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ORIGINAL CONTRIBUTIONS

Virtual Reality Single-Port Sleeve Gastrectomy Training Decreases Physical and Mental Workload in Novice Surgeons: An Exploratory Study

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Abstract

Background Novice surgeons experience high levels of physical and mental workload during the early stages of their curriculum and clinical practice. Laparoscopic sleeve gastrectomy is the first bariatric procedure worldwide. Feasibility and safety of single-port sleeve gastrectomy (SPSG) has been demonstrated. An immersive virtual reality (VR) simulation was developed to provide a repetitive exercise to learn this novel technique. The primary objective of this study was to evaluate the impact of the VR training tool on mental and physical workload in novice surgeons. The secondary objective included an evaluation of the VR simulator.

Methods A monocentric-controlled trial was conducted. Ten participants were divided into two groups, the VR group and the control group (without VR training). Surgery residents participated in a first real case of SPSG and a second case 1 month later. The VR group underwent a VR training between the two surgeries. Mental and physical loads were assessed with self-assessment questionnaires: NASA-TLX, Borg scale, and manikin discomfort test. The VR simulator was evaluated through presence, cybersickness, and usability questionnaires.

Results This study showed a decrease of the mental demand and effort dimensions of NASA-TLX between the first and the second surgery in the VR group ($P < .05$). During the second surgery, a marginally significant difference was shown concerning the mental demand between the two groups. Postural discomfort of the VR group decreased with practice ($P < .01$), mainly between the first and the second surgery ($P < .05$). Furthermore, participants characterized the VR simulator as realistic, usable, and very useful to learned surgery.

Conclusion This exploratory study showed an improvement in mental and physical workload when novice surgeons trained with VR (repetitive practice, gesture improvement, reduction of stress, etc.). Virtual reality appears to be a promising perspective for surgical training.

Keywords Single port · Sleeve · Obesity · Learning · Simulation · Virtual reality · Human factors

Introduction

Novice surgeons experience high levels of physical and mental workload during the early stages of their curriculum and clinical practice [1, 2]. Recently the rise of computer sciences allowed the development of new training tools, used in the medical field for the acquisition of knowledge and technical skills [3, 4]. Virtual environments applied to healthcare are used in two domains: (1) applications for patients as the treatment of phobia [5], addictions [6],

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analgesia [7], neurological diseases [8], or physical disabilities [9] and (2) applications for physicians: virtual reality (VR) can assist medical activity (e.g., medical imaging) but can also be used for training and teaching purposes [10, 11]. Laparoscopic sleeve gastrectomy is the first bariatric procedure worldwide, commonly performed using laparoscopic multiport. Feasibility and safety of a single-port sleeve gastrectomy (SPSG) has been demonstrated [12, 13]. It is now a standardized minimally invasive procedure requiring adequate teaching and training to acquire skills. The stapling of the gastric pouch stage is one of the most crucial and technical steps during SPSG, which may be associated with complications such as leaks or bleeding. Therefore, a SPSG simulator was designed in this study for this specific step.

The objective of the study was to explore the impact of an immersive virtual reality simulator on the workload perception of surgery residents. This experiment hypothesized that training with the VR simulation would benefit novice surgeons' workload.

For this purpose, the National Aeronautics and Space Administration—Task Load index (NASA-TLX) and the Borg scale associated with manikin discomfort test were used. Questionnaires (regarding the sense of presence, simulator sickness, and usability) and stereoscopic test were also used in this study to assess the VR experience concerning the solution developed here.

Material and Methods

This is a prospective controlled simulation study conducted from January 2018 to September 2018, to assess the impact of a virtual reality single-port sleeve gastrectomy training on physical and mental workload in novice surgeons.

Participants

Ten residents in surgery from the Institut Mutualiste Montsouris in Paris participated in the experiment (last year graduation/or first professional experience). The participants were 6 men and 4 women ($M = 30.2$ years old; $SD = 1.22$). They all had the same level of experience in laparoscopic surgery. The residents were selected because of their little experience in the field of laparoscopic surgery, and especially none of them had previously performed a single-port sleeve gastrectomy. They were divided in two groups (VR group and control group) depending on the timing of their internship (January 2018–May 2018: VR group, May 2018–September 2018: control group). All residents signed an informed written consent.

Material

The VR training module was designed by *VirtualiSurg* company on HTC Vive headset (2016 version, Dual AMOLED, 1080 × 1200 pixels per eye, 90 Hz, 110°). The virtual training module represents a virtual world of an operating theater (Fig. 1) and focuses on a specific aspect of the surgery: the use of endo-cutter stapler. Real instruments of bariatric surgery were used, with sensors integrated, to interact with the virtual scene instead of standard HTC controllers. The virtual operation lasted 20 min (similar to real life duration of surgery; 21.9 ± 6.2 min).

Procedure

Residents in surgery participated in two sleeve gastrectomies under the supervision of an expert senior surgeon, the first one during their internship, and a second one a month later. The VR group underwent VR training sessions between those two surgeries. For the VR group, the protocol was as follows: (1) first operating theater intervention (identified as OT1) with senior surgeon; (2) training phase with VR (including a tutorial of the simulator before the VR sessions); (3) second operating theater intervention (OT2) with the same senior surgeon (Fig. 2). Residents were in the first operator position during stapling (OT1 and OT2). Twenty patients were included in this study, no differences were found between groups or surgeries regarding age (39 ± 11.9 years old), weight (120 ± 19.2 kg), sex (male = 40%, female = 60%), or stapling operation duration (21.9 ± 6.2 min). Each learner of the VR group performed six VR sessions over a period of 1 week. The control group did not train with VR (no substitution training). After each training (real surgeries and VR sessions), participants answered surveys on mental and physical workload. Three questionnaires specific of virtual environments and software usability have been filled once after VR sessions.

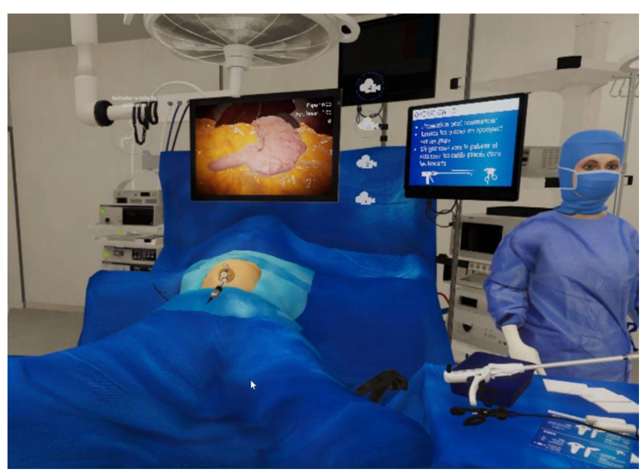


Fig. 1 Screenshot of the virtual operating theater

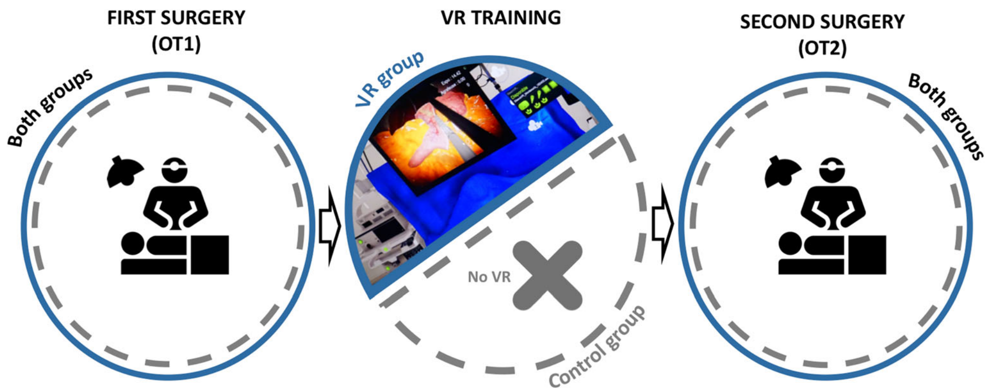


Fig. 2 Experimental protocol: participants from both groups performed the first surgery in the operating theater (noted OT1 in the text). VR group performed training on VR module (noted VR training or VR sessions). Then, all participants performed a second surgery in the operating theater (noted OT2)

Primary Endpoints: Measurement of Mental and Physical Loads

The primary endpoints were the measurement of mental workload with the NASA-TLX score [14] and the measurement of physical workload evaluated with Borg scale and the manikin discomfort test [15, 16]. The NASA-TLX is a subjective tool to rate perceived workload composed of six dimensions rated on a 100-point scale on each dimension (mental demand, physical demand, temporal demand, performance,[1] effort, and frustration). The Borg scale is a numerical scale that ranges from 6 (no exertion at all) to 20 (maximal exertion) on the level of subjective exertion during physical activity. The manikin discomfort score (also named postural discomfort) allowed participants to express their physical discomfort during the task on a scale of 0 (no complaints) to 10 points (extreme amount of complaints), with an identification on a manikin drawing.

Secondary Endpoints: VR Experience

The secondary endpoints included three specific questionnaires of virtual environments and software usability about VR simulation. VR experience would rely on the sense of presence, and the impact on performance and learning [17–19]. Presence is defined as "subjective experience of being in one place or environment, even when one is physically situated in another" [20], and VR immersion can lead to side effects such as simulator sickness or cybersickness (nausea, eyestrain, and general visual discomfort; [21]), linked to conflict between visual and vestibular systems [22]. Side effects could impact negatively the VR experience and limit the progress of the training. To control these aspects, the Simulator Sickness Questionnaire (SSQ; [23]) and the presence questionnaire (PQ; [20]) were used in this study. In addition, to give a more global feedback of subjective usability and interest of the VR simulator, the SUS questionnaire [24] including open questions was administered to participants of the VR group ($n = 6$). Participants of the VR group also performed a stereoscopic test (*Titmus Stereotest* with circles, animals, and fly parts) to assess their stereoscopic visual acuity (e.g., a stereoblind person), in order to avoid a negative impact on their VR performance [25, 26].

Statistics Analysis

Comparison of the self-assessed workload results between the two groups was analyzed with a Mann–Whitney *U* test. Evolution of the workload self-assessment results in VR group was analyzed using a Friedman test and a Wilcoxon test in the control group. Data were analyzed with SPSS version 23 software.

Results

Workload scores and VR experience were analyzed to evaluate the benefit of the immersive virtual reality simulation. Results of the stereoscopic test (*Titmus Stereotest* with circles, animals, and fly parts) confirmed that all the participants of the VR group possessed a stereo vision with a good binocular disparity (e.g., 9/9; 40 s of arc on the Titmus stereotest/circle part).

Primary Endpoints: Measurement of Mental and Physical Workload

Results of each dimension of the NASA-TLX score are displayed in Table 1. Significant differences were found in the mental demand dimension ("How much mental and perceptual activity was required?"), with a decrease of the score in the VR group ($P < .05$), while an increase was observed in the control group ($P = .066$). Participant's mental demand (thinking, deciding, calculating, etc.) seems to decrease with the VR training. These results are reinforced by the comparison between the two groups for the mental demand score in

[1] In NASA-TLX, performance is the only dimension with an inverse range, the scale going from good (0) to poor (100), while in other dimensions, the scale going from low (0) to high (100). RTLX score was used in this study [27].

Table 1 NASA-TLX scores for each dimension in the VR group and control group (median and IQR: interquartile range)

	VR group				Control group		
	OT1 Median IQR	VR Median IQR	OT2 Median IQR	P*	OT1 Median IQR	OT2 Median IQR	P**
Mental demand	82.5 (66.25; 96.25)	65.65 (48.12; 75)	70 (40; 76.25)	.05	62.5 (51.25; 72.75)	80 (76.25; 83.75)	.066
Physical demand	35 (16.25; 58.75)	33.12 (28.43; 50.93)	47.5 (28.75; 58.75)	.513	45 (17.5; 57.5)	52.5 (23.75; 58.75)	.715
Temporal demand	32.5 (5; 46.25)	33.75 (25.62; 41.87)	37.5 (10; 70)	.513	27.5 (17.5; 67.5)	57.5 (16.25; 65)	.465
Performance	80 (48.75; 83.75)	47.5 (39.37; 58.43)	52.5 (37.5; 61.25)	.097	22.5 (20; 70)	62.5 (30; 68.75)	.285
Effort	80 (50; 95)	56.25 (33.75; 67.18)	62.5 (40; 72.5)	.031	37.5 (13.75; 50)	55 (42.5; 75)	.109
Frustration	42.5 (32.5; 51.25)	45 (32.81; 55.93)	37.5 (15; 62.5)	.878	50 (23.75; 83.75)	50 (31.25; 50)	.655

*Friedman test

**Wilcoxon test

the second surgery (Fig. 3). In this dimension, the control group obtained a marginally significant high score (M = 78.75, SD = 6.29, Med = 80), when compared to VR group (M = 50.16, SD = 26.15, Med = 70; P = .08).

Effort dimension ("How did you have to work, mentally and physically?") displayed similar positives results, with a high score in OT1, decreasing throughout VR sessions and OT2 (Table 1; $P < .05$). Less effort (physically and mentally) was required for residents to accomplish the task. While, other result of NASA-TLX dimensions score did not show statistically significant differences; VR training appeared to be beneficial to decrease mental workload amongst interns.

Concerning physical load of the VR group, the postural discomfort mean score decreases with practice: 5 points[2] (SD = 2.36, Med = 5.5) in OT1, 1.52 points (SD = 0.90, Med = 1.5) in VR sessions, and 1.41 points (SD = 1.96, Med = 0.75) in OT2 ($P < .01$). The VR training decreases the sense of discomfort mainly between the first and the second surgery (post hoc Wilcoxon test; $P < .05$; Fig. 4). However, no significant difference was found between OT1 and OT2 in the control group or between groups. Discomforts were localized to upper limbs (shoulder and lower arms in priority), then neck and lower back. The Borg scale showed a median physical effort, from 10.45 (SD = 1.62, Med = 10.25) to 12.16 (SD = 2.48, Med = 12.5) in the VR group (on 20 points scale range) and from 9.9 (SD = 2.75, Med = 11) to 11.5 (SD = 1.9, Med = 12) in the control group, without differences between sessions or groups.

Secondary Endpoints: VR Experience

SSQ results showed a majority of "none" side effects/symptoms (68%), then "slight" (28%), "moderate" (2%), and none of the participants indicated "severe" symptom out of the 16 questions. No differences were perceived in *Nausea* and *Oculo-motor* categories [28].

For the Presence Questionnaire, a mean score considered as intermediate to strong (M = 4.72/7, SD = 0.65)[3] was obtained. Participants felt overall rather present during the virtual task (see Fig. 5 for a sample of questions). Best scores were obtained in *control* (M = 5.66/7, SD = 0.91) and *realism* (M = 4.76/7, SD = 1.75) categories, followed by the *quality of interface* (M = 4.66, SD = 0.64). *Haptic* score was the lowest of all dimensions (M = 3.83/7, SD = 1.74).

Participants also filled out a SUS questionnaire. A mean score of 68.33 points was obtained (SD = 11.69), considered as an *acceptable* to a *good* device [29]. Open questions were included in the study to evaluate the benefits of the VR simulation during the training phase. Residents highlighted the positive aspects of the VR module in surgical training as "best practice of stapler/curved instrument" (n = 5/6), "improvement of gesture/best accuracy" (n = 4/6), or "to reduce stress" (n = 3/6), and on the VR experience "feeling like in the operating theatre/very realistic" (n = 2/6).

Discussion

Healthcare simulation can be defined as "an imitation of some real thing, state of affairs, or process for the practice of skills, problem solving, and judgment" [30]. Screen-based and virtual reality simulation have many advantages as portability (easy to move), distribution and replicability (usable by many learners at different places in the world), repeatability (for rare

[2] Postural discomfort score is based on manikin body part of Corlett and Bishop [16]. Here, the score range from 0 to 10, with 0 being none discomfort and 10 extreme discomfort.

[3] The PQ measure is divided in seven categories: realism (seven questions), possibility to act/control (four questions), quality of interface (three questions), possibility to examine (three questions), self-efficacy/performance (two questions), sounds (not evaluated here), and haptic (two questions). The questionnaire contains 21 items and is measured through an 8-point semantic differential scale (e.g., from "not at all" to "completely").

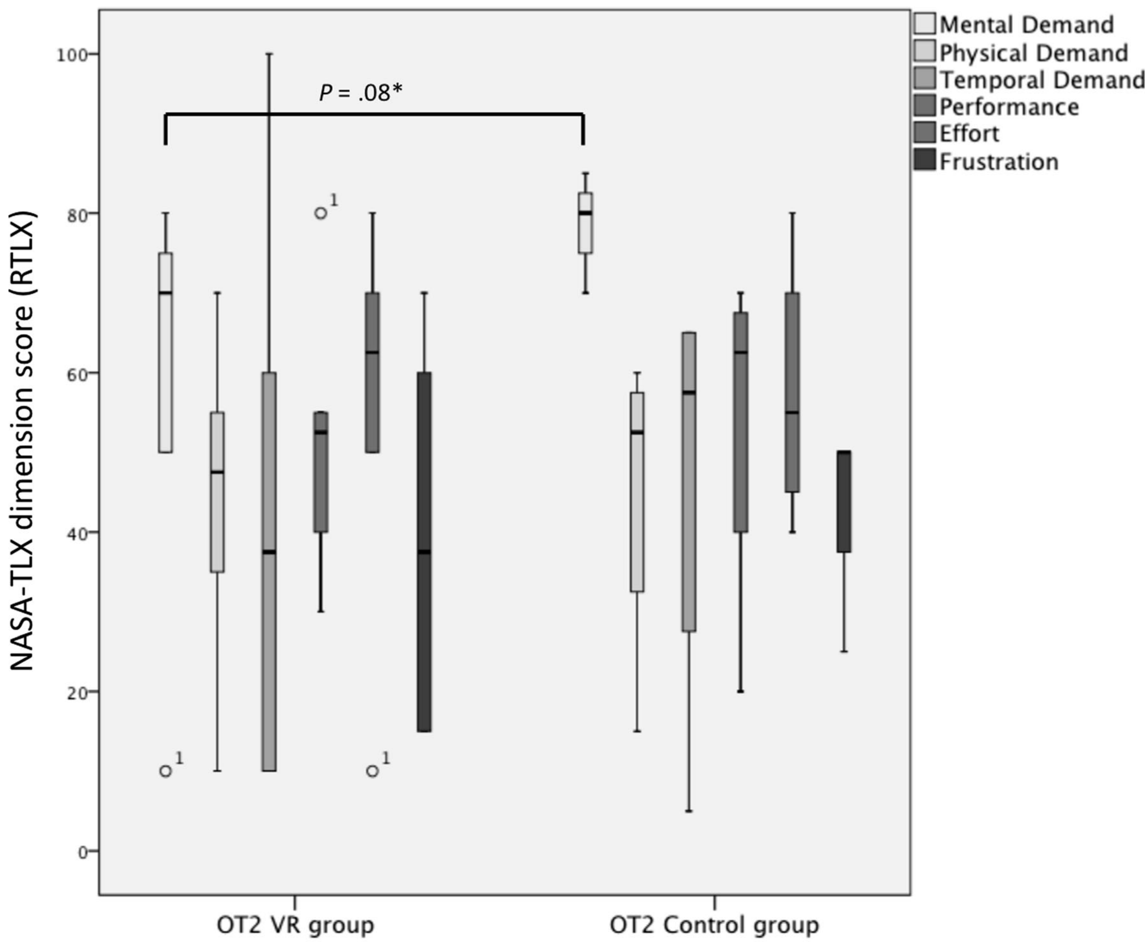


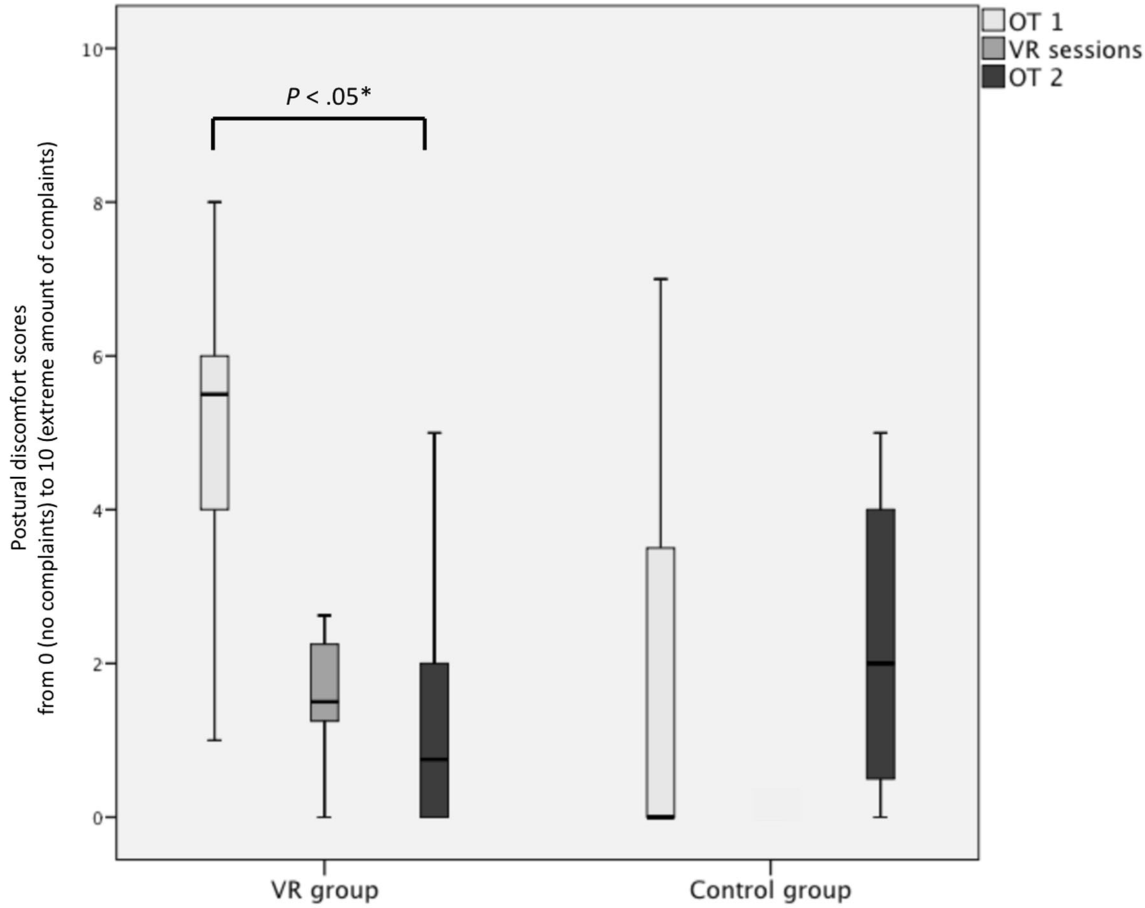
Fig. 3 Box-whisker plots of NASA-TLX dimension scores (median, quartile, range) of the second surgery (OT2)

case, seen less frequently in a regular practice), and even be remotely usable [31, 32]. A recent report of a consulting company *Grand View Research*[4] showed that virtual reality and augmented reality in healthcare is expected to reach 5.1 billion dollars by 2025 in the world. More and more commercially fully immersive solutions are developed by companies for training. However, few studies have demonstrated the real impact on learning of these tools. Most of the existing studies are recent (less than 5 years old) and cannot be exhaustive (medical situation, acquisition of know-how and/or knowledge, satisfaction, memorization, acceptability, etc.). In surgery, and even more for novices, fatigue, stress, or also workload could impact task completion [1, 2]. Practice, especially by simulation, could improve expertise in both technical and non-technical skills [11]. In laparoscopic surgery, VR simulation provides basic surgical skill training [33], even if devices are limited by the lack of realistic haptic feedback [34]. In recent years, technology has evolved greatly and a complete VR simulator could be used for routine training such as the VR single-port sleeve gastrectomy training presented here (with immersive virtual world and haptic devices). VR with head-mounted display simulation offers a new model for surgical training [35, 36] awaiting further research for definitive validation.

The goal of this research was to assess the benefit of a VR simulator designed to train single-port sleeve gastrectomy (more specifically the endo-cutter stapler phase). Ten residents in surgery followed a training program of single-port sleeve gastrectomy, and self-assessment questionnaires (NASA-TLX, Borg scale, and postural discomfort test) were used to analyze mental and physical workload during real and simulated surgical task [37, 38]. In mental demand and effort dimensions, a decrease in these scores was observed in the VR group between the first and the second surgery, while an increase was observed for the control group. Similar results were observed concerning physical workload.

Furthermore, residents evaluated the VR device designed in this study as an interesting simulation tool for

[4] Augmented reality (AR) & virtual reality (VR) in Healthcare Market Report, 2025. Available from https://www.grandviewresearch.com/industry-analysis/virtual-reality-vr-in-healthcare-market.



* Post hoc Wilcoxon test

Fig. 4 Box-whisker plots of postural discomfort score (median, quartile, range), in the VR group and control group

training with an important sense of presence in the virtual task, which could facilitate learning. VR simulation is perceived by residents as an opportunity to improve technical skills and the manipulation of surgical instruments, and also to reduce stress. Learners acquire self-confidence and real surgical practice becomes less complex and more accessible. However, haptic system will be improved in the next version. Finally, no severe symptom in the simulator sickness questionnaire was reported.

The study has some limitations. First, the small sample size limits the interpretation of our results ($n = 10$); our study would need to be replicated with a larger cohort. Secondly, virtual reality training was proposed to one group but no substitution training was proposed to the control group. Thirdly,

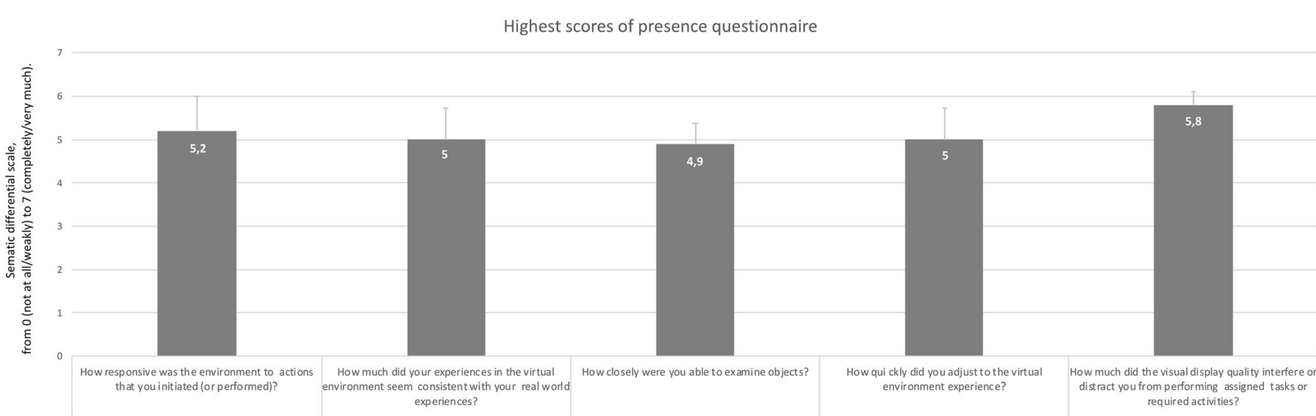


Fig. 5 Highest scores of presence questionnaire in the five first categories (mean and standard error)

the real cases of surgery were, of course, not standardized and then could be more or less complicated (e.g. clinical difficulties, external events, etc.), this could be explained the increase of some scores in the control group. Further analysis will have to be carried out concerning VR contribution with regard to the technical dimensions as performance, temporal gain, or precision [39]. A technical checklist is currently designed by the research team to analyze these dimensions.

Conclusion

In this exploratory study, the interest of immersive virtual reality simulation for single-port sleeve gastrectomy was presented. The simulator could improve surgical practice and decrease the physical and mental workload of learners. Future prospects inspired by this research will be done to evaluate this device on more learners to validate these first results and analyze more precisely technical aspects of the task.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval Statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Statement Informed consent was obtained from all individual participants included in the study.

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