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

20
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Summary statement

27

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.

39

40

41 **Keywords:** virtual reality simulation; non-technical skills; healthcare training; medical
42 education; systematic review.

43

44 **Virtual reality simulation in non-technical skills training for healthcare professionals: a**
45 **systematic review**

46 **Introduction**

47 With the publication of *To Err is Human* in 1999⁽¹⁾ and *Safety at the Sharp End*⁽²⁾,
48 attention was drawn to the importance of human factors in operational teams, identifying
49 skills that were first described for crew resource management in aviation and other high-risk
50 industries. Flin described these non-technical skills (NTS) as “the cognitive, social and
51 personal resource skills that complement technical skills, and contribute to safe and efficient
52 task performance”⁽²⁾. In Flin’s taxonomy, NTS included individual cognitive skills (e.g.,
53 situation awareness, decision-making, coping with stress and management of fatigue) and
54 interprofessional social skills (e.g., cooperation and teamwork, conflict resolution,
55 leadership). Evidence that human factors have an impact on surgical performance⁽³⁾ led to the
56 development of training programs focusing on NTS to improve patient safety⁽⁴⁾. Using Flin’s
57 taxonomy, several tools (i.e. ANTS, NOTSS, SPLINTS) have been designed to provide
58 surgical teams with a common language to discuss and develop the human factors that are
59 critical for patient safety⁽⁵⁾.

60 Several studies have demonstrated the efficiency of simulation for knowledge
61 acquisition and for technical⁽⁶⁻⁸⁾ and non-technical^(9,10) skills training in healthcare. Training
62 healthcare professionals to manage rare or critical events in a standardized manner and
63 without risk for the patient has become a major challenge⁽¹¹⁾. Although the benefits of
64 simulation have been well documented, the human resources required for mannequin or
65 standardized patient-based simulation and the availability of human resources in simulation
66 centers remain scarce. However, various simulation methods have recently been developed
67 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

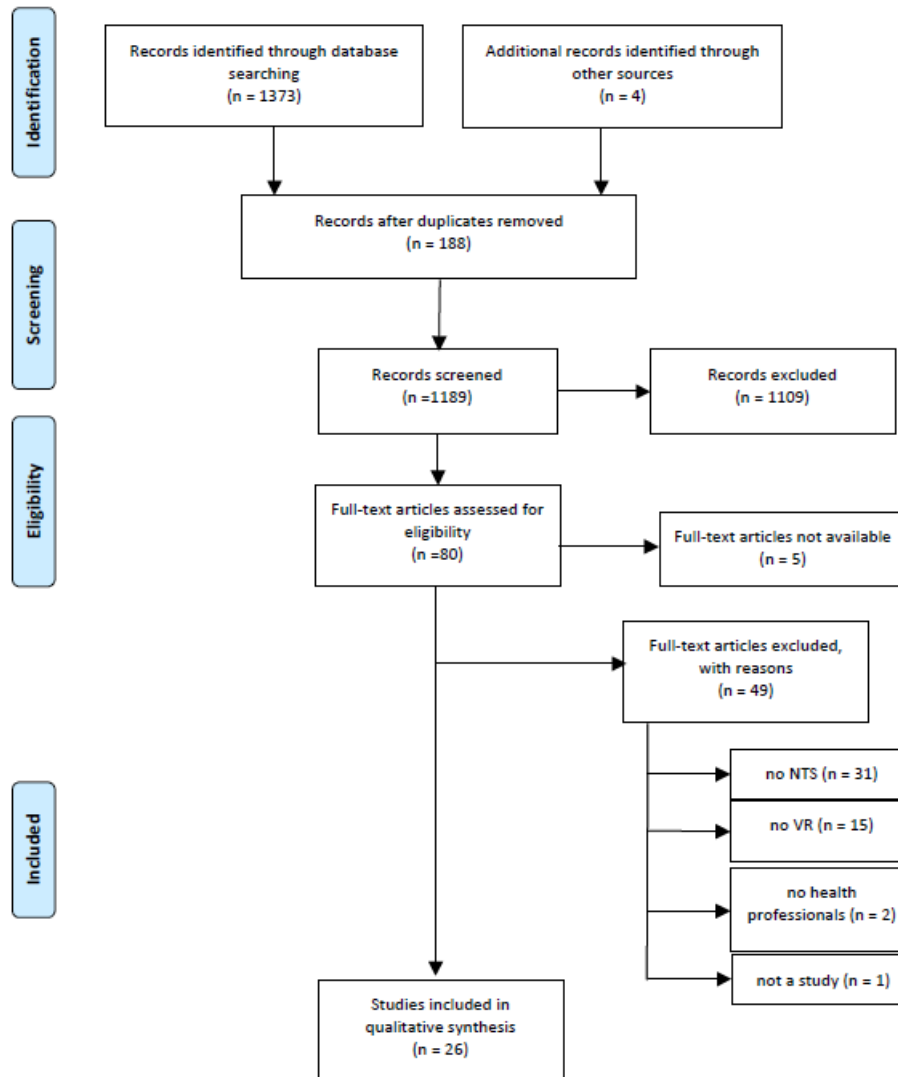
142 remediation (cognitive behavioral therapy, rehabilitation) that also use VR technologies but
143 are out of the scope of this review.

144 This initial 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).



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 assessed
 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 interprofessionalism^(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

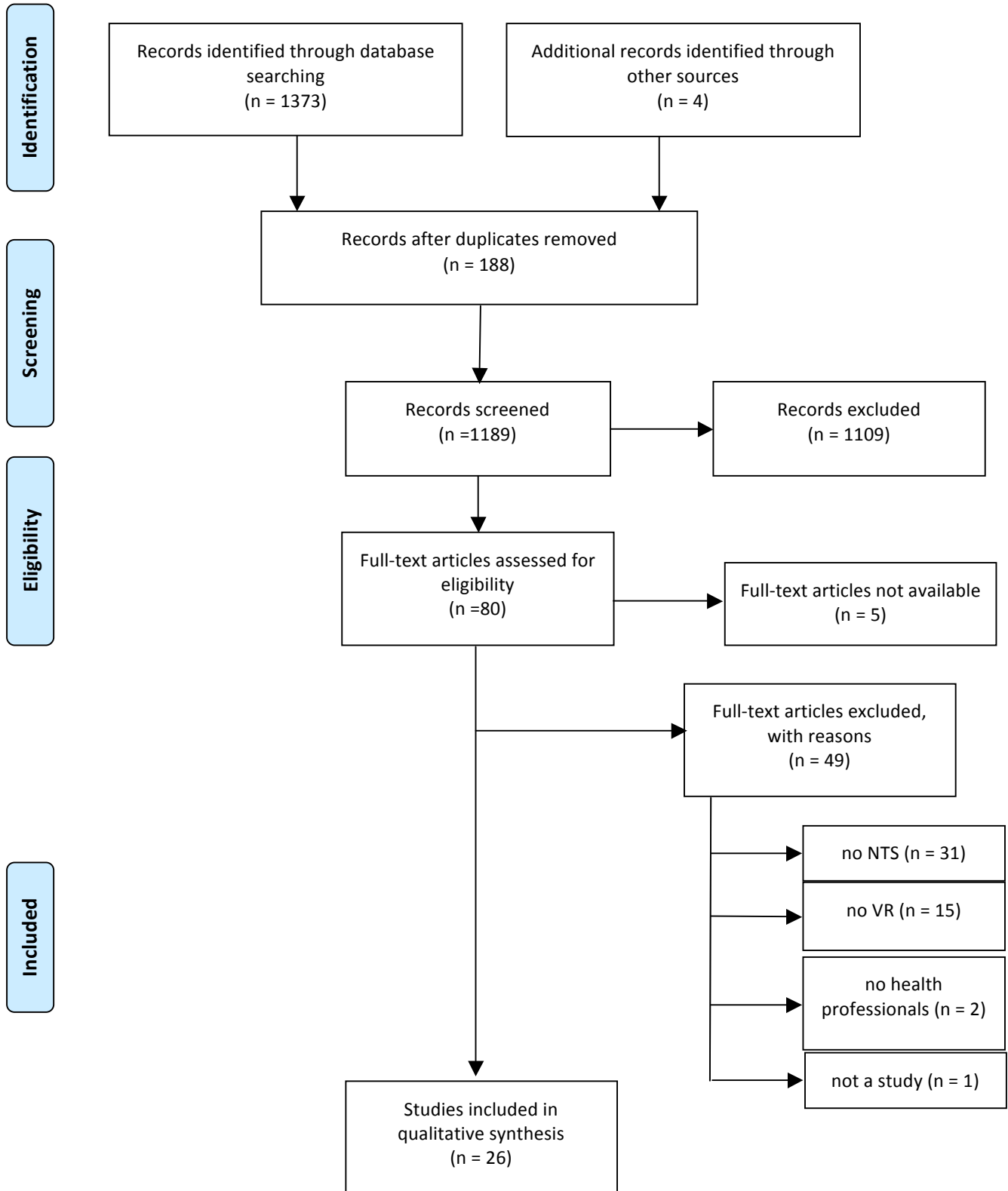


Table 1

DOMAIN	ARTICLE REFERENCES	N	POPULATION	VIRTUAL REALITY SYSTEM			VR SIMULATOR	NON TECHNICAL SKILLS						OUTCOMES (KIRKPATRICK'S LEVEL)				
				SB	VW	IVE		SA	DM	COM	TW	LD S	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		

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 Mentor™ and Percmentor (Symbionix USA Corp., Cleveland, OH, USA)	X	X	X	X	X			X	X		
urology	Paige et al., 2007 ⁽⁴⁶⁾	10	Senior surgery resident, nurse anesthetist and circulating nurse	X		Symbionix LapMentor	X		X	X				X			
urology	Shamim Khan et al., 2013 ⁽³⁵⁾	38	Specialist registrars of different grades and urological nurses	X		Uro Mentor™ and Percmentor (Symbionix 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, Research, 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	

gastroenterology	Khan et al., 2017 ⁽²⁹⁾	42	Novice endoscopists	X		EndoVR simulator Healthcare Montreal, Canada)	endoscopy (CAE Canada, Quebec,	X	X	X	X	X				X	X	
laparoscopic surgery	Maschuw et al., 2008 ⁽³¹⁾	40	Inexperienced and advanced surgical residents	X		LapSim® (Surgical Science, Sweden)	Goteborg,						X				X	
laparoscopic surgery	Sankaranarayana n 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™ (Symbionix 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⁾	<ul style="list-style-type: none"> Determine feasibility of creating a VR operating room Evaluate simulator for face and construct validity 	<ul style="list-style-type: none"> Construct validity : metric data Face validity : Likert-scale questionnaires (realism, inclination to use), Bedford Workload Scale and modified NASA-Task Load Index scale 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Assess validity of distributed simulation environment for NTS training Evaluate educational impact 	<ul style="list-style-type: none"> Face, content and construct validity : questionnaires NOTECHS Educational impact : questionnaires completed after the simulations 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Evaluate feasibility, acceptability, content validity and educational impact of simulation-based curriculum integrating NTS 	<ul style="list-style-type: none"> NOTSS Content validity : post-study questionnaire 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Determine feasibility and reliability of skills assessment 	<ul style="list-style-type: none"> 7-point NTS competency scale for paramedics and T-NOTECHS (Trauma Non-Technical Skills Scale) 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Evaluate (SA) Situation Awareness self assessment instrument Analyze SA training in virtual settings 	<ul style="list-style-type: none"> SA : 9-items questionnaire + trainee’s own opinion of his or her SA during training Concentration/attention : 10-items instrument 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Establish face validity, usefulness and fidelity of virtual OR fire training 	<ul style="list-style-type: none"> Perceived usefulness and face validity : questionnaire 	<ul style="list-style-type: none"> Face validity established with high degree of satisfaction and usefulness 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	<ul style="list-style-type: none"> Open-ended questions : improvements and preferences 	
Greci et al., 2013 ⁽²⁷⁾	<ul style="list-style-type: none"> Develop and evaluate a virtual learning curriculum 	<ul style="list-style-type: none"> Open-ended questions : technical challenges, course content, immersion Interviews and focus groups 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Validate a simulation-based curriculum for cognitive and integrative competencies 	<ul style="list-style-type: none"> Global performance : Integrated Scenario Global Rating Form (ISGRF) Communication skills : Communication Global Rating Scale (CGRS) 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Determine efficiency of a Virtual Emergency Department to train mass-casualty incidents (team skills) 	<ul style="list-style-type: none"> Immersion, level of comfort, confidence, usefulness for clinical skills and team training : questionnaire Focus group 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Examine perceived usability of Second Life (SL) as an immersive virtual environment Study clinical decisions 	<ul style="list-style-type: none"> Perceived usability : System Usability Scale (SUS) Situation awareness : questionnaire with 27 items 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Evaluate effectiveness of a simulation-based training curriculum of NTS on novice endoscopists' performance of clinical colonoscopy. 	<ul style="list-style-type: none"> Modified Objective Structured Assessment NTS (M-OSANTS) ISGRF Integrated Scenario Communication Rating Form (ISCRF) 	<ul style="list-style-type: none"> 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

		<ul style="list-style-type: none"> • General Self Efficacy Scale (GSE) 	
Khanal et al., 2014 ⁽³⁰⁾	<ul style="list-style-type: none"> • Evaluate efficacy of delivering advanced cardiac life support (ACLS) using a virtual reality simulator 	<ul style="list-style-type: none"> • Team performance : electronic checklist based on ACLS guidelines assessed by experts • Final questionnaire on training experience 	<ul style="list-style-type: none"> • 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⁾	<ul style="list-style-type: none"> • Evaluate usability of the environment • Evaluate learning effectiveness of scenarios • Evaluate integration into curriculum 	<ul style="list-style-type: none"> • Debriefing: exploration of team interactions • Satisfaction survey and questions on learning in the environment 	<ul style="list-style-type: none"> • 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⁾	<ul style="list-style-type: none"> • Explore impact of self-belief of surgeons on laparoscopic performance using a VR simulator 	<ul style="list-style-type: none"> • General Self Efficacy (GSE) score • Technical metrics : time, economy of motion and damage parameters 	<ul style="list-style-type: none"> • 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⁾	<ul style="list-style-type: none"> • Evaluate perception of simulated scenarios • Evaluate effectiveness for communication and teamwork during OR crisis 	<ul style="list-style-type: none"> • Teamwork assessment: communication, coordination and situational awareness • Questionnaire on perception of training effectiveness and specific attributes of teamwork 	<ul style="list-style-type: none"> • Sessions were found effective/very effective for improving teamwork, communication and recognizing problems in the OR
Riesen et al., 2012 ⁽³²⁾	<ul style="list-style-type: none"> • Improve interprofessional competencies • Determine acceptability of a blended learning environment 	<ul style="list-style-type: none"> • Self-perceived changes in interprofessional attitudes and competence : IEPS, ICCAS • Team performance assessment : TOSCE • Students perceptions : program assessment tool, and 16-item questionnaire 	<ul style="list-style-type: none"> • Significant differences pre and post workshop were found in ICCAS and IEPS scores • Significant improvement across 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

Rogers, 2011 ⁽⁴⁹⁾	<ul style="list-style-type: none"> Investigate how a simulation in Second Life can encourage teamwork and collaborative problem solving 	<ul style="list-style-type: none"> Individual interviews: clinical judgement, teamwork and interpersonal skills 	<ul style="list-style-type: none"> Critical Life simulation is an artificial social structure where problem-based scenarios can be created Students can co-construct mental models experiencing 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⁾	<ul style="list-style-type: none"> Evaluate feasibility of integration of a VR simulator in an immersive simulation Investigate construct and face validity for training human factor skills during a crisis scenario 	<ul style="list-style-type: none"> Questionnaires : realism (face validity) and potential for use in team training for both technical and human factor skills 	<ul style="list-style-type: none"> 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 Feasibility, face and construct validity of a realistic crisis scenario integrating a VR simulator has been shown
Sankaranarayana n et al., 2016 ⁽³⁴⁾	<ul style="list-style-type: none"> Establish face and construct validity of an immersive VR system Assess the effects of distractions and task interruptions 	<ul style="list-style-type: none"> 5-point Likert-scale subjective feedback questionnaire : realism, immersive experience, and effects of distractions and interruptions 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Establish feasibility and acceptability of simulation training for NTS 	<ul style="list-style-type: none"> Interviews : perception of simulated environment Feasibility, acceptability and construct validity : questionnaires 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Test utility and acceptability of a virtual learning environment (VLE) Examine change in teamwork attitudes in interprofessional communication 	<ul style="list-style-type: none"> Effectiveness : TeamSTEPPS -TAQ (Teamwork Attitude Questionnaire) Utility : Time to complete scenarios and answers to questions within scenarios Acceptability : Likert-scale type questions 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Propose an introduction to TeamSTEPPS communication tools for nursing and medical students 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> Learner recognition of the SBAR communication tool was high across groups Knowledge of which component of SBAR was missing was lower across 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⁾	<ul style="list-style-type: none"> Study quality of information transfer and teamwork during a simulated critical event Assess gathering and sharing of critical information 	<ul style="list-style-type: none"> Communication skills: Critical Patient Information checklist and Interprofessional Communication Skills checklist 	<ul style="list-style-type: none"> 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
Williaert et al., 2011 ⁽³⁷⁾	<ul style="list-style-type: none"> Evaluate whether a part-task rehearsal of a surgical procedure on a VR simulator is as effective as a full-task one 	<ul style="list-style-type: none"> Non-technical skills : NOTSS Face validity and usefulness : questionnaire Emotional, cognitive and physical stress : short version of State Trait Anxiety Inventory (STAI) questionnaire 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Measure usability of simulator Explore relationship between mental workload and surgical performance during crisis 	<ul style="list-style-type: none"> Cognitive workload : 3-item questionnaire and Surgery Task Load Index (SURG-TLX) Questionnaire : face validity and training value 	<ul style="list-style-type: none"> 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⁾	<ul style="list-style-type: none"> Evaluate VLE for leadership and trauma management by comparing users' experience with a 	<ul style="list-style-type: none"> Leadership skills : EMCRM (Emergency Medicine Crisis Resource Management) scale 	<ul style="list-style-type: none"> 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
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