Serious games in surgical education
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Game-based training improves problem-solving ability in the operation room: a randomized controlled trial

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Submitted
ABSTRACT

**Background:** Equipment-related malfunctions are directly related to one-fourth of the adverse events in the surgical theatre. A serious game trains residents to recognize and respond to equipment failure in minimally invasive surgery (MIS), related to lighting, gas transport, electrosurgery and pathophysiological disturbances. This randomized controlled trial explored whether game-based training improved surgical residents’ response to equipment-related problems in the surgical theatre significantly.

**Methods:** Thirty-one surgical residents with no previous experience in MIS took part in a standardized basic laparoscopy training course. Fifteen residents were randomly assigned to the game-enhanced curriculum, whereas sixteen were assigned to the regular curriculum. In the post-test, participants performed a MIS task in a live anesthetized pig model, during which three standardized equipment malfunction scenarios occurred. Observers recorded the problems recognized and solved, time required and participants’ technical performance.

**Results:** Twenty-four participants completed the post-test (both groups n = 12). The game group recognized and solved more problems than the control group (67% vs. 42%, p = 0.14 and 59% vs. 33%, p = 0.029). The time in which problems were recognized and solved did not differ significantly. Random effects modelling of game performances showed a significant improvement in game score per three-minute session.

**Conclusions:** Surgical residents who trained about an hour with a custom-made serious game responded significantly better to equipment-related problems during surgery than residents trained using a standard training curriculum. These results imply that serious gaming is indeed an effective method for non-routine events training in surgery involving MIS equipment.
INTRODUCTION

Minimally invasive surgery (MIS) has been widely adopted in various surgical procedures, reducing overall patient morbidity whilst improving cosmetic results. However, the surgeon’s increased workload in a technology-dependent environment increases the chance for errors to occur. Errors relating to the equipment occur frequently in the laparoscopic suite and pose a significant threat to patient safety. A recent systematic review shows that equipment malfunctions are to be held responsible for nearly a quarter of the adverse events in the OR.

Standardized MIS training courses aim to develop knowledge and psychomotor skills and are part of surgical training in many countries (e.g. Fundamentals of Laparoscopic Surgery (FLS)). However, these curricula do not educate surgical trainees to deal with the laparoscopic environment or with equipment-related errors. Recent studies show that long-term knowledge preservation regarding MIS equipment after basic laparoscopy courses is poor. Furthermore, experienced professionals are insufficiently equipped to solve laparoscopic equipment-related problems, when they encounter them during MIS. Additional training methods focusing on long-term knowledge retention and dealing with non-routine events during MIS are therefore much needed.

A serious game was developed to train surgical personnel in recognizing and solving equipment-related problems in MIS. Serious games are digital applications that are fun to play and engaging, while they supply the player skills, knowledge or attitudes useful in reality. Serious games enhance voluntary play among trainees, which makes them interesting training solutions in surgery. This serious game is based upon an attractive, challenging entertainment game that requires the player’s attention. The laparoscopic equipment is virtually embedded in the gameplay and possible malfunctions subsequently influence the game’s screen, lighting and auditory signals. Changes partly occur outside the player’s direct attentional focus, resembling the OR environment. The serious game’s construct validity was established in a previous study.

This study aimed to determine the value of the serious game on surgical trainees’ problem-recognition and problem-solving capabilities during equipment malfunctions in the laparoscopic OR. The hypothesis was that trainees who followed a game-enhanced curriculum would recognize and solve more equipment-related problems than trainees who followed the regular curriculum.
METHODS

Study Design
This randomized, single-blinded two-armed trial was conducted at a tertiary academic center in the Netherlands. Institutional ethics approval was requested, but not deemed necessary by the institutional ethics committee.

Participants
Participants were residents in their first or second year of general surgical training participating in the standard a basic laparoscopic training course (BLTC). They were required not to have any experience in MIS as a primary surgeon. Participants were enrolled into either the control group (regular BLTC curriculum) or the intervention group (game-enhanced BLTC curriculum). Randomization was conducted using a sealed opaque envelope with equal probability of group allocation. Participants were not blinded due to the nature of the intervention.

Setting
The basic laparoscopic training course is an obligatory part of the surgical residency training curriculum in The Netherlands and is modeled after FLS principles. The two-day curriculum consists of lectures on theoretical background of MIS (laparoscopic instrumentation, laparoscopic tower, pneumoperitoneum, electrosurgery and vessel sealing, ergonomics, cholecystectomy, appendectomy and hernia repair), technical skills training on a laparoscopic box trainer (peg transfer, cord placement, rubber band placement and cutting; and cholecystectomy on a cadaver liver), after which they had a hands-on interactive training session on a live anesthetized pig model (trocar positioning, cholecystectomy, appendectomy).

Intervention
The game-enhanced curriculum consisted of the regular BLTC, enhanced by two separate 30-minute sessions of serious gaming, containing an estimated 10 play sessions (Figure 1). The participants received an individual login and standardized instruction tutorial before commencing the game. The control group followed the regular BLTC curriculum. They had the opportunity to explore the laparoscopic tower during the intervention group’s gaming sessions.

Serious game
The Situational Awareness Game (Weirdbeard B.V., Amsterdam, The Netherlands) was designed to train surgical trainees in recognizing and responding to equipment problems of the laparoscopic tower (Figure 2). Educational content included problem
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scenarios of screen and lighting (19), gas transport and pneumoperitoneum (5), electrosurgery (2) and pathophysiological disturbances related to MIS (2). The player plays a popular digital entertainment game. The main objective in the game is to create rows of three similar blocks (Figure 2, left). This task, although not requiring any professional expertise, demands the player’s full attention. However, the laparoscopic tower is virtually embedded in the gameplay and in order to progress, one must be able to solve laparoscopic equipment-related problem scenarios. The game screen relates to the camera and lighting, handling blocks to the electrosurgical unit and the appearance of the visual field to the pneumoperitoneum. Per three-minute game session, the player encounters approximately six problem scenarios (Figure 2, centre). By pausing the game, the player enters a ‘troubleshooting mode’ (Figure 2, right), in which a laparoscopic tower is depicted, including Olympus Exera II CLV 180 lightsource, Olympus UHI-3 insufflator, Olympus Exera II CV-180 videoprocessor, EndoEYE HD Video Laparoscope and Surgmaster UES-40 electrosurgical unit (all: Olympus co., Tokyo, Japan). The simulated MIS unit in the game corresponds to the unit used in the BLTC.

By selecting the correct equipment and actions, the player can resolve the encountered problem, after which he or she can play again (and ‘score’ again). He or she receives feedback and points after doing so correctly. The participants’ performance in the game was measured through the amount of scenarios recognized and solved, the time required and the amount of correct / incorrect actions required to solve the problem.

Figure 1. Curriculum followed by both groups in the Basic laparoscopy course.
Outcome Assessment

All participants performed two standardized task on a live anesthetized pig model as the primary surgeon, consisting of (1) searching the small bowel for a Meckel’s diverticulum and (2) performing a biopsy of the parietal peritoneum. During their procedure, they were assisted by two OR nurses and a camera navigator. Three standardized equipment problem scenarios occurred: (1) failure of the insufflation and pneumoperitoneum, (2) failure of the electrosurgical unit and (3) saturation change on the anesthesia monitor (Table 1).

Primary outcome measures were the proportion of problems recognized and solved; secondary outcome measure was the time required to do so. These parameters were registered by an independent assessor, blinded to group allocation. Problem recognition was defined as the participant verbally or otherwise indicating that a problem had occurred <2 minutes after onset of the “symptoms”; problem solving was defined as solving it <2 minutes after problem recognition.

The participants’ technical skills were assessed by an experienced surgeon blinded to group allocation, using an Objective Structured Assessment of Technical Skills (OSATS) form. The participants received a standardized instruction before the test, during which

Figure 2. The serious game (screenshots).
Left: Main screen, with mini-game (below), the patient's vital signs, and a supervising surgeon (above).
Centre: During the mini-game, the player deals with problem scenarios that resemble real-live problems in MIS, for example the darkened screen.
Right: After the player recognizes the problem scenario, he or she can solve it by selecting the correct action on a simulation of the MIS equipment.
they were told that they would be judged by technical skills assessment (OSATS). They were instructed to use and coach the OR personnel present as they would normally do, and talk aloud in case of trouble.

**Sample Size**

Prior to the trial, a pilot study was performed in which eight surgical residents with no MIS experience as primary surgeon were assessed using the set-up described above. Using an alpha of 0.05, a power of 0.80, a population standard deviation (SD) of 0.186, and an estimated effect size of 50%, the required size for each group was 12. The dropout rate was estimated at 20%.

**Statistical Analysis**

Descriptive statistics were calculated for all variables. All data were not-normally distributed and thus Mann-Whitney U tests were applied to calculate the differences in the primary and secondary outcome measures. Subgroup analyses were performed assessing the performance of both groups on the individual problem scenarios. Differences were calculated using Pearson Chi-square tests. To estimate the learning curves during the Game-enhanced curriculum group’s individual play sessions were calculated using a random effects model.

Analyses were performed using the IBM Statistical Package for Social Sciences version 20 (IBM corp., Armond, NY, USA) and R version 2.15 (R Foundation for Statistical Computing, Vienna, Austria).

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**Table 1.** Participants encountered three standardized problem scenarios during the final assessment.

<table>
<thead>
<tr>
<th>Problem scenario</th>
<th>Cause</th>
<th>Symptoms</th>
<th>Timing</th>
<th>Correct steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Insufflator</td>
<td>Gas tank closed upon start</td>
<td>- Alarm Insufflator (auditory)</td>
<td>From start</td>
<td>- Check insufflator - Check gas tank - Check gas tubes - Check trocar position and valves</td>
</tr>
<tr>
<td>malfunction</td>
<td></td>
<td>- Loss pneumoperitoneum</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Insufflator gas bar empty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Electro-surgery</td>
<td>Patient grounding plate</td>
<td>- Alarm (auditory)</td>
<td>From start electro-coagulation task (±3 mins)</td>
<td>- Check display electrosurgical unit - Check cables - Check patient grounding plate</td>
</tr>
<tr>
<td>malfunction</td>
<td>not fit</td>
<td>- Electrocoagulation failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Pulse saturation</td>
<td>Pulse oxymeter not fit</td>
<td>- Auditory pulse signal fails to appear</td>
<td>Simultaneous with scenario #2</td>
<td>- Check anaesthesia monitor - Check pulse oxymeter</td>
</tr>
<tr>
<td>change</td>
<td></td>
<td>- Flat line anaesthesia monitor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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RESULTS

Participant characteristics
Thirty-one participants of the BLTC were randomized between May 2013 and April 2014. In total, 24 completed the curriculum and the assessment according to protocol (N = 12 in both groups, Figure 3). For four participants, the test could not be completed due to an incident at the test site closing down the facility. For a further three participants, disturbances that occurred during the test were deemed to violate the protocol in terms that heterogeneity of surgical circumstances to deviate beyond normal variability.

None of the participants had experience as primary surgeon in MIS. The game-enhanced curriculum group completed an average of 11.8 game sessions, relating to about 60 minutes of gameplay. There were no differences between age, gender, technical score (OSATS), postgraduate year or experience in conventional surgery. The Regular curriculum group contained slightly more residents in their two-year preparatory training for a specialty other than general surgery (e.g. orthopedic, plastic, cardiothoracic surgery or urology). An overview of the demographic characteristics is shown in Table 2.

![Flowchart of the participants through the study protocol.](image)
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Primary outcome

The game-enhanced curriculum group recognized a median of 67% of the problems (Interquartile range (IQR) 33 – 92%) compared to 42% (IQR 33 – 67%) in the Regular curriculum group, (Figure 4, \( p = 0.14 \)). The game-enhanced curriculum group solved a median of 59% (IQR 33 – 67%) compared to 33% (IQR 8 – 33%) in the Regular curriculum group (Figure 4, \( p = 0.03 \)).

Subgroup analysis

The insufflator malfunction scenario was solved by 8/12 participants (67%) in the Game-enhanced curriculum group, compared to 3/12 participants (25%) in the Regular curriculum group \( (p = 0.06) \). The electrosurgery malfunction scenario was solved by 10/12 participants (83%) in the Game-enhanced curriculum group, compared to 8/12 participants (67%) in the Regular curriculum group \( (p = 0.35) \). Finally, the saturation change scenario was solved by 2/12 participants (17%) in the Game-enhanced curriculum group, compared to 0/12 participants (0%) in the Regular curriculum group \( (p = 0.14) \).
Chapter 6

Learning curve

The participants in the Game-enhanced curriculum group each completed a mean 11.8 game sessions (SD 1.7), in which they played a mean 63.9 problem scenarios (SD 13.0). In the first four game sessions, they solved a mean 48.1% of the problems (SD 14.5); in

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**Figure 4.** Boxplots depicting problems recognized and solved in Game-enhanced and Regular curriculum groups. Boxes depict median and interquartile range, the error bars the 90% range.

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**Figure 5.** Estimated learning curve of naïve players per game session. Grey lines depict the estimated learning curves per participant (N = 12), black line depicts the estimated average.
the second four sessions 54.5% (SD 9.9) and in the third four sessions 69.3% (SD 14.5). Their learning curve during the game sessions was estimated using a linear regression model with random intercepts (Figure 5). This shows a 2.3% improvement in proportion of solved cases per three-minute session ($p < 0.001$). Within the Game-enhanced curriculum group, there was no significant correlation between the proportion of problems solved in the game and the proportion problems solved in the post-test (Spearman’s rho $=-0.32, p = 0.31$).

**DISCUSSION**

This randomized controlled trial effectively demonstrates that one hour of practice on a custom-made serious game results in an improved problem-solving performance concerning equipment-related problems in the MIS theatre. The importance of training laparoscopic equipment failure scenarios is emphasized by the relative poor performance of the control group, showing that current laparoscopy training courses are insufficient to train pupil’s ability to recognize and respond to non-routine events in the MIS environment. Participants in the game group were not only able to solve more equipment-related problems, they were also more likely to solve equipment failure problems that did not occur in their area of focus (e.g. insufflation of the pneumoperitoneum and vital parameters), indicating an improved situational awareness. This has considerable implications for both the surgical training curriculum and patient safety in the OR.

Serious gaming is an innovative training method that is currently being explored in medical pre- and postgraduate training\(^{12\text{-}14}\). A well-designed serious game appeals to the intrinsic motivation of the trainee to play, while educational content is fitted in a subtle, ‘stealthy’ fashion\(^ {15}\). Through repeated, voluntary interaction with the content, games lead to experiential learning\(^ {16}\). Although the effectiveness of serious games to enhance ‘technical’ surgical skills has been shown in previous studies\(^ {17\text{-}19}\), this is the first study in which a serious game is systematically assessed for its capacity in training correct anticipation to non-routine adverse events in the surgical theatre.

Other studies have proven the effectiveness of serious games for laparoscopic psychomotor skills training (‘technical’ skills). Jalink et al. compared performance of surgeons and non-surgeons on a specifically developed Wii™-based serious game and a laparoscopic box trainer, finding a significant, high correlation\(^ {17}\). Badurdeen et al. found similar correlations between performance on Wii™ based entertainment games and laparoscopic box trainer scores\(^ {18}\). Youngblood et al. compared training results of medical students in trauma management between a serious game and patient simulator, finding a significant, comparable improvement in skills in terms of a behavioral performance evaluation scale\(^ {20}\). To the knowledge of the authors, this study is the first to prove the
effect of a serious game in terms of performance improvement in the surgical environment (i.e. predictive validity).

A second strength is that the serious game intervention was applied within the regular curriculum. Participants in the control group participated in the customary BLTC, which includes lectures on laparoscopic instrumentation and the laparoscopic tower. These lectures include handling specific equipment-related problem scenarios. This substantially increases the generalizability of the study results, whereas the systematic game-enhanced curriculum and the regular curriculum are compared and not merely a “trained” and a “non-trained” group.

A potential limitation to the study is the relatively high dropout rate (22.5%). Although 31 participants were initially recruited, only 24 completed the post-test according to the protocol, equaling the minimum required number in the power analysis. A higher inclusion number was deliberately obtained because of suspected high dropout rates based on literature\textsuperscript{21}. All participants failed due to logistical reasons and none refused to partake in the test. The test protocol was complex, relying heavily on performance of the study personnel in staging the test setting and equipment failure scenarios. This led to protocol violations in three occasions. Ultimately, group sizes and baseline characteristics (technical performance, previous surgical experience and demographic characteristics) did not differ significantly. Selection bias due to dropout therefore seems limited.

A second limitation is that retention of learning in time was not measured. Due to use of live animal models and participants in clinical employment in multiple teaching hospitals, such a setting was considered not feasible.

The serious game used in this study is unique in terms that the gameplay resembles a popular arcade-type animated game, in which important surgical content was embedded. Whereas most currently available medical serious games apply realistic graphical simulations to mimic reality\textsuperscript{12}, this animated approach has deliberately be chosen to preserve interest of the player, which is especially novel to the field. It has been shown that high graphical fidelity to the medical construct (e.g. near-perfect graphical depiction of the operation room) is not necessary to teach important medical content, as long as the game’s functional fidelity (e.g. resemblance of important ‘cues’ in the action or procedure) remains adequate\textsuperscript{22}. This implies that future surgical training does not necessarily have to take place in realistic e-learning or simulation modules, but could be delivered through entertaining and attractively animated videogames. Simple and compelling games are known to be fun, reinforcing and even addictive\textsuperscript{23}. This aims to captivate the user and improving interaction time.

The place of serious gaming in the surgical residency curriculum is somewhat ambiguous. Its main advantage is the ability to invoke ‘voluntary play’ by using motivational
triggers such as competition and attractive gameplay. This distinguishes serious games from less challenging simulators, which are frequently left untouched by trainees, unless they are obligated. As the optimal effect of serious games is reached through the trainee’s intrinsic motivation (‘voluntary play’), ‘obligatory play’ of serious games in the surgical curricula thus seems a contradiction in terms. However, because non-routine events training carries clinical importance in terms of patient safety, the achievement of a minimally required level of expertise for trainees seems inevitable.

**Conclusions and recommendations**

This randomized controlled trial shows that surgical trainees that follow a game-enhanced curriculum have a significantly higher ability to solve equipment-related problems in the MIS theatre than surgical trainees that follow the regular curriculum. Equipment failure is known to lead to procedural delays and represents a potential threat to patient safety. Future research should determine the value of ‘voluntary play’ of serious games compared to an obligated minimally required level-of-performance, and relate these findings to the long-term retention of performance.

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