Surgical Endoscopy
https://doi.org/10.1007/s00464-019-07267-y

Different cognitive styles can affect performance in laparoscopic surgery skill training

Armin Paul Mathias[1,3] · Peter Vogel[2] · Markus Knauff[1]

Received: 6 August 2019 / Accepted: 12 November 2019

Abstract

Background The lack of depth cues and haptic feedback makes minimally invasive surgery a cognitive challenge. It is therefore important to know which individuals are expected to perform well in minimally invasive surgery. In cognitive psychology, methods are available with which one can measure different cognitive thinking styles. It is well known that these cognitive styles correlate with many different tasks. We investigated whether this method can also predict performance on a box trainer (Lübeck Toolbox®), a device for training laparoscopic surgery. If so, the method might help to select and train those people who will most likely develop high skills in minimally invasive surgery.

Methods Thirty medical students and thirty non-medical students performed five laparoscopic surgical tasks on a box trainer. We measured the time required and the errors participants made on each task. Their cognitive style was measured with a method from cognitive psychology that distinguishes between people who think visually, spatially, or verbally. Furthermore, all students completed a subset of a standard intelligence test (Wechsler Adult Intelligence Scale) and three subtests of the German Medical University Admission Test (TMS).

Results Participants with spatial thinking styles performed best on the box trainer. Visual and verbal cognitive styles impeded box trainer performance. Performance on the box trainer could also be predicted by the TMS and IQ scores.

Conclusions The study shows for the first time that a standard method from cognitive psychology can be used to distinguish between different cognitive styles in surgical education and that these different cognitive styles affect performance on a box trainer. Since the correlation between box trainer performance and surgical proficiency is well documented, the method might be an efficient way to reduce errors and to elevate patient safety in laparoscopic surgery.

Keywords Box trainer · Spatial cognition · Cognitive styles · Medical assessment · Laparoscopic surgery

Minimally invasive surgery has been established as a standard technique for many surgical operations. Reduced blood loss as well as a shortened recovery time and other advantages made it the preferred choice in many cases [1, 2]. However, for the surgeon laparoscopic surgery is demanding and a cognitive challenge. This can also result in more errors and reduced patient safety [3]. It is therefore important to select the best skilled surgeons and to find efficient training methods that can help to increase proficiency and reduce errors in laparoscopic surgery.

Different training systems for minimally invasive surgery are available. The transferability of training effects on these box trainers and simulators to the operating room is well demonstrated [4, 5]. Furthermore, cost-effective box trainers are not inferior to expensive simulators. A study by Vitish-Sharma et al. showed that training on both, box trainers and simulators, improves basic laparoscopic skills [6].

Although evaluation studies about box trainers exist, it is still unclear if it is the appropriate training method for all surgeons. One of the core problems in laparoscopy is the lack of depth cues and haptic feedback [7, 8]. Accordingly, previous research suggests that visuospatial ability is essential for laparoscopic surgery. Several studies

✉ Armin Paul Mathias
armin.mathias@psychol.uni-giessen.de

Markus Knauff
markus.knauff@psychol.uni-giessen.de

[1] Department of Psychology, Experimental Psychology and Cognitive Science, Justus Liebig University, Otto-Behaghel-Strasse 10F, 35394 Giessen, Germany

[2] Department of General, Visceral and Minimally Invasive Surgery, Hospital Bad Hersfeld, Bad Hersfeld, Germany

[3] Medical School, Justus Liebig University, Giessen, Germany

show that visual and spatial cognitive ability correlates with surgical performance [9] especially in low experience people [10]. The correlation is also stronger in more complex tasks [11]. This raises the question whether surgeons benefit more or less from training with a box trainer.

Research from cognitive psychology shows that people possess different thinking styles with respect to learning and problem-solving. Some think more based on *language*, some use *visual imagination*, and some construct and manipulate *spatial–mental representations*. So, do people with specific cognitive styles benefit more from box trainers than others? Can different cognitive styles predict performance on a box trainer and potentially in minimally invasive surgery in the operating room? In other academic disciplines the effect of cognitive styles on learning and performance is well documented, e.g., in the education of students of chemistry [12], or in mechanical reasoning [13]. The present study explored such effects of cognitive style on learning of minimally invasive surgery.

According to Blazhenkova and Kozhevnikov "cognitive styles refer to psychological dimensions representing consistencies in an individual's manner of cognitive functioning, particularly with respect to acquiring and processing information […]." ([14] p. 638). The authors distinguish between people with three different cognitive styles: *object visualizers*, *spatial visualizers*, and *verbalizers*. In this study, we refer to these people as *visualizers*, *spatializers*, and *verbalizers*, respectively. Typically, visualizers often use visual–mental imagery when processing cognitive tasks, creating vivid detailed images of existing objects. Spatializers are good in spatial orientation and process the spatial relations between objects and regions in a more abstract way. Spatializers perform well on tasks of spatial thinking and orientation, while visualizers have their strength in recognizing pictures of objects. Verbalizers use language-based cognitive strategies.

Blazhenkova and Kozhevnikov have developed the so-called *Object-Spatial Imagery and Verbal Questionnaire (OSIVQ)* which provides an efficient way to distinguish between individuals that fall in the subclasses of visualizers, spatializers, and verbalizers. The authors show that these three cognitive styles correlate with already existing visual and spatial imagery tests (e.g., mental rotation test, paper folding test, degraded shape recognition as well as with a verbal subtest of the SAT) [14].

The goal of the present study was to examine whether different cognitive styles influence the performance in a box trainer, which might be of importance for learning laparoscopic techniques. In addition, the study examined if selected tasks from the Wechsler Adult Intelligence Scale, a standard intelligence test, and from the *German Medical University Admission Test* (which is similar to other admission tests used in many other countries) correlate with box trainer performance.

Methods

Subjects

Participants were recruited on a voluntary basis via the university email list. Financial compensation was granted. Informed consent was obtained before the study started. Subjects included 30 medical students (15 women; first- to sixth-year) and 30 non-medical students (15 women). Mean age was 24.20 years ($SD = 3.24$). Exclusion criteria was experience with box trainers or with minimally invasive surgery. Dentistry students were not allowed to participate in the study. The study has been conducted according to the principles expressed in the Declaration of Helsinki and was ethically approved by the Department of Psychology at the University of Giessen, Germany. All participants were properly instructed and indicated that they consent to participate by signing the informed consent form. They could withdraw from the task at any time.

Materials

Box trainer tasks: To measure box trainer performance, we used the Lübeck Toolbox®, a commercial box trainer designed by surgeons from Lübeck University, Germany. Participants had to do five of the six tasks from that box trainer inventory (the last, minimally invasive suturing, was too difficult for the study). The tasks are illustrated in Fig. 1. In task 1, participants had to sort plastic hollow cylinders by color (white or blue) in boxes. In task 2, participants had to weave a string between tense rubber bands. In task 3, similar to task 1, participants had to grasp plastic hollow cylinders from one side and move them to the other side and then the reversed procedure while grasping a tense rubber band with the other hand, to train bi-manual eye-hand coordination. In task 4 and 5, subjects had to cut out a simple and a more difficult form of the upper layer of a double-layered compress, without cutting the lower layer.

For each individual the time needed to complete the task and errors were measured. No time limit was set. Errors were defined as follows: In task 1 and 3, when participants dropped and flipped over plastic hollow cylinders; in task 2, if the subject produced an incorrect weaving; and in task 4 and 5, when cutting beyond the line as well as cutting the lower layer occurred.

Participants stand in front of a desk on which the box trainer was set on. The box trainer was connected to a 32″ TV monitor. As an illustration, see Fig. 2. To adjust

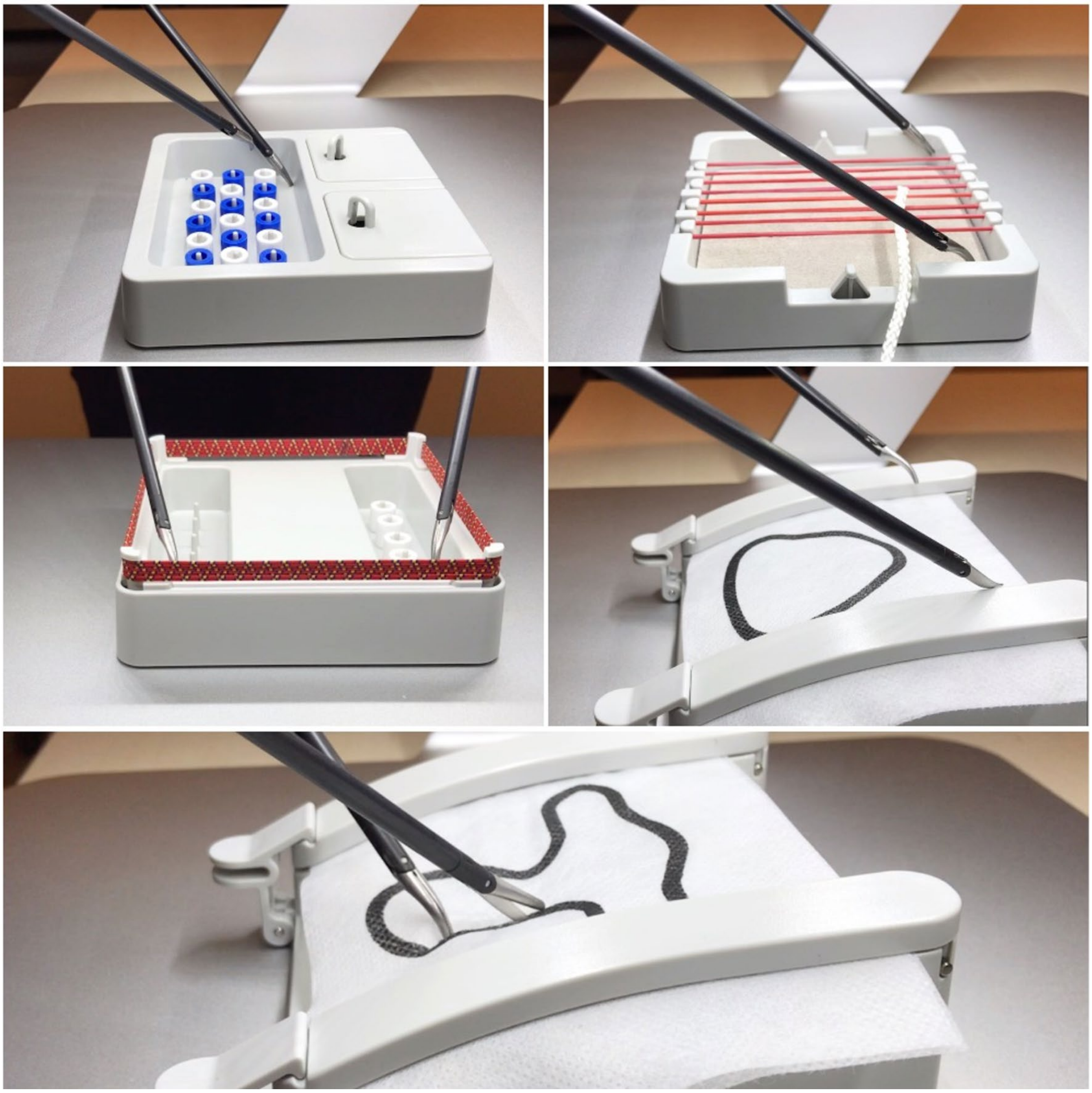

Fig. 1 Box trainer tasks the participants had to perform

Fig. 2 Box trainer setup

body height differences, plates could be put under the box trainer and the monitor stand. Laparoscopic instruments used in the study were standard graspers and a scissor. For task instruction, videos from the box trainer website were used. The inner space of the box was filmed while the participants were performing the tasks.

Object-Spatial Imagery and Verbal Questionnaire (OSIVQ): To measure the participants' cognitive styles, we used the OSIVQ designed by Blazhenkova and Kozhevnikov [14]. The questionnaire consists of 45 statements representing the different cognitive styles. Participants had to use a five-point Likert scale to rate to which extent they agreed or disagreed with the statements (strong disagree = 1, strong agree = 5). Some examples are presented in Table 1. To obtain the scores for each participant, the mean value on

Table 1 Examples of the statements in the OSIVQ. Participants had to use a five-point Likert scale to rate to which extent they agreed or disagreed with the statements (strong disagree = 1, strong agree = 5)

(1) I was very good in 3D geometry as a student
(2) If I were asked to choose between engineering professions and visual arts, I would prefer engineering
(3) My images are very colorful and bright
(4) When reading fiction, I usually form a clear and detailed mental picture of a scene or the room that has been described
(5) When explaining something, I would rather give verbal explanations than make drawings or sketches
(6) My verbal skills are excellent

A spatializer would agree with statements (1) and (2), a visualizer would agree with statements (3) and (4), and a verbalizer would agree with statement (5) and (6). The mean values on the verbalizer, visualizer, and spatializer items were computed for each participant; e.g., 3.2 on the visualizer scale, 4.2 on the spatializer scale, and 3.5 on the verbalizer scale for a single participant. This participant would have been categorized as a spatializer

the verbalizer, visualizer, and spatializer items were computed (seven items were excluded for reasons of reliability and validity). All items and task instructions were translated into German. There was no time limit for answering the questionnaire.

German Medical University Admission Test ("Test for Medical Studies", TMS): From the TMS, [15] we selected three tasks which we considered relevant for surgical performance. In the *Matching Patterns* task (task 1), participants were presented a (medical) picture, e.g., a schematic microscoping image. Then five smaller pictures were presented. Participants had to decide which of the small pictures showed a small portion of the larger picture. This is a highly visual task. Participants had seven minutes and twenty seconds for eight tasks. The *Tube Figures* task (task 2) resembles the Stumpf-Fay Cube Perspectives Test in which participants see a picture of a tube folded into a transparent cube and have to decide from which viewpoint a second picture of the same object was taken [16]. This task consisted of eight figures; participants had five minutes for completion. This is a highly spatial task. In the *Concentrated and Careful Work* task (task 3), participants´ ability to work carefully and quickly was assessed. On a sheet, 40 lines were filled only with Cs and Os, randomly distributed. Every C that is followed by an O had to be marked. A time limit of eight minutes was set. For statistical evaluation, the percentage of correctness in the first two tasks, as well as a score for the third task (every correct marking minus the wrong markings and the overlooked previous Cs) was used.

Visuo-spatial IQ Test/Mosaic Test: The *Mosaic Test* is a subtest of a standard intelligence test (block design test, Wechsler Adult Intelligence Scale) which measures the visuospatial intelligence of the individual (for an illustration of the test see [17]). With bicolored cubes, participants have to build the given plane patterns. For the first five tasks four cubes were needed. For the other five tasks nine cubes were needed. Time and success of building the patterns were measured. In the end, a score from zero to sixty-eight points was generated for each participant.

Procedure

Each subject completed a demographic questionnaire documenting education level, age, handedness, visual disorders, recreational video game playing, and making music. Then participants performed the box trainer tasks. Before doing each task, they were shown two instruction videos. After completing the box trainer tasks, participants filled out the OSIVQ questionnaire, and then the Mosaic Test was conducted. Finally, they completed the three tasks from the German Medical University Admission Test. For each participant, about 2 h of testing was required.

Statistical analysis

Statistical analysis was performed using SPSS for Windows, version 25.0 (IBM, Armonk, NY, USA). For correlation analysis a Pearson product moment correlation was used. The Mann–Whitney U Test was used for group differences. To control for speed-accuracy trade-offs, the rate correct score (RCS) was computed by combining time and errors made in the box trainer. The RCS is often used in cognitive psychology and is defined as follows: $RCS = C/\sum RT$, C is the number of correct responses and RT is the (reaction) time. In this study, C was computed by 100 minus the total amount of all committed errors in the box trainer tasks, and the denominator is the time needed to complete all five box trainer tasks. A higher RCS corresponds to a better box trainer performance. Significance level was set to a p value of less than 0.05, p values were corrected for multiple comparisons for each subset of tests (Benjamini–Hochberg test for false discovery rate).

Results

OSIVQ—box trainer performance relationships: For each participant, the score on the three scales (verbalizer, visualizer, and spatializer) was computed by averaging the ratings on the items for each of the three scales separately. They could vary between 1 and 5. Over the group of participants, the mean on the visualizer scale was $M = 3.44$ ($SD = 0.48$), for the spatializer scale $M = 3.05$ ($SD = 0.77$), and for the verbalizer scale $M = 3.20$ ($SD = 0.63$). Based on the individuals' scores, an individual cognitive style was assigned to each participant. The individual´s cognitive style scale with the highest mean was decisive. 24 participants were classified as visualizers, 16 as spatializers, and 18 as verbalizers. 2 participants had the same values on two scales and were thus not assigned to one group.

Then two statistical analyses were computed. The first analysis explored to which cognitive style the best performing participants belonged to. Among the 25% best (fastest) participants, most were spatializers (60%). As shown in Fig. 3, on average, the group of visualizers needed 38.05 ($SD = 11.33$) minutes and committed 15.67 ($SD = 9.07$) errors. The spatializers needed 33.00 ($SD = 8.52$) minutes to perform the tasks and they committed 13.44 ($SD = 7.28$) errors. The verbalizers needed 37.70 ($SD = 7.93$) minutes and committed 17.17 ($SD = 10.53$) errors. The corresponding RCS for visualizers, spatializers, and verbalizers were 2.41, 2.77, and 2.32, respectively. The differences between the RCS of spatializers and the other groups were statistically significant ($p = 0.048$).

Then we compared the 25% of subjects with the highest ratings on the spatializer scale with the 25% of subjects who rated lowest on this scale. The participants with highest ratings on the spatializer scale were significantly better than the ones with the lowest ratings (2.86 vs. 2.31, $p = 0.038$).

In the second analysis, Pearson´s r correlations were computed between the RCS in the box trainer tasks and the scores on the cognitive style scales. The score on the spatializer scale correlates significantly with the RCS ($r = 0.35$, $p = 0.035$). Thus, a higher score on the spatializer scale resulted in better box trainer performance. There were no significant correlations between the other two cognitive style scores and the box trainer performance ($r = 0.21$, $p = 0.13$ for the visualizer scale; $r = -0.11$, $p = 0.39$ for the verbalizer scale). Thus, these two scales were not able to predict the box trainer performance.

Mosaic Test—box trainer performance: Pearson´s r correlations were computed between the RCS and the Mosaic Test score. The box trainer performance correlates significantly with the Mosaic Test score ($r = 0.37$, $p = 0.007$). Thus, people who performed better on the Mosaic Test were also better in the box trainer tasks.

German Medical University Admission Test ("Test for Medical Studies", TMS)—box trainer performance: Pearson´s r correlations were computed between box trainer performance and the TMS scores. The RCS correlates significantly with the score in the Matching Patterns task ($r = 0.40$, $p = 0.007$).

There were no significant correlations between the Tube Figures task and box trainer performance ($r = 0.20$, $p = 0.13$). However, a further analysis yielded a tendentially significant correlation between box trainer performance and the

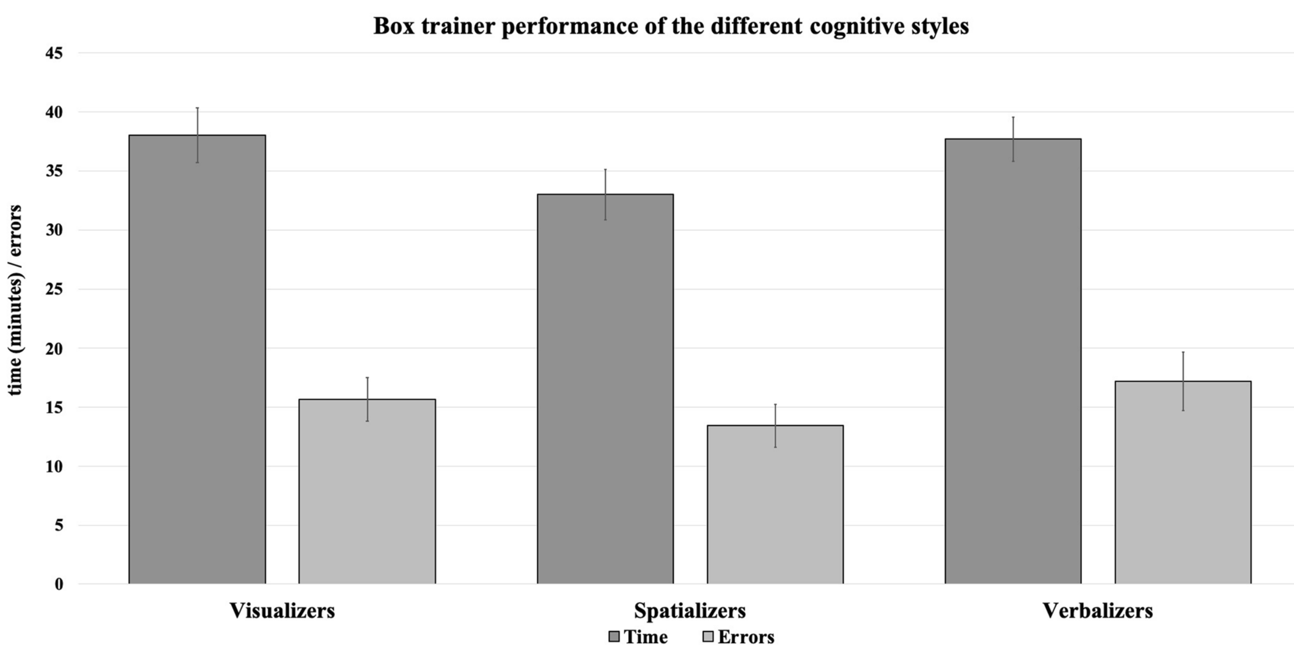

Fig. 3 Box trainer performance of the three different cognitive styles. The spatializers needed the least time to complete and committed the least number of errors. Error bars: standard error

Tube Figures task only for the group of non-medical students ($r = 0.35$, $p = 0.08$). Box trainer performance correlates significantly with the score in the Concentrated and Careful Work task ($r = 0.37$, $p = 0.007$). Thus, people who performed better on the TMS tasks were also better in the box trainer tasks. There were no significant differences between medical and non-medical students and male and female participants.

Discussion

The intention of this study was to explore the connection between cognitive styles and abilities and the proficiency in laparoscopic surgery under the standardized conditions of the box trainer. The results show that (1) different cognitive styles can be used to predict performance on a box trainer, (2) participants with spatial thinking styles performed best on the tasks, (3) and performance on the box trainer could also be predicted by the tasks from the German Medical University Admission Test as well as by the subset of the intelligence test.

The result that spatial thinking styles can facilitate cognitive performance, while a visual cognitive style can impede performance, is well known from the cognitive psychology of reasoning and problem-solving. The reason is that visual information can put extra load on working memory, which can hinder learning and reasoning effectiveness [18–20]. This is called the visual impedance effect [21]. Similar effects have been found, for instance, in university students of chemistry that had to learn molecular models in organic chemistry [12]; in mechanical reasoning, where participants had to mentally simulate the functions of technical systems [13]; in dyslexia [22]; and in logical reasoning [21, 23].

The present results have important consequences for the use of box trainers in the education and selection of experts for laparoscopic surgery. Previous studies already showed correlations between visuospatial ability and minimal invasive surgery (for a review see [24]), and between box trainer performance and performance in actual minimally invasive surgery [25, 26]. The present results go beyond these findings by showing for the first time that a standard method from cognitive psychology can be used to distinguish between different cognitive styles in surgical education and that these different cognitive styles affect performance on a box trainer. Since the correlation between box trainer performance and surgical proficiency in the operating room is well documented, the method might help to select and train those people who will most likely develop high skills in minimally invasive surgery. This is important as patient safety and error minimization should be the prioritized aims in improving surgery.

The OSIVQ is not a method to measure differences in cognitive abilities. It tests which thinking style people prefer, but these cognitive styles can be more or less efficient for solving different tasks and problems. The present study shows that a spatial thinking style is probably the most efficient for laparoscopic surgery. However, the present study also yielded reliable correlations between box trainer performance and tests for cognitive abilities. The Mosaic Test is part of a standard intelligence test and measures visuospatial cognitive abilities. The TMS is also a cognitive ability test that is used in Germany to select those candidates who will be admitted to the medical school. The German test is similar to tests in other countries.

The combination of a cognitive style test and test for cognitive abilities might be a good way to select and educate surgeons with particular skills in laparoscopic surgery. The method might also be more efficient than recent attempts to use immersive virtual reality in minimal invasive surgery, which is technically demanding and costly [27].

One possible limitation of our study is that all participants were inexperienced in surgery. Studies in the skills training field have demonstrated that the role of cognitive factors can change significantly with experience. With learning, skills become increasingly automatic, and thus become cognitively less demanding [28, 29]. For example, learning to drive is initially very cognitively demanding, but with practice it becomes rather automatic and thus demands less cognitive control [7]. In a similar way, the ability of experienced surgeons may help them to transfer their skills to new tasks and to cope with various internal or external disturbances [30]. A goal of future research thus is to study how the role of spatial abilities changes as experience is acquired. An insightful discussion of the effects of expertise on spatial cognitive abilities can be found in [7]. A related question in our study is whether or not the differences between the different cognitive styles would disappear after several phases of learning in the box trainer. Currently, the results on this matter are equivocal [31–33]. In the evaluation study of the Lübeck Toolbox®, all participants reached proficiency, although some of them needed up to 80 repetitions to reach the goal for some tasks [26].

Another limitation might be that we could not directly explore the connection between the cognitive tests and the performance of surgeons in an actual operating room. We plan to conduct these studies in the future. Of course, this raises some ethical questions that must be carefully considered. Another problem is that our study mainly yielded correlations, which cannot be interpreted causally. In future experiments, we will therefore try to train participants to use particular cognitive styles and then measure how this affects their performance in surgery. Previous experiments in other domains have shown that such a training can be effective and lead to better performance on different tasks [12, 13].

Such controlled experiments might also help to understand one unexpected result in the present study. It is reasonable to assume that the Tube Figures task from the TMS test correlates with box trainer performance. However, this was only obtained for the non-medical students, not for medical students, which is a surprising result that needs further clarification. A possible other difficulty of our study is the long testing time of 2 h, which might have resulted in a lack of concentration towards the end of the testing. However, concentration over a long period of time is an essential ability for surgery.

We see at least two important questions for future research: First, several groups have shown strong correlations between teamwork, communication skills, good doctor-patient relationships, and patient safety [34]. A good doctor-patient relationship depends especially on good communication skills and improves medical care [35]. As we can hardly doubt that such factors are also essential for the safe practice of laparoscopic surgery, one task for future research is to develop methods for choosing and training medical student on these factors, which are equally efficient as the cognitive approach reported in this paper. Second, in the last years, several systems for robotic surgery have become available. Robotic surgery is similar to laparoscopic surgery. Yet, instead of holding and manipulating the surgical instruments himself, during robotic surgery, the surgeon sits at a computer to control the robot. It has been shown that such devices require shorter learning times than learning conventional laparoscopic surgery procedures [36, 37]. On the one hand, these systems for robotic surgery may thus have the potential to further reduce the importance of the surgeons' purely technical capabilities. Accordingly, the importance of communicative and social skills and the interaction with the patient outside the operation room could become even more important. On the other hand, robotic surgery systems are expensive and will not replace laparoscopy. Moreover, the use of robotic systems in the operation room places other very high cognitive demands on the surgeon. In this context, too, the question arises which persons are suitable for this type of surgical practice and how these persons can be efficiently prepared for these new requirements. In the present study, people with high spatial skills (spatializers) showed the best performance on the box trainer, and there are no obvious reasons why such spatial skills should be less important for surgeons performing robotic surgery. We will focus on such topics in our future research.

Conclusions

Patient safety and error minimization should be the prioritized aims in surgery. Of course, it depends on many psychological, social, technical, organizational, financial, and other aspects. In the last decades, much research focuses on these aspects of patient safety [38]. However, much less attention has been paid to the cognitive factors that might help to avoid errors and increase patient safety. The goal of this study was to bridge this gap. The present results can help to develop easy and effective ways of choosing and educating people who have the potential to become excellent surgeons particular for minimally invasive surgery.

Acknowledgements This research was supported by the Deutsche Forschungsgemeinschaft [DFG Grant KN 465/6-2 to Markus Knauff]. The authors thank all participants for taking part in this study.

Compliance with ethical standards

Disclosures Armin Mathias, Peter Vogel, and Markus Knauff have no conflicts of interest or financial ties to disclose.

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