The role of cognitive abilities in laparoscopic simulator training

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Abstract

Learning minimally invasive surgery (MIS) differs substantially from learning open surgery and trainees differ in their ability to learn MIS. Previous studies mainly focused on the role of visuo-spatial ability on the learning curve for MIS. In the current study, the relationship between spatial memory, perceptual speed, and general reasoning ability, in addition to visuo-spatial ability, and performance on a MIS simulator is examined. Fifty-three laparoscopic novices were tested for cognitive aptitude. Laparoscopic performance was assessed with the LapSim simulator (Surgical Science Ltd., Gothenburg, Sweden). Participants trained multiple sessions on the simulator until proficiency was reached. Participants showed significant improvement on the time to complete the task and efficiency of movement. Performance was related to different cognitive abilities, depending on the performance measure and type of cognitive ability. No relationship between cognitive aptitude and duration of training or steepness of the learning curve was found. Cognitive aptitude mediates certain aspects of performance during a training on a laparoscopic simulator. Based on the current study, we conclude that cognitive aptitude tests cannot be used for resident selection but are potentially useful for developing individualized training programs. More research will be performed to examine how cognitive aptitude testing can be used to design training programs.

Keywords: cognitive aptitude, minimally invasive surgery, simulator, skills training

Introduction

Surgeons increasingly perform minimally invasive surgery (MIS; Kalan et al., 2010). MIS differs from open surgery in two important ways: 1) surgeons have to mentally transform 2D images from the screen into 3D reality and 2) instrument response is inverted and prone to scaling (Gallagher and Smith, 2003; Greco et al., 2010). Learning surgical skills with MIS technology differs substantially from learning to perform open surgery (cf. Reznick and MacRae, 2006). Previous research has shown that innate abilities such as visuo-spatial ability play a role in the skill acquisition phase of MIS (see Anastakis et al., 2000, for a review). In the current study the influence of cognitive aptitude, such as visuo-spatial ability, on performance on a MIS simulator is examined. Assessment of these abilities could help to predict individual learning curves for MIS (Gallagher et al., 2003; Luursema et al., 2010) and to design individualized training programs.

Learning to use MIS technology depends on ergonomic factors related to the equipment, human (cognitive) factors, and training factors (Gallagher and Smith, 2003). Surgery with MIS instruments is indirect and requires a different posture compared with open surgery, often resulting in physical discomfort (Gallagher and Smith, 2003). Furthermore, perceptual and spatial problems arise. Surgeons need to interpret 3D information from 2D images and hand-eye coordination is difficult because of different perspective and magnification of objects perceived through the camera on the laparoscope (Hanna et al., 1998). Also, the movement of the instruments is limited to a fixed axis, the body wall, creating a ‘fulcrum effect’ (Gallagher and Smith, 2003). A movement with the instrument handle to the right will cause the actual instrument inside the patient to move to the left. The constraints of MIS place a higher demand on a surgeon’s perceptual and visuo-spatial abilities to control the instruments appropriately, increasing the learning curve needed to practice safe and efficient MIS (Department of Health, 2011). A surgeon’s cognitive aptitude, including perceptual and visuo-spatial abilities, is related to the learning curve for MIS (Gallagher et al., 2003; Luursema et al., 2010).

While MIS became more common in clinical practice, it appeared that the learning rate for MIS differed among surgeons. Not every surgeon developed their laparoscopic skills equally fast and some even did not learn them at all. MIS is easier to simulate in comparison to open surgery, therefore, surgical simulators have been developed to practice MIS in a safe environment (Feldman et al., 2004). In the future, training programs with MIS simulators could be used as selection and assessment tools for surgical trainees (see Carroll et al., 2009, for an example of using MIS simulators in selecting surgical trainees) to prepare them efficiently and effectively for actual practice and thereby improve patient safety. Also, training programs can be tailored according to the aptitude level of individual trainees (cf. McClusky et al., 2005).

Cognitive aptitude testing is currently used to assess trainees prior to laparoscopic simulator training at the Experimental Centre for Technical Medicine of University of Twente. At the start of training at the center, trainees take a cognitive aptitude test. They receive feedback on their performance, informing them how their level of cognitive aptitude is related to their performance on the simulator. Ultimately, this test helps to identify cut-off scores for cognitive aptitude.

The cognitive aptitude test used at the center consists of several, validated subtests measuring four aspects of cognitive aptitude: visuo-spatial ability, spatial memory, perceptual speed, and reasoning. Visuo-spatial ability, the ability to manipulate simple and complex mental representations, correlates reasonably well with performance on laparoscopic tasks (Hedman et al., 2006; Keehner et al., 2006; McClusky et al., 2005; Ritter et al., 2006; Wanzel et al., 2002). Correlations reported in the previously mentioned studies vary from .00 to .76 with a mean of .24, indicating a moderate effect, depending on the type of visuo-spatial ability test used and performance measure for laparoscopic ability. The highest correlations have been found between perceptual ability (as measured by the PicSOr test, see McClusky et al., 2005, and Ritter et al., 2006) and performance: .76 and .92. Based on Carroll's (1993) classification, spatial memory is often studied as a component of the visualization factor (Hedman et al., 2007). Spatial memory is the ability to record information about one's environment and its spatial orientation. Memory can be seen as an indicator of the ability to learn procedural aspects of the tasks. A study by Luursema (2010) showed that spatial memory is related to the early learning phase of a basic laparoscopic task. Perceptual speed is another cognitive ability that is associated with the ability to learn procedural aspects of a task, especially tasks that require a high level of speed and accuracy (e.g. see Ackerman and Beier, 2007). Perceptual speed is the ability to quickly identify a given shape or dissimilar shape from a number of alternatives. Laparoscopic surgery is highly time critical and the ability to quickly identify anomalies during a procedure is likely to be related to improved performance. Surprisingly, perceptual speed has not been studied extensively in relation to laparoscopic training. Only one study by Luursema (2010) showed that it is related to the efficiency of movement in early learning. Finally, Keehner et al. (2006) showed that reasoning ability is related to early learning of laparoscopic procedures. The influence of reasoning ability decreased as skill was acquired. Empirical evidence thus shows that cognitive aptitude is weakly to moderately related to the learning curve for MIS on a simulator, depending on the kind of cognitive ability, the type of laparoscopic task, as well as the stage of learning (early versus late learning).

However, a limited number of studies have examined the influence of cognitive aptitude over a longer training period. Also, in most studies the influence of different cognitive abilities was examined independent of each other, while these abilities might complement each other during initial learning (Keehner et al., 2006) and differentially impact late learning (Luursema, 2010). In the current study, the influence of cognitive aptitude on the performance of basic tasks on a laparoscopic simulator across time is investigated. This study uses a novel approach by examining different cognitive abilities in relation to each other, adding perceptual speed as a possible relevant factor for laparoscopic simulator performance, and investigating the effect of cognitive aptitude on the steepness of individual learning curves.

It is expected that the cognitive abilities visuo-spatial ability, spatial memory, perceptual speed, and reasoning predict the learning curve of trainees for basic tasks on a laparoscopic simulator. Trainees who are high level performers on the cognitive aptitude tests are expected to show high levels of performance in terms of 1) the number of practice sessions needed to reach proficiency, 2) time to complete the task, 3) damage to tissue, and 4) efficiency of movement on basic laparoscopic simulator tasks. Furthermore, it is expected that the cognitive abilities predict the steepness of the learning curve, i.e.

the learning curve of high level performers on the cognitive aptitude tests is steeper than that of low level performers.

Methods

Participants

Fifty-three students of the Technical Medicine program at University of Twente participated in this study, 26 male and 27 female. Mean age was 22.3 years (*SD* = 1.2, *range* = 22 – 26) and they were inexperienced with any kind of laparoscopic technique. Three students (5.7 %) indicated they were left handed. All reported normal or corrected to normal vision. Participation was a required part of the curriculum. An informed consent form was signed by all participants.

Materials

Cognitive ability tests. Visuo-spatial ability was measured with four tests: the Mental Rotation Test (Vandenberg and Kuse, 1978), the Paper Folding test, the Surface Development test (both from the Kit of factor-referenced cognitive tests, Ekstrom, French, Harman, & Dermen, 1976) and the Rotating Shapes test (constructed from a stimuli set of random two-dimensional nonsense shapes, cf. Cooper, 1975). Spatial memory was measured with an adapted version of the Corsi Block Tapping Test (Corsi, 1972). Perceptual speed was measured with two tests: the Number Comparison test and the Identical Pictures test (both from the Kit of factor-referenced cognitive tests, Ekstrom et al., 1976). Reasoning was measured with the Raven Advanced Progressive Matrices test (Raven, 1965) and a verbal reasoning test from the Groninger Intelligence Test (GIT; Luteijn & Van der Ploeg, 1983).

Correlations between the composite measures visuo-spatial ability, spatial memory, perceptual speed, reasoning, and the separate tests are shown in Table 1. Visuo-spatial ability was significantly correlated to all other composite measures. Spatial memory and perceptual speed were not significantly correlated while spatial memory and perceptual speed were. It should be noted that the Number Comparison and Identical Pictures tests, measuring perceptual speed, and the Raven Matrices and verbal reasoning from the GIT tests, measuring reasoning, did not correlate significantly with each other. Furthermore, the scores on the first session were significantly correlated to the scores on the second session (r=.426, p=.001). Reliability of each test was assessed with Guttman's Lambda 2 (cf. Sijtsma, 2009). Lambda's ranged from .333 to .962, with the lowest values for the reasoning tests (.333 for the Raven test and .360 for the GIT verbal reasoning test) and highest values for the Mental Rotation Test (.800) and Rotating Shapes test (.962).

Laparoscopic simulator. The experimental training set-up consisted of Immersion's VLI hardware. A 19" monitor provided visual feedback to the participant. Surgical Science's LapSim v.3.0.10 was used as training software.

Procedure

Cognitive aptitude assessment. Prior to the simulator training sessions, subjects participated in two group sessions to assess their cognitive abilities considered relevant to surgical training and practice, as outlined in the introduction. During the first of these sessions, tests for visuo-spatial ability, spatial memory, perceptual speed, and reasoning were administered on a computer. The tests were administered in two sessions to avoid fatigue of the participants. Each session lasted 45 minutes on average. Each test had a time limit. A demographics questionnaire with questions about gender, date and place of birth, and handedness was also part of the first session. During the second session, different tests for the same four abilities were administered. The mean score of each pair of tests for a specific cognitive ability was taken as an indicator for that ability, thus increasing the reliability of the measures of the cognitive abilities.

Possible practice effects were examined with paired samples *t*-tests. Overall, participants scored higher on the first session (M=.61) than on the second session (M=.48; $t(52)=8.806$, $p<.001$). Participants scored lower on visuo-spatial ability (M_1=.54, M_2=.67; $t(52)=-4.995$, $p<.001$) and spatial memory (M_1=.44, M_2=.49; $t(52)=-2.397$, $p=.020$) on the first session compared with the second session. They scored higher on reasoning (M_1=.63, M_2=.26; $t(52)=15.460$, $p<.001$) and perceptual speed (M_1=.88, M_2=.50; $t(52)=23.813$, $p<.001$) on the first session.

Simulator training. The simulator training sessions took place over a time span of two months, during which each participant engaged in weekly, 30 minute training sessions. Training was proficiency based, meaning that training was terminated as soon as a participant reached expert level performance on both tasks. However, if a participant did not reach expert level performance after seven consecutive sessions, training was terminated as well. Five participants (9%) did not reach expert level performance after seven sessions. Expert level performance for the tasks practiced on the simulator were determined in a study by Van Dongen (2011).

Two LapSim simulators were available for the study. Two participants trained at the same time individually on a LapSim laparoscopic simulator. Two standard exercises that come with the training hardware were selected for the current study; *Grasping* and *Instrument Navigation*. They were selected for their generic nature, and for the convenience of offering the same task alternately for both left and right hand, thus offering a similar challenge for both left handed and right handed participants. Grasping and Instrument Navigation were offered in three levels of difficulty, easy, medium, and hard. The Grasping and Instrument Navigation tasks are described in more detail by Van Dongen et al. (2007).

At the end of each session, all participants performed each task at the medium level to the best of their abilities. Performance on the last Grasping and Instrument Navigation task at the medium level of each session was used in the current analysis.

Performance variables

For each task, a number of performance variables was logged. Previous studies have shown that performance variables from laparoscopic simulators correlate well with subjective global ratings (Pellen, Horgan, Barton, & Attwood, 2009) and operative performance (Kundhal & Grantcharov, 2008). A study by Van Dongen et al. (2011) showed construct validity for the performance variables of the LapSim simulator. Performance variables were pooled into three compound performance variables Duration, Damage, and Motion efficiency. The compound variable Duration represents the addition of ‘Left hand time’ and ‘Right hand time’. Damage was calculated from the simulator-supplied variables ‘Tissue damage’ and ‘Maximum damage’. Motion efficiency was calculated from ‘Instrument path length’ and ‘Instrument angular path’, for both the left- and the right hand. Because the basic performance variables underlying Damage and Motion efficiency were in different units of measurement, the compound performance variables were transformed to z-scores. In this way, differences in both means and variances between sessions were retained.

This reduction procedure was executed for both the Grasping- and the Instrument navigation task, resulting in a pair of similar performance variables. The mean of each pair was used in the statistical analysis (e.g. ‘Damage Grasping’ + ‘Damage Instrument navigation’; divided by two makes ‘Damage’).

Statistical analysis

First the scores of all participants were examined for possible “outliers” (if a participant scored an extreme value (>3SD) on any of the three simulator training variables, this led to removal of all data for that participant on the indicated task, for the session where the extreme value was scored. If extreme values for a specific task are scored on three or more consecutive sessions, data from all sessions for this task were removed for that participant). No sessions or participants had to be removed from the analysis, either from the group of participants who passed the exam or the group who did not pass the exam.

Since none of the derived variables (the Duration, Damage, and Motion efficiency variables for the surgical simulator training tasks and the visuo-spatial ability, spatial memory, perceptual speed, and reasoning variables resulting from the cognitive aptitude test) deviated significantly from the normal distribution, as assessed by the Kolmogorov-Smirnov-1 test, parametric statistical analyses were used.

The design of the study involved multiple observations across time (i.e. the number of sessions participants practiced), nested within the simulator. The effects of visuo-spatial ability, spatial memory, perceptual speed, and reasoning were analyzed as well as the effect of the simulator on Duration, Damage, and Motion efficiency across the number of sessions participants’ practiced using multilevel modeling (see Zyphur et al., 2008, for an introduction to multilevel modeling). Multilevel modeling is appropriate in this context because it allows interpretable tests of the effects of session, simulator, and visuo-spatial ability, spatial memory, perceptual speed, and reasoning despite the differences in the number of observations (i.e. number of sessions) between participants. Analyses were performed using SPSS 18.0 Mixed Models. Restricted maximum likelihood criteria were employed. The repeated measures are the level 1 units, participants were the level 2 units of analysis, and simulator the level 3 units of analysis. Participants were included in the models as a random factor. Session and simulator were included as fixed factors. Visuo-spatial ability, spatial memory, perceptual speed, and reasoning were included as covariates.

First, correlation coefficients between the scores on the cognitive abilities and the number of sessions needed to reach proficiency were calculated.

After that, the effects of session and simulator were assessed without the covariates to examine the learning curve of the whole group. Next, separate analyses were performed for each covariate and each performance variable, followed by a multivariate analysis for each performance variable with all five covariates together in the analysis to assess the effect of each covariate controlling for the presence of the other covariates.

Finally, regression coefficients for Duration, Damage, and Motion efficiency were calculated for each participant, indicating the steepness of their individual learning curves. These regression coefficients were then entered into a multiple regression analysis with participants' regression coefficients of a performance variable (i.e. Duration, Damage, and Motion efficiency) as the dependent variable and visuo-spatial ability, spatial memory, perceptual speed, and reasoning as predictors.

Results

Across sessions, participants' performance improved on Duration, Damage, and Motion efficiency, see Figures 1, 2, and 3. Participants exited the study as soon as they had reached proficiency on the simulator, resulting in a smaller number of participants towards the end of the training (n=8 for session 7). The mean number of sessions needed to reach proficiency was 5.3 (*mode* = 6; *range* = 3 – 7). Note that the width of the 95% CI's increases (larger standard errors) towards the end of the training because of the diminishing number of participants.

<Insert Figure 1 here>

<Insert Figure 2 here>

<Insert Figure 3 here>

None of the cognitive abilities significantly correlated with the number of sessions needed to reach proficiency (visuo-spatial ability: r = -.008, spatial memory: r = -.026, perceptual speed: r = -.251, or reasoning: r = .018).

Table 2 shows the results of the effects of the cognitive abilities on the performance variables Duration, Damage, and Motion efficiency. The effect of each cognitive ability was assessed univariate and multivariate taking the effect of the other abilities into account.

<Insert Table 2 here>

Duration

Participants' performance on Duration significantly improved from the first session to the final session (main effect of session, p<.001). Also, participants' overall performance on Duration was better on one of the simulators (main effect of simulator, p=.016, see also Figure 1). Separate analyses were performed for the covariates visuo-spatial ability, spatial memory, perceptual speed, and reasoning with session and simulator as fixed factors. These analyses showed that the main effects of session and simulator were mediated by effects of visuo-spatial ability and reasoning, see Table 2. Participants who score higher on visuo-spatial ability (VSA) or reasoning (R) need less time to complete the tasks than participants who score lower on these abilities, however, correcting for the effects of the other covariates and the factors session and simulator, the effects of visuo-spatial ability and reasoning on Duration are diminished and no longer significant.

Damage

Participants' performance on Damage did not significantly improve from the first to the last session and did not differ between the simulators. Separate analyses were performed for the covariates visuo-spatial ability, spatial memory, perceptual speed, and reasoning with session and simulator as fixed factors. These analyses showed that none of the cognitive aptitude variables was significantly related to Damage, see Table 2. Taking the effects of the other covariates and the factors session and simulator into account, spatial memory (SM) and perceptual speed (PS) are significantly related to Damage. Damage scores increase as participants' scores on spatial memory increase, while Damage scores decrease as participants' scores on perceptual speed increase.

Motion efficiency

Participants' performance on Motion efficiency improved significantly from the first to the last session (main effect of session, p<.001). Also, participants' performance on Motion efficiency was better on one of the simulators (main effect simulator, p<.001, see also Figure 3). Separate analyses were performed for visuo-spatial ability, spatial memory, perceptual speed, and reasoning with session and simulator as fixed factors. These analyses showed that the main effects of session and simulator were mediated by effects of visuo-spatial ability, spatial memory, perceptual speed, and reasoning, see Table 2. Participants who score higher on visuo-spatial ability (VSA), spatial memory (SM), perceptual speed (PS), or reasoning (R) are more efficient in their movements than participants who score lower on these abilities. Taking the effects of the other covariates and the fixed factors session and simulator into account, only the effect of perceptual speed on Motion efficiency remains significant. Participants are more efficient in their movements as they score higher on perceptual speed.

Learning rate

The multiple regression analyses showed that the cognitive aptitude abilities taken together did not significantly predict the steepness of the learning curve for Duration (R^2=.115, p=.200), Damage (R^2=.031, p=.822) or Motion efficiency (R^2=.033, p=.804).

Discussion

In general, participants became quicker and more efficient in performing basic laparoscopic tasks on the simulator while damage to tissue remained constant. Cognitive aptitude was not related to the number of sessions needed to reach proficiency on the tasks nor did it predict the learning rate during training. Contrary to the expectations, participants who scored lower on cognitive aptitude did not need more practice sessions on the simulator to reach proficiency.

The cognitive aptitude abilities visuo-spatial ability, spatial memory, perceptual speed, and reasoning mediated only some aspects of performance when their influence was examined independently of the other abilities. All four aspects of cognitive aptitude were associated with higher efficiency of movement, while visuo-spatial ability and reasoning were associated with less time to complete the task for the duration of the training. No effects of cognitive aptitude on the amount of damage to tissue were found.

However, the role of cognitive aptitude changed when the influence of a cognitive ability was corrected for the effect of the other cognitive abilities. The effects of visuo-spatial ability and reasoning on duration diminished, whereas perceptual speed remained positively associated with the efficiency of movement, while spatial memory and perceptual speed were now associated with the amount of damage. The results from the current study suggest that some cognitive abilities are related to certain aspects of laparoscopic performance, in particular to the time to complete a task and efficiency of movement. Figure 4 presents an overview of the relationships and their strengths (represented by the standardized coefficients, β) between the cognitive abilities and performance variables found in the current study for both the univariate and multivariate model.

Previous research has shown that different cognitive abilities are related to performance of basic MIS tasks on a simulator (see e.g. Hedman et al., 2006, Keehner et al., 2006, and Luursema et al., 2010). In the current study, cognitive aptitude was most clearly related to efficiency of movement, a finding which has also been reported in other studies (Hedman et al., 2007; Luursema, 2010). The relationship between perceptual speed and efficiency of movement found in the current study replicates the findings of a study by Luursema, Verwey, and Burie (2012). Perceptual speed is related to the associative phase of learning, indicating that part of the laparoscopic tasks might have become automated during training. Visuo-spatial ability especially has been studied extensively for a variety of laparoscopic tasks and results are mixed (McClusky et al, 2005; Wanzel et al., 2002). Visuo-spatial ability might be most important for correctly handling the instruments. Surgeons need to be able to mentally represent the position of the instruments in relation to the anatomy and predict the consequences of their actions. The relationship between visuo-spatial ability and efficiency of movement in the current study supports this hypothesis.

We did not find a clear relationship between cognitive aptitude and duration of training, either measured by the time to complete tasks within sessions or the total number of sessions needed to reach proficiency in the tasks. This contradicts previous findings, which have shown that some cognitive abilities, such as perceptual ability (Gallagher et al., 2003; McClusky et al., 2005) and visuo-spatial ability (Schlickum et al., 2011), are associated with duration of training. In other studies, duration of training is often measured by the number of trials within one session needed to reach proficiency. Differences in the measurement of duration as well as differences in the stage of learning examined (early versus late learning) could possibly explain the mixed results found. Differences between trainees with higher level and lower level aptitude might level off after initial learning as they become more familiarized with the tasks. Another explanation could be that the tasks in the current study were too simplistic and not realistic of actual laparoscopic tasks performed in practice. However, a study by Luursema et al. (2012) has used the same tasks and did find a relationship between cognitive aptitude and laparoscopic simulator performance.

Most studies about the influence of cognitive aptitude on laparoscopic performance have investigated early learning, often limited to one session on a simulator (e.g.

Gallagher et al., 2003, Hedman et al., 2006, and Wanzel et al., 2002). An exception is the study by Keehner et al. (2006). They have examined the influence of cognitive aptitude over time and concluded that although individual differences between trainees diminished, visuo-spatial ability still predicted performance after twelve sessions. This result is in line with the findings from the current study. Visuo-spatial ability might remain important for performance, especially for more complex tasks. The tasks used in the current study were basic laparoscopic tasks and might have become automated already during the training. Progression of learning for laparoscopic tasks can best be determined by examining time to complete task, tissue damage, and efficiency of movement in relation to each other as together they are important for successful task performance. Though separate cognitive abilities might be related to speed or accuracy of task performance, the interplay between them seems relevant for overall performance and increased automation of the task. Further research is needed to distinguish the effects of separate cognitive abilities as well as general intelligence at different stages of learning and for different, more complex, laparoscopic tasks.

Contrary to the expectations, there was no effect of cognitive aptitude on the steepness of the learning curve across sessions. It should be noted that participants' individual learning curves were highly irregular. Performance after the first session often deteriorated before it improved again. We found that learning rates for trainees with different levels of cognitive aptitude are similar, but that trainees with higher levels of cognitive aptitude consistently outperform trainees with lower levels of cognitive aptitude across sessions. Further research will be performed to determine the exact relationship between cognitive aptitude and individual learning rates.

In the current study, the relationship between cognitive aptitude and laparoscopic performance was weak. This might partially be explained by limited reliability of some of the cognitive aptitude tests, more specifically the tests measuring reasoning. However, the sample size used to calculate the reliability of the cognitive aptitude tests was small which might have negatively affected reliability for some tests. Also, it should be noted that there was a significant difference between the two simulators on the performance variables time to complete the task and efficiency of movements. Participants were randomly assigned to one of the simulators and the two groups of participants did not differ significantly on the cognitive abilities. Therefore, the difference could be due to chance.

Also, the sample size is somewhat low given the complexity of the analyses. However, for testing the effect of a level-one variable, in this case the effect of the covariates on an individual's performance, the level-one sample size is of main importance (Snijders, 2005). Each individual's performance is predicted given the level of a certain covariate (or covariates) as well as the simulator on which they were trained. The power of this estimate depends on the total number of observations (Kreft & De Leeuw, 1998), which was sufficient in this study.

A limitation of the current study is that the relationship between cognitive aptitude and performance in the OR, either during laparoscopic or open surgery, was not measured. The ultimate goal is to find the right predictors for excellent surgical performance and cognitive aptitude testing could be used to complement other assessment instruments to select those students or residents that are fit for a career in surgery. The current study shows that cognitive aptitude testing needs to be developed further before it can be used as an additional assessment instrument during MIS training. In the future, cognitive aptitude testing might be used in combination with psychomotor skill testing on a MIS simulator to develop individualized training programs.

In conclusion, the relationship between cognitive aptitude and MIS performance on a simulator is complex. Depending on the kind of MIS procedure and trainees' stages of learning, different cognitive abilities play a role. Before cognitive aptitude testing can be used as an assessment or selection tool, more research is necessary to examine how cognitive abilities influence MIS performance at different stages of learning as well as the relationship between cognitive aptitude and operating room performance. MIS is a complex skill which might never be fully automated, therefore more general cognitive and reasoning abilities might still be important in late learning. Another question that remains is whether cognitive aptitude influences the steepness of individual learning curves and, if so, which abilities would predict this steepness best. Visuo-spatial ability is essential in early learning of MIS and might therefore be the best predictor of differences in learning curves.

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References

Ackerman, P. L., & Beier, M. E. (2007). Further exploration of perceptual speed abilities in the context of assessment methods, cognitive abilities, and individual differences during skill acquisition. *Journal of Experimental Psychology: Applied, 13,* 249-272.

Anastakis, D. J., Hamstra, S. J., & Ma-tsumoto, E. D. (2000). Visuo-spatial abilities in surgical training. *American Journal of Surgery, 179*, 469-471

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies.* (New York: Cambridge University Press)

Carroll, S. M., Kennedy, A. M. , Traynor, O., & Gallagher, A. G. (2009). Objective assessment of surgical performance and its impact on a national selection programme of candidates for higher surgical training in plastic surgery. *Journal of Plastic, Reconstructive & Aesthetic Surgery, 62*, 1543-1549

Cooper, L. A. (1975). Mental rotation of random two-dimensional shapes. *Cognitive Psychology 7,* 20-43.

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain. *Dissertation Abstracts International*, *34,* 819B.

Department of Health (2011). *A framework for technology enhanced learning.* (Londen: Crown). Retrieved June 12, 2012, from http://www.dh.gov.uk/publications

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive test.* Educational Testing Service.

Feldman, L. S., Sherman V., & Fried G. M. (2004). Using simulators to assess laparoscopic competence: Ready for widespread use? *Surgery, 135,* 28-42

Gallagher, A. G., Cowie, R., Crothers, I., Jordan-Black, J-A., & Satava, R. M. (2003). PicSor: An objective test of perceptual skill that predicts laparoscopic technical skill in three initial studies of laparoscopic performance. *Surgical Endoscopy, 17,* 1468-1471

Gallagher, A. G., & Smith, C. D. (2003). Human factors lessons learned from the minimally invasive surgery revolution. *Surgical Innovation, 10,* 127-139

Greco, E. F., Regehr, G., & Okrainec, A. (2010). Identifying and classifying problem areas in laparoscopic skills acquisition: Can simulators help? *Academic Medicine, 85,* s5-s8

Hanna, G. B., Shimi, S. M., & Cuschieri, A. (1998). A randomised study of influence of two-dimensional versus three-dimensional imaging on performance of laparoscopic cholecystectomy. *Lancet, 351,* 248–251

Hedman, L., Klingberg, T., Enochsson, L., Kjellin, A., & Felländer-Tsai, L. (2007). Visual working memory influences the performance in virtual image-guided surgical intervention. *Surgical Endoscopy, 21,* 2044-2050

Hedman, L., Ström, P., Andersson, P., Kjellin, A., Wredmark, T., & Felländer-Tsai, L. (2006). High-level visual-spatial ability for novices correlates with performance in a visual-spatial complex surgical simulator task. *Surgical Endoscopy, 20,* 1275-1280

Kalan, S., Chauhan, S., Coelho, R. F., Orvieto, M. A., Camacho, I. R., Palmer, K. J., & Patel, V. R. (2010). History of robotic surgery. *Journal of Robotic Surgery, 4,* 141-147

Keehner, M., Lippa, Y., Montello, D. R., Tendick, F., & Hegarty, M. (2006). Learning a spatial skill for surgery: How the contributions of abilities change with practice. *Applied Cognitive Psychology, 20,* 487-503

Kreft, I. G. G. & Leeuw, J. de (1998). *Introducing Multilevel Modeling.* Thousand Oaks, CA: Sage.

Kundhal, P. S. & Grantcharov, T. P. (2009). Psychomotor performance measured in a virtual environment correlates with technical skills in the operating room. *Surgical Endoscopy, 23,* 645-649

Luteijn, F., & Van der Ploeg, F. (1983). *Groninger Intelligentie Test.* (Lisse: Swets & Zeitlinger)

Luursema, J-M. (2010). See me, touch me, heal me: The role of visuo-spatial ability in virtual anatomical learning and surgical simulator training. Dissertation, University of Twente

Luursema, J-M., Buzink, S. N., Verwey, W. B., & Jakimowicz, J. J. (2010). Visuo-spatial ability in colonoscopy simulator training. *Advances in Health Sciences Education, 15,* 685-694

Luursema, J-M., Verwey, W. B., & Burie, R. (2012). Visuospatial ability factors and performance variables in laparoscopic simulator training. *Learning and Individual Differences (in press).* DOI 10.1016/j.lindif.2012.05.012

McClusky, D. A., Ritter, E. M., Lederman, A. B., Gallagher, A. G., & Smith, C. D. (2005). Correlation between perceptual, visuo-spatial, and psychomotor aptitude to duration of training required to reach performance goals on the MIST-VR surgical simulator. *American Surgeon, 71,* 13-21

Pellen, M. G. C., Horgan, L. F., Barton, J. R., & Attwood, S. E. (2009). Construct validity of the ProMIS laparoscopic simulator. *Surgical Endoscopy, 23,* 130-139

Raven, J. C. (1965). *Advanced Progressive Matrices. Sets I and II. London: H. K. Lewis & Co.* San Antonio, Texas.

Reznick, R. K., & MacRae, H. (2006). Teaching surgical skills: Changes in the wind. *New England Journal of Medicine, 355,* 2664-2669

Ritter, E. M., McClusky, D. A., Gallagher, A. G., Enochsson, L., & Smith, C. D. (2006). Perceptual, visuospatial, and psychomotor abilities correlate with duration of training required on a virtual-reality flexibly endoscopy simulator. *The American Journal of Surgery, 192,* 379-384.

Schlickum, M., Hedman, L., Enochsson, L., Henningsohn, L., Kjellin, A., & Felländer-Tsai, L. (2011). Surgical simulation tasks challenge visual working memory and visual-spatial ability differently. *World Journal of Surgery, 35,* 710-715

Sijtsma, K. (2009). On the use, misuse, and the very limited usefulness of Cronbach’s Alpha. *Psychometrika, 74,* 107-120

Snijders, T. A. B. (2005). Power and sample size in multilevel modeling. In: B. S. Everitt and D. C. Howell (eds.), *Encyclopedia of Statistics in Behavioral Science.* Volume 3, 1570-1573. Chicester: Wiley.

Vandenberg, S. G., & Kuse A. R. (1978). Mental rotations, a group test of threedimensional spatial visualization. *Perceptual and Motor Skills, 47,* 599-601.

Van Dongen, K. W., Ahlberg, G., Bonavina, L., Carter, F. J., Grantcharov, T. P., Hyltander, A., Schijven, M. P., Stefani, A., Van der Zee, D. C, & Broeders, I. A. M.

J. (2011). European consensus on a competency-based virtual reality training program for basic endoscopic surgical psychomotor skills. *Surgical Endoscopy, 25*, 166-177

Van Dongen, K. W., Tournoij, E., Van der Zee, D. C., Schijven, M. P., & Broeders, I. A. M. J. (2007). Construct validity of the LapSim: Can the LapSim virtual reality simulator distinguish between novices and experts? *Surgical Endoscopy, 21,* 1413-1417.

Wanzel, K. R., Hamstra, S. J., Anastakis, D. J., Matsumoto, E. D., & Cusimano, M. D. (2002). Effect of visual-spatial ability on learning of spatially-complex surgical skills. *Lancet, 359*, 230-231

Zyphur, M. J., Kaplan, S. A., Islam, G., Barsky, A. P., & Franklin, M. S. (2008). Conducting multilevel analyses in medical education. *Advances in Health Sciences Education, 13,* 571-582

Figure 1. Learning curves of the performance measure Duration for each simulator. Error bars represent the 95 % confidence interval.

Figure 2. Learning curves of the performance measure Damage for each simulator. Error bars represent the 95 % confidence interval.

Figure 3. Learning curves of the performance measure Motion efficiency for each simulator. Error bars represent the 95 % confidence interval.

Figure 4. Strength of relationships between the cognitive abilities Visuo-spatial Ability (VSA), Spatial Memory (SM), Perceptual Speed (PS), Reasoning (R) and the performance variables Duration, Motion efficiency and Damage. Relationship strength is represented by the standardized coefficient.

Table 1

Pearson Correlations Between Cognitive Aptitude Composite Measures VSA, SM, PS and R and the Cognitive Aptitude Tests.

	Cognitive aptitude	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1.	VSA	.402**	.365**	.393**	.609**	.656**	.704**	.854**	.275*	.319*	.444**	.056
2.	SM (Corsi Block Tapping Test)		.419**	.251	.221	.373**	.240	.312*	.455**	.161	.184	.163
3.	PS			.081	.144	.277*	.359**	.276*	.872**	.699**	.034	.105
4.	R				.178	.371**	.189	.348*	.038	.104	.793**	.535**
5.	Mental Rotation Test					.341*	.231	.340*	.047	.216	.219	.000
6.	Paper Folding						.280*	.373**	.114	.381**	.352**	.139
7.	Surface Development							.500**	.426**	.086	.340*	-.138
8.	Rotating Shapes								.198	.255	.343*	.118
9.	Number Comparison									.260	.012	.054
10.	Identical Pictures										.050	.129
11.	Raven Matrices											-.086
12.	Verbal reasoning GIT											

* $p < .05$

** $p < .001$

Table 2

Multilevel Model Analyses with Duration, Damage, and Motion Efficiency as Dependent Variables, Session and Simulator as Factors, and Visuo-spatial Ability (VSA), Spatial Memory (SM), Perceptual Speed (PS), and Reasoning (R) as Covariates.

	β	CI	*p*-value	β	CI	*p*-value
	Univariate			Multivariate*		
Cognitive ability	**Duration**					
VSA	-0.718	-1.187 – -0.249	.003	-0.512	-1.073 – 0.050	.074
SM	-0.571	-1.155 – 0.012	.055	-0.192	-0.888 – 0.504	.587
PS	-0.446	-1.383 – 0.491	.349	0.213	-0.840 – 1.266	.691
R	-0.992	-1.668 – -0.315	.004	-0.669	-1.403 – 0.065	.074
	Damage					
VSA	-0.231	-0.668 – 0.207	.300	-0.108	-0.638 – 0.423	.689
SM	0.217	-0.337 – 0.770	.411	0.766	0.104 – 1.428	.024
PS	-0.715	-1.592 – 0.161	.109	-1.159	-2.172 – -0.147	.025
R	-0.611	-1.266 – 0.045	.068	-0.701	-1.420 – 0.018	.056
	Motion Efficiency					
VSA	-0.787	-1.229 – -0.344	.001	-0.477	-1.005 – 0.050	.076
SM	-0.634	-1.192 – -0.076	.026	0.032	-0.623 – 0.687	.924
PS	-1.484	-2.360 – -0.608	.001	-1.107	-2.107 – -0.108	.030
R	-0.825	-1.483 – -0.166	.014	-0.479	-1.183 – 0.224	.181

** Corrected for All Other Covariates in the Model and the Fixed Factors Simulator and Session.*