Visuo-spatial Ability and Damage in Laparoscopic Simulator Training

Bachelor Thesis Psychology

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Abstract

The current study investigated the role of visuo-spatial ability on Damage in laparoscopic simulator training. Although most studies agree on the predictive power of visuo-spatial ability on surgical performance, it has been so far studied only in limited detail. This exploratory study used four individual visuo-spatial ability factors to determine its relationship on Damage, which is only scarcely investigated in this context. The term Damage is referred to as any negative consequence of an action to the virtual tissue, which was in this study defined by various exercise-dependent variables. Seven trainees participated in a training program from which the data for this study is acquired, comprising five training sessions with six exercises on the LapSIM simulator. Damage was characterized by an early significant improvement and only little advancements thereafter. The visuo-spatial ability factor Visualization was found to be of particular influence in the laparoscopic simulator training.

Introduction

Laparoscopic surgery is established as the preferred technique for many common procedures (Al-Abed & Cooper, 2009). This development is accompanied by the increased availability of laparoscopic simulators (Lamata, Gómez, Bello, Kneebone, Aggarwal, & Lamata, 2006), which provide an artificial learning environment. Numerous studies support findings of transfer from simulator training to operating room, which encourages the use of simulators (Hyltander, Liljegren, Rhodin, & Lönroth, 2002; Seymour, et al., 2002; Stefanidis, Acker, & Heniford, 2008; Stelzer, Abdel, Sloan, & Gould, 2009).

In the acquisition of laparoscopic skills, cognitive abilities have proven to be influential, especially for the early learning phase (Keehner, Lippa, Montello, Tendick, & Hegarty, 2006). This development is in accord with the theories of skill acquisition (Anderson, 1983; Fitts & Posner, 1967), which propose that cognitive abilities correlate with performance the most during declarative encoding, thereafter becoming less influential due to an increase in automaticity.

The Three-Stratum Theory by Carroll (1993) presents a hierarchical model of cognitive abilities, which is based on a thorough factor analytic study of more than 400 datasets. The three strata represent three different levels of generality over the domain of cognitive abilities and each stratum accounts for the variation in factor loadings at the next lower level. The general stratum corresponds to Spearman’s concept of general intelligence (Spearman, 1904). The broad stratum is associated with eight second-order factors, including visuo-spatial ability. The narrow stratum comprises highly specialized abilities, which can be measured by validated tests and compose the upper lying ability.

In particular visuo-spatial ability has been found to be a key predictor of laparoscopic performance (Eyal & Tendick, 2001; Hassan, et al., 2007; Keehner, Lippa, Montello, Tendick, & Hegarty, 2006). Risucci (2002) even found that surgeons tend to score higher than the general population on tests of visual-spatial ability. Visuo-spatial ability predicts laparoscopic performance in the early training stage (Hedman, Ström, Andersson, Kjellin, Wredmark, & Felländer-Tsai, 2006), and correlates with the speed in acquiring laparoscopic skills (Risucci, Geiss, Gellman, Pinard, & Rosser, 2001).

It is mostly investigated on the laparoscopic performance measures Time (Risucci, et al., 2000; Risucci, et al., 2001), Economy of motion (Hassan, et al., 2007; Wanzel, Hamstra, Caminiti, Anastakis, Grober, & Reznick, 2003), and a Total score of performance (Eyal & Tendick, 2001; Wanzel, Hamstra, Anastakis, D, & D, 2002). Yet, the role of visuo-spatial ability on measures of Damage has been so far only scarcely investigated. However, its further research might prove valuable, since the patients health must be the top priority of every physician.

In this sense, Damage might be a more vital indicator for laparoscopic performance than the duration or speed in performing. The current study examines the influence of visuo-spatial ability on Damage in an exploratory way. Following Carroll’s Three-Stratum Theory (1993), visuo-spatial ability has been investigated by the five factors it comprises, namely Visualization, Spatial relations, Speed of closure, Fluency of closure, and Perceptual speed.

Visualization is the ability to mentally manipulate relatively complex two-dimensional and three-dimensional figures and visual patterns. Among laparoscopic novices, Visualization is found to have high correlations with the factors Time (Risucci, et al., 2000; Risucci, et al., 2001), Economy of motion (Hassan, et al., 2007; Wanzel, et al., 2003), and Total performance (Eyal &

Tendick, 2001; Wanzel, et al., 2002). Only low but significant correlations have been found on Total error, and Tissue damage (Hassan, et al., 2007).

Spatial relations refers to mentally manipulating relatively simple visual patterns. It is found to influence positively the duration of training to reach a performance goal (McClusky III, Ritter, Lederman, Gallagher, & Smith, 2005; Ritter, McClusky III, Gallagher, Enochsson, & Smith, 2006).

Speed of closure refers to the ability of identifying incomplete visual objects and patterns, by matching them with their associated memory representations. This factor is not included in testing because prior studies could not confirm its importance concerning laparoscopic surgery (Risucci, et al., 2001; Wanzel, et al., 2002, Wanzel, et al., 2003).

Fluency of closure relates to apprehending and identifying complete but disguised or obscured visual patterns. It is the ability to differentiate a simple figure from a complex background. A high score on that ability is found to have a positive influence on Time, and Total error, in surgical training (Gibbons, Baker, & Skinner, 1986; Schueneman, Pickleman, Hesslein, & Freeark, 1984).

Perceptual speed is the speed in finding a known visual pattern. It is the ability to quickly and accurately compare visual figures or symbols. A significant correlation has been found between Perceptual speed and the duration of simulator training to reach a goal (McClusky III, et al., 2005), and a total score on plastic surgery tasks (Wanzel, et al., 2002).

In conclusion, visuo-spatial abilities are predictive for laparoscopic performance. Except for Speed of closure, all are found to be influential on at least a measure of time. It stands to reason that they might also play a prominent role for measures of Damage. Visualization has been most frequently studied in the context of surgical skills and has proven to have the strongest predictive power. In addition to that, it has shown an influence on Tissue damage and Total error, which makes it a promising predictor of Damage. The relationship between Damage and Economy of motion is so far unclear, though not the focus of this study. Individual visuo-spatial ability factors differ from each other in their complexity and processing speed. Therefore, different correlations with Damage may be expected, which may also alter throughout training. This exploratory study's aim is to reveal the relationship between visuo-spatial ability factors and Damage.

Method

Participants

Four surgical and three gynecological trainees from the Medisch Spectrum Twente hospital in Enschede participated in this study (three female, four male) with a median age of 29 years (range, 26-33 years). All participants were right handed and had no game experience but different previous surgical experience. The study was performed within a training program for basic laparoscopic skills and is based on data from the Department of Technical Medicine, University of Twente, the Netherlands.

Procedure

The study was organized in two phases. The first phase consisted of a two-part paper-and-pencil psychometric test to examine the participants' visuo-spatial ability factors Visualization, Spatial relations, Fluency of closure, and Perceptual speed (see Appendix A for testing details). The same factors were tested two times with different items to increase the test reliability. Their mean represents an indication of the corresponding ability. Additionally, data about the participants´ demographics and prior experience was collected.

The second phase of the study consisted of simulator training, which was spread over nine weeks, scheduled with a break of two to four days between each training block. This study was part of a training program, consisting training on two different simulators with three different levels of difficulty (see Appendix B for trainings scheme). Each participant underwent five training blocks, lasting approximately 45 minutes. For this study, the training on the LapSIM simulator with medium difficulty was chosen to be analyzed. By doing this, it was possible to study the data over the full five sessions. Each block comprised six exercises from the LapSim

Basic Skills software package. The exercises were Instrument navigation, Coordination, Grasping, Lifting and Grasping, Cutting, and Clip applying. A detailed description of the exercises can be found under www.surgical-science.com.

Apparatus

The LapSIM virtual reality simulator (see Figure 1) was used with a Virtual Laparoscopic Interface (VLI) by Immersion. The VLI consists of 2 handles with sensors using a 5-degree-of-freedom tracking system and was connected to computer running Microsoft Windows XP SP2, equipped with an Intel Pentium 4 CPU with 3.00 GHz, 504 MB of RAM, an onboard video card with 128 MB shared memory, and a 19” TFT monitor. Surgical Science’s LapSim v.3.0.10 with the Basic Skills software package v.3.0.2 was used as training software.

Figure 1. The LapSIM laparoscopic simulator.

Data reduction

In the course of the first paper-and-pencil test, eight numeric experience variables had been acquired, which are prior attendance of laparoscopy, and endoscopy, prior assistance in laparoscopy, and endoscopy, prior simulator experience in laparoscopy, and endoscopy, and prior procedures performed in laparoscopy, and endoscopy. These variables have been categorised into Experience. Category 1 represents little experience and is defined by an overall experience score of 0-30. Average experience is defined by an overall experience score of 30-100. Category 3 stands for high experience and is defined by an overall experience score of more than 100. The scores were categorised based on the given distribution, and in order to discriminate different levels of experience among the participants. As little experienced were three participants classified, as average experienced two, and as high experienced also two.

The measured variables by the LapSim simulator concerning Damage were Tissue damage frequency, Maximal tissue damage, Maximum stretch damage, Rip Failure, Badly placed clips, Dropped clips, and Blood loss. Each exercise logged these variables, which corresponded to its specific task (see Table 1). All variables were then merged into one compound variable per session, using the method of Luursema (in press).

Exercise	**Logged variables**
Instrument navigation	Tissue damage frequency Maximal tissue damage
Coordination	Tissue damage frequency Maximal tissue damage
Grasping	Tissue damage frequency Maximal tissue damage

Lifting and Grasping	Tissue damage frequency Maximal tissue damage
Cutting	Tissue damage frequency Maximal tissue damage Maximum stretch damage Rip Failure
Clip applying	Maximum stretch damage Blood loss Badly placed clips Dropped clips

Table 1. Specific Damage variables corresponding to the individual exercises.

Statistical analysis

All statistical calculations had been made using PASW Statistics 18.0 (SPSS Inc.). No outliers were identified by using the Kolmogorov-Smirnov test of normality. Because of no available data and therefore defined as missing was the fifth LapSim session for all exercises for participant 4. For the reason of too little discriminating power, the variables Hand dominance and Game experience were excluded from analysis.

Results

In order to measure a training effect throughout the five sessions, a repeated-measures ANOVA was carried out for the variable Damage. A significant decrease in Damage was observed, indicating that learning took place ($F(4, 20) = 5.3$, $p < .01$).

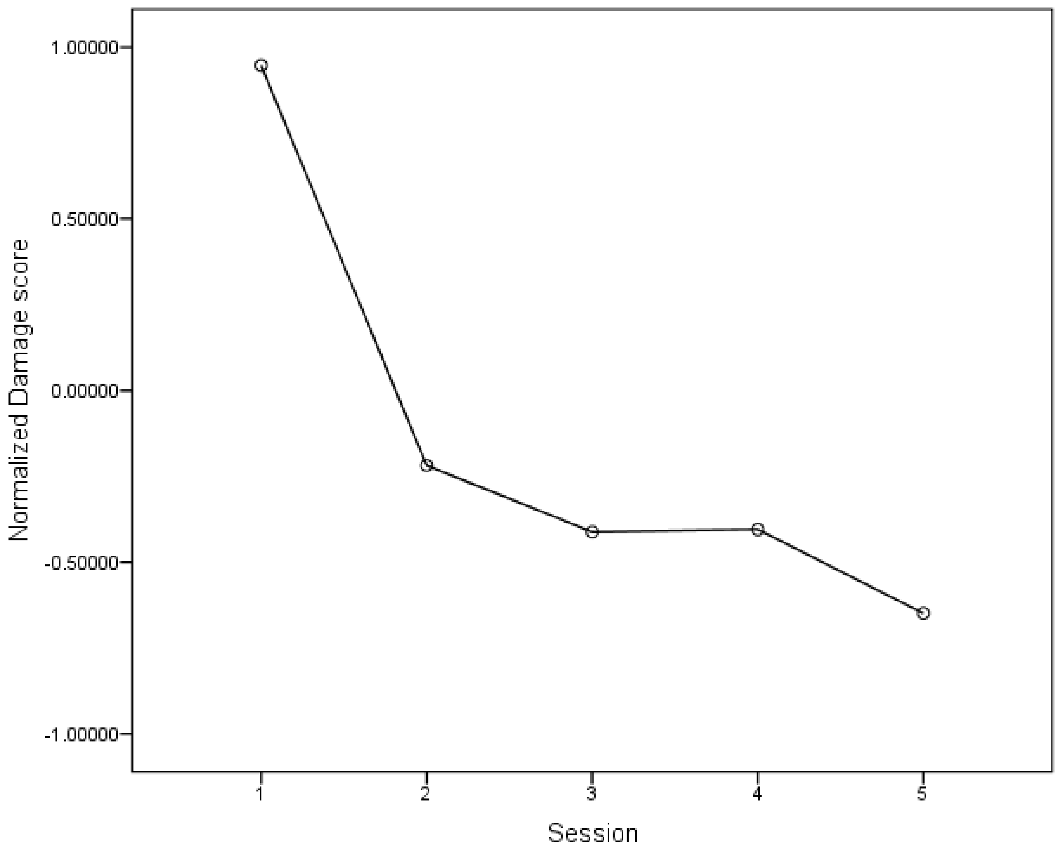

Figure 2. Learning curve of the inflicted damage across the training sessions in terms of z-scores.

To measure the contributions of the visuo-spatial ability factors, a repeated-measures ANCOVA was performed, with the visuo-spatial ability factors as covariates. No significant covariations were found. Likewise, the prior experience of the participants was analysed, which revealed to have no influence on the simulator training.

To examine the relationship of the individual visuo-spatial ability factors with each moment of the training, Pearson correlations were made. An alpha of less than .05 (two-tailed) was considered as significant. The visuo-spatial ability factor Visualization correlates significantly with the third training session ($r = -.78$, $p < .05$), and the fourth ($r = -.88$, $p < .01$). The correlation with the fifth session is almost significant ($r = -.74$, $p = .09$). For the visuo-spatial ability factors Spatial relations, Fluency of closure, and Perceptual speed, were no significant correlations found with the individual training sessions.

Discussion

This study investigated the involvement of visuo-spatial ability with Damage in laparoscopic simulator training. The visuo-spatial ability factors Visualization, Spatial relations, Fluency of closure, and Perceptual speed, were correlated with Damage for the whole simulator training as well as each training session apart. Additionally, the development of the participants' averaged Damage score was observed during the training. The results will be discussed in the following.

Throughout the training, the Damage score of the participants improved very quickly, with the most salient advancement from the first to the second session (see Figure 2 in the 'Results' section). Thereafter, the score improved relatively little till the fifth and last session, with almost no changes from the third to the forth one.

The major improvement at the very beginning of the training might represent for a great part the participants' familiarisation with the simulator. Although the following changes are much smaller in size, an overall ongoing improvement was observed. A clear saturation could be not identified, and therefore further improvements would be expected if the training was extended. The learning process concerning the avoidance of damage to the virtual tissue is recognised as ongoing and relatively slow.

However, the nature of simulator training might play an influential role in this issue. It is likely that real patients are considered much more seriously than virtual ones. Inflicted damage in simulator tasks has negative consequences to the participants score only, while in the operating room a patient's life may be at stake. In this sense, feedback given by virtual reality tissue is not equivalent with real one. Therefore, assessing damage in simulator training might be not entirely reflective of the participants' consciousness and skill towards avoiding damage.

No involvement of any visuo-spatial ability factor was identified for the whole training. Though, correlating them with each training session individually discovered Visualization to be of particular influence. In the last three sessions, Visualization has been found to contribute greatly, with negative correlations for Damage.

Visualization is the ability involved in manipulating more complex visuo-spatial representations (Carroll, 1993). What was observed is an increased involvement of Visualization just after the initial familiarisation phase with the simulator. At that point, it was directly associated with the skill development of damage avoidance, giving an indication of the required demands. The visuo-spatial skill of manipulating complex figures is therefore believed to be vital for the ongoing learning process of minimizing damage.

A lasting significance of Visualization in the context of laparoscopic simulator training was also reported by Keehner et al. (2006), though measured by a time-related performance variable. The similar relationship with Damage confirms Visualization as the main visuo-spatial ability factor predicting long-term laparoscopic performance. However, an involvement of other variables than visuo-spatial ability is also possible. Therefore, further research is necessary to confirm the role of Visualization and the other visuo-spatial ability factors with Damage as shown in this study.

Limitations

The current study underlies certain limitations. First of all, the number of participants, which is seven, might have been not enough to identify clearly the relationship of visuo-spatial ability and Damage. Another problem was the missing values from one participant for one session. An additional factor, which might had an influence, is the number of trials. Some of the participants have performed some tasks multiple times, especially after achieving a poor score. Therefore, the data from the first trials only was analysed. Because the data from this study was collected during a larger training program, the trials with different difficulty and another simulator might have distorted the data. Aside from that, there had been minor technical difficulties. Some participants have had occasionally problems in using the simulators, though support was always in reach.

Conclusion

Most studies use a measure of time to assess surgical performance (e.g. McClusky III, et al., 2005; Risucci, et al., 2001). The current study took Damage as a measure of surgical quality, shifting the priority to the prevention of harm rather than performing quickly. The learning curve of Damage reflects, except for a steep initial phase, a slow and ongoing development. Visualization, in particular, has been found to be involved in laparoscopic simulator training and the acquisition of damage avoidance skill. Reasearch on Damage would profit if investigated in a broader design, because unknown variables are likely to be involved. The results of this study and further research on Damage will lead us to a better understanding about its role and interaction with other variables in surgical simulator trianing. Consequently, this will help to set up better training programs for trainees, which promote the minimizing of Damage in future procedures.

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Appendix A

Psychometric tests

The participants' visuo-spatial ability factors were assessed two times with a battery of paper-and-pencil psychometric tests. Different tests for the same abilities were administered the second time. In testing, participants were asked to match the left figure with one from the right. The abilities were examined using the following tests.

Visualization

Mental rotation test (Vandenberg and Kuse, 1978) and Guay's visualization of viewpoints (Guay & Mc Daniels, 1976), as modified by Lippa, Hegarty, & Montello, 2002.

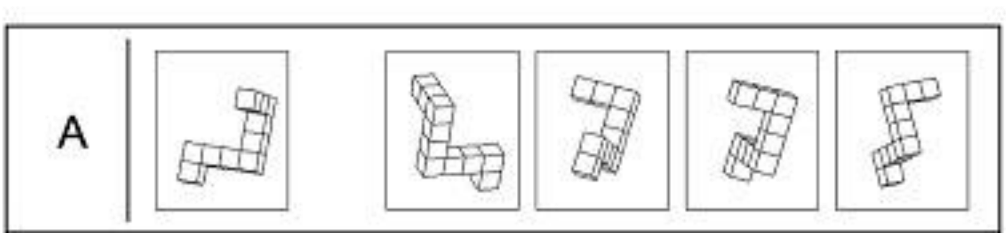

Figure A. Sample items of the Mental rotation test (Vandenberg and Kuse, 1978).

Spatial relations

Figures Test (Thurstone, 1938) and Cards Test (Thurstone, 1938).

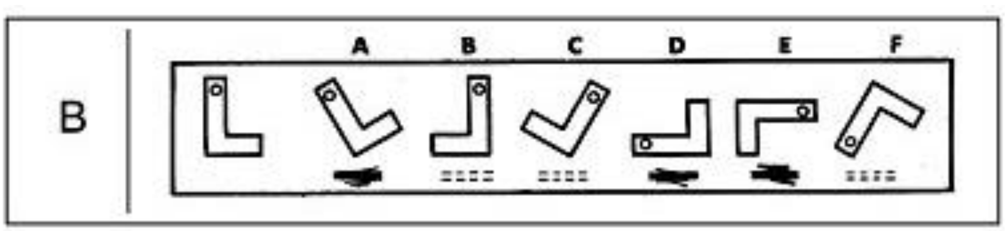

Figure B. Sample items of the Cards Test (Thurstone, 1938).

Fluency of closure

Hidden figures test (Ekstrom, French, Harman, & Dermen, 1976) and Hidden patterns test (Ekstrom, et al., 1976).

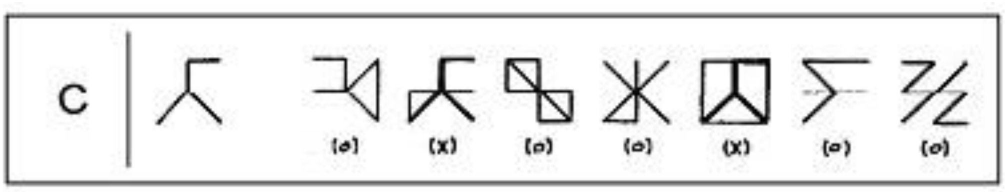

Figure C. Sample items of the Hidden figures.test (Ekstrom, French, Harman, & Dermen, 1976).

Perceptual speed

Number comparison test (Ekstrom, et al., 1976) and Identical pictures test (Ekstrom, et al., 1976).

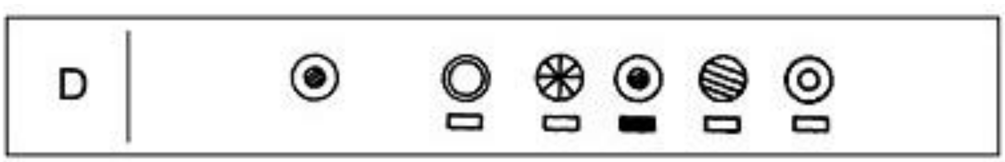

Figure D. Sample items of the Identical pictures test (Ekstrom, et al., 1976).

Appendix B

Simulator training

Two different simulators were used for training, the LapSIM simulator and the ProMIS simulator. The exercises of the LapSIM were in each trainings block Instrument navigation, Coordination, Grasping, Lifting and Grasping, Cutting, and Clip applying. All ProMIS exercises, except for Investigating and Locating & coordinating, were augmented reality tasks with tactile feedback.

LapSIM	ProMIS
Session 1	
Easy block Medium block	Investigating Object placement Needle handling
Session 2	
Easy block Medium block	Investigating Object placement Needle handling Sharp dissection
Session 3	
Medium block Hard block	Investigating Object placement Needle handling Knot tying Sharp dissection
Session 4	
Medium block Hard block	Locating & coordinating Object placement Needle handling Suturing Sharp dissection
Session 5	
Medium block Hard block	Locating & coordinating Object placement Needle handling Suturing Sharp dissection