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Saving robots improves laparoscopic performance: transfer of skills from a serious game to a virtual reality simulator

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Abstract

Background Residents find it hard to commit to structural laparoscopic skills training. Serious gaming has been proposed as a solution on the premise that it is effective and more motivating than traditional simulation. We establish construct validity for the laparoscopic serious game Underground by comparing laparoscopic simulator performance for a control group and an Underground training group.

Methods A four-session laparoscopic basic skills course is part of the medical master students surgical internship at the Radboud University Medical Centre. Four cohorts, representing 107 participants, were assigned to either the Underground group or the control group. The control group trained on the FLS video trainer and the LapSim virtual reality simulator for four sessions. The Underground group played Underground for three sessions followed by a transfer session on the FLS video trainer and the LapSim. To assess the effect of engaging in serious gameplay on performance on two validated laparoscopic simulators, initial performance on the FLS video trainer and the LapSim was compared between the control group (first session) and the Underground group (fourth session).

Results We chose task duration as a proxy for laparoscopic performance. The Underground group outperformed the control group on all three LapSim tasks: Camera navigation $F(1)=12.71$, $p<.01$; Instrument navigation $F(1)=8.04$, $p<.01$; and Coordination $F(1)=6.36$, $p=.01$. There was no significant effect of playing Underground for performance on the FLS video trainer Peg Transfer task, $F(1)=0.28$, $p=.60$.

Conclusions We demonstrated skills transfer between a serious game and validated laparoscopic simulator technology. Serious gaming may become a valuable, cost-effective addition to the skillslab, if transfer to the operating room can be established. Additionally, we discuss sources of transferable skills to help explain our and previous findings.

Keywords Serious game · Simulation center · Laparoscopy · Skill development · Psychomotor skills · Resident training

Newly immersed in a busy and often unpredictable clinical environment, residents find it hard to commit to structural laparoscopic skills training in our simulation facilities [1]. This is aggravated by a lack of official standards for certification [2], reduced workweek hours as a result of increased regulations [3, 4] and limited evidence of transfer to the operating room [5]. Serious gaming has been proposed as a way to improve this situation, reasoning that residents like computer games so much that they will spontaneously start practising when offered a serious game designed to improve laparoscopic skills [6], and that playing a laparoscopic serious game will help residents develop relevant clinical skills [7]. We present evidence for transfer of laparoscopic skills from a serious game to a well-validated virtual reality simulator, establishing construct validity for this game.

Construct validity was investigated for a laparoscopic game by comparing simulator performance for a gaming group and a control group. We demonstrated skills transfer between a serious game and a validated laparoscopic simulator.

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Serious gaming refers to the application or adaptation of computer games for non-recreational purposes, such as learning, training, or therapy [8]. Serious games are thought to be more engaging to the learner than traditional digital learning environments, and to offer 'stealth learning' [9, 10], i.e. the trainee is too busy having fun to notice improvement on key educational outcomes [7, 11]. Quantified, meaningful performance feedback and a digital environment that adapts to the skills level of the player are important elements of this approach [2, 12, 13]. In a recent review, Maurice Graafland and his colleagues found some indication for transfer from serious gaming to surgical skills [14] but overall evidence for the transfer of skilled performance between these modalities is lacking. Going beyond these earlier efforts, a serious game with the explicit goal to help players develop laparoscopic basic skills was developed at the University Medical Centre of Groningen in collaboration with Grendel Games (the game Underground [15]). In this game, the player has to nudge robots back to the surface from a complex, underground system of mine shafts, using probes that are similar to laparoscopic instruments (Fig. 2).

We have found one study that reports construct validity for the Underground game [16]. In this study, Underground performance is compared between a laparoscopic expert group and an internist group. Laparoscopic experts outperformed internists, which the authors assume is caused by their professional laparoscopic experience, thus establishing construct validity. Jalink et al. also report a positive correlation between Underground performance and performance on the FLS video trainer Peg Transfer task, which they suggest provides evidence for transfer from skills learned playing Underground to the FLS Peg Transfer task. The FLS Peg Transfer task is a well-validated method to train laparoscopic basic skills [17–20].

There are however a number of issues with their study. First, laparoscopic experts and internists may differ in more respects than laparoscopic experience alone. Surgeons have been shown to outperform matched controls on tests for visuospatial ability [21], so an alternative explanation for Jalink et al.'s findings may be that their laparoscopic experts simply are better equipped with relevant innate abilities to deal with novel psychomotor tasks. Second, the study only assessed performance on Underground and Peg Transfer, whereas a broad range of validated basic skills laparoscopic training tasks is available to more extensively contextualize Underground performance.

To investigate the relation between serious gaming and laparoscopic skills development, we compared a gaming group with a control group for performance on two validated laparoscopic basic skills simulators: the FLS video trainer [19] and the LapSim virtual reality simulator [22–24]. Given the positive face validity and limited construct validity found for Underground serious game by the earlier study of Jalink et al. [16] we expected the Underground group to develop transferable psychomotor skills supporting laparoscopic performance, and thus outperform the control group on validated laparoscopic simulators. Additionally, we discuss sources of transferable skills to help understand our own and previous findings.

Materials and methods

Study design

To research the potential of serious gaming for laparoscopic skills development, we compared laparoscopic simulator performance for two groups. Data for both groups were collected during a four-session basic skills laparoscopic simulator training course. The control group trained on the FLS video trainer and the LapSim virtual reality simulator for all four sessions; the Underground group trained on the Underground game for three sessions. The fourth session of the Underground group was a transfer session on the FLS video trainer and the LapSim. To assess the effect of playing Underground on laparoscopic simulator performance, initial performance on the FLS video trainer and the LapSim was compared between the control group (first session) and the Underground group (fourth session). All groups were aware of participating in a study; however, since each group consisted of two cohorts, students had no knowledge of the experimental conditions of other cohorts, negating a potential Hawthorne effect.

Participants

Between September and December 2015, 107 master students of Medicine (representing 91% of four cohorts) voluntarily enrolled in a laparoscopic basic skills simulation training course as part of their surgical rotation. The September and October cohorts ($n = 53$; 33 female, 20 male) formed the control group; the November and December cohorts ($n = 54$; 39 female, 15 male) formed the Underground group. In the Dutch system, each month a new group of students of Medicine start the rotations that form the bulk of the master track of Medicine. Consequently, there are no structural differences between the cohorts of our study in terms of knowledge or skills at the start of the basic skills laparoscopy course. All participants voluntarily signed an informed consent form, allowing us to scientifically analyse and publish their anonymized performance data. No formal ethics review was sought as this is not required for this type of study under Dutch law.

Training course design

For both groups, the laparoscopic basic skills course consisted of four, 1-h training sessions which needed to be completed within 1 month. Participants were required to schedule their sessions on different days in order to maintain a distributed practice schedule, which maximizes learning [25–27]. Students were asked to train in groups of three due to the limited capacity of our skills training facility. During the first training session, staff was present to explain the course setup and the use of the training technology. The other sessions were completed without supervision, except session four for the Underground group, which included an introduction to the training technology of that session.

Informed consent and demographic information (including previous gaming and laparoscopic experience) were collected during the first training session. We considered a participant to be a gamer if they reported spending an hour or more per week during a period of a year or more on playing computer games. We did not ask participants to differentiate between different types of games.

Underground training session

During an Underground training session, participants were tasked with freeing robots stuck in an underground mining complex and guiding them to the surface. Multiple obstacles needed to be cleared by drilling, heating, and more complicated movements with two in-game rigid robotic arms. The gameplay of Underground consists of a mixture of action and puzzles in an adventure game environment while the required physical actions are based on movements made during laparoscopic surgery [28]. Performance variables for this task were total playtime and reached level. These variables were automatically recorded by the Wii U. Students were informed that they had three 1-h sessions to play the game. The variable 'total playtime' reflects the amount of time the trainee took advantage of the available hours. No extra sessions could be scheduled.

Three copies of the game were available, so students did not have to rotate along different stations as they did during the simulator training sessions described below. Each student would continue training with their own personal login on the same Underground station throughout all three Underground sessions, to allow students to continue where they had left off during the previous session.

Simulator training session

During a simulator training session, participants rotated along three training stations, so that by the end of a session each student would have trained at every station (Fig. 1).

Station 1 was a support station for station 2. Students at station 1 monitored the performance of their colleague at station 2, and recorded the resulting data in an in-house developed application for generating individual learning curves. The resulting multi-session learning curves were contextualized by expert performance and mean peer-group performance on the same tasks to help the training student reflect on their performance.

At station 2 subjects performed three different tasks on a FLS video trainer. These tasks were as follows: Laparoscopic Labyrinth, Peg Transfer and Precision Cutting. During Laparoscopic Labyrinth, the participant has to trace a labyrinth with a felt marker attached to a customized laparoscopic grasper. We developed this task to help the trainee anticipate the amplification of movements due to the fulcrum effect. Peg Transfer and Precision Cutting are official FLS video trainer tasks and are fully described here: http://www.flsprogram.org/wp-content/uploads/2014/03/Revised-Manual-Skills-Guidelines-February-2014.pdf. Quantitative performance measures were collected by the participant at station 1 and consisted of total duration for each task, and error measures.

At station 3, the subject performed two different courses on the LapSim virtual reality trainer, each course consisting of the same three tasks. During the first course, participants were instructed to focus on damage control and during the second course on speed. This was reflected in the performance variables made available to the participants after finishing each task, with an emphasis on either error or duration measures. The tasks in each course were as follows: camera navigation, instrument navigation and coordination [29]. All tasks were located in a virtual, generalized

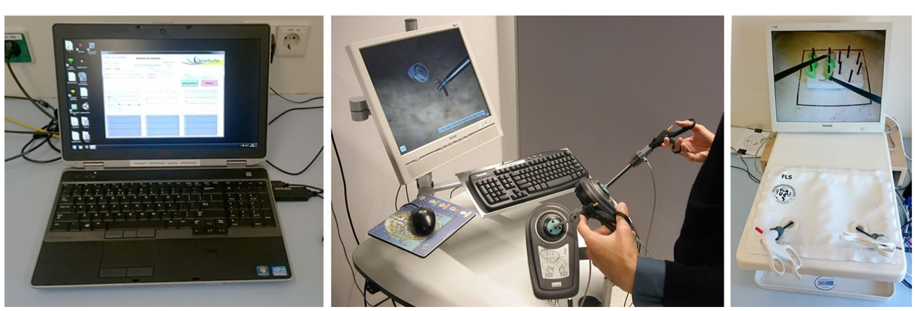


Fig. 1 Training stations for the simulator training sessions. To the left the observation station (1), to the right the FLS video trainer station (2) and in the middle the LapSim virtual reality station (3)

abdomen without specific anatomical landmarks. Simple tasks had to be performed such as zooming in with the virtual laparoscope on a small stone-like target object, or touching such a target object alternately with left- and right-hand virtual laparoscopic probes. All tasks were selected to train generic psychomotor camera and instrument handling basic skills. Performance data were automatically stored by the system and made available to the participant in the form of contextualized learning curves.

Apparatus

Simulator setup

Station one consisted of an Asus laptop running Windows 7, a König USB 2.0-analogue audio/video converter to mirror the screen from station two, an in-house developed software application to record performance and provide the participant feedback in the form of contextualized learning curves, and a stopwatch. The software application was developed in Microsoft Excel. The mirrored screen was captured for data evaluation with the freely available ISpy package [30].

Station two consisted of the FLS video trainer system [31, 32]; a 17-inch video monitor and all materials needed to complete the tasks for this station.

Station three consisted of Surgical Science's LapSim virtual reality training system (v.3.0), with a laparoscopic interface consisting of Simball hardware (G-coder Systems, Västra Frölunda, Sweden) and LapSim v.3.0 training software (surgical Science, Göteborg, Sweden).

Wii U setup

Each station consisted of a Nintendo Wii U with remote controllers and a LG 21″ HD LCD screen. The hardware was completed by a dedicated laparoscopic interface for the Wii U developed by Cutting Edge [Fig. 2].

Data preparation

Simulator tasks

Duration was used as performance variable for all six simulator tasks. The LapSim virtual reality simulator automatically records duration, for the FLS video trainer tasks duration was manually scored from screen video captures. For the FLS video trainer, only the Peg Transfer task was analysed. The Laparoscopic Labyrinth task is not an official FLS video trainer task and has not yet been formally validated. The FLS video trainer Precision Cutting task was used as a buffer task to allow students to switch simultaneously between stations, and so was often not completed by the participants. Duration data for the three LapSim tasks were analysed separately for each task. Error scores overall were too low for meaningful statistical analysis.

Underground game

Two variables were measured for the Underground game, total playtime and reached level. Total playtime is the total sum of playtime for each session. Reached level correlated strongly with playtime. Since reached level is a nominal variable (with little variation) and playtime has ratio data, we analysed playtime but not reached level to have more power.

Data analysis

Normality for all included dependent variables was confirmed by the Shapiro–Wilk test, allowing for parametric statistical testing. We performed ANOVAs to assess the impact of previous gaming experience on simulator performance in this study. ANOVAs were also used to assess the impact of playing Underground on simulator performance. To this end, duration scores of the first session of the control group were compared to the fourth session of the Underground group. Effect sizes for these analyses are reported as Cohen's *d*. To verify and elaborate on the results of Jalink

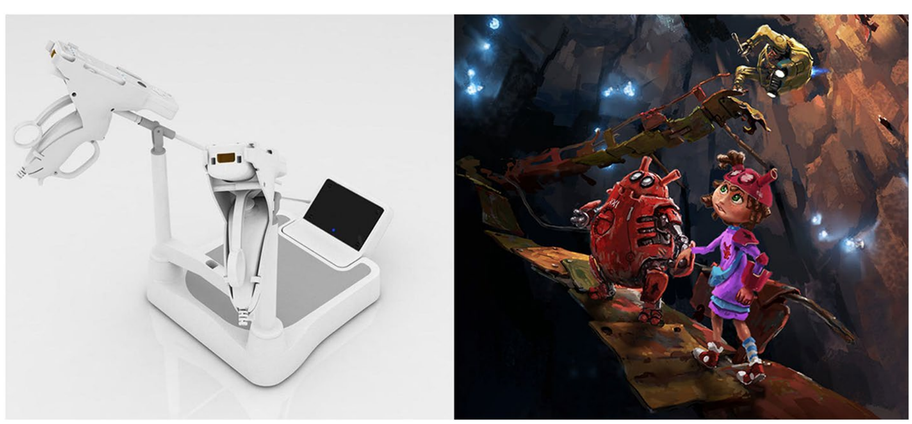


Fig. 2 Hardware interface to the Underground serious game for laparoscopic training, and an Underground gameplay impression

et al. [16], we used Pearson's product-moment correlation to assess the relation between Underground playtime and the simulators duration scores. Statistical analysis was performed with IBM's SPSS statistics v.23 package. Alpha for all analyses was set at 0.05.

Results

Participants

Data were excluded for 19 participants who were unable to complete the course due to scheduling conflicts, and for three additional participants for whom data could not be collected due to technical issues. Data for the remaining 85 students were included, in a baseline group of $n=50$ and an Underground group of $n=35$. Demographic data were missing for 33 subjects who did not fill out the digital form. Available demographic data are shown in Table 1. Testing this incomplete dataset, we found no significant demographic differences between the Underground group and the baseline group. Since both groups are drawn from a homogenous population, we consider it unlikely that the availability of complete demographics would change this outcome. Previous gaming experience did not impact simulator performance. Only two participants reported previous laparoscopic experience (one in each group). For both participants, this consisted of a single experience (one had assisted in the operating room, the other had trained on a simulator).

Table 1 Demographic data

	Baseline group ($n=50$)	Underground group ($n=35$)
Male	17	11
Mean age [age range] in years	23 [22–27]	23 [20–32]
Right-hand dominance	22	23
Self-reported game experience	7	8
Laparoscopic experience	1	1

For the baseline group, data were available for 25 out of 50 participants. For the underground group, this was 27 out of 35

Simulator performance Underground group versus baseline group

Summative mean playtime over all three sessions for the laparoscopy game Underground was 156 min, with a standard deviation of 19 min. There was no difference in FLS video trainer performance between the control group and the gaming group ($F(1)=0.28$, $p=.60$, cohen's $d=0.14$), but the Underground group outperformed the control group on all LapSim tasks (Fig. 3). For Camera navigation, this amounted to $F(1)=12.71$, $p<.01$, cohen's $d=0.85$; Instrument navigation $F(1)=8.04$, $p<.01$, cohen's $d=0.70$; and Coordination $F(1)=6.36$, $p=.01$, cohen's $d=0.61$. On average, 156 min of gaming led to a 21% performance increase in speed on the LapSim virtual reality simulator.

Concurrent validation/correlation

Although we found no difference between groups for FLS video trainer performance, we did find a significant correlation within the Underground group for Underground playtime and Peg Transfer duration ($r=-.51$, $p<.01$). We found no significant correlation between Underground playtime and duration for any of the LapSim tasks.

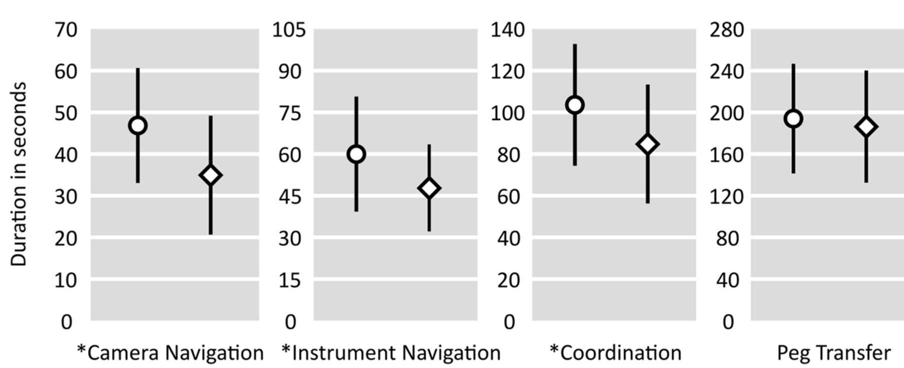
Discussion

We found transfer of skills from the serious game Underground to the LapSim virtual reality simulator, but not the FLS video trainer, supporting construct validity for the Underground game.

Underground and the FLS video trainer

Confirming the findings of Jalink et al. [16], we found a significant correlation between Underground gameplay duration

Fig. 3 Simulator task performance (means and standard deviations in seconds) for the control and Underground groups. The control group is represented by circles, the Underground group by diamonds. Significant differences between groups are indicated by an asterisk



and performance on the FLS video trainer Peg Transfer task within the Underground group. However, between groups, we did not find a benefit for playing Underground on Peg Transfer performance, arguing against an explanation for Jalink et al.'s results in terms of transfer of skills. Likely, a motivational rather than a skills-related variable is responsible for this result i.e. people that like playing Underground are also more motivated to learn to perform well on the FLS video trainer. However, if the Underground group had been allowed more time gaming, there might have been transfer to the FLS video trainer Peg Transfer task as well.

Transfer patterns

Having established transfer of skill from the laparoscopic serious game Underground to the LapSim virtual reality simulator but not to the FLS video trainer, questions remain as to the potential of transfer of skills from Underground to the operating room. Transfer of skills to the operating room has been established for both the LapSim and the FLS video trainer [33, 34], and transfer of skills has also been established between the LapSim and the FLS video trainer [35]. Additionally, professional operating room experience translates to better initial performance on both the LapSim and FLS video trainers [19, 36] (Table 2).

In order for transfer of skills to occur, the settings between which there should be transfer need to have characteristics in common [37]. What these characteristics are for the different modalities of laparoscopic training and operating room performance is currently not known, but a number of candidates have been posited:

Similarity of movement and dimensional similarity

Badurdeen et al. [38] hypothesize that games that require the player to move in three dimensions with a motion sensor controller are more useful than gameplay with a joystick or button-push controller. Additionally, games that require navigation in a virtual 3D environment should show more transfer to laparoscopy compared to 2D games [39–41]. All settings explored in this study share these two similarity characteristics, yet we found no transfer between the FLS video trainer and Underground. Similarity of movement and dimensional similarity are not sufficient to explain the transfer we found.

Table 2 Transfer patterns between three simulation technologies and the operating room (OR)

Transfer from\to	Underground	FLS trainer	LapSim	OR
Underground	X	No	Yes	??
FLS trainer	??	X	Yes	Yes
LapSim	??	Yes	X	Yes
OR	??	Yes	Yes	X

'Realism'

According to Rosenberg and colleagues, highly realistic simulation of laparoscopy is the only way to gain laparoscopic aptitude [42]. Our results and the results of other studies discussed here do not support this proposal, and notions such as realism, resemblance, or physical fidelity are currently being discouraged as theoretical tools [43]. The notion of *functional task alignment*, as proposed by Hamstra and his colleagues [44], provides a more sensible framework for work in this area. Functional task alignment proposes a shift from considerations of resemblance to a more analytic approach to simulation design.

Along these lines, we would like to propose three potential sources of transfer that would help explain the transfer patterns reviewed in the first paragraph of this section (Table 2).

Digital mediation

Both Underground and the LapSim present the player with a virtual environment, whereas the operating room and the FLS video trainer are not subject to digital mediation. Differences between virtual and actual physics, and also the presence or absence of haptic feedback may explain transfer between the FLS video trainer-operating room and LapSim-Underground pairs.

Educational framework

The educational setup of both the FLS video trainer and the LapSim is similar in terms of providing small and conceptually simple, repetitive exercises with an emphasis on quantified performance feedback (guided by expert performance levels). This sets the FLS video trainer and LapSim apart from both Underground and the operating room, which follow a linear narrative with changing tasks and no detailed performance feedback. This explanation fits the transfer between the FLS video trainer and the LapSim trainers, and would predict positive transfer between Underground and the operating room.

Unpredictability

The operating room, Underground and the LapSim are set apart from the FLS video trainer by having integrated a degree of unpredictability in their tasks, which requires ad hoc decision making during performance. The different levels of situational awareness this implies may explain the lack of transfer between Underground and the FLS video trainer.

Limitations

Duration is an indirect performance variable, dependent on more informative variables such as efficiency of movement, errors and complications. Without such more direct variables, task duration cannot be fully interpreted [45]. We were not able to collect movement or error variables, as Underground does not report such additional variables, and error measurements for both the FLS video trainer and the LapSim typically show a strong floor effect. Organizations designing simulators are advised to invest in making such additional variables available for trainees, and to design simulator tasks that facilitate training for damage control.

We only researched the effect of one serious game on the development of laparoscopic skills. At the time of writing and to our best knowledge Underground is the only serious game that focuses on basic laparoscopic skills development. Previous studies that looked at the relation between gaming and laparoscopic skills development found conflicting results [14]. However, since Underground is specially developed to resemble and facilitate the psychomotor components of laparoscopy, we feel a direct comparison of non-dedicated games with Underground would be of limited utility.

The groups in our study were composed of cohorts who were aware of participating in a study but not of whether they were in the experimental group or the control group. This eliminates a potential Hawthorne effect (which would cause the experimental group to perform better because they know they are getting the special treatment).

Lastly, dropout rates were fairly high. As our laparoscopic basic skills course at that time was not mandatory, and time available for extracurricular activities was limited, students were not always able to complete the full four sessions of our training course.

Future research

To provide a more solid foundation for the use of serious gaming to train surgical skills such as those needed for laparoscopy, transfer of skills between games such as Underground and the operating room needs to be established. Studies comparing Underground performance for novices and experienced laparoscopists would support this effort. Variables such as digital mediation, procedural differences based on educational implementation, and unpredictability may all impact transfer of skills and experimental studies exploring their role would help simulator and training course design. An important premise of the advocates of serious gaming that was not addressed in our current study is that gaming is intrinsically motivating for the current generation of students, which should lead to spontaneous training, thus alleviating scheduling concerns viz-a-viz simulator training. We are currently analysing data from a follow-up study that addresses this issue.

Conclusions

We demonstrated skills transfer from a serious game to validated laparoscopic simulator technology. Serious gaming may become a valuable, cost-effective addition to the skillslab, if transfer to the operating room can be established. To optimize transfer, more work is needed to understand the sources of transfer of laparoscopic skills.

Compliance with ethical standards

Disclosures Mr. IJgosse, Prof Dr. van Goor and Dr. Luursema have no conflicts of interest or financial ties to disclose.

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