

Augmenting Surgery: Medical Students' Assessment and Ergonomics of 3D Holograms vs. CT Scans for Pre-Operative Planning

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Abstract

INTRODUCTION: Mixed reality (MR) allows surgeons to pre-operatively assess patients' anatomy (e.g., tissue to be removed). However, medical students have limited access to this technology, and express both the desire to try it and suspicious attitudes.

OBJECTIVES: To assess students' experience with traditional vs. innovative technology for pre-operative planning.

METHODS: 11 medical students analyzed a lung cancer case using CT scans or a 3D hologram (MR) and assessed the technology in terms of mental workload, emotions and formative value.

RESULTS: MR resulted in less cognitive load and effort, shorter response time and more positive emotions. No differences emerged in formative value, but the students expressed the desire to be trained both in traditional and innovative technology for pre-operative planning.

CONCLUSION: Medical students respond positively to "hands-on" experiences of technology for pre-operative planning. The time may be ripe to include MR in medical formation.

Keywords: Mixed Reality, Augmented Reality, Pre-operative evaluation, surgery, medical students, medical training, medical formation

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1. Introduction

New technologies are changing the ways professionals perform medical activities. For example, eHealth or technologies based on the internet and web applications are more and more used to assist patients in health

management and treatment adherence, as well as to support monitoring by physicians and other health professionals [1–3]. More recently, Artificial Intelligence solutions are featured in medical practice, usually as diagnostic support tools within a precision medicine approach [4,5]. A technology that received a huge deal of attention and development in the last

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decades, especially in the field of surgery, is Mixed Reality (MR) [6–8]. While Virtual Reality refers to devices that fully immerse the users within virtual simulations (also employed in surgery education) [8], MR could be defined as the merging of real and digital stimuli, aimed at enriching user's perception and interaction; in the literature it could be referred to also as "augmented reality" (AR) or "augmented virtuality" (AV), depending on whether the emphasis is put on the real or the digital stimuli.

In surgery, MR display technologies could be used both intra-operatively and pre-operatively. In the first scenario, the surgeon performs the intervention while a display superimposed on the patient's body shows relevant, but normally invisible medical information that helps to improve accuracy [9,10]. In the heart surgery branch, for example, the three-dimensional image data have potential benefits of high mobility, gesture control, and angle independency of users [11]. In particular, MR increases effectiveness in managing diseases and delivering appropriate care by assisting physicians to identify problems and decide among available decisive interventions. For instance, the opportunity to visualize multiple holograms simultaneously allows physicians and surgeons to integrate multiple medical information, promoting the accuracy of diagnosis and intervention. In addition, as an endoscopy screen, MR allow surgeons to adjust in size and position according to their preferences [12].

At pre-operative level, 3D holograms could be used in advance and/or right before the surgical intervention to gather information on patient's anatomy and support planning of the best strategy. For example, the surgeon could use such 3D models of the patient's organs to assess tumor location and extension, to identify portion of tissue to be removed, to select the correct trajectories to place implants [11], [12] etc. Moreover, from a cognitive point of view, 3D holographic models offer professionals and learners an invaluable support in spatial imagination and mental rotation, cognitive abilities individuals could be more or less skilled in and that notably affect the effectiveness of surgery planning [11,13,14].

The great potentialities of MR have been also shown in the orthopedic open surgery as a training system. The realism of simulated surgical cases and adequate prototypes to generate a synthetic model guarantees a realistic haptic feedback that improves users' satisfaction [15].

Recently, growing evidences have shown the positive use of MR also in teaching. In the health sciences in particular, the improvements in learning are also often associated with the positive reactions of students to technology as useful pedagogical approach [16]. Finally, MR can also be applied in the field of Serious Games and Gamifications (MRSGs), that can consequently be considered as a novel MR educational learning framework under a both formal and informal

approach that increases students' motivation and engagement [17].

For all these reasons, the introduction of innovative technologies seems to be necessary and requested, especially in the field of healthcare. In this regard, the literature reveals the importance of involving the entire system of care, considering MR applications as well as education and teaching to understand the terms of real changes and possible benefits.

2. Related Work

While MR technologies for pre-operative planning are becoming more and more widespread in surgical practice, their implementation within medical education curricula is relatively rare. Specifically, MR has been often tested as a tool to support anatomy learning in medical students, but not to train pre-operative planning for surgery. For example, Kupuc, Kapakin and Goktas [18] showed that medical students using mobile-based MR tools obtained higher academic achievement in anatomy learning than a control group, and also reported lower cognitive load. Analogous results have been found by other studies, that also emphasize how these technologies tend to be positively received by medical students and to boost their motivation [19,20].

A review by Zhu and colleagues [21] investigated the effectiveness of using AR in health education. The authors highlighted three main strengths: it can be implemented in different health areas and aimed at all levels of learners; it improves education by reducing the amount of practice needed and the failure rate, promoting better performance accuracy, grabbing the student's attention more easily, supporting a better understanding of spatial relationships, and providing experiences with new types of genuine scientific inquiry and better evaluation of trainees; finally, the AR appears to be accepted by the participants, who consider it useful, valid, reliable and applicable. An important part of the literature reports that medical students have positive attitudes towards digital technology for learning and future practice, but this is especially true when they get the possibility to engage in hands-on experiences soon in their study curricula. Indeed, medical students may also develop suspicious or negative attitudes towards technologies for medicine. If they were trained to use "traditional" tools and practices only, they may fear finding themselves unprepared when asked to become proficient in advanced technology in the field. Moreover, attitudes towards technology are generally influenced by pre-existing tech savviness and computer self-efficacy, namely beliefs about one's own ability to use technology effectively, which in turn are partially determined by individual and cultural factors [22]. For example, despite performance data do not show significant differences, females tend to feel less

confident than males when learning and using new technology [23].

Attitudes towards technology are relevant to its use and should not be underestimated [24–26]. Poor attitudes towards a given technology by professionals who are supposed to use it could lead to waste of resource to promote or force acceptance within the organization, and even to technology abandonment and return to previous technological infrastructures. Education and training certainly play a role in the formation of informed and objective attitudes towards technology and could promote proper usage in future practice.

The introduction of practice into training has long been considered fundamental, especially in advanced education. Students need to be able to put into practice what they have studied in books in order to acquire valuable knowledge and expertise grounded in real-life experience [27]. In particular in the field of health care, experience is of fundamental importance. A study on professionals working in primary care has shown how the possibility of having an integrated teaching-service program in Primary Care is a fundamental practice [28]. A tool that has proved to be very useful within practice is the use of technologies. Especially in the field of medicine, they can provide a real test bed for students and postgraduates who soon will have to deal with patients in flesh and blood. Furthermore, technologies in medical practice support the aim of an interprofessional working system, aimed at developing more appropriate treatments [29]. Despite the presence of numerous evidences in favor of the use of practice and in particular of technology in study paths, still few programs offer this possibility.

In order to assess the adequacy of MR technology for preoperative planning as a learning tool, compared with more traditional means, it is paramount to analyze its ergonomics properties as well as medical students' emotional and attitudinal responses. In particular, one of the most important factor to consider is mental workload. A fundamental concept in ergonomics, mental workload refers to the amount of attentional resources necessary to perform a task as a function of task demand, environmental context in which the task is performed, and past experience of the individual with the task [30,31]. Mental workload influences quality and time of task performance and it is usually assessed by considering multiple dimensions separately [31], namely cognitive load or the amount of cognitive resources requested by the task (e.g. thinking, reasoning, observing); physical load or the amount of physical effort exerted (e.g., pulling, pushing); temporal demand or the perceived time pressure; effort or the subjective amount of resources devoted to the task; performance or the subjective evaluation of one's own achievement; and frustration or the emotional component which potentially altered the quality of final outcomes.

Furthermore, while mental workload evaluation focuses on the user experience, it is important to assess the usage properties of the technology involved in the task. This could be done by analyzing perceived usability or easiness of use [32].

Finally, recent reviews [33] confirm the idea that emotions play an important role in technology-based learning environments, especially enjoyment and positive emotions directly affect control, cognitive support and final achievement, while anxiety exerts the opposite influence on all variables. For this reason, it is important to analyze emotions within learning environments that feature hands-on experiences with technologies, as those are related to the formation of attitudes that promote proper usage [34].

The objective of this study is twofold: (1) to analyze performance and mental workload associated with two technologies, namely traditional computer tomography (CT) scans vs. a 3D hologram (MR), when used by medical students to simulate pre-operative planning; and (2) to analyze emotional and attitudinal responses by medical students to the task performed with the two technologies.

3. Methods

3.1. Sample

Eleven medical students (1 female, Min. age=23, Max. Age=28, $m=24.1$, $SD=1.4$) voluntarily participated in the study. At the time of the research, they were enrolled in the fifth (6) or sixth (5) year of a master degree in medicine. Participants were told they would have used medical tools to simulate a pre-operative evaluation of a patient about to undergoing surgery.

3.2. Instruments

Operators

This section includes the tools and stimuli that were presented to the research participants. All participants analyzed the same lung cancer case by interacting with either the CT scans or a 3D hologram (MR) of a patient anatomy. The case was a 50-year-old male patient with a contrast-enhanced, solid lesion of the left upper lobe. PET FDG was positive and endoscopic biopsy confirmed the presence of a lung adenocarcinoma.

CT scans were visualized on the computer screen of a laptop, a LENOVO ThinkPad with a Intel Core i5 processor, CPU M430, 2.27 GHz. CT scans were displayed on RadiAnt DICOM viewer, one of the most common software in the field. By using the computer

mouse, participants were able to browse all the available sections of the scans (Coronal, Sagittal, Axial).

The displayed 3D hologram (ARTINESS, Milan, Italy) processed preoperative CT data within a custom-designed software application that runs on the Microsoft HoloLens (Microsoft Corporation, Redmond, WA), a commercial mixed-reality headset (Fig. 1). The HoloLens is cordless and allows the user to directly see the physical environment, but with digital objects superimposed onto it. This provides true 3D depth perception integrated in the physical environment, with benefits in terms of high mobility, angle independency, and gesture control for direct interaction. Allowing hand gesture recognition for manipulation of the digital object, full use of the MR visualization tool is possible in an OR without breaking the surgical scrub. Analogous technologies have been prototyped and tested in numerous surgery contexts [11,35,36].

Measures

This section includes all the measures taken during the experiment. As time measures, the experimenter took:

- total time: time in seconds since when the participant received the questions to answer until the end of the entire task (signaled by the participant);
- response time: average time between the participant receiving one question and the first response to it.

The participants filled in the following questionnaires:

- For the analysis of mental workload, NASA TLX (task load index) [37], the most widely used measure for the construct. It comprises six items referring to six subscales, namely mental demand, physical demand, temporal demand, effort, (evaluation of own) performance, frustration. Each item is accompanied by a description that helps to understand the dimension (e.g., for mental demand: “How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?”). Participants rate the pre-operative analysis task on each dimension using a 0-100 Likert scale;
- Italian version of the System Usability Scale [38,39], a ten 1-5 items questionnaire to assess easiness-of-use of the technology; while a detailed investigation of usability would require the implementation of specific methods such as cognitive walkthrough or heuristics analysis [32], it could be assessed with questionnaires to obtain a general evaluation as a property of the technology [38]; while it could not be construed as a complete usability analysis, the SUS could be considered evaluation of global satisfaction towards usability [40]. To obtain the 0-100 score 1 should be subtracted from all odd-numbered items and responses to even-numbered items should be

subtracted from 5. Finally the items are summed and multiplied for 2.5;

- A measure for emotional experience, namely Visual Analogue Scales (VAS) to quantify the intensity of specific emotions on 9-point Likert scales (Fear, Joy, Sadness, Anger, Anxiety, Surprise); VAS items were phrased as such: “Please, select a number to say how much do you feel the corresponding emotion RIGHT NOW” (with the categorical emotions following along with the Likert scales). Such a measure is used often when assessing emotions in complex tasks involving technology use [41];
- Three ad-hoc questions to assess perceived formative/educational value of the task and technology. Specifically, participants rated their agreement on a 1-7 Likert scale with the subsequent sentences: “It would be useful to be able to use this technology within university courses”; “To use this technology regularly would be positive for my formation”; “By using the technology, I have felt learning something new”. Responses to the three items were averaged to obtain a single index.

3.3. Procedure

All participants were presented with the same real-life case of lung cancer. The participants were welcomed in a quiet room by an experienced researcher and instructed in the task. Before being introduced to the experimental operators, they responded to predetermined questions to record their demographics (age, gender, course year). Then the main task of the study was introduced. Specifically, the medical students had to imagine performing pre-operative planning and given a list of questions to respond by analysing the case. The questions were previously identified by the second author who is an experienced surgeon and a professor in medicine, and were selected to be adequate to the expertise level of the students: they regarded primarily the location of tumoral masses and their morphological properties.

The first group (5) observed the CT scans of the patient; the second group (6) observed a 3D hologram by wearing the Microsoft HoloLens (fig. 1). All the participants were given three minutes to familiarize with either the software for CT scans or the Microsoft HoloLens, with the experimenter providing basic information to use the technologies. Besides the obvious differences related to the usage of the devices (e.g., CT scans were observed on a computer screen by using mouse and interface, while the Microsoft HoloLens were wore on the head), the experimental setting was kept as similar as possible to avoid the influence of external factors on the experience and the performance. None of the participant reported any kind of discomfort.

Participants were given a maximum of fifteen minutes to complete the task, which consisted in providing their responses by speaking so that the experimenter could take note of them on a structured sheet (this was done to not resemble a “school assignment” by having participants filling in a sheet themselves, and also to not disrupt the observation experience in the MR participants who were wearing the headset). Participants were given a maximum of ten minutes to analyse the CT scans or the 3D hologram, with the instruction to end the task themselves when they felt having finished and were sure of their answers.

Immediately after the case analysis task, participants filled out the questionnaires on the spot, by using the Qualtrics platform. When finished, participants were debriefed by the experimenter and asked questions on their experience and opinion about the formative value of the task and the technologies involved. Finally, they were thanked for their participation and left the room.

3.4. Data Analysis

Statistical analyses were performed using SPSS version 16 (SPSS Inc., Chicago, IL, USA) software. Independent samples t-test were run on all the dependent variables of the study, comparing group “CT scan” and group “MR” (3D hologram).



Figure 1. Example of CT scans (coronal section, above) and 3D hologram as seen by the research participants.

4. Results

Results from the independent samples comparisons are reported in table 1.

Regarding NASA TLX, the task performed with the 3D hologram (MR) was characterized by significantly less cognitive load and effort than the task performed with

Table 1. Independent samples t-tests

	MR (M, SD)	CT Scan (M, SD)	t	p
NASA Mental	40.1, 10.9	58.8, 13.5	2.522	.033*
NASA Physical	15.1, 9.5	6.8, 8.9	-1.492	.170
NASA Temporal	16.5, 16.3	34.4, 23.2	1.500	.168
NASA Effort	26, 16.2	57, 20.5	2.799	.021*
NASA Performance	66.6, 25.6	45, 16.5	-1.621	.139
NASA Frustration	50.5, 34.6	58, 30.2	.377	.715
SUS Usability	82.5, 10.9	66, 15.8	-1.967	.072
Anger	1.8, 2	2.2, 2.5	.290	.779
Fear	1.3, 0.51	2.4, 1.5	1.628	.138
Sadness	1.5, 1.2	1.7, 1.5	.290	.779
Joy	6.5, 1.5	3.8, 1.7	-2.714	.024*
Surprise	7.8, .7	3, 1.2	-8.057	.000**
Anxiety	2.1, 1.8	3.5, 1.2	1.250	.247
Mean	5.9, 0.4	6.3, 0	1.945	.084
Formative Value				
Total Time	323, 62.3	474.2, 129.9	2.539	.032*
Response Time	91.6, 50.1	394.4, 156.7	4.500	.001**

the CT scans. None of the technologies was assessed as more usable by the participants, although it could be noticed that the 3D hologram received a mean of 82.5 and the CT scan received a mean of 66, respectively a high and a slightly-below acceptable SUS score [40]. Negative emotions lead to no significant differences, while the task performed with the 3D hologram (MR) was associated to more positive emotions (joy) and surprise than the task performed with the CT scans. The task with the 3D hologram (MR) outperformed the task with the CT scans both in terms of response time and time of completion. No significant differences emerged in the sample regarding the perceived formative value of the tools.

5. Discussion

The present study explored the medical students' reactions and attitudes towards pre-operative planning performed by using either traditional CT scans or mixed reality (MR) based on a 3D hologram. Results from the NASA TLX showed that the two technologies were not different in terms of physical demand, which reflects the similarity among the two versions of the experimental setting.

Despite the fact that, when using the Microsoft Hololens, participants were technically able to move around the hologram, they tended to remain still and rotate the virtual figure. In any case, both the visualization of CT scans on a normal computer screen and that of the 3D hologram were not associated to physical strain, fatigue or any kind of physical discomfort. Conversely, the hologram was deemed less demanding in terms of mental load and subjective effort. This is certainly related to the more natural interaction with the 3D hologram, which is seen in front of the user and could be manipulated by intuitive gestures. On the contrary, the CT scans should be navigated by individually browsing the three body sections (coronal, sagittal, axial) and require mental effort to translate the position of organs and tumoral masses on a mental 3D representation. However, using both the tools did not lead to significant frustration nor to negative emotions. The 3D hologram was associated to more joy and surprise in the sample than the CT scans: this highlights that the innovative technologies may be positively received by the professionals and especially by young generations, but also that results may be influenced by a "novelty effect" of the innovative tool and so should be interpreted with caution for what regards the tools' intrinsic experiential properties.

While subjective usability did not differ between the tools, the task performed with the 3D hologram was completed in shorter time than with the CT scans: when confronted with a 3D, movable digital representation the medical students had not the necessity to recruit additional cognitive processes to recreate a mental image of the patient's lungs. Therefore, they were quicker in identifying and analysing the tumoral masses.

Finally, conditions did not differ regarding perceived formative value; however, the relatively high values, along with the results related to high positive and low negative emotions, show that the participants enjoyed the experience regardless of the technology involved and recognized it as a positive learning opportunity. Indeed, the responses to the debriefing questions at the end of the experiment showed that students would appreciate receiving intensive and hands-on training on both innovative and traditional devices. Some comments in this line could be reported for their anecdotal value:

"We almost never get the opportunity to interact directly with the CT scans. It was nice to put myself to the test"

"I think I would understand some anatomy and pathology stuff more quickly if I could do this every day"

"Do you think we will see this (the hologram) again in the class? I hope so!"

"The hologram was very clear and easy to use but I think I would have both the hologram and the scans if I really had to take decisions (about the surgery)"

6. Conclusions

This study explored performance and attitudes by medical students using either an innovative or a traditional technology to simulate preoperative planning. Results from the ergonomics measures (i.e., time measures, mental workload, usability) are promising for what regards the effectiveness and reliability of MR for preoperative planning, consistently with published literature [11,12,42]. While MR is not expected to replace CT scans in medical practice, results from the present study join others in supporting their integration with more traditional means.

Medical students did not show resistance to MR; on the contrary, the hologram showed remarkable ergonomic features and the experience as a whole was positively received. A novelty effect probably played a role in the participants' evaluations, consistently with emotions, so one should be cautious in considering the participants' opinions as indicative of intrinsic properties of the technologies. However, the results show that MR could be used effectively not only in medical practice, but also as a learning tool that goes beyond the mere planning task by promoting the acquisition of competences in terms of anatomy and pathology. Furthermore, medical students got the opportunity to confront with a real patient-case as well as a glimpse of future practice in the surgery field.

A limitation of the study is the small sample size; future study could replicate this contribution involving more participants with the aim of generalizing results to other countries and healthcare contexts as well. For example, a recent systematic review and meta-analysis by Parekh, Patel, Patel, and Shah [43] showed the relevant application of augmented reality also in the medical area. Similarly, Pulijala and colleagues [44] evidenced the useful application of immersive technology in surgical training methods, highlighting the importance of improvement in young surgeons' self-confidence and knowledge. The present study contributes to this area showing that medical students positively evaluated

ergonomics properties and formative value in MR for surgery planning.

The technologies used in this study could be considered expensive or difficult to learn, however the technology, by its nature, gets progressively smaller and cheaper, becoming more affordable for everyone. Virtual reality, for example, is now used with cardboard, a low-cost stereoscopic display that people can easily connect to smartphones to obtain an immersive virtual reality experience. Compared to higher-end VR devices like the Oculus Rift, the cardboard is significantly less expensive (about 10\$) and therefore has the potential for mass consumer use [45]. A wide adoption of MR solutions such as that described here may motivate developers to create affordable devices and applications that would considerably reduce implementation issues.

As the main implications of the present study, results show that it is feasible to present medical students with advanced technologies and tasks (i.e., preoperative planning), while collecting data on their responses both in terms of technology evaluation and perceived formative value. While it is paramount to analyze MR technologies' efficiency and ergonomics according to health professionals, it is also useful to explore the response by medical students who could obtain positive educational outcomes from encountering high-level resources within controlled contexts.

7. Recommendations

Indeed, implementing simulations and hands-on experiences with both traditional and innovative technologies appears beneficial, not only for educating students to the technologies themselves, but also to support learning of basic knowledge and skills. At the same time, implementing these technologies in formation enriches the educational contents with a consequential boost on learners' engagement. Medicine university courses shall consider to include hands-on experiences (e.g., focused seminars) about medical tools, which do not involve risks for patients, yet allow learners to gain desirable outcomes and possibly improve their own commitment to the medical mission. Moreover, MR technology developers should take into account not only professionals', but also medical students' responses to innovative devices in that these could provide important information on how to productively explore new contexts for wide adoption of the MR resources. Finally, future research on this area may explore the relationship between human factors properties of the technologies, perceived formative value and actual academic improvement of medical students, in order to promote the design of MR devices and software that will support the development of medical expertise.

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