Systematic review

Systematic review of serious games for medical education and surgical skills training

M. Graafland[1], J. M. Schraagen[2] and M. P. Schijven[1]

[1]Department of Surgery, Academic Medical Centre, Amsterdam, and [2]Netherlands Organization for Applied Scientific Research, Soesterberg, The Netherlands

Correspondence to: Dr M. P. Schijven, Department of Surgery, Academic Medical Centre, PO Box 22660, 1100 DD Amsterdam, The Netherlands (e-mail: m.p.schijven@amc.uva.nl)

Background: **The application of digital games for training medical professionals is on the rise. So-called 'serious' games form training tools that provide a challenging simulated environment, ideal for future surgical training. Ultimately, serious games are directed at reducing medical error and subsequent healthcare costs. The aim was to review current serious games for training medical professionals and to evaluate the validity testing of such games.**

Methods: **PubMed, Embase, the Cochrane Database of Systematic Reviews, PsychInfo and CINAHL were searched using predefined inclusion criteria for available studies up to April 2012. The primary endpoint was validation according to current criteria.**

Results: **A total of 25 articles were identified, describing a total of 30 serious games. The games were divided into two categories: those developed for specific educational purposes (17) and commercial games also useful for developing skills relevant to medical personnel (13). Pooling of data was not performed owing to the heterogeneity of study designs and serious games. Six serious games were identified that had a process of validation. Of these six, three games were developed for team training in critical care and triage, and three were commercially available games applied to train laparoscopic psychomotor skills. None of the serious games had completed a full validation process for the purpose of use.**

Conclusion: **Blended and interactive learning by means of serious games may be applied to train both technical and non-technical skills relevant to the surgical field. Games developed or used for this purpose need validation before integration into surgical teaching curricula.**

Paper accepted 19 April 2012

Published online in Wiley Online Library (www.bjs.co.uk). **DOI:** 10.1002/bjs.8819

Introduction

Patient safety concerns call for the need to train medical personnel in simulated settings to reduce cost and patient morbidity. Technological innovations, such as virtual reality simulation and e-learning applications, have led to consistent improvement in learning outcomes, and already play a role in surgical residency training programmes[1–3]. A potent concept for medical education is interactive learning through 'serious games'. A serious game is formally defined as an 'interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge or attitudes useful in reality'[4]. Serious games are designed with primary objectives other than entertainment and therefore clearly differ from conventional video games. They can be played on platforms such as personal computers, smartphones or video game consoles and can apply multimodal interactive content in any virtual environment. They present an ideal playground to engage players in simulated complex decision-making processes like those required in medical training[5].

Serious games provide a balanced combination between challenge and learning. Playing the game must excite the user, while ensuring that the primary goal (acquiring knowledge or skills) is reached seemingly effortlessly, thus creating a 'stealth mode' of learning[5,6]. Players are challenged to keep on playing to reach the game's objective. This corresponds well to Ericsson and colleagues' theory of deliberate practice; as players are not naturally 'good' at a game, intentional repetitive training makes a player become an expert[7]. Games hold clear advantages over conventional learning methods owing to their competitive elements, entertainment aspects and feedback mechanisms[8,9].

To date, many medical professionals may still have a rather outdated view of the average 'gamer', as being someone who is too young to vote, afraid of daylight and killing mystical dwarves in games like World of Warcraft® (Blizzard Entertainment, Versailles, France) in their parents' basement. Contrary to this view, adults are avid users of digital devices, and playing video games is in fact an important part of their lifestyle. The average video game player is 37 years old and has been playing games for over 12 years[10]. Forty-two per cent of all game players are women, and women aged over 18 years represent a significantly greater share of the game-playing population than boys aged 17 years or younger (37 *versus* 13 per cent respectively)[10,11].

Although game-based learning is becoming a new form of education throughout healthcare, scientific research on its effectiveness is rather limited. Ideally, training instruments measure certain parameters ('game-metrics') to assess the trainees' performance. If training and testing of healthcare professionals such as surgical trainees is to be carried out in digital game-based environments, strict requirements should be met. Use of these games and interpretation of the underlying game-metrics must be reliable, valid and cause-specific. Thorough scientific research on validity testing is mandatory before serious games can be applied to surgical training curricula in a valid manner.

The aim of this review was to identify the value of serious games for training professionals in the medical and, in particular, the surgical field. The first objective was to assess the background of serious games for the purpose of training professionals in medicine and their usability in surgical postgraduate training. The second was to assess the validity of serious games as a teaching method according to criteria regarded as best evidence.

Methods

Search criteria

A systematic search was performed of peer-reviewed literature on serious games used to educate professionals in medicine. Serious games were defined as digital games for computers, game consoles (such as PlayStation®, Sony, Tokyo, Japan; Nintendo®, Nintendo, Kyoto, Japan), smartphones or other electronic devices, directed at or associated with improvement of competence of professionals in medicine. Professionals in medicine were defined as individuals responsible for patient care (doctors, nurses, physiotherapists, paramedics, etc.) in institutionalized settings. Serious gaming, e-learning and virtual reality simulation tend to overlap and strict subdivision frequently proves to be difficult[6]. This search focused on game-based learning programmes, excluding papers on virtual reality simulation and e-learning as far as possible.

Study selection and assessment of serious games

PubMed, Embase, the Cochrane Database of Systematic Reviews, PsychInfo and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) (all from January 1995 to April 2012) were searched for key terms (serious gam* OR videogame* OR video gam* OR gaming) AND (medical education OR educat* OR training). The last search date was 12 April 2012. In addition, reference lists of relevant articles were searched. In the search of the CINAHL database, the limitation 'peer-reviewed articles' was added. Only completed trials were regarded as relevant. No reports were excluded based on language.

The titles and abstracts of all reports were screened for the previously mentioned search criteria. All articles deemed 'relevant', 'dubious' or 'unknown' were examined in full text. Data on serious games were extracted from all papers, including name, type, platform, purpose, target population and the presence of validation studies. If necessary, additional information was sought on the publisher's website or through correspondence with the authors.

Review of validation studies

Studies designed to validate serious games were assessed for achievement of steps in the validation process, according to criteria regarded as best evidence (*Table 1*)[12,13]. The predominant question to be addressed by validity testing is whether the instrument measures what it is intended to measure[12]. Content must be reviewed by experts on the subject. The instrument's face validity must be valued by both novice trainees and experts to gain acceptance. The parameters by which performance is objectified should be scrutinized for their representation of the skills they are intended to measure (construct validity). After these measurements have been performed, the instrument should be compared with current methods of teaching in order to assess alignment in outcome or unexpected deviations (concurrent validity). The transfer of skills acquired on the instrument to performance in reality ('predictive validity') is the final step in the validation process.

Table 1 Validity types for games relevant to education of medical professionals[12,13]

	Description	Criteria for achievement
Content validity	The degree to which game content adequately covers the dimensions of the medical construct it aims to educate (or is associated with)	Uniform and positive evaluation of game content and associated testing parameters by expert medical specialist panel
Face validity	Degree of resemblance between medical constructs featured in game play and in reality, as assessed by novices (trainees) and experts (referents)	Uniform and positive evaluation of the game as a valuable learning environment among novice and expert medical specialists
Construct validity	Inherent difference in outcome of experts and novices on game play outcome parameters	Outcome differences considered to be of significance between players of different medical specialist level of skill
Concurrent validity	Concordance of study results using a concept instrument (e.g. game) and study results on an established instrument or method, believed to measure the same medical theoretical construct	Outcome parameters show correlation considered to be significant between game and an alternative, established training method
Predictive validity	The degree of concordance of a concept instrument (e.g. game) outcome and task performance in reality, based on a validated scoring system	Metrics show correlation considered to be significant between outcome parameters of a game and performance results on the medical construct featured in the game in real life after performers have been trained using the game

Data on validation studies were extracted in accordance with the *Cochrane Handbook for Systematic Reviews of Interventions*[14] and concerned methodological aspects (study design, intention to treat, randomization, concealment of allocation, blinding, follow-up, other possible bias), details of the serious game (as in previous section), study population, details on intervention, primary and secondary endpoints, instruments, timing, results of measurements performed and funding. The quality of randomized controlled trials was assessed systematically using the Cochrane Collaboration's tool for assessing risk of bias, resulting in the trial being deemed at either low or high risk of bias[14]. Observational studies were assessed by means of the methodological index for non-randomized studies. This validated instrument grades studies on a weighted 12-item scale, with a maximum score of 16 for non-comparative studies and 24 for comparative studies[15]. The achievement of steps in the validation process based on data extracted from the articles was judged by two reviewers who were not involved in production of any of the games and/or writing of the study articles. In case of disagreement between these two reviewers, a third reviewer was consulted.

Results

The systematic search identified 1151 articles. A total of 25 articles were found to be relevant, describing a total of 30 serious games (*Fig. 1*). These 30 games were divided into two categories. Category 1 consisted of 17 serious games developed specifically for educational purposes. Category 2 consisted of 13 commercially available games associated with, but not developed specifically for, improvement of skills relevant to medical personnel. Pooling of data was not performed because of the heterogeneity of study designs and serious games.

Serious games designed for an educational purpose

Nineteen articles discussed 17 serious games specifically designed to train professionals in medicine (category 1). The majority of these are highly relevant to surgical trainees. *Table 2* shows an overview of these games. Pulse! (BreakAway, Hunt Valley, Maryland, USA), 3DiTeams (Applied Research Associates, Raleigh, North Carolina, USA), CliniSpace™ (CliniSpace, Los Altos Hills, California, USA) and its predecessor Virtual ED (Stanford University, Stanford, California, USA) were developed as platforms for training critical care, for example advanced trauma life support[16,17,19]. These platforms provide possibilities for team training. Burn Center™ (360 ED, Orlando, Florida, USA) is used to train treatment of burn injuries in an accredited multidisciplinary course[27]. The Off-Pump Coronary Artery Bypass (OPCAB) game and the Total Knee Arthroplasty game (both University of Ontario Institute of Technology, Toronto, Ontario, Canada) have been developed to train decision steps in a virtual operating room[21,22]. Other topics include triage and basic life support. Two augmented reality environments were developed, in which virtual reality is projected over a real environment either by wall projection (Cave Automated Virtual Environment, CAVE™; Electronic Visualization Laboratory, University of Illinois, Chicago, Illinois, USA)[23] or via a head-mounted display (Project Touch; Center for Telehealth, University of New Mexico, Albuquerque, New Mexico, USA)[28].

Ten of these serious games have multiplayer functions, useful for team training, and seven of these ten games

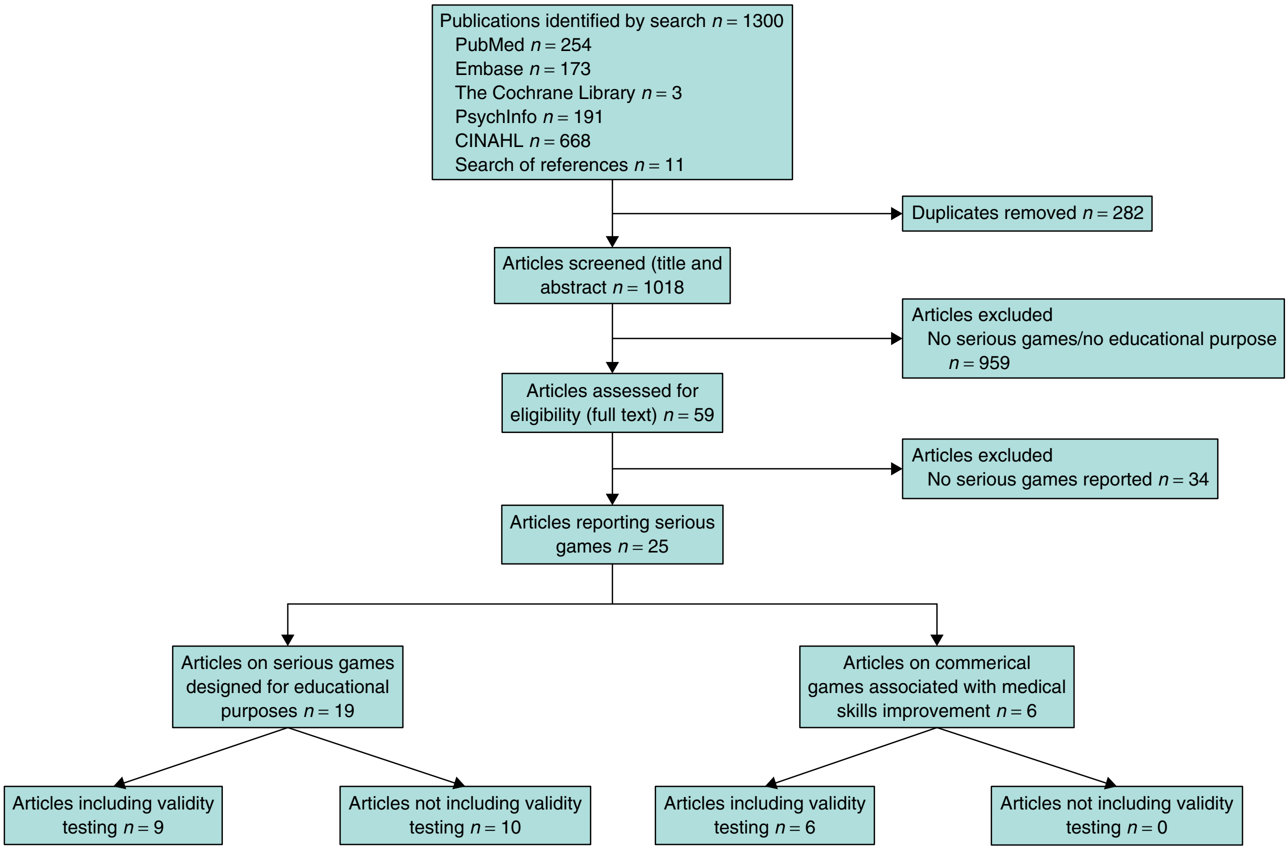

Fig. 1 Search strategy for literature on serious games used in education of medical professionals. CINAHL, Cumulative Index to Nursing and Allied Health Literature

were designed specifically for this purpose[16–20]. Methods for measuring performance vary: articles on three games, Pulse!, OPCAB and Total Knee Arthroplasty, describe an intrinsic scoring system based on the accurate or inaccurate choices made by the trainee[16,21,22], whereas other games rely on external assessors to judge performance[17,19,20,23].

Eight serious games underwent steps in validity testing[19,20,22,23,25,26,29–31] (*Table S1*, supporting information). Virtual ED was evaluated in a randomized controlled trial, in which 30 novices were assigned randomly to manage six patient cases in either Virtual ED or human patient simulators[19]. Team leadership performance was assessed by three assessors in one pre-test and one post-test case on a standardized scale. Results showed similar skills improvement for both groups, thus proving concurrent validity. Medical content was designed by an independent institution[20].

Virtual ED II (Stanford University) was tested with regard to face validity by means of a questionnaire on its usability among 22 physicians and nurses with an average of 4 years of experience[31]. A majority felt immersed in the virtual world, felt the game improved their confidence and believed the cases were useful in learning clinical skill management, proving face validity.

Triage Trainer (Blitz Games Studios, Leamington Spa, UK) was compared with a conventional card-sort exercise in a non-randomized controlled trial among 91 doctors, nurses and paramedics[26]. Raters found a significant increase in triage accuracy for the Triage Trainer group in post-test cases, compared with the control group, proving concurrent validity.

Triage training on the CAVE™ system was evaluated among 15 residents, who were randomly assigned to triage 14 cases in either CAVE™ or on human patient simulators. Concurrent validity was not proven as the control group performed significantly better on the post-test[23].

Nuclear Event Triage Challenge and Radiation Hazards Assessment Challenge (HST Division, Harvard Medical School, Boston, Massachusetts, USA) were evaluated in

Table 2 Overview of serious games developed specifically for educational purposes (category 1), ranked according to purpose

Serious game	Game type	Platform	Purpose	Multiplayer	Target groups	Implemented in clinical practice
Acute and critical care						
3DiTeams[16]	Game-based simulation	Computer	Team training in acute and critical care	Yes	Physicians, nurses	No
CliniSpace™[17]	Game-based simulation	Computer	Team training in acute and critical care	Yes	Physicians, nurses	No
HumanSim®[18]	Game-based simulation	Computer	Platform for scenario-based education, e.g. team training in acute care, critical care	Yes	Physicians, nurses, emergency medical personnel, students	No
Pulse![16]	Game-based simulation	Computer	Acute care and critical care	Yes	Physicians	No
Virtual ED[19]	Game-based simulation	Computer	Team training in acute and critical care	Yes	Physicians, nurses	No
Virtual ED II[20]	Game-based simulation	Computer	Team training in acute care, triage in mass casualty events involving hazardous materials	Yes	Emergency room physicians and nurses	No
Virtual operating room						
Off-pump Coronary Artery Bypass game[21]	Game-based simulation	Computer	Training operation steps for off-pump coronary artery bypass[21]	Yes	Surgical trainees	No
Total Knee Arthroplasty game[22]	Game-based simulation	Computer	Training operation steps for total knee arthroplasty	No	Surgical trainees	No
Triage						
CAVE™ triage training[23]	Immersive learning environment	Projected	Triage training	No	Physicians	No
Code Orange™[24]	Game-based simulation	Computer	Triage and organization in mass casualty incidents	Yes	Physicians, nurses	No
Nuclear Event Triage Challenge[25]	Game-based simulation	Computer	Triage in nuclear events	No	First responders	No
Peninsula City[20]	Game-based simulation	Computer	Team training in triage in mass casualty events, hazardous materials	Yes	Physicians, nurses	No
Triage Trainer[26]	Game-based simulation	Computer	Triage in mass casualty incidents	No	First responders	No
Other purpose						
Burn Center™[27]	Game-based simulation	Computer	Triage and resuscitation of burned patients	No	Physicians, nurses	Multimodal training course
OLIVE cardiopulmonary resuscitation training[17]	Game-based simulation	Computer	Training basic life support	No	Medical personnel (not specified)	No
Project Touch[28]	Immersive learning environment	Projected	Platform for scenario-based education, e.g. team training in acute care, critical care	Yes	Physicians, nurses, students	No
Radiation Hazards Assessment Challenge[25]	Game-based simulation	Computer	Assessment of radiation hazard after nuclear event	No	Physicians, nurses, emergency medical personnel	No

CAVE™, Cave Automated Virtual Environment; OLIVE, On-Line Interactive Virtual Environment. HumanSim®, Applied Research Associates, Raleigh, North Carolina, USA; Code Orange™, BreakAway, Hunt Valley, Maryland, USA; Peninsula City, Stanford University, Stanford, California, USA. Developers of other games are cited in main text.

one study[25]. The author failed to describe the results in detail, so criteria for concurrent validity were not met.

The Total Knee Arthroplasty game was tested for usability among 14 orthopaedic residents, but criteria for face validity were not met[22]. The effect of cardiopulmonary resuscitation training on the OLIVE (On-Line Interactive Virtual Environment; Science Applications International Corporation, McLean, Virginia, USA) system was

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evaluated among 12 medical students for increase in self-efficacy, but the study design did not correspond to formal validity testing[29].

Steps in the validation process and face validity have been made for Triage Trainer[26], Virtual ED[19] (concurrent validity) and Virtual ED II[31] (face validity) but these steps have yet to result in a completed formal validation process.

Commercially available games associated with training skills

Six studies assessed 13 commercially available games that were associated with, but not specifically designed for, training laparoscopic psychomotor skills (category 2)[32–37]; *Table S2* (supporting information) provides an overview of these games. They include sports games, action games, adventure games and shooting games on different platforms. Every game had an intrinsic scoring system. Performance in these games was compared with performance on different instruments for training laparoscopic psychomotor skills to test their concurrent validity. An overview of the results shown in *Table S3* (supporting information)[32–37].

The study by Rosser and colleagues[36] showed a clear association between performance in three video games (Silent Scope™, Konami, Tokyo, Japan; Star Wars Racer Revenge™, LucasArts, San Francisco, California, USA; Super Monkey Ball™ 2, Sega, Tokyo, Japan) and laparoscopic handling speed and errors made in laparoscopic box trainer exercises, thus proving concurrent validity. Studies by Badurdeen and colleagues[33] and Rosenberg and colleagues[32] show clear correlations between laparoscopic handling speed and video game performance in five games (Amped™ 2 and Top Spin™, Microsoft, Redmond, Washington, USA; Charge™, Pose Mii™ and Shooting Range™, Nintendo), compared with an animal model and a laparoscopic box trainer. This correlation only partially resembles concurrent validity, as movement proficiency was not significantly correlated.

Schlickum and colleagues[34] randomized two groups of students to systematic video game training with Half-Life™ (Valve Corporation, Bellevue, Washington, USA) and Chessmaster® (Ubisoft Entertainment, Montreuil, France). The Half-Life™ group had significantly improved scores on a validated laparoscopy simulator and an endoscopy simulator, whereas the Chessmaster® group improved only on the endoscopy simulator. No clear correlation between measured parameters was shown, so no concurrent validity was proven.

Studies on Marble Mania™ (Nintendo) and Super Monkey Ball™ (Sega) had insufficient design for conclusions to be drawn about validity for learning laparoscopic psychomotor skills[35,37].

Discussion

Serious games form an innovative approach to the education of medical professionals, and surgical specialties are eager to apply them for a range of training purposes. They have been adopted for various different goals, for example as an adjunct to existing simulator training or as a stand-alone method. Two forces play a driving role in the development and introduction of serious games. First, game developers do not want to 'miss out' on the medical market and may be afraid that thorough validation studies will postpone their introduction. Second, the market is eager to adopt serious gaming as it appears to be more attractive than learning 'the old fashioned way'. Marketing and commercial forces may lead to the haphazard introduction of educational instruments that are not scrutinized for their content in itself, nor for their proper transfer of content. It is important for game designers and educators to cooperate in designing and validating a serious game for a specific educational problem or to address a specific lack of knowledge or skills. Only then do they have solid grounds for integrating the serious game as a teaching tool in surgical curricula[12,13].

Serious games first undergo testing of the system's reliability, to address whether the same measurement tool yields stable and consistent results when repeated over time. Subsequently, the application must undergo a validation process, preferably in the order described in *Table 1*. Errors and deficiencies should be corrected when encountered. When the outcomes of validity studies are unfavourable, the instrument cannot be seen as a valid teaching instrument for a specific skill.

The search identified 17 serious games designed specifically for educational use in medicine, of which several were of specific interest to surgical practice. Other games were not linked directly to surgical practice, but could be viewed as generally interesting because of methods of education. Further research should define valid performance parameters and complete formal validation programmes, before serious games can be seen as fully fledged teaching instruments for professionals in the medical and surgical field.

Although a serious game does not necessarily have to be developed for an educational purpose to be an educational tool, such games cannot be seen as fully completed training tools. All games found in the search in this category were used to train laparoscopic psychomotor skills. Eight games showed a statistically significant correlation with speed of handling in specific tasks on a box trainer or a live animal model[32,33,36]. However, only three of these video games improved movement proficiency of laparoscopic handling in a box trainer set-up, which implied concurrent validity for teaching of laparoscopic psychomotor skills[36]. Until researchers have completed a full validation process for these games, they cannot be considered to be of true value in curricula for surgical resident training, which currently employ validated virtual reality simulators or laparoscopic box training and Objective Structured Assessment of Technical Skills[38].

Schlickum and colleagues[34] showed that performance on laparoscopic psychomotor abilities was improved not only by games that actually used the trainees' visuospatial ability, but also by simple two-dimensional games that required only cognitive and attention skills. Video games have been shown to increase visuospatial and attention skills[39,40]. Furthermore, visuospatial abilities and human visual working memory have been associated with laparoscopic handling performance[41]. The relationship between visuospatial and cognitive skills, video games and laparoscopic psychomotor skills is complex, and therefore an interesting subject for future research. Optimizing the game-metrics of these games to suit a validation process may lead to novel methods for teaching laparoscopic psychomotor skills. Challenging serious games for training laparoscopic psychomotor skills could lead to solutions for the popularity problem of virtual reality simulators among surgical residents[42,43].

Serious games allow multiple professionals to train simultaneously on one case (teamwork) and allow one professional to train multiple cases simultaneously ('multitasking'). These non-technical skills are recognized as critical in reducing medical errors in dynamic high-risk environments, such as the operating room or the emergency department[44–46].

The current commitment to reduce error in clinical practice has led to recognition of team training in managing crisis situations, such as anaesthesia crisis resource management[47,48] and emergency medicine crisis resource management, and may also be of use to surgical residents[49]. Crisis resource management is derived from aviation, and focuses on nurses and physicians together in crisis situations[50]. Serious games allow such training in a relatively cheap, readily available environment with a large variety of cases, providing an alternative to expensive high-fidelity simulators[16–19]. Serious games also present training environments for disaster situations and mass casualty incidents, including combat care[20,23,25–27,31]. Realistic virtual surroundings, in which sights, sounds and confusion are mimicked, provide a complete experience and improved preparation[23,26]. Alongside the training of crisis management, serious games can be used for training everyday clinical activities and skills for junior doctors, such as decision-making abilities in surgical procedures or care of patients with burns[21,22,27].

Serious gaming as a way to prevent medical error will function optimally if games are designed to fit into residency teaching programmes[51]. Postgraduate education in most Western countries is based on competency-based training, in which assessment and performance of the trainee is integrated. Competency frameworks such as CanMEDS[52] have been developed for this purpose. The more recent introduction of entrustable professional activities, aimed at integrating these competencies into everyday clinical activities, allows a true outcome-based approach to specialist training[53]. Simulation and serious gaming represent ideal teaching methods to optimize the knowledge and skill of residents before they are entrusted with procedures in real patients. Educators and game designers should direct serious games at training these entrustable professional activities to maximize their benefits for patient safety.

Initial development costs of serious games can be high[54]. The expected revenue, in terms of better patient care and prevention of error, provides a decisive argument for investing in such development. Insurance companies can play an important role. When a basic game structure has been developed, it can function as a platform for different institutions and departments to upload their content of choice[16]. This can lead to games becoming widely usable training methods, keeping additional development costs relatively low.

Acknowledgements

M.G. is funded by grant PID 101060 from Agentschap NL, a funding agency of the Dutch Ministry of Economic Affairs. M.P.S. and J.M.S. are funded partly by grant PID 101060. The funding agency had no role in the design and conduct of the study; collection, management, analysis and interpretation of the data; and preparation, review or approval of the manuscript.
Disclosure: The authors declare no conflict of interest.

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Supporting information

Additional supporting information may be found in the online version of this article:

Table S1 Studies on validity testing of serious games developed specifically for educational purposes (category 1), ranked according to steps in validation process tested and achieved (Word document)

Table S2 Overview of commercially available games associated with training laparoscopic psychomotor skills (category 2) (Word document)

Table S3 Studies on validity testing of commercially available games associated with, but not specifically developed for, training medical skills (category 2) (Word document)

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