Surg Today (2015) 45:1280–1290
DOI 10.1007/s00595-014-1046-6

ORIGINAL ARTICLE

Impact of examinees' stereopsis and near visual acuity on laparoscopic virtual reality performance

Henry Hoffmann · Rebecca Ruiz-Schirinzi · David Goldblum · Salome Dell-Kuster · Daniel Oertli · Dieter Hahnloser · Rachel Rosenthal

Received: 27 February 2014 / Accepted: 15 September 2014 / Published online: 11 October 2014

Abstract
Purpose Laparoscopic surgery represents specific challenges, such as the reduction of a three-dimensional anatomic environment to two dimensions. The aim of this study was to investigate the impact of the loss of the third dimension on laparoscopic virtual reality (VR) performance.
Methods We compared a group of examinees with impaired stereopsis (group 1, $n = 28$) to a group with accurate stereopsis (group 2, $n = 29$). The primary outcome was the difference between the mean total score (MTS) of all tasks taken together and the performance in task 3 (eye–hand coordination), which was a priori considered to be the most dependent on intact stereopsis.
Results The MTS and performance in task 3 tended to be slightly, but not significantly, better in group 2 than in group 1 [MTS: −0.12 (95 % CI −0.32, 0.08; $p = 0.234$); task 3: −0.09 (95 % CI −0.29, 0.11; $p = 0.385$)]. The difference of MTS between simulated impaired stereopsis between group 2 (by attaching an eye patch on the adominant eye in the 2nd run) and the first run of group 1 was not significant (MTS: $p = 0.981$; task 3: $p = 0.527$).
Conclusion We were unable to demonstrate an impact of impaired examinees' stereopsis on laparoscopic VR performance. Individuals with accurate stereopsis seem to be able to compensate for the loss of the third dimension in laparoscopic VR simulations.

Keywords Laparoscopy · Virtual reality · Simulation · Stereopsis · Visual impairment

Introduction

Laparoscopic surgery is increasingly used and widely accepted for multiple procedures in surgery. It has been shown to provide several advantages in postoperative recovery [1–3], and to result in oncological outcomes comparable to conventional open surgery [4–7]. Moreover, technology has continuously improved since the first laparoscopic procedures were performed. However, since there are some fundamental differences compared to open surgery, sophisticated training of junior surgeons is of the utmost importance, especially with regard to their psychomotor skills.

One of the major challenges in laparoscopic surgery is the loss of the third dimension, and therefore, the transformation of two-dimensional (2D) information as presented on the screen into a three-dimensional (3D) working area. Other specific challenges inherent to laparoscopy are the divergence of the visual and working axis, necessary compensation for reduced image quality and pixilation [8], the reduction in the degrees of freedom, the fulcrum effect (dissonance between visual input and proprioceptive feedback, since the tip of the instrument moves in the opposite

H. Hoffmann (✉) · S. Dell-Kuster · D. Oertli · R. Rosenthal
Department of Surgery, University Hospital Basel, Spitalstrasse 21, 4031 Basel, Switzerland
e-mail: henry.hoffmann@usb.ch

R. Ruiz-Schirinzi · D. Goldblum
Department of Ophthalmology, University Hospital Basel, Basel, Switzerland

S. Dell-Kuster
Basel Institute for Clinical Epidemiology and Biostatistics, Basel, Switzerland

D. Hahnloser
Department of Surgery, University Hospital Lausanne, Lausanne, Switzerland

direction of the surgeon's hand) [9] and the reduced haptic feedback.

While the loss of the third dimension represents an ongoing challenge for surgical trainees and even experienced surgeons, individuals with impaired stereopsis, accounting for up to 2.2 % of the population [10–12], have to deal with this limitation every day. These individuals rely on monocular depth cues, such as lighting, outline, texture, interposition or overlap and the motion parallax [13]. Investigations on the relationship between visual function and driving ability have found only weak evidence of an increased risk of accidents in subjects with impaired stereopsis [14]. Therefore, individuals with impaired stereopsis are assumed to compensate for this visual deficit in daily life.

We thus hypothesized that individuals with impaired stereopsis would perform better at tasks relying on a 2D screen compared to individuals with accurate stereopsis. An investigation of this hypothesis is relevant in an experimental setting to better understand the impact of the loss of the third dimension on laparoscopic performance.

The aim of our present study was to compare the performance of VR laparoscopy tasks in individuals with impaired stereopsis (group 1) to the performance of similar individuals with accurate stereopsis (group 2) (primary outcome). Additionally, we compared the performance in individuals with accurate stereopsis at task repetition with an eye patch covering the adominant eye (simulating impaired stereopsis) to the initial performance without the eye patch (secondary outcome) in subjects with accurate stereopsis based on our hypothesis that individuals with accurate stereopsis would perform better without the eye patch than with it. This assumption was based on the presence of a larger visual field without the eye patch, despite the lack of stereopsis in both cases due to the 2D screen.

Methods

Subjects

This study was designed as an experimental setting to investigate this special aspect of visual impairment in VR laparoscopy. Considering the low incidence of significantly impaired stereopsis among individuals, and especially among surgeons, we recruited laymen rather than surgeons in the Departments of Surgery and Ophthalmology of the University Hospital Basel using public placards with an illustration of the aims of this study. A Lang stereo test picture was provided as a validated screening test for stereopsis [15]. The inclusion criteria were an age between 18 and 65 years and written informed consent to participate in the study. Individuals with deuteranomaly (reduction in sensitivity to the green area of the spectrum), protanomaly (reduction in sensitivity to the red light of the spectrum) and experience in surgery were excluded.

Participants were divided into two groups: participants with impaired stereopsis (group 1) and participants with accurate stereopsis (group 2). Impaired stereopsis was defined as a true monocle for at least 4 years or a functional monocle with a vision acuity of less than 0.05 or impaired stereopsis due to strabismus with or without optical correction.

The study was approved by the local ethics committee.

Baseline characteristics questionnaire

A questionnaire was completed by all subjects to obtain general information, such as the subjects' age, gender, hand dominance, optical corrections (glasses, lenses) and experience with videogames and virtual reality (flight simulators, race simulators).

Ophthalmological examination

An ophthalmologist examined all study participants, and the examination included the corrected and uncorrected distance (cDVA) and near visual acuity (cNVA), refraction, stereo acuity, ocular dominance, color perception and a complete ophthalmic slit lamp and funduscopic examination. The cDVA was determined using a Snellen chart [16] at 5 m; the cNVA was assessed with a Landholt C LogMAR visual chart (2.6 min arc; Oculus, Wetzlar, Germany). Binocular function was evaluated using the Lang stereo test I + II [17], Titmus fly test (Stereo Optical Co, Chicago, Illinois, USA) and TNO test [18].

The TNO test required red–green glasses, and the Titmus fly test required polarizing viewers. All viewers and red–green glasses were worn over prescription glasses. Tests were administered according to the instructions provided in the information manuals accompanying the tests. Briefly, stereo acuity tests were held parallel to the facial plane at a distance of 40 cm. Accurate stereopsis was determined to be present if disparities between an arc of 1200 and 15 seconds were recognized (high number of seconds for the arc, gross stereopsis; lower number of seconds for the arc, fine stereopsis; i.e., the lower the number of seconds for the arc, the harder it is to recognize). Impaired stereopsis was determined if disparities for arcs up to 550, 200, 40 and 15 seconds were not recognized in any of the Lang test I, II, Titmus housefly and TNO test, respectively.

Ocular dominance was tested using the kaleidoscope test. The participants were instructed to hold a kaleidoscope using both hands and to look through it. The eye that was underneath the kaleidoscope was considered to be the dominant eye.

Simulator tasks

The simulator tasks were run in a standardized environment in a surgical skills training room including adequate illumination, an operating distance to the simulator and the use of optical correction (if applicable). Two simulators with identical hardware and software were used to conduct the virtual reality tasks. The hardware consisted of the LAP Mentor™ express hardware (Simbionix™ USA Corp., Cleveland, OH 44106, USA), running with a 17-in. widescreen (resolution 800 × 600 pixel) and three non-haptic devices. The software runs on a Windows XP operating system and simulates real-time high-resolution graphics. A choice of laparoscopic instruments was simulated, such as graspers, scissors, a clip applier and hook electrode, with realistic instrument handles connected to the manipulation robots.

The following six tasks referring to the LAP Mentor™ basic tasks module (Simbionix USA Corp., Cleveland, OH 44106, USA) were each performed twice:

Basic task number 1 (camera manipulation): this task consisted of the location of 10 targets (red balls) using the 0° scope camera, and capturing the targets with the focus of the viewfinder. When the focus turned red, a photo was taken by pressing the camera button.

Basic task number 3 (hand–eye coordination): two tools (electrocautery hooks) were available in this task, one red and one blue. The subject had to locate each flashing target (red and blue balls) and touch it with the tip of the corresponding tool.

Basic task number 6 (two-handed maneuvers): using two grasping tools, a jelly mass had to be moved aside to expose the underlying targets (balls). While holding the jelly aside with one grasper, the other tool was used to grasp the balls and place them into an endobag.

Basic task number 7 (cutting): using a grasper and endoscissors, safe cutting and separation of a circular form from a ring had to be performed. One tool was used for gentle retraction of the form to expose a safe cutting area. Accurate cutting with the other hand was then required.

Basic task number 8 (electrocautery, limited to 3 min): this task involved using a hook electrode to cut bands, which were fixed between two pillars. Only highlighted bands were allowed to be cut, so gentle retraction of the other bands was required before cutting through the highlighted band.

Procedural task number 2 (clipping and cutting): with the simulated gallbladder already exposed, a blunt grasper was used to pull the simulated Hartmann's pouch at a marked area in the correct position according to the indicated arrow direction. Once correct and constant retraction was achieved, a blue segment appeared on the simulated cystic duct and cystic artery. This was clipped twice proximally and once distally in the blue area as close as possible to the gallbladder neck. Once the clips were safely applied, a green segment appeared between the clips, where dissection was finished with the endo-scissors.

Before the first run, the aims and measures of each task were presented and explained on the screen by the instructor in a standardized manner. The first run of each task was performed without an eye patch (Fig. 1a), while the second run was performed with an eye patch covering the adominant eye (Fig. 1b).

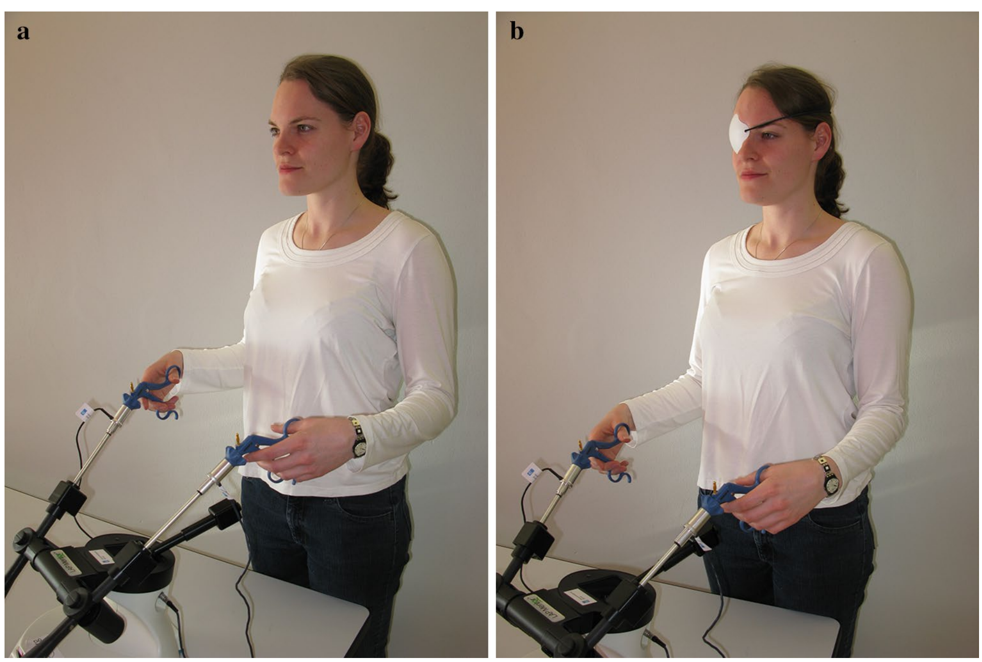

Fig. 1 Participant performing simulator tasks at the LAP Mentor™: **a** without eye patch (binocular) and **b** with eye patch (monocular) to simulate impaired stereopsis

A number of parameters, such as the task completion time (in seconds), tool tip travel distances (in cm; the lower the distance, the higher the economy of movement), as well as the task efficiency, safety, accuracy and horizon maintenance (in %), were instantly recorded by the simulator. These outcome parameters were grouped as follows: time in s (evaluated for all tasks, $n = 6$, however, not taken into account for task 8, since this task was limited to 3 min), path length of the camera (task one, $n = 1$) and right/left hand instrument (all other tasks, $n = 5$ right and $n = 5$ left) in cm, and the accuracy in % (of maintaining the horizon in task 1, of touching the targets in task 3, of collecting the balls in task 6, of retracting the object in task 7, and of cutting highlighted bands in task 8, $n = 5$). The latter was transformed into 100-accuracy (%) in order to obtain the same direction (positive versus negative) for all three dimensions.

Statistical analysis

All data were handled anonymously. The ophthalmological and baseline data retrieved from the questionnaires were entered into an Excel spread sheet (Microsoft Office XP), cross-checked by a second member of the study team and provided with a unique participant identifier, corresponding to the simulator login number. The simulator export automatically generated an Excel spreadsheet with the unique participant identifier and all performance parameters. According to the current guidelines for reporting observational data (STROBE) [19], we avoided significance tests for the evaluation of differences in baseline characteristics.

Faced with a high number of outcome variables delivered by the simulator for each of the six tasks, we summarized these outcome variables with a meaningful overall performance score (mean total score, MTS) as described previously [20]. In brief, we standardized the results of the outcome variables to mean zero and unit variance, and then calculated their average. When interpreting the results of the mean total score, the smaller its value, the better the performance (allowing negative values).

In addition to the mean total score, task 3 was evaluated separately, because this was the task that was a priori considered to be the most dependent on intact stereopsis. Since the path length of the right hand and the total task time for task 7 were initially used for sample size calculation as outlined below, we additionally compared the first run for task 7 between groups 1 and 2.

A generalized estimating equation (GEE) model for the mean total score, as well as for the score of task 3, with an exchangeable correlation matrix and an interaction term between stereopsis yes/no and the first and second runs was built in order to answer both the study hypotheses with the same model. The first hypothesis, associated with whether there was a difference in the mean score in participants with accurate and impaired stereopsis at the first run without the eye patch, can be read in the group variable stereopsis (yes/no).

The second hypothesis, regarding whether individuals in group 2 performed better without the eye patch than with the eye patch covering the adominant eye, could not simply be answered by comparing the first run without an eye patch and the second run with an eye patch, since there is a strong learning effect with repetition. Therefore, we had to estimate the learning effect in the participants in group 1, in whom the coverage of their adominant eye was not supposed to have any relevant effect due to their already reduced or absent function even without patch; i.e., the difference between the second and first runs in this group can be fully attributed to the learning effect. On the other hand, the difference in group 2 between the second and first runs would be diminished by a reduction in the visual field in the second round. Assuming a similar learning effect in both groups, this difference in group 2 between the second and first runs [i.e., the point estimate and 95 % confidence interval (CI) of the interaction term] can be regarded as the contribution of the effect of the eye patch in patients with intact stereopsis. Furthermore, these analyses were adjusted for age and the near visual acuity of the dominant eye. Additionally, a sensitivity analysis was performed after excluding three patients with a near visual acuity of the dominant eye of less than 0.6 [21].

Sample size

The sample size calculation was derived from data obtained during a previous simulator study, in which the two parameters (time and path of the right hand in task 7) discriminated subjects based on their levels of skill [22]. We decided to calculate the sample size for both parameters and to consider whichever resulted in more participants. To show a difference in the time of task 7 of 60 s, with a standard deviation (SD) of 60 s, with 80 % power and an alpha error of 0.05, 18 participants would have been needed per group. To show a difference of 150 cm in the path length of the right instrument in task 7 with an SD of 160 cm, 20 participants would have been needed per group. To compensate for possible non-normality and dropouts, we aimed to enroll 25 participants per group.

Results

Baseline characteristics

A total of 57 participants were included in the study (Table 1). Twenty-eight participants showed impaired

Table 1 The baseline characteristics of the study participants

Characteristics	Group 1 Participants with impaired stereopsis ($n = 28$)	Group 2 Participants with accurate stereopsis ($n = 29$)
Age, median (IQR)	48 (36–58)	34 (28–47)
Female gender, *n* (%)	17 (61 %)	22 (76 %)
Right-handedness, *n* (%)	28 (100 %)	27 (93 %)
Experience with videogames, *n* (%)	9 (32 %)	13 (45 %)
Experience with virtual reality, *n* (%)	3 (11 %)	4 (14 %)
Glasses, *n* (%)	14 (50 %)	9 (31 %)
Contact lenses, *n* (%)	6 (21 %)	5 (17 %)
Dominant eye right, *n* (%)	12 (43 %)	17 (59 %)
Near visual acuity (right), median (IQR)	0.75 (0.03–1)	1 (1–1)
Near visual acuity (left), median (IQR)	0.9 (0.5–1)	1 (0.9–1.2)
Distance visual acuity (right), median (IQR)	0.75 (0.09–1)	1 (1–1)
Distance visual acuity (left), median (IQR)	1 (0.5–1)	1 (1–1)
Near visual acuity in dominant eye, median (IQR)	1 (0.85–1.23)	1 (1–1)
Near visual acuity in dominant eye in logMar, median (IQR)	0 (−0.09 to 0.07)	0 (0–0)

stereopsis (group 1), while 29 participants were found to have accurate stereopsis (group 2). The median age of the participants was 48 years (IQR 36–58) in group 1 and 34 years (IQR 28–47) in group 2. The predominant gender was female in both groups (61 % in group 1, 76 % in group 2). The visual acuity was lower in group 1 (Table 1).

Stereopsis tests

The results of the stereopsis tests are given in Table 2. The Lang test I and II were not perceived at all in 96 % ($n = 27$) of the subjects in group 1, whereas almost all participants in group 2 (97 %, $n = 28$) fully identified the figures. The target pf the Titmus housefly test was not visualized at all in 57 % ($n = 16$) of subjects and only partially seen in 43 % of the subjects ($n = 12$) in group 1. In contrast, 72 % ($n = 21$) of the participants in group 2 visualized all of the targets in the test. The target of the TNO test was not seen at all in 86 % ($n = 24$) and only partially identified in the remaining 14 % ($n = 4$) of the subjects in group 1, while 14 % ($n = 4$) saw the butterfly. All participants in group 2 could visualize the target butterfly. Eighty-six percent ($n = 25$) of them could partially and 4 % could fully perceive the target of the TNO test.

Comparison between groups 1 and 2 during the first run without the eye patch (primary outcome)

1. Comparison not adjusted for age and near visual acuity of the dominant eye.

(a) Mean total score (MTS).

The MTS values for group 1 ($n = 28$) and group 2 ($n = 29$) are presented in Fig. 2 and Table 3. Participants with accurate stereopsis tended to perform better in the first run than those with impaired stereopsis [mean difference of −0.20 (95 % CI −0.40, 0.01); $p = 0.061$].

(b) Task 3.

There was not enough evidence that participants with accurate stereopsis performed better in the first run than those with impaired stereopsis (mean difference −0.09, 95 % CI of −0.30, 0.11; $p = 0.367$), when evaluating the overall score of task 3 (Table 4). The four simulator performance parameters contributing to the overall task 3 score (path of the right and left instruments, time to complete the task and 1-accuracy) are shown in Figs. 3a–d. Whereas participants with accurate stereopsis showed a slightly better performance concerning the economy of movement of both hands (Figs. 3a and b) and a similar performance concerning accuracy (Fig. 3d), participants with impaired stereopsis tended to be slightly faster than those without (Fig. 3c).

(c) Task 7 (task used for sample size calculation).

Participants with impaired stereopsis showed a slightly worse performance concerning the economy of movement of the right hand, as well as the time required to perform the test, but the differences

Table 2 The performance of the participants in tests for stereopsis

	Group 1 ($n = 28$), impaired stereopsis	Group 2 ($n = 29$), accurate stereopsis
Lang test I		
Completely unseen	27 (96 %)	0
Partially seen	1 (4 %)	1 (3 %)
Completely seen	0	28 (97 %)
1200	1 (4 %)	29 (100 %)
600	0	29 (100 %)
550	0	28 (97 %)
Lang test II		
Completely unseen	27 (96 %)	0
Partially seen	1 (4 %)	1 (3 %)
Completely seen	0	28 (97 %)
600	1 (4 %)	29 (100 %)
400	1 (4 %)	28 (97 %)
200	0	28 (97 %)
Titmus housefly		
Completely unseen	16 (57 %)	0
Partially seen	12 (43 %)	8 (28 %)
Completely seen	0	21 (72 %)
800	12 (43 %)	29 (100 %)
400	7 (25 %)	29 (100 %)
200	5 (18 %)	29 (100 %)
140	2 (7 %)	29 (100 %)
100	1 (4 %)	27 (93 %)
80	0	25 (86 %)
60	0	24 (83 %)
50	0	23 (79 %)
40	0	21 (72 %)
TNO Test		
Butterfly seen	4 (14 %)	29 (100 %)
TNO test completely unseen	24 (86 %)	0
TNO test partially seen	4 (14 %)	25 (86 %)
TNO test completely seen	0	4 (14 %)
480	1 (4 %)	28 (97 %)
240	1 (4 %)	28 (97 %)
120	0	25 (86 %)
60	0	23 (79 %)
30	0	6 (21 %)
15	0	4 (14 %)

Note that for the numbers (%) of individuals given for the seconds of the arc, the number of individuals who had seen at least up to the indicated arc is indicated. As a consequence, some participants may be listed for several arcs of different lengths

were small and showed a big heterogeneity, and were not statistically significant (data not shown).

2. Comparison adjusted for age and near visual acuity of the dominant eye.

   (a) Mean total score.

   After adjusting for the age and near visual acuity of the dominant eye, the difference in the mean total score between the two groups was even less marked, at −0.12 (95 % CI −0.317, 0.077; $p = 0.234$, Table 3). In contrast, age was a borderline significant independent predictor (point estimate 0.07, 95 % CI −0.006, 0.153; $p = 0.068$), and impairment of the near visual acuity showed a statistically significant influence on the performance (point estimate 0.11, CI 0.021, 0.201, $p = 0.016$). However, in the sensitivity analysis that excluded the three participants with near visual acuity of the dominant eye less than 0.6, this

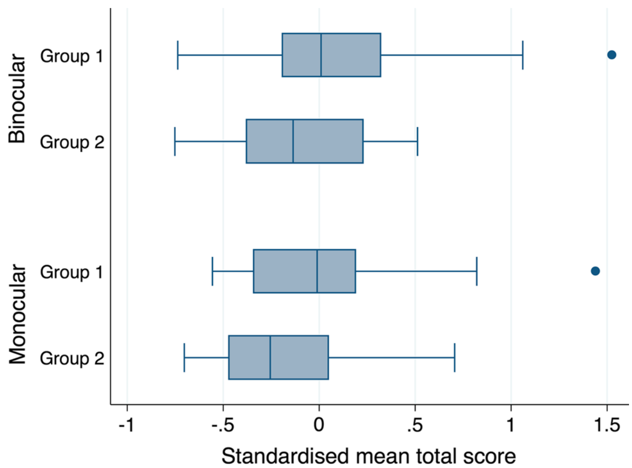

Fig. 2 The standardized mean total score (MTS) of the first run (binocular) and the second run (monocular)

effect was diminished and did not reach the significance level at 5 % (output not shown).

(b) Task 3.

The differences in the performance of task 3 remained similar after adjusting for age and the near visual acuity of the dominant eye, with a difference in the mean task 3 score of −0.09 (95 % CI of −0.29, 0.11; $p = 0.385$) (Table 4). Although age showed no significant impact on the difference in the scores ($p = 0.716$), impairment of the near visual acuity seemed to have a significant impact on the mean scores in task 3 (point estimate −0.46; 95 % CI −0.81, −0.10; $p = 0.005$). Again, this influence diminished in the sensitivity analysis that excluded the three participants with near visual acuity of the dominant eye of less than 0.6, and did not reach the significance level at 5 % (output not shown).

Table 3 The results of the analysis of the mean total score of participants with and without stereopsis and with and without an eye patch using the GEE to adjust for multiple observations per participant ($n = 57$)

	Not adjusted for age or the near visual acuity of the dominant eye		Adjusted for age and the near visual acuity of the dominant eye	
	Point estimate (95 % CI)	*P* value	Point estimate (95 % CI)	*P* value
Difference in the mean scores: participants with accurate vs. impaired stereopsis (first run without eye patch = first hypothesis)	−0.20 (−0.40; 0.01)	0.061	−0.12 (−0.32, 0.08)	0.234
Difference between the second and first runs in participants with impaired stereopsis (group 1), or the 'pure learning' effect	−0.08 (−0.16; −0.00)	0.039	−0.08 (−0.16, −0.00)	0.039
Interaction group × run: 'eye patch' effect [assuming that learning is the same in participants with accurate and impaired stereopsis (second hypothesis)]	0.00 (−0.11; 0.11)	0.981	0.00 (−0.11; 0.11)	0.981
Age (per 10-year increase)			0.07 (−0.01; 0.15)	0.068
Near visual acuity of the dominant eye (logMar) (per 0.1 unit increase)			0.11 (0.02; 0.20)	0.016
Intercept: mean total score (MTS) in participants with impaired stereopsis in the first run without the eye patch	0.11 (−0.04; 0.25)		−0.25 (−0.62; 0.13)	

Table 4 The results of an analysis of the mean scores of task 3 in participants with and without stereopsis and with and without an eye patch using the GEE to adjust for multiple observations per participant ($n = 57$)

	Not adjusted for age or the near visual acuity of the dominant eye		Adjusted for age and the near visual acuity of the dominant eye	
	Point estimate (95 % CI)	*P* value	Point estimate (95 % CI)	*P* value
Difference in scores on task 3: participants with accurate vs. impaired stereopsis (in the first run without an eye patch = first hypothesis)	−0.09 (−0.30; 0.11)	0.367	−0.09 (−0.29, 0.11)	0.385
Difference between the second and first runs in participants with impaired stereopsis (group 1), or the 'pure learning' effect	−0.11 (−0.25; 0.03)	0.110	−0.11 (−0.25, 0.03)	0.110
Interaction group × round: 'eye patch' effect [assuming that learning is the same in participants with accurate and impaired stereopsis (second hypothesis)]	0.06 (−0.13; 0.26)	0.527	0.06 (−0.13; 0.26)	0.527
Age (per 10-year increase)			−0.01 (−0.09; 0.06)	0.716
Near visual acuity of the dominant eye (logMar) (per 0.1 unit increase)			0.12 (0.04; 0.21)	0.005
Intercept: mean total score (MTS) in participants with impaired stereopsis in the first run without an eye patch	−0.49 (−0.64; −0.35)		−0.46 (−0.81; −0.10)	

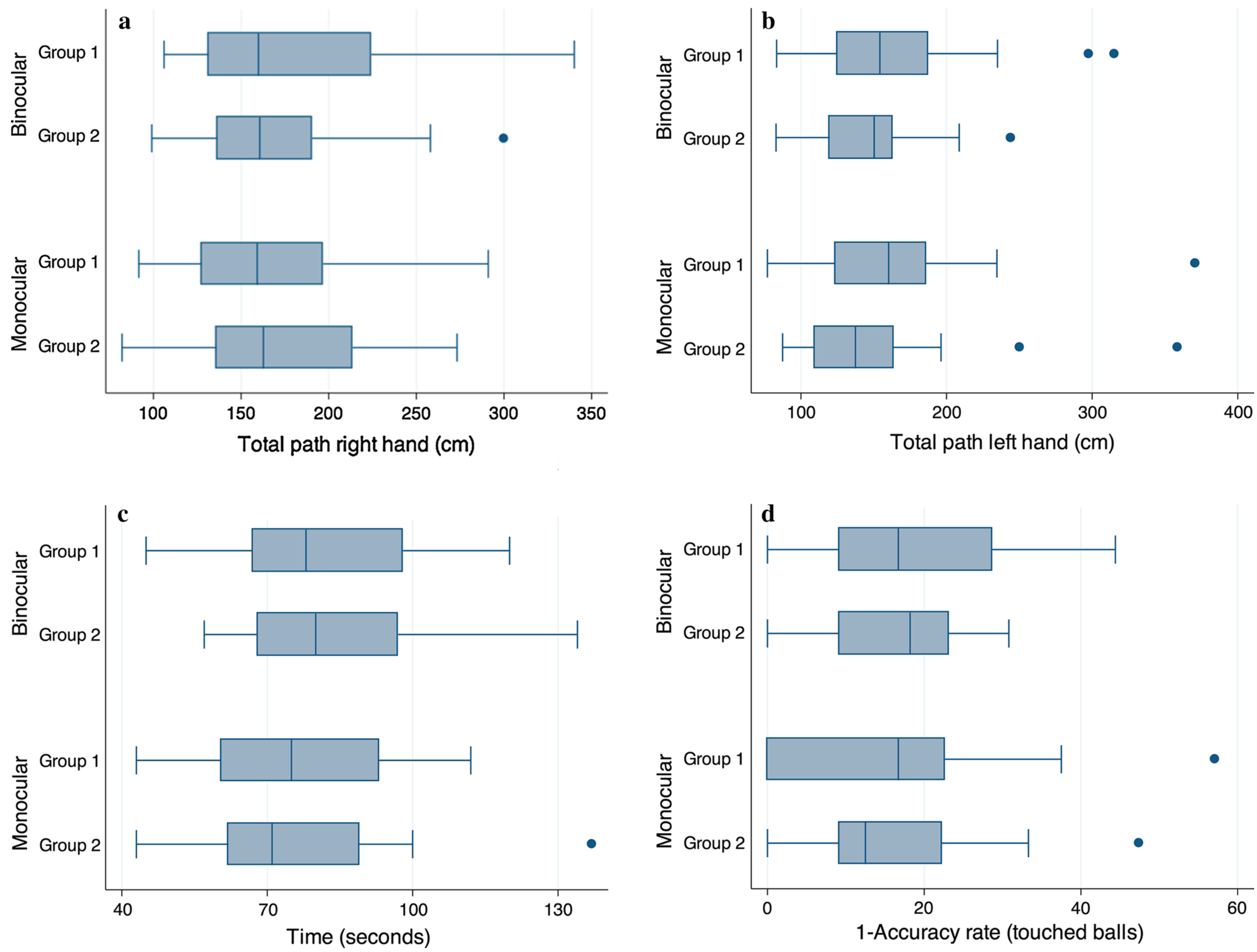

Fig. 3 **a** The total path length of the right hand (cm) during task 3. **b** The total path length of the left hand (cm) during task 3. **c** The time (s) required to finish task 3. **d** The accuracy rate (*touched balls*) in task 3

Analysis of the performance with and without the eye patch (secondary outcome)

(a) Mean total score.

As shown in Table 3, attendees with impaired stereopsis (group 1) significantly improved from the first to the second attempt by −0.084 (CI −0.164, −0.004; $p = 0.039$). This difference was considered to be due to the 'pure learning effect'. Assuming that learning was the same in all participants regardless their stereopsis, we estimated how much the participants with accurate stereopsis were impaired by the eye patch by considering the interaction term between the group and run. The change in the differences between the second and first runs was 0.001 (95 % CI −0.111, 0.114, $p = 0.981$). This was not a meaningful change after adjusting for age and the near visual acuity. In other words, the eye patch did not seem to impair the performance in participants with accurate stereopsis.

(b) Task 3.

The difference between the second and the first rounds of group 1 was −0.11 (CI −0.025, 0.03, $p = 0.110$) in task 3, which was again considered to be due to the 'pure learning effect' (Table 4). The change in the differences between the second and first rounds between the two groups was 0.06 (CI −0.13, 0.26, $p = 0.527$). Assuming that the pure learning effect was the same in both groups, it was possible that participants with accurate stereopsis were somehow negatively influenced by the eye patch, although the difference was not statistically significant.

Discussion

This study shows that (1) simulator performance was similar in individuals with impaired stereopsis and those with accurate stereopsis, after adjusting for age and the near visual acuity and (2) individuals with accurate stereopsis are not impaired by a small reduction in the visual field, as simulated by an eye patch. Individuals with accurate stereopsis seem to be able to compensate for the loss of the third dimension and small reductions in the visual field.

The present study had the following strengths: To the best of our knowledge, the impact of the examinees' stereopsis and near visual acuity on laparoscopic VR performance has never been investigated. We initially conducted the experiment using standardized procedures, carried out by an interdisciplinary team of experts. All ophthalmological examinations were carried out by one ophthalmologist. The VR test sessions were conducted using standardized instructions by one team member. Second, the problem of multiple testing when performing a variety of VR tasks with multiple performance outcomes was addressed by creating a standardized mean total score. Moreover, the additionally evaluated task 3 was chosen prior to data analysis, because it was considered to be the most dependent on intact stereopsis. Third, in contrast to many studies in the field, the number of participants was determined according to a formal sample size calculation.

The impact of depth perception on laparoscopic performance in simulated peg transfer and threading tasks was previously investigated in 91 third-year medical students [23]. Assessing depth perception using the graded circle test, a depth perception defect (test score ≤ 7) was found in 15.4 % of the subjects ($n = 14$). On initial performance, students with impaired depth perception scored significantly lower than those with accurate perception. However, both groups similarly increased performance after training, and the post-training scores adjusted for baseline did not differ between the two groups. This study thus shows that impaired depth perception impacts the initial performance, not the learning capacity. Whether the performance may achieve the same level as that in individuals with accurate stereopsis could not be answered by that investigation. The number of participants with impaired stereopsis was relatively low, and there was an important difference in the group size. Similarly, in a study involving 70 ninth-semester medical students performing three cataract surgery-training modules, the simulator performance score correlated with the stereoacuity in two out of three tasks [24]. However, it should be taken into account that cataract surgeries, as well as the simulator tasks, were conducted under stereoscopic vision. Therefore, these results may not be directly compared to the setting in our study, where we used a 2D screen.

In another investigation, the performance of 14 individuals with strabismus was compared to an age-matched control group of 14 individuals with normal stereopsis in a peg transfer task [25]. The authors concluded that further research was necessary, since the strabismus group performed worse, but there was significant overlap between the groups.

Although the above-mentioned studies must be interpreted with care, they suggest an overall disadvantage of an impairment in the trainees' stereopsis when performing laparoscopy. We hypothesized that the experience of the reliance on monocular depth cues in daily life in individuals with impaired stereopsis could actually be an advantage in laparoscopic surgery (not in open surgery or 3D laparoscopy). Our results do not suggest such an advantage; however, they also did not suggest a disadvantage when corrected for age and the near visual acuity.

In a study investigating the role of depth cues in 45 medical students and surgeons with intact stereopsis, similar reliance on the three-depth cues (stereo, texture and outline) was found [13]. Whereas the reliance on depth cues was correlated with better simulator performance in students, it was correlated with worse performance in surgeons. The authors of that study concluded that surgeons have adapted to the 2D images using 3D mental maps and relying on experience rather than basic cues. This may be an explanation for the similar performance of both groups: the advantage of the experience of participants with impaired stereopsis in a 2D setting was outweighed by the fact that they were being confronted with a completely new environment, where they could not rely on previous experience. However, it is possible that individuals with impaired stereopsis may compensate for the loss of the third dimension in real life, but they may struggle to compensate for that visual deficit when precise surgical tasks on 2D laparoscopic screens need to be conducted.

It is known that the incidence of impaired stereopsis in the general population is 2.2 % [10–12], but the true incidence of impaired stereopsis in surgical fellows is unclear. Medical students with impaired stereopsis may less frequently opt for a surgical career, because they may think that perfect visual capacity is an indispensable skill for a successful surgical career. Although we would expect impaired stereopsis to indeed to be a drawback in open surgery, we did not find a disadvantage in the 2D laparoscopic setting.

The implementation of high-definition 3D scopes, cameras and screens has paved the way for resolving one of the "big five" challenges in laparoscopic surgery; the loss of the third dimension. The advantages of 3D optics in robotic surgery have been described [26, 27], but this technique is mainly limited by its availability and costs [28]. This increases the importance of generally available and economically reasonable techniques in laparoscopic surgery, like 3D laparoscopy. Whereas some early studies comparing 3D to 2D laparoscopy showing no advantage of 3D over 2D laparoscopy were limited by drawbacks in the quality of the 3D images [29, 30], high-definition (HD) 3D systems with similar quality compared to 2D HD systems have been developed [27]. In a study investigating the users' performance comparing 2D HD and 3D HD scopes in 20 medical students and 10 experienced laparoscopic surgeons, the authors found that the use of 3D HD cameras and state-of-the-art 3D monitors permitted superior task efficiency in both groups [27]. However, the possible advantages of 3D laparoscopy concerning surgical efficiency and junior surgeons' learning curves may be partially outweighed by negative visual effects (eye fatigue, impaired visual attention) and the lack of routine implementation of 3D technology in operating theaters [31].

For daily clinical practice, the results of our study suggest that individuals with accurate stereopsis seem to compensate for the loss of the third dimension and are not further impaired by a small reduction in the visual field in laparoscopic VR laparoscopic simulations. However, based on the present study, we are unable to draw any conclusions on the comparison of 2D versus 3D screens. Moreover, efficient hand–eye coordination seems to play an important role. In an investigation on gaze control using the same VR hand–eye coordination task evaluated in our study (task 3), experts were found to mainly focus on the target, while locating the tools with peripheral vision, whereas novices spent a similar amount of time focusing on the target and the tools, and thus needed to switch between the two to comprehend their relative positions [32]. In a follow-up study on the two-handed maneuvers task (task 6), experienced surgeons were found to have a longer aiming fixation (quiet eye duration) to precisely perform grasping, and made fewer grasping attempts [33]. It is thus not surprising that eye metrics have been suggested to be useful as an objective assessment parameter for surgical skills [34]. Based on these results, the participants in our study are not expected to need peripheral vision for tool tracking, since they were novices and probably were focusing on the tools to locate them. This may explain why individuals with accurate stereopsis were not further impaired by the eye patch.

This study is associated with some possible limitations. First, the study participants in the two groups differed concerning age and the near visual acuity of the dominant eye. We addressed this shortcoming by including age and the near visual acuity as confounders in our analysis. Second, the number of participants was limited. Although we performed a formal sample size calculation, due to the lack of literature in the field in the same setting, we based our calculations on previous published investigations using the same simulator. We cannot, however, exclude the possibility that the lack of a difference between groups was due to a lack of power. Third, the mere learning effect for the simulator is considerable, and thus, to answer the second research question, we assumed the learning effect to be similar in both groups. This assumption is supported by previous findings of similar improvement after training in participants with impaired and accurate depth perception [23]. Fourth, this study used laypersons as subjects instead of surgeons for pragmatic reasons, which are mainly explained by the low incidence of impaired stereopsis and the presumably especially low incidence among surgeons, because individuals with impaired stereopsis are assumed to opt less frequently for a surgical career. Thus, our study results may not be simply extrapolated to surgeons. However, we had no intention to investigate methods for selecting candidate surgeons, but rather chose the setting to carry out a hands-on experiment to test our hypothesis. Of note, because it included laypersons, the study had to be limited to simulated performance. We therefore may not extrapolate our results to operating room performance. Fifth, since the LAP Mentor™ with its screen resolution of 800 × 600 pixels on a 17-in. screen does not present real images, but a Virtual Reality image, the visual cue might not be enough to compensate for the loss of a 3D view. However, our investigation may be a helpful starting point for the design of a follow-up study with surgeons, as outlined below.

In conclusion, individuals with accurate stereopsis seem to be able to compensate for the loss of the third dimension and a small reduction in the visual field in simulated VR laparoscopic surgery. Although these findings support the use of HD 2D vision in laparoscopic surgery, they do not rule out an additional advantage of HD 3D screens in laparoscopic surgery.

As noted above, our present results can provide a starting point for a follow-up study with surgeons. We propose that a study should be performed to investigate the learning curves comparing participants with impaired versus accurate stereopsis, and hypothesize that there would be a longer time until proficiency in individuals with impaired stereopsis. Using an eye tracking device may yield further information regarding visual compensatory mechanisms and strategies in participants with impaired stereopsis. Although the incidence of stereopsis is very low and gathering participants is difficult, this study should be repeated in surgeons. Another interesting approach would be to investigate the impact of impaired stereopsis in precise open surgical tasks or using 3D-cameras and screens, where intact stereopsis is required. Those results could then be compared to the participants' performance on 2D screens.

Acknowledgements The authors would like to thank Martina Vitz and Jéròme Gapany of the Laparoscopic Training Center Zurich, Switzerland, for their support in the realization of this study. This study was supported by a grant from the Swiss National Science Foundation (No. 3200B0-120722/1). Part of this work was presented at the Annual Meeting of the Swiss Society of Ophthalmology (SOG) in 2012.

Conflict of interest Henry Hoffmann, Rebecca Ruiz-Schirinzi, Salome Dell-Kuster and Professors David Goldblum, Daniel Oertli, Dieter Hahnloser and Rachel Rosenthal have no conflicts of interest or financial ties to disclose.

References

1. Ohtani H, Tamamori Y, Noguchi K, Azuma T, Fujimoto S, Oba H, et al. A meta-analysis of randomized controlled trials that compared laparoscopy-assisted and open distal gastrectomy for early gastric cancer. J Gastrointest Surg. 2010;14:958–64.
2. Liu Z, Zhang P, Ma Y, Chen H, Zhou Y, Zhang M, et al. Laparoscopy or not: a meta-analysis of the surgical effects of laparoscopic versus open appendicectomy. Surg Laparosc Endosc Percutan Tech. 2010;20:362–70.
3. Sauerland S, Jaschinski T, Neugebauer EA. Laparoscopic versus open surgery for suspected appendicitis. Cochrane Database Syst Rev. 2010;10:CD001546.
4. Kuhry E, Schwenk WF, Gaupset R, Romild U, Bonjer HJ. Long-term results of laparoscopic colorectal cancer resection. Cochrane Database Syst Rev. 2008;2:CD003432.
5. Jayne DG, Thorpe HC, Copeland J, Quirke P, Brown JM, Guillou PJ. Five-year follow-up of the Medical Research Council CLASICC trial of laparoscopically assisted versus open surgery for colorectal cancer. Br J Surg. 2010;97:1638–45.
6. Buunen M, Veldkamp R, Hop WCJ, Kuhry E, Jeekel J, Haglind E, et al. Survival after laparoscopic surgery versus open surgery for colon cancer: long-term outcome of a randomised clinical trial. Lancet Oncol. 2009;10:44–52.
7. Fleshman J, Sargent DJ, Green E, Anvari M, Stryker SJ, Beart RW, et al. Laparoscopic colectomy for cancer is not inferior to open surgery based on 5-year data from the COST Study Group trial. Ann Surg. 2007;246:655–62 (discussion 662–4).
8. Gallagher AG, Ritter EM, Lederman AB, McClusky DA, Smith CD, et al. Video-assisted surgery represents more than a loss of three-dimensional vision. Am J Surg. 2005;189:76–80.
9. Nisky I, Huang F, Milstein A, Pugh CM, Mussa-Ivaldi FA, Karniel A. Perception of stiffness in laparoscopy—the fulcrum effect. Stud Heal Technol Inform. 2012;173:313–9.
10. Xu L, Wang Y, Li Y, Wang Y, Cui T, Li J, et al. Causes of blindness and visual impairment in urban and rural areas in Beijing: the Beijing Eye Study. Ophthalmology. 2006;113(1134):e1–11.
11. Maberley DAL, Hollands H, Chuo J, Tam G, Konkal J, Roesch M, et al. The prevalence of low vision and blindness in Canada. Eye. 2006;20:341–6.
12. Rahi JS, Cumberland PM, Peckham CS. Visual impairment and vision-related quality of life in working-age adults: findings in the 1958 British birth cohort. Ophthalmology. 2009;116:270–4.
13. Shah J, Buckley D, Frisby J, Darzi A. Depth cue reliance in surgeons and medical students. Surg Endosc. 2003;17:1472–4.
14. Dunbar G, Holland CA, Maylor EA. Older pedestrians: a critical review of the literature. Road safety research report. London: The Department for Transport. 2004.
15. Brown S, Weih L, Mukesh N, McCarty C, Taylor H. Assessment of adult stereopsis using the Lang 1 stereotest: a pilot study. Binocul Vis Strabismus Q. 2001;16:91–8.
16. Sue S. Test distance vision using a Snellen chart. Community Eye Heal. 2007;20:52.
17. Nüssgens Z, Czerwonka B, Roggenkämper P. Examinations on the new Lang test. Strabismus. 1993;1:69–73.
18. Okuda FC, Apt L, Wanter BS. Evaluation of the TNO-random-dot stereogram test. Am Orthopt J. 1977;27:124–30.
19. Vandenbroucke JP, von Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. PLoS Med. 2007;4:e297.
20. Rosenthal R, Schäfer J, Hoffmann H, Vitz M, Oertli D, Hahnloser D. Personality traits and virtual reality performance. Surg Endosc. 2013;27:222–30.
21. Klein R, Klein BE, Linton KL, De Mets DL. The beaver dam eye study: visual acuity. Ophthalmology. 1991;98:1310–5.
22. Rosenthal R, Geuss S, Dell-Kuster S, Schäfer J, Hahnloser D, Demartines N. Video gaming in children improves performance on a virtual reality trainer but does not yet make a laparoscopic surgeon. Surg Innov. 2011;18:160–70.
23. Suleman R, Yang T, Paige J, Chauvin S, Alleyn J, Brewer M, et al. Hand–eye dominance and depth perception effects in performance on a basic laparoscopic skills set. JSLS. 2010;14:35–40.
24. Selvander M, Åsman P. Stereoacuity and intraocular surgical skill: effect of stereoacuity level on virtual reality intraocular surgical performance. J Cataract Refract Surg. 2011;37:2188–93.
25. Barry GP, Simon JW, Auringer D, Dunnican W, Zobal-Ratner J. Performance of strabismic subjects using a validated surgical training module: a pilot study. J AAPOS. 2009;13:350–3 (353.e1–2).
26. Palep JH. Robotic assisted minimally invasive surgery. J Minim Access Surg. 2009;5:1–7.
27. Storz P, Buess GF, Kunert W, Kirschniak A. 3D HD versus 2D HD: surgical task efficiency in standardised phantom tasks. Surg Endosc. 2011;26:1454–60.
28. Pedraza R, Ramos-Valadez DI, Haas EM. Robotic-assisted laparoscopic surgery of the colon and rectum: a literature review. Cir Cir. 2011;79:384–91.
29. Hanna GB, Shimi SM. Cuschieri a. Randomised study of influence of two-dimensional versus three-dimensional imaging on performance of laparoscopic cholecystectomy. Lancet. 1998;351:248–51.
30. Hanna GB, Cuschieri A. Influence of two-dimensional and three-dimensional imaging on endoscopic bowel suturing. World J Surg. 2000;24:444–9.
31. McLachlan G. From 2D to 3D: the future of surgery? Lancet. 2011;378:1368.
32. Wilson M, McGrath J, Vine S, Brewer J, Defriend D, Masters R. Psychomotor control in a virtual laparoscopic surgery training environment: gaze control parameters differentiate novices from experts. Surg Endosc. 2010;24:2458–64.
33. Wilson MR, McGrath JS, Vine SJ, Brewer J, Defriend D, Masters RSW. Perceptual impairment and psychomotor control in virtual laparoscopic surgery. Surg Endosc. 2011;25:2268–74.
34. Richstone L, Schwartz MJ, Seideman C, Cadeddu J, Marshall S, Kavoussi LR. Eye metrics as an objective assessment of surgical skill. Ann Surg. 2010;252:177–82.