19 The authors declare that they have no conflict of interest.

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26 **Summary statement**

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28 This systematic review, conducted in accordance with PRISMA guidelines, is aimed to

29 review current research in virtual reality for healthcare training, specifically pertaining to non-

30 technical skills. PsycInfo and Medline databases were queried for relevant articles published

31 through December 2017. Of the 1377 publications identified, 80 were assessed for eligibility

32 and 26 were finally included in the qualitative synthesis. Overall, the use of virtual training

33 for non-technical skills is recent in healthcare education, and has increased since 2010.

34 Screen-based VR simulators or virtual worlds are the most frequently used systems. The non-

35 technical skills addressed in VR simulation include mainly teamwork, communication and

36 situation awareness. The majority of studies evaluate the usability and acceptability of VR

37 simulation, and few studies have measured the effects of VR simulation on non-technical

38 skills development.

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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.

68   With the development of technology and the "laparoscopic surgery revolution"[12],

69   Virtual Reality (VR) simulators are being used more widely in both professional practice

70   and education programs[13,14]. VR is a broad concept that encompasses three categories of

71   simulators: screen-based VR simulators, virtual worlds, and immersive virtual reality

72   environments. First, screen-based VR simulators have been used since the nineties to

73   develop psychomotor skills for endoscopic surgery[15]. They consist of an interface

74   comprising a computer and monitors coupled to mechanical devices or haptic units[16]. This

75   kind of simulator requires very little set-up time and can be used repeatedly by learners for

76   practice in different pathologies and with a number of anatomical variations[17]. Second,

77   virtual worlds are three-dimensional virtual environments based on multiplayer online

78   gaming, allowing users to free themselves from geographical proximity or time constraints

79   (individual connection and full time access)[18–20]. For health professionals, medical

80   furniture, instruments, devices, tools and characters are added to create dedicated medical

81   virtual worlds[21]. Lastly, immersive virtual reality environments combine three-dimensional

82   imaging, interactions with the environment, possible haptic feedback and head-mounted

83   displays (HMD) or cave automatic virtual environments (CAVE, room-sized cube VR

84   environments) to immerse the user and occlude the real world in order to provide a feeling

85   of presence[13,22].

86   The effects of VR-based training on healthcare professionals have mostly been studied

87   in relation to the development of technical skills, either surgical (e.g., procedure, planning,

88   knowledge of instruments) or psychomotor (e.g., dexterity, accuracy, speed)[23,24]. The use of

89   VR simulation-based training for the development of NTS seems to be less common. In view

90   of the recent developments described above, a systematic review of how VR has been used

91   for NTS skills training and assessment could provide powerful new insights into the value and

92   efficiency of this technique. This paper provides such a review, focusing on the use of virtual

93 reality in the evaluation and development of a predefined set of cognitive and

94 interprofessional social skills required by healthcare professionals.

95 METHODS

96 **Data source and search strategy**

97 This systematic review followed the guidelines of the Preferred Reporting Items for

98 Systematic Reviews and Meta-Analyses (PRISMA)[25]. The PICOS worksheet and search

99 strategy[26] were used to organize our research topics and terms, combining five concepts:

100 Population, Intervention, Comparison, Outcome and Settings. Based on this framework, we

101 produced a comprehensive research equation: "(nurs* OR scrub nurse OR surgeon* OR

102 medical student OR nursing student OR health* OR clinical) AND (virtual reality OR virtual*

103 OR virtual gaming simulation OR immers* OR serious game) AND (skills training OR

104 training OR medical education) AND (non-technical skill* OR cognitive skill* OR team* OR

105 leadership OR communicat* OR decision making OR task management)". We searched two

106 main databases, Psycinfo and Medline, because they both cover our fields of interest

107 (healthcare, VR and NTS) and because their query forms are very similar, allowing us to use

108 the same research equation. The search was conducted in May 2017 with a final extraction for

109 screening on 11th December 2017.

110 **Selection criteria**

111 Inclusion of articles was based on the following criteria: 1) Focus on healthcare

112 professionals working in teams; 2) Focus on Virtual Reality used in an educational or training

113 context that includes outcomes data; 3) Focus on NTS in line with Flin's pre-defined set of

114 NTS referring to cognitive skills (situation awareness, decision-making, stress and

115 management fatigue) and interprofessional social skills (cooperation and teamwork, conflict

116 resolution, leadership). To get the most reliable source of scientific information, only

117 publications in peer-reviewed journals were considered. Since VR is a relatively new

118   technology, the period chosen for study selection was between 2007 and 2017. Finally, to

119   have an international overview, only articles written in English have been retained.

120   **Study selection and eligibility criteria**

121   We extracted 1373 references, 460 on Psycinfo and 913 on Medline. Four others found on

122   Google Scholar while reading on the subject were added, thus making a total of 1377

123   references. We removed 188 abstracts in duplicate, resulting in 1189 titles and abstracts to

124   read for selection. At this stage of the process, 1109 references were excluded.

125   In accordance with the first selection criterion, study populations that did not involve

126   health professionals (e.g. pedestrians, cyclists, students, athletes or patients) were removed, as

127   well as those working in smaller teams or solo (e.g. dentists, pharmacists and vets).

128   Following the second selection criterion, articles dealing with learning methods that were

129   not the focus of this study were deleted (e.g., e-learning, e-classroom, web-based learning,

130   telemedicine, mobile applications, social networks). According to the same criterion, some

131   references were also excluded because the term "virtual" was used without referring to virtual

132   reality (e.g., virtual teams, virtual communities, virtual classroom, virtual consultations and

133   virtual patients). There is a vast literature on the "Virtual Patient", focusing on the

134   interpersonal social skills of healthcare professionals required to facilitate accurate diagnosis,

135   give appropriate advice, and instruct patients about treatment. As these skills do not come

136   within the scope of our predefined set, these references were not included in the present

137   review.

138   Finally, according to the third criterion, articles that did not address NTS were excluded:

139   knowledge representation (anatomy, physiology, histology, 3D planning for radiotherapy),

140   technical skills, interpersonal patient-physician relationship (diagnosis, notification of critical

141   results or pathology), psychiatric disorders (dementia, post-traumatic stress disorder), or
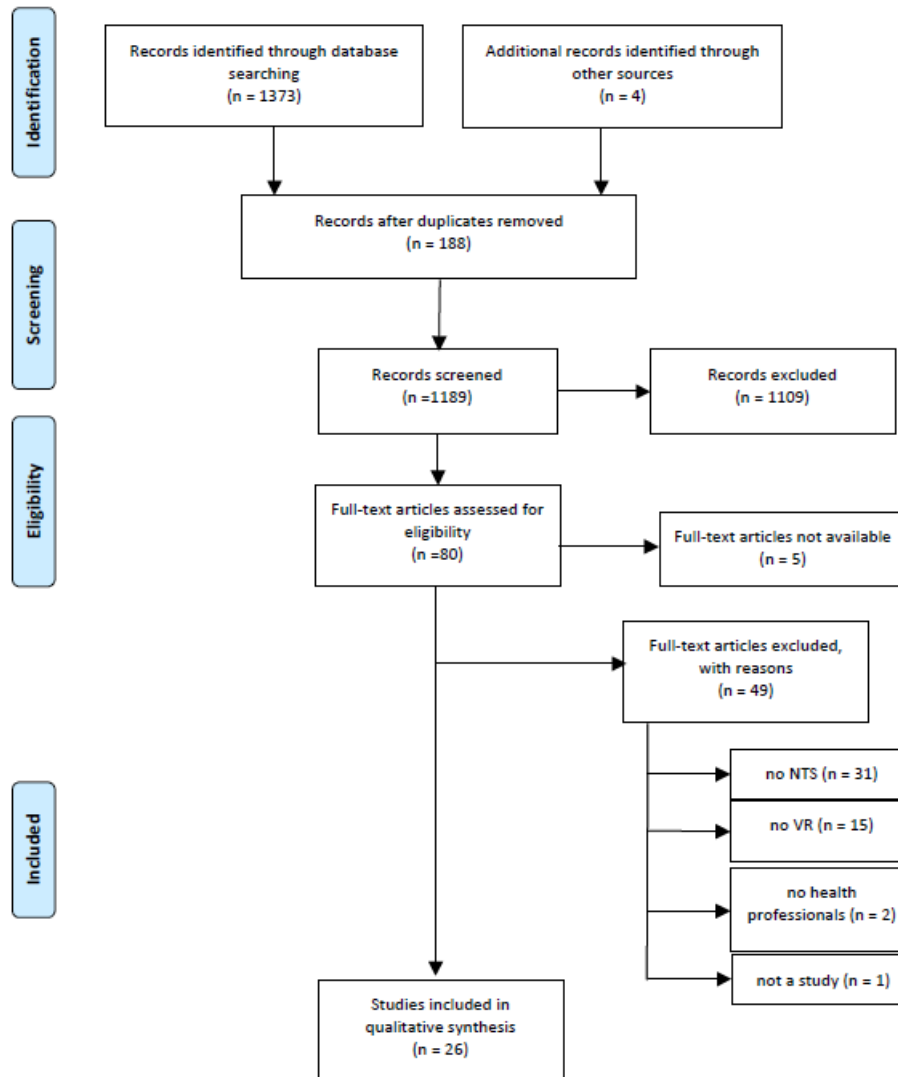
142 remediation (cognitive behavioral therapy, rehabilitation) that also use VR technologies but

143 are out of the scope of this review.

144   This inital selection included 80 articles with abstracts that were insufficiently clear to

145 decide whether or not they were eligible, and these were uploaded in order to read the full

146 text. However, five remained unavailable even after their main authors were contacted by e-

147 mail, which reduced the number of articles to read to 75.

148   After the full-text analysis, 49 articles were excluded for four reasons: 1) they did not

149 involve NTS (n= 31), 2) they did not use virtual reality (n= 15), 3) they did not involve health

150 professionals (n= 2), or 4) it was a review article with no experiment (n=1).

151 **Selection bias (interrater reliability)**

152   To check the validity of the study, a sample of the articles (30%) was independently

153 coded by the second author. Based on the eligibility criteria, the second coder decided

154 whether or not to examine an article in depth. After reviewing the abstract and full text, the

155 two coders, meaning the first and second authors, agreed on 26 articles, 11 that should be

156 selected and 15 rejected. Their opinions only diverged on the implementation of NTS in one

157 article (3.7%), which was eventually excluded (Cohen Kappa = .92). The selection process is

158 summarized in the flowchart (see Figure 1).

Identification

Records identified through database
searching
(n = 1373)

Additional records identified through
other sources
(n = 4)

Screening

Records after duplicates removed
(n = 188)

Records screened
(n =1189)

Records excluded
(n = 1109)

Eligibility

Full-text articles assessed for
eligibility
(n =80)

Full-text articles not available
(n = 5)

Full-text articles excluded,
with reasons
(n = 49)

no NTS (n = 31)

no VR (n = 15)

no health
professionals (n = 2)

not a study (n = 1)

Included

Studies included in
qualitative synthesis
(n = 26)

159

160 **Figure 1.** Flowchart of systematic review

161

162 To obtain a descriptive analysis of the results of this review, we drew up a comparative table,

163 focusing on medical specialties, VR simulator typologies, study populations, and assessd

164 NTS. For the latter, when assessment tools were mentioned, presence or absence of their

165 validity evidence in the virtual environment was also examined. Another criterion for the

166 analysis was outcomes, according to Kirkpatrick's levels (see Table 1, Supplemental Digital

167 Content 1, which shows the characteristics of the studies included in the review). This

168 framework was chosen because the Kirkpatrick Model[27] is frequently used to evaluate

169 training programs; for example, it was recently used to evaluate serious games for training

170 healthcare professionals[28]. This model has four levels: 1) affective reactions after the training

171 program, 2) improvement of knowledge and skills, 3) change of behavior and transfer of

172 skills in professional contexts, 4) increased patient care quality and reduced costs.

173

174 RESULTS

175 **Study characteristics**

176   VR is a recent technology and, as expected, the number of articles published per year

177 over the last decade on this subject is rather low although it has been increasing, with a peak

178 of seven articles in 2015. The median number of articles published per year is two

179 (interquartile range [IQR] = 3-1, *min* = 0, *max* = 7).

180   Regarding sample size, the average number of participants was 39.69 (*min* = 10, *max*

181 = 148, *SD*= 37.33). Looking more closely at their study design, 17 studies used an

182 experimental design (pre-test/post-test, group comparisons or control/test group

183 comparisons)[29–44], nine were observational studies[18–20,45–50], and one was based on

184 qualitative interviews[51].

185 **Medical specialties**

186   Emergency medicine[18,19,32,44,47] and health education[20,37,41,50,51] stand out from the

187 rest with five articles each, but the latter includes issues that potentially concern all specialties

188 or health professionals in different sectors. Next are urology[29,30,40,48] and

189 gastroenterology[33,34,45,46] with four articles each. A further eight articles dealt with

190 interprofessionality[18,32,37,41,47–50].

191 **Study populations**

192   Most of the studies include a range of professions: nurses feature in eight

193 articles[19,20,32,37,38,40,48,49], surgeons[33,35,38,39,43,45,46] in seven, and five articles mention other

194 professionals[18,19,32,37,38]. With regard to students, 12 articles involve residents or postgraduate

195   trainees[18,33,35,36,38–40,42,44–46,48], ten concern health students regardless of their level or

196   specialty[30,31,39,41,44–47,50,51], and three articles mention trainees[29,34,38].

197   **VR systems**

198   In the studies selected for review, two technologies are equally represented: Screen-

199   based VR simulators in 12 studies[29,30,33,34,36,38–40,42,43,48,49] and virtual worlds in 12 articles[18–

200   20,31,32,35,37,41,44,47,50,51]. Immersive virtual worlds are less common, as they are found in only

201   three studies[39,45,46].

202   **NTS and assessment metrics**

203   Among the 26 studies, the most frequently investigated NTS is teamwork, which is

204   mentioned in 19 articles[18,19,29–32,34,35,37,38,40–42,45,47–51]. After that is communication

205   (15/26)[18,29,30,32–34,37,38,40–42,47–50], followed by situation awareness (10/26)[18,20,29–31,34,42,46,48,51],

206   decision-making (8/26)[18,20,29,30,32,34,40,42], leadership (8/26)[18,29,30,34,37,41,42,44], and stress

207   management (6/26)[18,36,39,43,44,46]. Most studies measured more than one NTS construct, with

208   the exception of three articles focusing specifically on stress management[36,39,43], three others

209   on teamwork[19,35,45], and one on communication[33].

210   Specific metrics for NTS assessment are mentioned or described in detail in 16

211   articles[18,20,29–37,41–44,49], ten of which[18,29,30,33,34,37,41–44] mention and use specific validated

212   assessment tools for NTS in the operating room or in a clinical environment (i.e. NOTECHS,

213   NOTSS, T-NOTECHS, CGRS, M-OSANTS, TOSCE, T-TAQ, SURG-TLX, EMCRM).

214   These assessment tools are presented as validated for simulation[52,53], but none of them

215   mention their validation in the very specific context of VR simulation. Four articles[31,34,36,42]

216   use scales designed for a specific NTS, but are not specific to the operating room or to health

217   professionals (i.e. situation awareness, self-efficacy, anxiety). Six articles[18,20,32,35,43,49] use

218   their own tools or checklists, or open-ended questions rather than a questionnaire. Again,

219   none of these tools or checklists take into consideration the specificity of VR simulation, but

220   are simply transferred from real life or traditional simulation contexts.

221   **Outcome measures**

222   The levels of assessment of the simulators or scenarios used in the studies reach

223   Kirkpatrick's level 1 (affective reactions) in 19 articles[18–20,29,30,32,37–48,51] and level 2

224   (learning: attitude, knowledge) in 18[18,20,29–37,39,41–44,49,50]. Level 3 (behavior) is only reached

225   in two articles[33,34] that describe a test of skills transfer to the clinical environment in order to

226   evaluate behavioral changes among trainees. No studies were found that reached level 4

227   (results) evaluating the effect of simulation on patient care quality and cost.

228   Overall, this review demonstrates that few medical specialties use virtual reality for

229   NTS training. The most frequently used systems are screen-based VR simulators or virtual

230   worlds, while immersive virtual worlds are rarely used. The most frequently studied NTS are

231   the interpersonal and interprofessional social skills needed for effective medical teams,

232   including teamwork and communication, together with situation awareness, which is a crucial

233   cognitive ability.

234   **Objectives and findings of the studies**

235   Two main categories of study objectives emerged from our review (see Table 2, Supplemental

236   Digital Content 2, which shows the objectives, measures and main findings of the studies).

237   The majority of studies are simulator or scenario centered, with a clear goal of

238   establishing the acceptability of the technology for NTS training. This is the goal of 20

239   articles[18–20,29,31,35–39,41–49,51]. As VR has only been introduced in healthcare training recently,

240   it seems logical to assess this first. The general conclusion of these studies is that VR

241   simulators offer promising opportunities for NTS training of health professionals. Their

242   acceptability as an NTS training tool is validated either directly[37,41] or through one or more

243   of its predictors as defined by Nielsen's model of system acceptability[54]: validity or

244 fidelity[18,29,38,39,42,45,46], usefulness or utility[41,42,44,46], efficiency, effectiveness or

245 efficacy[19,35,47,48], and usability[20,43,47]. The acceptability of VR simulators is not assessed

246 alone but together with teamwork[19,35,37,38,41,45,47,48,51], situation awareness[20,31,46], stress

247 management[39,43,46], self efficacy[36], and leadership[44], or with several NTS using a dedicated

248 assessment tool such as NOTECHS or NOTSS[18,29,42].

249   The purpose of the six remaining articles, among the most recent ones of this review,

250 is to propose different uses of VR simulation. One includes a virtual reality program that

251 focuses on communication tools as an initial introduction to team communication

252 strategies[50]. The other five are curriculum centered, their objectives being to incorporate

253 NTS training modules using VR simulators in the medical curriculum: four of them describe

254 distributed simulation[30,33,34,40], in other words, the use of VR simulators initially designed for

255 teaching technical skills in wider settings or scenarios[29], and the fifth[32] addresses

256 emergency preparedness using a virtual world.

257

258 DISCUSSION

259   There are few medical specialties that use virtual reality simulation for NTS and their

260 goals vary. First, virtual worlds are used in healthcare education and in emergency medicine

261 to provide practice opportunities for rare events or extreme situations that are difficult to set

262 up in real life. Second, screen-based VR simulators are used for technical skills training in

263 domains involving laparoscopic surgery or robotic-assisted surgery, such as

264 gastroenterology[33,34] and urology[30,40] curricula. In the latter, NTS are introduced

265 progressively in VR simulation scenarios as trainees develop their technical skills[55]. This is

266 congruent with the conclusions of Shamim-Khan et al. (2013)[40] and Rudarakanchana et al.

267 (2014)[38] who observed that junior trainees focus more on technical skills and feel that the

268 introduction of NTS adds stress and anxiety due to the need to multitask. It also follows the

269   hierarchy of core, procedural and team skills proposed by Windsor (2009), who illustrates it

270   with a musical analogy of note, melody and harmony: just like musicians begin to learn

271   playing a note before trying to play a melody and then join an orchestra, core skills such as

272   knot tying, dissecting or suturing, for example, should be trained before procedural skills (i.e.

273   how to dissect out a pathology). Then, team skills can be trained[12]. Nevertheless, this

274   progression does not enjoy consensus and must be considered for each set of NTS. For

275   example, the addition of cognitive skills likely to help error-detection to technical skills

276   training can result in more effective learning[56].

277   Screen-based VR simulators or virtual worlds are thus the most frequently used

278   systems. Immersive virtual worlds are less commonly used and are mentioned in only three

279   articles[39,45,46], two of them using head-mounted displays[39,46]. They were published between

280   2015 and 2016, which corresponds to the time when HMD such as Oculus Rift or HTC Vive

281   became mainstream, even though immersive VR simulation is not a new technology in

282   healthcare as it has been used since the early 2000s[57]. It will be interesting to see how these

283   devices will be used in the future as their comfort and fields of view improve, and how they

284   can be integrated into new surgical training modules.

285   One of the major interests of VR is its realism, which is stressed in several

286   studies[29,38,39,42,45,46]. Even though avatars may sometimes behave awkwardly, and haptic

287   feedback may be approximate or missing, participants still recognise the main features of their

288   environments or work organizations. This contributes to the feeling of immersion mentioned

289   in two articles[19,39]. These two notions are of particular interest in that they help trainees gain

290   confidence[19,29,37,42] by providing them with new learning opportunities, such as discovering

291   an emergency room without stress[47], or being able to develop the skills needed to react to

292   disasters when training in an unfamiliar environment[32]. However, the degree of realism

293   expected in a VR simulator has to be questioned for each scenario: if more haptic feedback,

294 such as somatosensations or kinematic interactions, is expected with a high degree of fidelity,

295 too much realism for an avatar in virtual worlds can lead to anxiety and rejection, due to the

296 uncanny valley phenomenon. According to this theory, participants react favorably to

297 environments that are very similar or very dissimilar to reality, but are uncomfortable with

298 intermediate realism[58,59].

299   The affective component of learning has been described as one of the four key criteria

300 for simulation-based learning, which is centered on the learners' needs and for which

301 motivation and self-efficacy are key concepts[60]. With this in mind, many VR simulators

302 allow participants to replay their session, helping them recognize and analyze both their

303 interactions and their emotions[61]. The emotional impact of VR simulation on self-efficacy is

304 emphasized and appreciated by trainees[44], as well as the opportunity provided by some

305 scenarios to communicate with other disciplines before any clinical practice[47] or to

306 experience human interactions in problematic environments[51]. In terms of motivation, VR

307 simulation seems to be of particular interest as it is described as a highly rated learning

308 experience[37], preferred to standard didactic lectures[46], and seen as excellent preparation for

309 clinical situations[47].

310   Another interest of VR simulation is data generation because VR simulators can track

311 and record every action. The data are used to give learners feedback on their performance and

312 progress over time through their profile, allowing them to verify their skills acquisition and

313 become proactive in their learning. But they also help educators better understand their

314 students' learning processes, allowing them to adjust their inputs and complement their

315 traditional teaching methods with appropriate simulations[50]. In addition, as most VR

316 simulators and scenarios can be used in different cultural and geographic environments, the

317 collected data could also be used for further intercultural studies of NTS[50].

318   The most frequently studied NTS are interpersonal and social skills, such as teamwork

319   and communication. As a cognitive skill, situation awareness also features frequently, as it is

320   a crucial personal skill, especially in dynamic environments such as medical settings where it

321   can impact decision-making and communication[62]. While the capacity of VR environments

322   to recreate realistic situations makes it suitable for stress management training, none of the

323   articles selected for this review discuss fatigue management. Even though VR is used to that

324   end for patient-focused psychological therapy, healthcare professionals may not perceive

325   fatigue and stress management as an issue warranting the use of simulation scenarios.

326   Most studies are set up to assess a simulator or scenario, reaching Kirkpatrick's level 1

327   (affective reaction) or 2 (learning). According to these articles, VR simulators offer NTS

328   training opportunities for healthcare students, as their feasibility, usability, validity,

329   acceptability or effectiveness have been validated in different situations. However, their

330   conclusions recommend further studies. The impact of VR simulation on NTS training still

331   requires more systematic assessment in routine clinical practice in order to validate a possible

332   transfer of skills for health professionals and to determine whether it achieves its ultimate goal

333   of improving patient safety (Kirkpatrick's level 4). This is challenging because patient safety

334   is multifactorial, and because, as this review shows, validated tools to assess NTS are not

335   systematically used, making large-scale comparisons difficult. Furthermore, few studies

336   mention the inclusion of NTS training using VR simulators in the curriculum as a way of

337   helping students progress.

338   To continue the development of VR systems for NTS training, four lines of research

339   are required. First, studies are needed regarding the validation of specific NTS assessment

340   tools for VR simulation. So far, these tools have not been validated, which may impact their

341   evaluation in these specific environments. Second, studies are needed to estimate the different

342   technical possibilities offered by VR technologies for NTS training, such as mixed and

343 augmented reality. Third, debriefing is considered a key element for skills transfer in

344 simulation-based training[63]. While this has been studied in different simulation contexts[64]

345 and with different frameworks[65], specific debriefing methods for VR simulation are scarce.

346 Avatar-based debriefing[66], for example, could be developed for health education. Fourth,

347 future studies should evaluate the effects of these training methods at different levels of

348 learning: attitudes, skills, transfer of skills, and cost-benefit ratio. In particular, more studies

349 are needed in the near future to investigate the transfer of skills to the operating room

350 (Kirkpatrick's level 3) and to validate VR simulation as an efficient training tool for NTS. But

351 what is really missing is the impact of these tools on the quality of care for patients and on the

352 overall cost of care (Kirkpatrick's level 4), which has not yet been established.

353 **Limitations**

354 As our search was limited to 2 databases, there is a risk that some relevant articles

355 were missed. The decision to select only articles written in English also excludes studies

356 published in other languages. Our search may also have been limited by the definitions of VR

357 and NTS, as the keywords may not have used a very specific terminology, such as *avatar*, *3-*

358 *dimensional*, *HMD*, *mixed* or *augmented reality*. Augmented reality, the integration of digital

359 information into the physical world in real time, or mixed reality, the use of real objects to

360 enhance simulations, are related to virtual environments or VR settings[67]. Thus, some studies

361 may use simulators based on VR technology but not specify it in their keywords. However, in

362 order to be as comprehensive as possible for this review, the search request was replicated,

363 replacing virtual reality with augmented and mixed reality: 58 articles were found but none of

364 them dealt with NTS training.

365 Another limitation of this review is that NTS are not always defined and explicitly

366 operationalized in studies and are sometimes concealed behind technical skills on which they

367 are highly dependent. Finally, a limitation concerns Virtual Patient simulation, focusing on

368   the interpersonal social skills of healthcare professionals with their patient. It was decided that

369   this did not come within the set of skills defined for this review. However, there is a vast

370   literature on Virtual Patients, which are frequently used in virtual worlds and virtual

371   immersive environments. A systematic literature review concerning the development of

372   interpersonal social skills and communication with patients via VR could thus be examined in

373   another paper.

374

375   **Conclusion**

376   In conclusion, VR simulation systems are a recent development in health education. The use

377   of VR simulators has increased for technical skills training, but to a lesser extent for NTS (i.e.

378   cognitive and interprofessional social skills). This systematic review of articles published

379   from 2007 to 2017 shows that screen-based VR simulators or virtual worlds are the most

380   frequently used systems, and teamwork, communication or situation awareness are the most

381   frequently addressed NTS. The evaluation of VR systems as training tools is essential, but

382   there has, so far, been little systematic research. The majority of studies evaluate the usability

383   and acceptability of VR simulation, and few studies have measured the effects of VR

384   simulation on non-technical skills development.

385   Nevertheless, the development of VR technologies and the portability of VR systems

386   offer a very promising outlook for the future training of healthcare professionals. The wide

387   range of possible scenarios that can be simulated, especially for NTS training, will

388   undoubtedly contribute to the "successful integration of simulation throughout the fabric of

389   healthcare"[11].

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579   **Figure Legends**

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581   **Figure 1.** Flowchart of systematic review

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

584   review

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586   Supplemental Digital Content 2. PDF, **Table 2.** Objectives, measures and main findings of

587   studies included in the review

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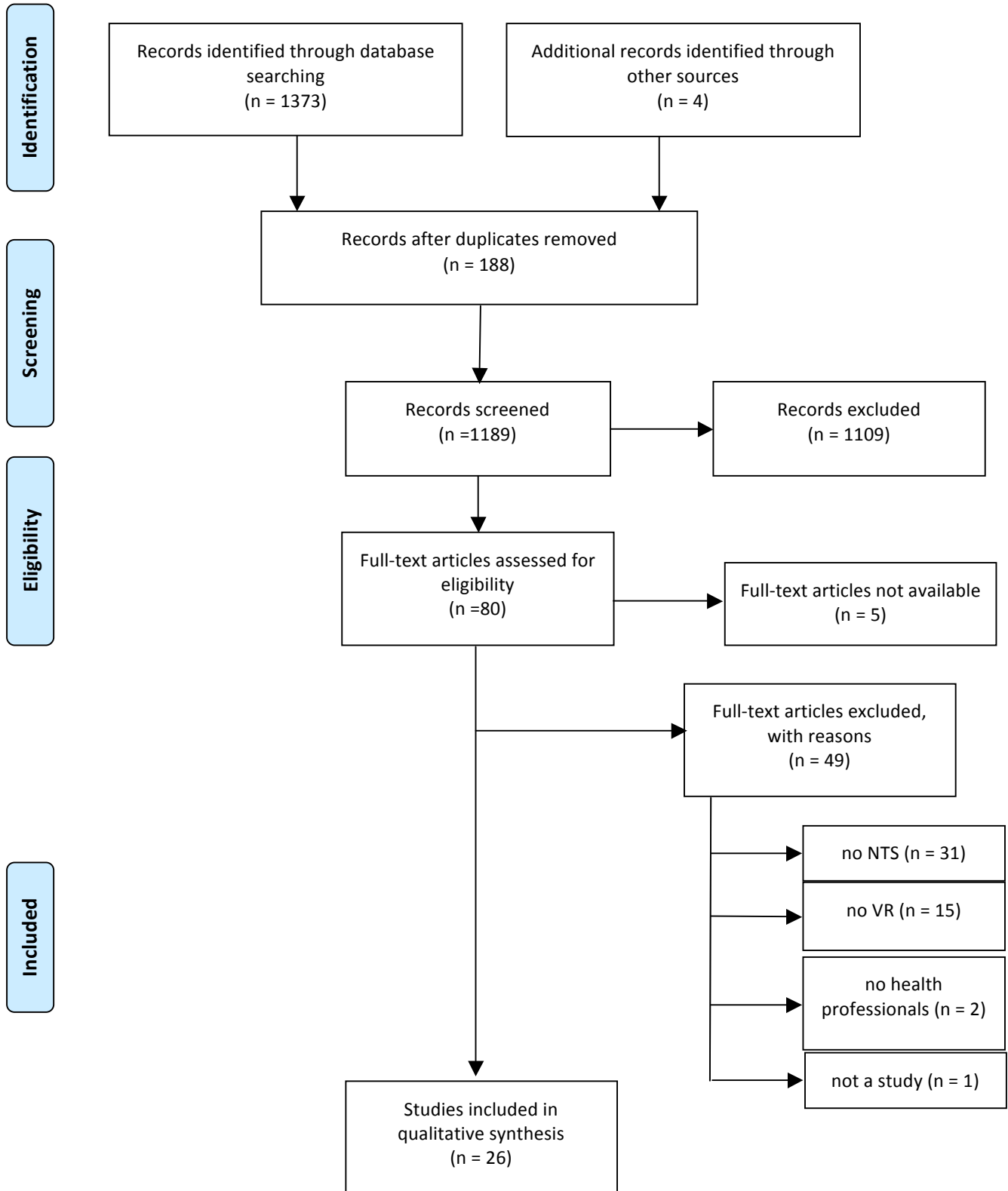
Figure 1. Flowchart of systematic review

Table 1

DOMAIN	ARTICLE REFERENCES	N	POPULATION	VIRTUAL REALITY SYSTEM			VR SIMULATOR	NON TECHNICAL SKILLS							OUTCOMES (KIRKPATRICK's LEVEL)			
				SB	VW	IVE		SA	DM	COM	TW	LDS	SM	FM	1	2	3	4
emergency medicine	Cohen et al., 2013[41]	23	Ambulance practitioner, surgical registrars, emergency department consultants		X		Second Life® + OpenSimulator	X	X	X	X	X	X		X	X		
emergency medicine	Greci et al., 2013[27]	14	Emergency department nurses and hospital administrators		X		MUVE (Multi User Virtual Environment) using Second Life®		X	X	X				X	X		
emergency medicine	Heinrichs et al., 2010[43]	22	Physicians and nurses		X		VED II (Virtual Emergency Department) an online virtual world				X				X			
emergency medicine	King et al., 2012[45]	15	Medicine, nursing, respiratory therapy, pharmacy, speech language pathology, diagnostic medicine sonography students		X		Second Life®			X	X				X			
emergency medicine	Youngblood et al., 2008[39]	30	Medical graduates and students		X		3D Virtual World (internet-based virtual emergency department)					X	X		X	X		
health education	Hudson et al., 2015[44]	12	Nurses		X		Second Life®	X	X						X	X		
health education	Riesen et al., 2012[32]	60	Recent graduates from nursing, paramedic, police and child and youth service programs		X		Web.Alive™			X	X	X			X	X		
health education	Rogers, 2011[49]	16	Nursing students		X		Second Life®	X			X				X			
health education	Sweigart et al., 2016[36]	109	Health professional students		X		VLE with avatar			X	X	X			X	X		
health education	Umoren et al., 2017[48]	144	Nursing and medical students		X		VLE with avatar			X	X					X		

Specialty	Author	N	Participants			Simulator											
urology	Brewin et al., 2015[24]	20	Experienced and trainee urologists	X		TURP Simulator (Limbs and Things©, Bristol, UK) distributed simulation environment	X	X	X	X	X			X	X	
urology	Brunckhorst et al., 2015[25]	32	Medical students	X		Uro Scopic Trainer (Limbs and Things©, Bristol, UK) + Uro MentorTM and Perc-mentor (Simbionix USA Corp., Cleveland, OH, USA)	X	X	X	X	X			X	X	
urology	Paige et al., 2007[46]	10	Senior surgery resident, nurse anesthesist and circulating nurse	X		Simbionix LapMentor	X		X	X				X		
urology	Shamim Khan et al., 2013[35]	38	Specialist registrars of different grades and urological nurses	X		Uro MentorTM and Perc-mentor (Simbionix USA Corp., Cleveland, OH, USA)		X	X	X				X		
gastroenterology	Dorozhkin et al., 2016[42]	49	Students to attending surgeons		X	VEST OR Simulator (Virtual Electrosurgical Skill Trainer) with Oculus Rift HMD	X					X		X		
gastroenterology	Abelson et al., 2015[40]	33	Surgeons, residents and medical students		X	ICE STORM platform (Integrated Clinical Environment; Systems, Training, Operations, Researsh, Methods) (Lockheed Martin Corporation, Oswego, NY)				X				X		
gastroenterology	Grover et al., 2015[28]	33	Novice endoscopists	X		EndoVR endoscopy simulator (CAE Healthcare Canada, Montreal, Quebec, Canada)			X					X	X	

Specialty	Author	N	Participants				Simulator / System										
gastroenterology	Khan et al., 2017[29]	42	Novice endoscopists	X			EndoVR endoscopy simulator (CAE Healthcare Canada, Montreal, Quebec, Canada)	X	X	X	X	X				X	X
laparoscopic surgery	Maschuw et al., 2008[31]	40	Inexperienced and advanced surgical residents	X			LapSim® (Surgical Science, Goteborg, Sweden)						X			X	
laparoscopic surgery	Sankaranarayanan et al., 2016[34]	16	Surgeons and residents	X		X	Gen2-VR© system (HMD) and Gen1 VR (VBLaST-PT©)						X			X	X
vascular surgery	Rudarakanchana et al., 2014[33]	32	Experienced or trainee endovascular specialists, interventional radiology trainees and assistants, interventional radiology or vascular surgery consultants, scrub nurses and radiographers	X			(VIST)-C, Mentice, Gothenburg, Sweden			X	X				X		
vascular surgery	Willaert et al., 2011[37]	20	Junior medical residents	X			AngioMentorExpress™ (Simbionix USA Corp., Cleveland, OH, USA)	X	X	X	X	X				X	X
cardiology	Khanal et al., 2014[30]	148	Certified clinicians		X		Second Life®			X					X		
cardiopulmonary resuscitation	Creutzfeldt et al., 2010[26]	12	Medical students		X		Multiplayer virtual world (OLIVE, SAIC inc.)	X		X					X		
Orthopedic surgery	Wucherer et al., 2015[38]	19	Junior surgeons	X			VR surgical procedural simulator						X			X	X
Post Anesthesia Care Unit (PACU)	White et al., 2015[47]	43	Nurses	X			2 Virtual Humans displayed on 2 screens (Wizard of Oz setup: converse with trainee)			X	X				X		

Note. N= Number of participants. Virtual reality system is coded : SB : Simulation-based virtual reality simulator ; VW : virtual world ; IVE : Immersive virtual environment.

Non technical skills are coded : SA : Situation awareness ; DM : Decision making ; COM : Communication ; TW : Teamwork ; LDS : Leadership ; SM : Stress management ;

FM : Fatigue management.

Table 2

ARTICLE REFERENCES	OBJECTIVES	OUTCOME MEASURES	MAIN FINDINGS
Abelson et al., 2015[40]	• Determine feasability of creating a VR operating room • Evaluate simulator for face and construct validity	• Construct validity : metric data • Face validity : Likert-scale questionnaires (realism, inclination to use), Bedford Workload Scale and modified NASA-Task Load Index scale	• Training environment evaluated as realistic • 82% of participants felt low workload or had enough spare capacity for additional tasks. All participants had minimal mental, physical, and temporal demand and none reported requiring a high amount of effort to complete the simulation • No statistically significant difference between attendings and trainees for all responses
Brewin et al., 2015[24]	• Assess validity of distributed simulation environment for NTS training • Evaluate educational impact	• Face, content and construct validity : questionnaires • NOTECHS • Educational impact : questionnaires completed after the simulations	• Good learning environment for NTS, judged realistic • NTS of experienced urologists significantly better than trainees establishing construct validity • All trainees felt more confident • Kirkpatrick level 1 evidence and indirect evidence of learning (Kirkpatrick level 2)
Brunckhorst et al., 2015[25]	• Evaluate feasibility, acceptability, content validity and educational impact of simulation-based curriculum integrating NTS	• NOTSS • Content validity : post-study questionnaire	• 100 % of experts agreed integration of full immersion simulation was a useful tool for teaching non-technical skills • Curriculum-trained group : significantly higher NOTSS scores than control group • Feasibility of delivery of the curriculum was rated 9.27/10, enjoyment and productivity was scored at 9/10, difficulty of curriculum rated 4.93/10
Cohen et al., 2013[41]	• Determine feasability and reliability of skills assessment	• 7-point NTS competency scale for paramedics and T-NOTECHS (Trauma Non-Technical Skills Scale)	• Significant and strong correlations between expert assessors suggest reliability to carry out NTS assessments in virtual environments in major incident scenarios • No significant correlations between expert and self-assessment for NTS
Creutzfeldt et al., 2010[26]	• Evaluate (SA) Situation Awareness self assessment instrument • Analyze SA training in virtual settings	• SA : 9-items questionnaire + trainee's own opinion of his or her SA during training • Concentration/attention : 10-items instrument	• SA increased from the first to the last scenario • Perception of SA corresponded to calculated SA • Correlation between SA and concentration
Dorozhkin et al., 2016[42]	• Establish face validity, usefulness and fidelity of virtual OR fire training	• Perceived usefulness and face validity : questionnaire	• Face validity established with high degree of satisfaction and usefelness • 33/49 participants preferred this modality of training over a traditional one • 47% of subjects offered suggestions on how to make the simulator look and feel more realistic

	module in VEST simulator	• Open-ended questions : improvements and preferences	
Greci et al., 2013[27]	• Develop and evaluate a virtual learning curriculum	• Open-ended questions : technical challenges, course content, immersion • Interviews and focus groups	• All students improved postcourse disaster preparedness knowledge scores • Emerging themes : team communication, team planning, team decision making • Functioning in an unfamiliar environment was evaluated as requiring similar skills as during a disaster where rapid decision making with incomplete information
Grover et al., 2015[28]	• Validate a simulation-based curriculum for cognitive and integrative competencies	• Global performance : Integrated Scenario Global Rating Form (ISGRF) • Communication skills : Communication Global Rating Scale (CGRS)	• Participants significantly outperformed control group with respect to colonoscopy-specific performance, communication skills and global performance during the integrated scenario format assessment 4 to 6 weeks after training
Heinrichs et al., 2010[43]	• Determine efficiency of a Virtual Emergency Department to train mass-casualty incidents (team skills)	• Immersion, level of comfort, confidence, usefulness for clinical skills and team training : questionnaire • Focus group	• 68% of the participants felt immersed • Everyone felt they learned how to interact in the simulation • "Useful","Very Useful", or "Extremely Useful" for clinical skills training for 82% participants • Participants gained confidence in ability to handle incidents
Hudson et al. , 2015[44]	• Examine perceived usability of Second Life (SL) as an immersive virtual environment • Study clinical decisions	• Perceived usability : System Usability Scale (SUS) • Situation awareness : questionnaire with 27 items	• SL considered usable in providing practice with complex scenarios of insulin administration. Perceived usability decreased among experienced nurses • No significant association between years of nursing experience and SA scores was found.
Khan et al., 2017[29]	• Evaluate effectiveness of a simulation-based training curriculum of NTS on novice endoscopists' performance of clinical colonoscopy.	• Modified Objective Structured Assessment NTS (M-OSANTS) • ISGRF • Integrated Scenario Communication Rating Form (ISCRF)	• To inform the potential implementation of NTS into postgraduate gastrointestinal curricula, non-technical performance will be determined by comparing the scores from the M-OSANTS, ISGRF, ISCRF and GSE for both conditions and at 3 different times

		General Self Efficacy Scale (GSE)	
Khanal et al., 2014[30]	• Evaluate efficacy of delivering advanced cardiac life support (ACLS) using a virtual reality simulator	• Team performance : electronic checklist based on ACSL guidelines assessed by experts • Final questionnaire on training experience	• No statistically significant difference in improvement of skills between groups • VR-based ACLS training simulator is significantly cheaper, easier to organize, and facilitates users to practice in a team from disparate locations without requiring an evaluator
King et al., 2012[45]	• Evaluate usability of the environment • Evaluate learning effectiveness of scenarios • Evaluate integration into curriculum	• Debriefing: exploration of team interactions • Satisfaction survey and questions on learning in the environment	• Students appreciated to visualize the Emergency Room setting in a low-pressure situation • It provided students with opportunities to communicate with other disciplines, which they would not have had until in clinical practice • Students felt it was great preparation for non-virtual scenarios for clinical situations
Maschuw et al., 2008[31]	• Explore impact of self-belief of surgeons on laparoscopic performance using a VR simulator	• General Self Efficacy (GSE) score • Technical metrics : time, economy of motion and damage parameters	• No significant differences were found in gender or in GSE score between both groups • Motions of advanced trainees were more economic than novices, but no significant difference in time, error score and right instrument movements. • Novices GSE scores negatively correlates with economy of motion and time, while for advanced residents it is independent of laparoscopic performance
Paige et al., 2007[46]	• Evaluate perception of simulated scenarios • Evaluate effectiveness for communication and teamwork during OR crisis	• Teamwork assessment: communication, coordination and situational awareness • Questionnaire on perception of training effectiveness and specific attributes of teamwork	• Sessions were found effective/very effective for improving teamwork, communication and recognizing problems in the OR
Riesen et al., 2012[32]	• Improve interprofessional competencies • Determine acceptability of a blended learning environment	• Self-perceived changes in interprofessional attitudes and competence : IEPS, ICCAS • Team performance assessment : TOSCE • Students perceptions : program assessment tool, and 16-item questionnaire	• Significant differences pre and post workshop were found in ICCAS and IEPS scores • Significant improvement accross the 3 simulations in all competencies • Program and learning experience were highly rated • Learner confidence and performance can be improved through education delivered in a virtual environment

	Aim	Methods / Assessment	Results
Rogers, 2011[49]	• Investigate how a simulation in Second Life can encourage teamwork and collaborative problem solving	• Individual interviews: clinical judgement, teamwork and interpersonal skills	• Critical Life simulation is an artificial social structure where problem-based scenarios can be created • Students can co-construct mental models expericencing human interaction in problematic environment • Critical Life could develop cognitive understanding of team-orientated procedural and problem-based decision-making skills.
Rudarakanchana et al., 2014[33]	• Evaluate feasability of integration of a VR simulator in an immersive simulation • Investigate construct and face validity for training human factor skills during a crisis scenario	• Questionnaires : realism (face validity) and potential for use in team training for both technical and human factor skills	• Experienced team leaders were significantly faster than trainees • Realism of the environment was scored very high and realism of the VR simulator was rated high • Trainees rated the simulation more useful for technical skills training, and experts believed it more useful in enhancing communication skills • Feasability, face and construct validity of a realistic crisis scenario integrating a VR simulator has been shown
Sankaranarayanan et al., 2016[34]	• Establish face and construct validity of an immersive VR system • Assess the effects of distractions and task interruptions	• 5-point Likert-scale subjective feedback questionnaire : realism, immersive experience, and effects of distractions and interruptions	• Performance decreased with added distractions and interruptions • Subjects rated interruptions very high in their ability to affect performance and music distraction received the lowest mean rating • Simulators rated as realistic to present distractions and interruptions in a simulated OR, immersion evaluated as intermediate.
Shamim Khan et al., 2013[35]	• Establish feasability and acceptability of simulation training for NTS	• Interviews : perception of simulated environment • Feasability, acceptability and construct validity : questionnaires	• Construct-validity established : Seniors performed significantly better than junior trainees in all simulation sessions • Increased cognitive load for trainees on VR simulator : pressure/anxiety about the unknown and interplay between technical and non-technical skills
Sweigart et al., 2016[36]	• Test utility and acceptability of a virtual learning environment (VLE) • Examine change in teamwork attitudes in interprofessional communication	• Effectiveness : TeamSTEPPS -TAQ (Teamwork Attitude Questionnaire) • Utility : Time to complete scenarios and answers to questions within scenarios • Acceptability : Likert-scale type questions	• Positive student feedback on ease of use and perceived effectiveness for teaching communication and professionalism t • Scores on the T-TAQ revealed significant positive changes in leadership, situation monitoring, mutual support, and communication

Umoren et al., 2017[48]	• Propose an introduction to TeamSTEPPS communication tools for nursing and medical students	• MCQ questions during the progression of the scenarios : designation of a TeamSTEPPS strategy, identification of a missing component of this strategy and possible selection of another strategy	• Learner recognition of the SBAR communication tool was high accross groups • Knowledge of which component of SBAR was missing was lower accross groups • Students demonstrated increased correct recognition of strategies as they progressed through the scenarios • When they had the choice, students were more likely to chose the Two-Challenge Rule than the CUS
White et al., 2015[47]	• Study quality of information transfer and teamwork during a simulated critical event • Assess gathering and sharing of critical information	• Communication skills: Critical Patient Information checklist and Interprofessional Communication Skills checklist	• A substantial percentage of participants did not share 3 critical items and 87% of the participants missed a dosage error • Items on Communication Checklist were missed by a substantial number of participants (introduction of self and task, closed-loop communication) • No statistically significant relationship between scores and years of nursing •
Willaert et al., 2011[37]	• Evaluate whether a part-task rehearsal of a surgical procedure on a VR simulator is as effective as a full-task one	• Non-technical skills : NOTSS • Face validity and usefulness : questionnaire • Emotional, cognitive and physical stress : short version of State Trait Anxiety Inventory (STAI) questionnaire	• Both groups scored acceptable scores in all categories of NOTSS • Simulated procedure was found highly realistic. Simulation helped participants in decision-making, confidence, reduction of anxiety, and communication. Both strategies were as effective on stress levels • For a moderately difficult case, a part-task patient specific VR rehearsal is as effective as a full-task one
Wucherer et al., 2015[38]	• Measure usability of simulator • Explore relationship between mental workload and surgical performance during crisis	• Cognitive workload : 3-item questionnaire and Surgery Task Load Index (SURG-TLX) • Questionnaire : face validity and training value	• Training resulted in a decrease of time, but significantly slower performances when crises • The more workload was experienced, the poorer was the surgical performance. • Telephone call seemed more disturbing compared to patient discomfort
Youngblood et al., 2008[39]	• Evaluate VLE for leadership and trauma management by comparing users' experience with a	• Leaderdhip skills : EMCRM (Emergency Medicine Crisis Resource Management) scale	• All participants evaluated simulation as "useful" or "very useful" to assess and manage trauma patients in Emergency Department (ED) • All participants showed significant improvement in team leadership • Students emphasized emotional impact of simulation in VLE • Both mannequin-based and VLE simulation of ED cases are valid training methods to improve EMCRM team leadership skills

high-fidelity patient simulator (PS)	• Assessment of learning experience : debriefing and questionnaire