Impact of 3D vision on mental workload and laparoscopic performance in inexperienced subjects

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Mental workload; Laparoscopic surgery; 3D imaging; 2D imaging

Abstract
Objective: To assess the effect of vision in three dimensions (3D) vs. two dimensions (2D) on mental workload and laparoscopic performance during simulation-based training.

Materials and methods: A prospective, randomized crossover study on inexperienced students in operative laparoscopy was conducted. Forty-six candidates executed five standardized exercises on a pelvitrainer with both vision systems (3D and 2D). Laparoscopy performance was assessed using the total time (in seconds) and the number of failed attempts. For workload assessment, the validated NASA-TLX questionnaire was administered.

Results: 3D vision improves the performance reducing the time (3D = 1006.08 ± 315.94 vs. 2D = 1309.17 ± 300.28; p < 0.001) and the total number of failed attempts (3D = .84 ± 1.26 vs. 2D = 1.86 ± 1.60; p < 0.001). For each exercise, 3D vision also shows better performance times: “transfer objects” (p = 0.001), “single knot” (p < 0.001), “clip and cut” (p < 0.05), and “needle guidance” (p < 0.001). Besides, according to the NASA-TLX results, less mental workload is experienced with the use of 3D (p < 0.001). However, 3D vision was associated with greater visual impairment (p < 0.01) and headaches (p < 0.05).

Conclusion: The incorporation of 3D systems in laparoscopic training programs would facilitate the acquisition of laparoscopic skills, because they reduce mental workload and improve the performance on inexperienced surgeons. However, some undesirable effects such as visual discomfort or headache are identified initially.

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Impacto de la visión 3D sobre la carga mental y el rendimiento laparoscópico en individuos sin experiencia

Resumen

Objetivo: Evaluar el efecto de la visión en 3 dimensiones (3D) en comparación con 2 dimensiones (2D) sobre la carga mental de trabajo soportada y el rendimiento laparoscópico en ejercicios de simulación.

Material y métodos: Se llevó a cabo un estudio prospectivo aleatorizado cruzado en sujetos sin experiencia en laparoscopia. Se incluyeron 46 participantes, los cuales completaron 5 ejercicios en pelvitrainer basados en un programa validado usando ambos sistemas de visión. El rendimiento se evaluó mediante el tiempo transcurrido y el número de errores cometidos, y la carga mental de trabajo a través del cuestionario validado NASA-TLX.

Resultados: Los participantes realizaron las actividades mejor con la visión 3D de forma global en términos de tiempo (3D = 1.006,08 ± 315,94 vs. 2D = 1.309,17 ± 300,28; p < 0,001) y número total de errores (3D = 0,84 ± 1,26 vs. 2D = 1,86 ± 1,60; p = 0,001). Cuando se analizó el tiempo de forma independiente por ejercicios, el uso de 3D mostró diferencias estadísticamente significativas en: «transferencia de objetos» (p = 0,001), «sutura» (p < 0,001), «clipar y cortar» (p < 0,05) y «manejo de la aguja» (p < 0,001).

Además, el uso de la visión 3D produjo menos carga mental de trabajo de acuerdo con los resultados del NASA-TLX (p < 0,001), aunque se asoció con un mayor malestar visual (p < 0,01) y dolor de cabeza (p < 0,05).

Conclusión: La incorporación de sistemas 3D en cirugía laparoscópica facilitaría la adquisición más temprana de habilidades laparoscópicas, ya que se asocia a un mejor rendimiento y menor carga mental de trabajo en sujetos sin experiencia, si bien existen inicialmente algunos efectos indeseables como malestar visual o dolor de cabeza.

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Introduction

The development of laparoscopy has been one of the greatest advances in the history of surgery, offering advantages over conventional surgery, such as less invasiveness, a decreased length of hospital stay, a rapid socio-occupational reintegration and the possibility of a more precise technique thanks to an expanded surgical field, among others. In contrast, the absence of depth perception and a generally longer operating time, associated with non-ergonomic positions, can lead to increased surgeon fatigue.

Over the past few years, laparoscopy has made progress thanks to the incorporation of stereoscopic systems. 3D technology allows the surgeon to have depth awareness and a better definition of the operative field, thus being able to perform a safer and more accurate technique, as well as to reduce operative time. In urology, many procedures could benefit from this technology; however, few studies comparing 2D and 3D visualization in urological procedures have been conducted so far.

The aim of this study was to compare 3D and 2D visualization through the assessment of mental workload and laparoscopic performance in a training program for laparoscopic urologic skills on subjects with no previous experience.

Materials and methods

Design and study variables

A prospective, randomized, crossover study was conducted on fifth-year medical students from the University of Córdoba (Spain), with no previous laparoscopic experience. All of them gave their verbal consent to participate in the study and for the publication of results. Ethical standards of the committee on human experimentation and the 1975 Helsinki Declaration were applied.

They completed 5 pelvitrainer exercises based on a program validated by the European Association of Urology (e-BLUS), with some small modifications, as shown in Table 1. A statistical analysis was carried out using Cronbach’s alpha to assess scale reliability and the degree of reliability.

Subjects were randomly assigned to 2 groups, the 2D–3D or the 3D–2D group, in order to determine the type of camera with which they would start the activity (Fig. 1). A one-month washout period between both assessments was considered to reduce the residual learning of the skills acquired in the first activity.

The following basic population variables were collected: age, gender, vision problems and dominant hand. Performance was measured by time (in seconds) and the number of mistakes made during the procedure (Table 1). Mental workload was assessed using the validated Task Load Index (NASA-TLX) questionnaire, which allows the calculation of an overall workload score. This questionnaire distinguishes between 6 different dimensions: (1) effort, regarded as the mental and physical effort required to achieve your personal performance level; (2) mental demand, this being the mental and perceptual activities required by the task; (3) physical demand, or the amount of physical activity to be applied; (4) time demand, or the perceived time pressure, taking into account the relationship between the time required for the activity and the available time; (5) performance, that is to
say, how individuals feel satisfied with the level achieved; and (6) frustration level, which indicates to what degree the subject feels insecure, stressed, angry, etc.

The study includes 2 phases, first a weighting, which will be done before the activity input. It assesses the importance of each of the dimensions for the individual. Definitions for each dimension are included and all of them are peer-compared. The individual must select from each pair the one he perceives as the largest source of burden. From this, a total score is obtained for each of the different dimensions.

After this task, a scoring phase will take place. Individuals assess on a scale from 0 to 100 the activity they have just performed in each of the dimensions. These values are multiplied by the value obtained in the weighting phase and the result must be added and divided by 15, thus obtaining the overall mental workload index.

Depth perception, image quality, visual discomfort and headache were measured using a scale from 0 (very poor depth perception and image quality; no visual discomfort or headache) to 20 (perfect depth perception and

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Error</th>
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<tbody>
<tr>
<td>Exercise 1</td>
<td>Transferring objects one by one from one side to the other and vice versa. Both hands must be used when transferring from one side to the other</td>
<td>Fall of an object</td>
</tr>
</tbody>
</table>
image quality; maximum degree of visual discomfort and headache) after each assessment.

Finally, participants were asked to identify the camera which had provided greater ease for the implementation of the activity (dichotomous: 2D/3D) and the task they had felt more comfortable with (polytomous with one single option: 1/2/3/4/5).

**Spaces and equipment**

The tasks were carried out in an experimental operating room using the same pelvitrainer (Simulap-IC05). We used a movable camera, which was guided by 2 urologists with laparoscopic experience who were randomly distributed (3D or 2D). During the activities, an urologist with several years of laparoscopic experience assessed in an adjacent room the mistakes made, as well as the time spent in the different activities by each of the participants, on a 2D screen.

Prior to the outset of the study, a professional with laparoscopic experience gave a 4-h course using a pelvitrainer with a 2D fixed camera and explained notions of cutting and stitching. Likewise, participants were shown a video with the exercises comprising the e-BLUS program and which they would subsequently develop. Each participant was given 3 min prior to the exercise in order to become acquainted with the different camera systems and tools, which were identical in all cases.

For the task with 2D vision, we used a KARLSTORZ FULL HD (Karl Storz, Munich, Germany) camera and, for 3D vision, a TipCam® 1 3D (Karl Storz, Munich, Germany) camera.

**Statistical analysis**

Accepting an alpha risk of 0.05 and a beta risk of 0.20, 36 subjects were required to detect a difference equal to or greater than 200 s. A standard deviation of 300 s was assumed.

Eventually, it was decided that 48 patients would be recruited in order to work with a power of 90%.

A descriptive analysis was done by calculating the absolute and relative frequency for qualitative variables and the mean and standard deviation for quantitative variables.

Consistency of the assessment method (e-BLUS), given the modifications made to the validated model, was assessed on the first measurement using Cronbach’s $\alpha$ analysis. The result of Cronbach’s test was $\alpha = 0.75$. The first task could be removed, since $\alpha$ was increased by 0.2 units when it was excluded from this statistical calculation ($\alpha = 0.77$).

Student’s t test for independent data and the Chi-square test were used to compare the basal characteristics of the subjects in the 2 groups. For the paired analysis of mean test time, overall errors and of the results of the NASA-TLX questionnaire, we used Student’s t test for paired data, as adjusted by Finner’s test. A mixed ANOVA of the 2 groups, intra- and intergroup, was conducted to control for the potential residual learning bias between both assessments.

Statistical analyses were performed using SPSS v17.0 and Epidat 3.1 software.

**Results**

Forty-eight subjects were randomized into 2 groups. Two participants were not included in the analysis since they did not complete the 2 phases of the study. No significant differences were observed when comparing both groups. Basal characteristics of the subjects are shown in Table 2.

When comparing the use of 2D with 3D vision, we observed a more rapid performance of the tasks with this latter method, as well as a lower number of errors ($p < 0.001$), as can be seen in the comparison table of 2D vs. 3D in terms of time and number of mistakes made in the 5 tasks (additional material).

The intra-group analysis showed that the participants who began their task with 2D vision (2D–3D group) completed it in less time and with a lower number of mistakes than when they subsequently performed the same activity using 3D ($p < 0.001$). However, in the group that started with 3D vision (3D–2D group), performance did not improve when using 2D, with the exception of task 2. Besides, performance worsened in task 3 ($p < 0.05$) and showed a trend for an increased number of mistakes ($p > 0.05$) that is shown in the comparison table between intra- and intergroups with regard to time and mistakes, which is included in the additional material.

The analysis between groups showed that participants took more time when performing their tasks with 2D vision as compared with 3D in both assessments (1st and 2nd assessment) ($p < 0.001$). The participants of this analysis also made more mistakes when using 2D, but we only obtained statistically significant differences in the second assessment ($p < 0.05$), as illustrated in the intra- and intergroup comparison table with regard to time and mistakes (additional material).

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**Table 2** Baseline characteristics of the participants.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups</th>
<th>$p$</th>
<th>All</th>
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<tr>
<td></td>
<td>2D–3D ($n = 23$)</td>
<td>3D–2D ($n = 23$)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.04 ± 0.71</td>
<td>21.96 ± 0.37</td>
<td>NS</td>
</tr>
<tr>
<td>Sex (female)</td>
<td>19 (82.6%)</td>
<td>20 (87.0%)</td>
<td>NS</td>
</tr>
<tr>
<td>Vision problems (yes)</td>
<td>15 (65.2%)</td>
<td>15 (65.2%)</td>
<td>NS</td>
</tr>
<tr>
<td>Dominant left hand</td>
<td>2 (8.7%)</td>
<td>2 (8.7%)</td>
<td>NS</td>
</tr>
</tbody>
</table>

The variable ‘‘age’’ is expressed as mean± SD, whereas ‘‘sex’’, ‘‘vision problems’’ and ‘‘dominant left hand’’ are expressed by absolute number (intrigroup percentage).

NS, not significant.
When analyzing the different dimensions of the NASA-TLX scale, we obtained differences in favor of a lower mental workload with 3D in the overall result (p < 0.001). When independently assessing each dimension, we also observed a lower workload in most of them with 3D (p < 0.001), with a considerable difference in frustration. The exceptions were the burden on mental demand (p = 0.05) and on performance (the latter being more favorable with 2D; p < 0.05) (Table 3).

With the 3D system, depth perception (3D = 16.08 ± 2.98 vs. 2D = 6.52 ± 4.75; p < 0.001) and image quality (3D = 16.21 ± 3.45 vs. 2D = 12.13 ± 3.66; p < 0.001) were higher than with the 2D system; however, there was a greater perception of visual discomfort (VD) (3D = 6.86 ± 5.82 vs. 2D = 3.78 ± 4.32; p < 0.01) and headache (HA) (3D = 2.91 ± 4.76 vs. 2D = 1.22 ± 1.91; p < 0.05).

When analyzing the participants with sight problems (+) vs. those who did not have any (−), no significant differences were found in VD or HA, irrespective of the camera system used: (VD 3D: [−] 7.00 vs. [+]: 6.80; p = 0.91); (VD 2D: [−] 3.12 vs. [+]: 4.13; p = 0.45); (HA 3D: [−] 2.12 vs. [+]: 3.33; p = 0.41) (HA 2D: [−] 1.12 vs. [+]: 1.27; p = 0.81).

The participants indicated that the exercise they performed with greater ease was the fifth task with 3D vision (n = 20; 43.5%), followed by tasks 1 (23.9%) and 3 (19.6%). There was a participant who found no improvement when using 3D and preferred to use 2D.

Discussion

Thanks to technology, surgery has evolved over the last few decades, with less invasive and safer techniques. In recent years, the developments in devices and cameras have been increasing.9

Despite the improvement that 2D laparoscopic surgery10 has entailed, it still has a number of drawbacks, such as a long learning curve and the lack of depth perception. These disadvantages become more apparent in the case of complex pelvic procedures which require intracorporeal stitching. In this regard, the introduction of 3D vision systems might mitigate these constraints.6

The results published in the literature with regard to the use of 3D vision have been contradictory so far.5,6,11–16 This may be due to the fact that most of them were conducted using as participants experienced surgeons who would have already surpassed the learning curve and for whom the advantages brought by 3D vision might not be so obvious.6

In the present study, we have been able to observe how subjects with no laparoscopic experience show an improvement in terms of time and the number of mistakes made when using a 3D system to perform their tasks. Similar results have been published by other authors.5,6,13,17 Besides, the use of this system increased both accuracy and execution speed, especially in those activities which are more demanding and require greater depth perception (task 3, “stitching” and task 5 “management of needles”). This would be of great importance within the field of urology, where stitching is used in surgical techniques such as radical prostatectomy, partial nephrectomy and pyeloplasty.

Although from our study it could be deduced that the use of 3D vision does not prepare surgeons for 2D surgery,
given the results of the 3D-2D group, this deduction would be wrong, since the participants did not reach the learning curve at any time, and the washout period aims to eliminate the acquired knowledge. We can only conclude that the use of 3D in laparoscopy facilitates and improves the performance of inexperienced individuals.

We have assessed mental workload in accordance to the NASA-TLX system. The validity of this system has been proven in numerous studies, making it the safest indicator for mental workload.16–23 This is the first study to use this questionnaire within urology to prove that participants have a lower mental workload when performing their tasks with 3D, with the dimension of frustration reaching greater significance. This must be emphasized, since it is a common factor among those subjects starting their learning curve in laparoscopy. These results are in line with those obtained in previous studies.24

More recently, it has been demonstrated that, with the new 3D devices, improvements in depth perception do not entail any drop in image quality.17 As confirmed in our study, the perception of image quality is greater when using a 3D camera.

The three-dimensional system caused greater visual discomfort and headaches, according to McDougall and Chan15,25; however, none of the participants had to cease their activities due to nausea or headache. All the students preferred 3D, and only one participant did not subjectively find greater ease when using 3D, showing greater visual discomfort and headache. These side effects might be associated with the need for glasses in order to display the 3D image. Technological progress of these systems may probably eliminate the need for glasses for a correct visualization of images, thus mitigating these effects.

Despite the one-month washout period we applied based on previous studies,26 a certain degree of residual learning can be inferred since an improvement was observed in task 2 (no depth perception was required), irrespective of the vision system used in the second phase of the study. By using randomization and a mixed ANOVA analysis, we were able to control this bias, thus confirming the superiority of 3D visualization.

Although the results were obtained using a program with certain modifications, the result of Cronbach’s test showed good consistency of the program, so we do believe that it accurately assessed laparoscopic skills.

Our study has a series of limitations, the variation of the e-BLUS model and the potential residual learning despite the washout period. However, the homogeneity of the participants, assessment masking and camera mobility provided validity to the study for its extrapolation to inexperienced surgeons.

The inclusion of 3D visualization in new devices makes laparoscopic skills easier to people with no laparoscopic experience, providing greater speed, accuracy and less mental workload, although it might cause greater visual discomfort and headaches at the beginning of the process.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

The authors express their gratitude to the fifth-year medicine students who took part in this study, and also to the surgical nursing department for their disinterested collaboration.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.acuroe.2015.03.006.

References

Mental workload and laparoscopic performance: 3D vision


