Career Interest and Psychomotor Aptitude Among Medical Students

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OBJECTIVE: The primary objective is to assess psychomotor aptitude of medical students interested in pursuing a procedural career. Secondary objectives include exploring the relationship between actual and perceived aptitude, and identifying predictors of superior aptitude.

DESIGN: This is a cross-sectional, multisite study in which participants completed a paper survey, four visuospatial aptitude assessments, and a laparoscopic simulation modeled after the Fundamentals of Laparoscopic Surgery (FLS) peg transfer test (used as a proxy for psychomotor aptitude).

SETTING: Johns Hopkins University School of Medicine and Mayo Clinic School of Medicine.

PARTICIPANTS: All second-year medical students who had not yet initiated clinical rotations were eligible. Sixty-four students participated.

RESULTS: Students interested in a procedural career exhibited superior psychomotor aptitude (faster FLS task completion time), and a majority of these students correctly identified themselves as having above-average aptitude compared with peers. However, over one quarter of all students, regardless of career interest, incorrectly over- or under-rated their psychomotor aptitude. Upon completing their preclinical curriculum, a minority of students felt prepared to participate or assist in their surgical clinical rotations.

CONCLUSIONS: Prior to embarking on their clinical rotations, over one quarter of medical students lack awareness of their psychomotor aptitude and many do not feel prepared to participate in the next phase of their training. Early aptitude testing and introduction to laparoscopic training may assist in career selection, preparedness, and success. (J Surg Ed 76:1526–1533. © 2019 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: aptitude, medical students, laparoscopic training, visuospatial skill

COMPETENCIES: Medical Knowledge, Patient Care, Practice-Based Learning and Improvement, Systems-Based Practice

INTRODUCTION

Current challenges in surgical education include limitations on time for training due to resident work-hour restrictions and nonclinical demands, as well as the increasing diversity and complexity of surgical procedures. As a result, trainees are expected to achieve proficiency in procedures with fewer opportunities for repetition and efficiency in skill acquisition becomes essential. In an effort to adapt to these constraints, there has been an increasing interest in assessment of medical students' technical aptitude prior to residency application.

Proxies for technical aptitude, such as visuospatial (VSP) tests, perceptual and psychomotor skill assessments, have been shown—to varying degrees—to correlate with surgical simulator and operating room performance.[1-6] Certain studies suggest that novice surgeons with superior performance on VSP aptitude tests perform better on laparoscopic simulators in areas such as economy of movement and completion time.[3,7] VSP and psychomotor aptitude has also been shown to impact proficiency learning curves,

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

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  1931-7204/$30.00 https://doi.org/10.1016/j.jsurg.2019.04.006

with high aptitude learners rapidly achieving proficiency in a simulated procedure, while others may make little or no progress.[3] However, other studies have demonstrated a correlation between VSP scores and robotic skills, but no association with traditional laparoscopic skills.[21]

In theory, it would be ideal for all surgical residency applicants to have high technical aptitude—among other nontechnical skills essential for the professional development of an effective surgeon. However, there is conflicting evidence regarding students' capability to self-identify and select into a procedural field based on upon their inherent abilities; some students may perform lower on technical simulations than applicants applying to nonprocedural fields.[8,9]

In response to these concerns, some residency programs have included a form of aptitude testing into their residency selection process;[10] however, this takes place after a student has selected a surgical field for their career. Little is known about when and whether to identify those future trainees with lower psychomotor aptitude, how best to provide them with early exposure and training opportunities, and what impact this self-knowledge might have on their career aspirations.

This pilot study seeks to explore the relationships between medical students' career interests and their actual versus perceived psychomotor aptitude. The primary aim of this study was to assess the psychomotor aptitude of students interested in entering a procedural career compared to their peers. Our hypothesis is that there is a positive correlation between interest in a procedural field and psychomotor skills. Secondary aims were to determine the correlation between a student's perceived aptitude and their actual performance on laparoscopic simulation, and to identify predictors of superior performance.

MATERIALS AND METHODS

This cross-sectional study was offered to all second-year medical students at Johns Hopkins University School of Medicine and Mayo Clinic School of Medicine from July 2015 to July 2017. Recruitment consisted of a verbal announcement followed by an email invitation, and all participants provided written informed consent. Each participant completed (1) a written survey, (2) VSP assessment (VSP), and (3) psychomotor assessment in a single session lasting <1 hour. A research coordinator administered testing sessions in a standardized fashion. Participants were compensated with a $10 coffee gift card.

The survey included demographic information and a self-assessment of VSP skills and dexterity, presented as a continuous scale ranging from "exceptionally poor" to "exceptionally good." It also asked students to quantify their experience with the following activities: surgical suturing and simulation, video gaming, knitting, and woodworking, as well as their satisfaction with their hands-on/procedural skills training during medical school. Participants were asked to report their interest in a procedural career. Procedural fields included OB/GYN, all surgical subspecialties, interventional and intensivist fields.

VSP aptitude assessments included 4 cognitive tests to assess 2D-3D visual spatial ability: S-1 Card Rotations Test, S-2 Cube Comparisons Test, SS-3 Map Planning Test, and VZ-3 Surface Development Test, all licensed from Educational Testing Service's Kit of Factor-Referenced Cognitive Tests.[11] These tests were developed by a 4-year research program sponsored by the Office of Naval Research, aimed at identifying individuals' aptitude in 23 domains, including VSP skills. The S-1 Card Rotations Test assesses image rotation and the ability to see differences in figures. The student is given an image, with 8 subsequent similar images.[11] They must select if the image is the same as the index image and merely rotated, or different. Similarly, in the S-2 Cube Comparisons Test, the student must compare 2 blocks side by side, with a unique symbol on each of the 6 faces of the block and determine if they are same (and rotated) or different.[11] The SS-3 Map Planning Test tests the ability to find the shortest route between 2 spaces as quickly as possible.[11] Finally, the VZ-3 Surface Development Test requires the learner to try to imagine how a piece of paper can be folded to form an object.[11] The VSP tests used in this study were selected because they are designed to assess an individual's ability to comprehend, differentiate, and make decisions regarding 2-dimensional images that depict 3-dimensional structures—skills that are important in laparoscopic procedures.

Each of the individual test components have been studied for validity evidence in the predictive assessment of psychomotor skills and the subsequent performance of a surgical task. For example, a negative correlation has been demonstrated between performance on the Cube Comparison Test and duration of training to reach simulator benchmarks in an endoscopic task in fourth-year medical students.[12] Similarly, performance on the Map Planning Test has been shown to positively correlate with final performance on a simulated endovascular task among third- and fourth-year medical students.[1] The 4 tests were selected to measure skills relevant to laparoscopic surgery. Each paper test consisted of a short practice test followed by the official timed tests. Psychomotor skills assessment was performed using the peg transfer task from the Fundamentals of Laparoscopic Surgery (FLS).[13] Participants were provided instructions for completion of the peg transfer task using both written and verbal instruction. No formal training was offered. The task was completed 3 times per

participant, and total time (sec) and number of peg drops were recorded. For each of the 3 trials, a 10 second penalty per peg drop was added to the final time. Final scores were then calculated by taking the average of each participant's 3 trials (FLS time). Participants were allowed a maximum of 300 seconds to complete the task at which point testing would end.

Statistical Analysis

Participant characteristics are summarized with counts and percentages for categorical variables, and either mean ± standard deviation or median (interquartile range) for continuous variables. Outcomes of interest included stated interest in pursuing a procedural career, self-rated VSP and psychomotor skills, FLS time, and VSP score. Characteristics of those with a procedural interest were compared to those with no interest using *t* tests and Wilcoxon rank sum tests as appropriate for continuous variables, ordinal variables were compared using Mantel-Haensel chi-square tests, and nominal discrete characteristics were compared using chi-square tests. The association between FLS time and VSP score was evaluated using Spearman's correlation and regression methods. Similarly, regression methods were used to evaluate the association between FLS time and other participant characteristics. All statistical tests were 2-sided and p values less than 0.05 were considered statistically significant. All analyses were conducted using SAS version 9.4 and R version 3.1.1. This study was IRB approved by the IRB of Johns Hopkins University, and deemed exempt by the Mayo Clinic IRB.

RESULTS

Of approximately 210 eligible second-year medical students invited to participate, a total of 64 participated in this study. The average age was 25.6 ± 2.4 years (range: 22-33 years) and 53.1% of participants were female. Procedural interest was endorsed by 33 (51.6%) of participants. There was no significant difference in age, gender, or prior experience with surgical suturing or simulation, video games, knitting, or woodworking between participants with a reported interest in a procedural career and participants unsure or not interested (Table 1). Higher self-rated VSP aptitude and agreement with the statement "I am good with my hands" were associated with self-reported interest in a procedural career ($p = 0.044$ and $p = 0.010$, respectively). Upon completion of their second and final preclinical year, a minority of students felt satisfied with their hands-on training (21.9%) or felt prepared to participate in their surgical clerkships (14.1%). These numbers did not differ significantly by career interest (Table 1)

Predictors of Psychomotor Aptitude

Mean adjusted completion time for the FLS peg transfer task was 129 seconds. Faster completion time for the FLS peg transfer task (FLS time) was associated with higher self-reported experience with suturing, surgical simulation, and woodworking. FLS time was not associated with gender or experience with video games (Table 2).

Students' stated career interest (procedural vs. nonprocedural) was associated with FLS time (Fig. 1, Table 3). Mean FLS time was significantly faster among students interested in pursuing a procedural career than among students who were unsure or uninterested (118.0 (±38.1) seconds vs. 141.0 (±47.7) seconds, respectively, $p = 0.048$). Furthermore, the interquartile range for students interested in a procedural career was tighter than for the unsure or uninterested group (92.3-119.0 seconds vs.103.3-150.0 seconds, respectively) (Table 3).

Performance on VSP tests did not correlate with FLS time and had a Spearman correlation coefficient of −0.0363 (Fig. 2). Regardless of procedural interest, students with higher VSP scores were not significantly more likely to have faster FLS times.

Self-rated and Actual Psychomotor Aptitude

Higher self-rated dexterity was associated with faster FLS peg transfer time ($p < 0.001$) (Table 2). Students' self-rated dexterity was compared to their performance on the FLS peg transfer test; students were considered to have correctly self-rated themselves if these 2 measures were concomitant. For example, a student who self-rated their dexterity as "below average" subsequently performed slower than average for this cohort on the FLS task. Overall, the majority of students (71.9%) correctly self-identified; however, 28.1% of students incorrectly self-rated themselves as having superior or inferior dexterity (Table 3). Specifically within the group of students interested in a procedural career, over one quarter of students incorrectly self-rated their dexterity as either above or below average, with 15.2% ($n = 5$) over-estimating this parameter and 12.1% ($n = 4$) underestimating.

DISCUSSION

Psychomotor aptitude testing has become an increasingly popular tool for assessing and selecting medical students and surgical trainees.[14] While this may encourage the selection of trainees of high aptitude into respective surgical programs, it does little for the trainee who demonstrates lower aptitude on the interview day, or

TABLE 1. Participant Demographics

	Procedural Interest			
	No (*N* = 31)	**Yes (*N* = 33)**	**Total (*N* = 64)**	**p Value**
Age				0.21
Mean (SD)	26.0 (2.4)	25.2 (2.2)	25.6 (2.3)	
Median (IQR)	25 (24, 28)	25 (24, 26)	25 (24, 26)	
Gender				0.077
Male	11 (35.5%)	19 (57.6%)	30 (46.9%)	
Female	20 (64.5%)	14 (42.4%)	34 (53.1%)	
Self-rated dexterity (mm)†				0.27
Mean (SD)	61.1 (13.8)	65.2 (15.8)	63.2 (14.9)	
Median (IQR)	63 (50, 74)	73 (53, 75)	68 (50, 75)	
Self-rated VSP (mm)†				0.044*
Mean (SD)	59.3 (18.1)	68.5 (17.9)	64.0 (18.5)	
Median (IQR)	56 (50, 75)	75 (50, 76)	68 (50, 75)	
Good with hands				0.010**
Likely not	1 (3.2%)	0 (0.0%)	1 (1.6%)	
Not sure	11 (35.5%)	4 (12.1%)	15 (23.4%)	
Possibly yes	18 (58.1%)	21 (63.6%)	39 (60.9%)	
Definitely yes	1 (3.2%)	8 (24.2%)	9 (14.1%)	
Surgical suturing				0.059
Never	4 (12.9%)	1 (3.0%)	5 (7.8%)	
Minimal	11 (35.5%)	6 (18.2%)	17 (26.6%)	
Moderate	15 (48.4%)	20 (60.6%)	35 (54.7%)	
Extensive	1 (3.2%)	6 (18.2%)	7 (10.9%)	
Surgical simulation				0.23
Never	8 (25.8%)	3 (9.1%)	11 (17.2%)	
Minimal	15 (48.4%)	18 (54.5%)	33 (51.6%)	
Moderate	8 (25.8%)	11 (33.3%)	19 (29.7%)	
Extensive	0 (0.0%)	1 (3.0%)	1 (1.6%)	
Video games/play station				0.85
Never	4 (12.9%)	4 (12.1%)	8 (12.5%)	
Minimal	5 (16.1%)	8 (24.2%)	13 (20.3%)	
Moderate	11 (35.5%)	9 (27.3%)	20 (31.3%)	
Extensive	11 (35.5%)	12 (36.4%)	23 (35.9%)	
Knitting/crochet				0.39
Never	10 (32.3%)	17 (51.5%)	27 (42.2%)	
Minimal	7 (22.6%)	7 (21.2%)	14 (21.9%)	
Moderate	8 (25.8%)	6 (18.2%)	14 (21.9%)	
Extensive	6 (19.4%)	3 (9.1%)	9 (14.1%)	
Carpentry/wood work				0.10
Never	19 (61.3%)	11 (33.3%)	30 (46.9%)	
Minimal	9 (29.0%)	12 (36.4%)	21 (32.8%)	
Moderate	2 (6.5%)	7 (21.2%)	9 (14.1%)	
Extensive	1 (3.2%)	3 (9.1%)	4 (6.3%)	
Satisfied with hands on training				0.41
Dissatisfied/neutral	10 (32.3%)	15 (45.5%)	25 (39.1%)	
Satisfied/very satisfied	21 (67.7%)	18 (54.5%)	39 (60.9%)	
Satisfied with procedural training				0.66
Dissatisfied/neutral	23 (74.2%)	27 (81.8%)	50 (78.1%)	
Satisfied/very satisfied	8 (25.8%)	6 (19.2%)	14 (21.9%)	
Prepared to participate				0.41
Disagree/neutral	25 (80.6%)	30 (90.9%)	55 (85.9%)	
Agree/strongly agree	6 (19.4%)	3 (9.1%)	9 (14.1%)	
Prepared to assist				0.83
Disagree/neutral	24 (77.4%)	23 (71.9%)	47 (74.6%)	
Agree/strongly agree	7 (22.6%)	9 (28.1%)	16 (25.4%)	

*$p < 0.05$.
**$p < 0.01$.
†Question presented as a continuous scale ranging from "exceptionally poor" to "exceptionally good."

TABLE 2. Predictors of Psychomotor Aptitude (as Measured by FLS)

		Mean Time (sec)	p Value
Gender	Male/female	127.3 vs. 130.8	0.75
Self-rating	Dexterity**	−1.26†	<0.001
	Visuospatial**	−1.05†	<0.001
Experience	Suturing**	118.5 vs. 149.6‡	0.006
	Surgical simulation**	121.8 vs. 132.5‡	<0.001
	Video games	128.6 vs. 130.4‡	0.88
	Knitting/crochet	131.9 vs. 127.6‡	0.71
	Carpentry/woodwork	121.4 vs. 131.1‡	0.48
Satisfaction with	Hands-on training	129.2 vs. 129.1§	1.00
	Procedural training	116.5 vs. 132.7§	0.23
Perceived preparedness	To participate	120.5 vs. 130.6§	0.53
	To assist	113.3 vs. 134.9§	0.094

**p < 0.01.
†per 1 mm increase.
‡Moderate/extensive vs none/minimal.
§Agree/strongly agree vs neutral/disagree/strongly disagree.

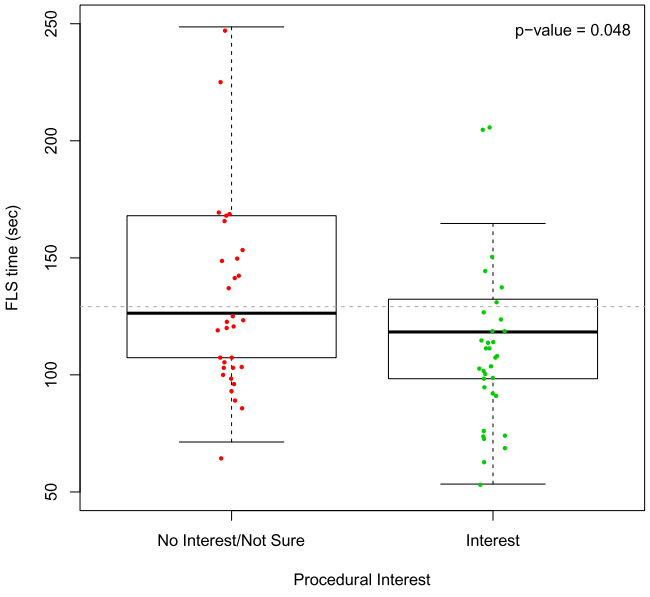

FIGURE 1. Performance on FLS peg transfer task, by interest in procedural career. The dashed horizontal line represents the overall mean FLS time of 129 seconds.

the one with self-perceived low aptitude but high trainability from applying to a procedural field altogether. Assessing medical student aptitude earlier could be an important step in preparing learners for career selection and in identifying those who will and will not likely have subsequent efficient and successful acquisition of skill during residency.

In our study, students with a stated procedural interest demonstrated better psychomotor performance than those without an interest. This could be potentially explained if students with an interest in procedural fields possess a higher level of self-confidence than peers less interested in procedural fields, which could subsequently influence performance. Lower procedural confidence could also lead to nonparticipation in this study altogether. However, even among interested students, one-quarter performed below the mean (Fig. 2). Additionally, between one quarter and one third of students interested in a procedural career were unable to correctly self-rate their psychomotor aptitude compared to their peers (Table 3). This suggests that some students may have limited self-awareness regarding psychomotor aptitude. Students may be making career decisions with incomplete or inaccurate information, or without considering aptitude alongside other factors. The authors suggest that the current medical education paradigm should aim to help students understand and develop their technical skills in a validated, transparent manner earlier in their medical education.[15]

TABLE 3. Students Whose Self-rated Measure of Dexterity (above average vs. below average of 63.2 mm) Matched Their Performance on the FLS Peg Transfer Task (faster vs. slower than average time of 129 seconds)

% Correctly Self-rated	Interested	Unsure or Not Interested	Total
Faster than average	16/24 (66.7%)	13/18 (72.2%)	29/42 (69.0%)
Slower than average	5/9 (55.6%)	11/13 (84.6%)	16/22 (72.7%)
Total	21/33 (63.6%)	24/31 (77.4%)	45/64 (70.3%)

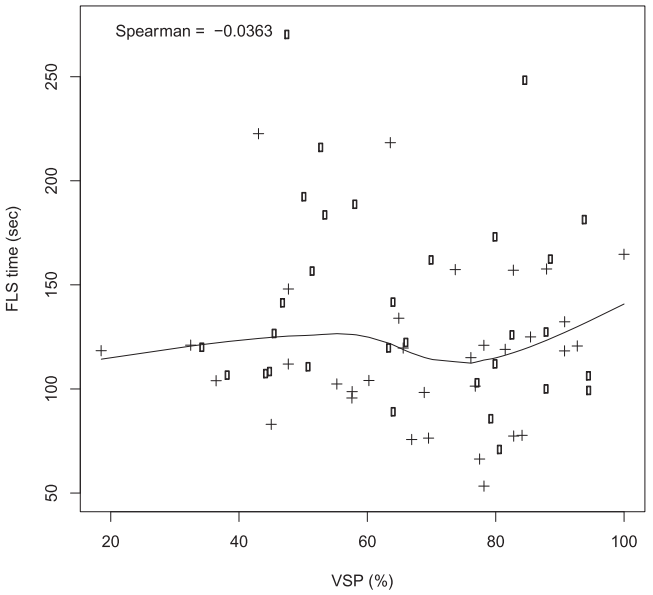

FIGURE 2. Relationship between completion time for FLS peg transfer task and performance on visuospatial perception tests, by stated interest in procedural field (✚ Interested in procedural field; ▯ Not interested in procedural field).

Existing literature suggests that medical student performance on psychomotor tests, such as the FLS peg transfer task, is a strong predictor of initial performance on virtual reality simulators, a primary training modality for laparoscopic surgery.[16,17] Studies support the utility of such testing by identifying learning curves between low and high aptitude trainees.[3] One study identified a very troubling group—those that fail to improve despite repeat attempts at simulation, those which struggle to improve.[14] Buckley et al. adeptly highlight the potential risk and disappointment of the young trainee that struggles during training and may ultimately have limited career prospects, and they emphasize our responsibility as educators to those trainees.[3] In contrast, there may be individuals of lower initial performance or "aptitude" yet who are highly trainable, who with early exposure to simulation training during medical school could improve performance prior to clinical rotations, career selection and residency applications. While aptitude testing can inform resource allocation for low performing trainees already in residency programs, we argue that early exposure to training models and aptitude tests could provide learners with insight into their performance and learning curves before selecting their career path.

Our findings support much of what is often assumed regarding the relationship between career interest, psychomotor aptitude, and self-assessment, as well as highlight a potential educational gap and opportunity for early intervention. The minority of students in our study expressed satisfaction with their hands-on training in the preclinical years or their preparedness to participate in surgical clerkships. More could be done to prepare students for clerkships and create a forum for self-assessment and training to best position them for their future and for choosing a career. Future research into methods of skills instruction and assessment, including the timing of such assessments and implications of the outcomes is needed.

Strengths of this study include its large sample size relative to similar studies in the existing literature, inclusion of students interested in procedural and nonprocedural fields, and enrollment of participants from 2 medical schools. There were some limitations. Although no students received prior formalized surgical skills training, our cohorts performed very well at peg transfer. The mean time to complete peg transfer in our cohort was 119 ± 37.7 seconds, which is faster than some reports of first-year surgical residents (194 ± 66 seconds), and comparable to other mean resident times following a year of structured practice (101 ± 58 seconds).[18,19] Students may have performed below their peers, but above average in national benchmarks. Reasons for this performance include probable past informal simulator practice, and may impact generalizability. Another potential weakness was our use of peg transfer alone for psychomotor testing, a task that may assess a limited domain of psychometric skill. Furthermore, psychomotor aptitude was evaluated during a single encounter. This introduces the possibility of high or low performance due to chance and not actual skill. FLS peg transfer was selected given its simplicity, ease of administration and grading, and supported literature on outcomes, thus supporting potential feasibility for use as a future tool across larger cohorts. It may be best utilized as a part of a panel of tests rather than a sole measure of psychometric skill. We should also recognize that skill was assessed in a simulated environment, not in the operating room setting.

Although the Kit of Factor-Referenced Cognitive Tests is widely used to assess VSP aptitude, we did not find a correlation between superior performance on the VSP test and faster FLS completion time. VSP testing should be further studied prior to incorporating as a sole metric in screening for residency applicants. Alternatively, in an era where laparoscopic simulation is widely available, use of a laparoscopic simulation test itself may negate the need for other tests designed to assess a potential surgeon's VSP aptitude. Finally, this cohort of students reported interest as second-year medical students, and may not reflect the ultimate cohort of students that apply to procedural fields, with the possibility of crossover.

CONCLUSION

Some medical students interested in pursuing procedural fields lack awareness of their technical aptitude. Traditional

metrics of VSP aptitude may have limited application in assessment of laparoscopic aptitude; however, laparoscopic simulation itself may be a useful tool to identify and aid students with an interest in a procedural field but who may have psychomotor aptitude below their peers. These individuals may benefit from targeted, early interventions, and more research should be dedicated to exploring the utility of psychomotor testing to help guide career decisions and improve performance among candidates interested in procedural fields.

AUTHORS' CONTRIBUTION

1. Amy Weaver (Division of Biomedical Statistics and Informatics, Mayo Clinic) provided help and oversight with data analysis.
2. Emily Murphy, MD (Harvard Medicine-Pediatrics Residency Program) provided help with data collection.
3. Sue Eller, Johns Hopkins Minimally Invsaive Surgical Training and Innovation Center, helped organize and coordinate space for the study.

REFERENCES

1. Ahlborg L, Hedman L, Murkes D, et al. Visuospatial ability correlates with performance in simulated gynecological laparoscopy. *Eur J Obstet Gynecol Reprod Biol*. 2011;157:73–77. http://doi.org/10.1016/j.ejogrb.2011.02.007.
2. Groenier M, Groenier KH, Miedema HaT, Broeders IaMJ. Perceptual speed and psychomotor ability predict laparoscopic skill acquisition on a simulator. *J Surg Educ*. 2015: 1–9. http://doi.org/10.1016/j.jsurg.2015.07.006.
3. Buckley CE, Kavanagh DO, Nugent E, Ryan D, Traynor OJ, Neary PC. The impact of aptitude on the learning curve for laparoscopic suturing. *Am J Surg*. 2014;207:263–270. http://doi.org/10.1016/j.amjsurg.2013.08.037.
4. Grantcharov TP, Funch-Jensen P. Can everyone achieve proficiency with the laparoscopic technique? Learning curve patterns in technical skills acquisition. *Am J Surg*. 2009;197:447–449. http://doi.org/10.1016/j.amjsurg.2008.01.024.
5. Siska VB, Ann L, Gunter DW, et al. Surgical skill: trick or trait. *J Surg Educ*. 2015;72:1247–1253. http://doi.org/10.1016/j.jsurg.2015.05.004.
6. McClusky Da, Ritter EM, Lederman aB, h-spatial, and psychomotor aptitude to duration of training required to reach performance goals on the MIST-VR surgical simulator. *Am Surg*, 71, 13-21. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15757051
7. Gallagher A, Cowie R, Crothers I, Jordan-Black J, Satava. PicSOr: an objective test of perceptual skill that predicts laparoscopic technical skill in three initial studies of laparoscopic performance. *Surg Endosc*. 2003;17:1468–1471.
8. Tang CG, Hilsinger RL. Jr., Cruz RM, Schloegel LJ, Byl F.M. Jr., Rasgon BM. Manual Dexterity aptitude testing: a soap carving study. *JAMA Otolaryngol Head Neck Surg*. 2014;140:243–249.
9. Panait L, Larios JM, Brenes RA, Fancher TT, Ajeman MS, Dudrick SJ, Sanchez JA. Surgical skills assessment of applicants to general surgery residency. *J Surg Res*. 2011;170:189–194.
10. Williams JF, Watson SL, Baker DK, et al. Psychomotor testing for orthopedic residency applicants: a pilot study. *J Surg Educ*. 2017;74:820–827. https://doi.org/10.1016/j.jsurg.2017.02.004. Epub 2017 Mar 7.
11. Ekstrom RB, French JW, Harman HH. Kit of Factor-Referenced Cognitive Tests. Princeton, New Jersey: Educational Testing Service; 1976.
12. Ritter EM, McClusky DA, Gallagher AG, Enochsson L, Smith CD. Perceptual, visuospatial, and psychomotor abilities correlate with duration of training required on a virtual-reality flexible endoscopy simulator. *Am J Surg*. 2006;192:379–384.
13. Van Herzeele Ian, Donoghue KGLO, Aggarwal R, Vermassen F, Darzi A. From the Society for Clinical Vascular Surgery Visuospatial and psychomotor aptitude predicts endovascular performance of inexperienced individuals on a virtual reality simulator. *YMVA*. 2010;51:1035–1042. http://doi.org/10.1016/j.jvs.2009.11.059.
14. Fundamentals of Laparoscopic Surgery. (2014). FLS Manual Skills Written Instructions and Performance Guidelines, revised February 2014. www.flsprogram.org.
15. Ogunyemi D, Alexander C, Tangchitnob E, Kim DS. Mini surgical simulation, role play, and group and behavioral interviews in resident selection. *J Grad Med Educ*. 2016;8:410–416.
16. Grantcharov TP, Funch-Jensen P. Can everyone achieve proficiency with the laparoscopic technique? Learning curve patterns in technical skills acquisition. *Am J Surg*. 2009;197:447–449. http://doi.org/10.1016/j.amjsurg.2008.01.024.

17. McClusky Da, Ritter EM, Lederman aB, h-spatial, and psychomotor aptitude to duration of training required to reach performance goals on the MIST-VR surgical simulator. *Am Surg*, 71(1):13-21. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15757051.

18. El-Beheiry M, McCreery G, Schlachta CM. A serious game skills competition increases voluntary usage and proficiency of a virtual reality laparoscopic simulator during first-year surgical residents' simulation curriculum. *Surg Endosc*. 2016. [Epub ahead of print] PMID: 27572069.

19. Connor EV, Raker C, Wohlrab KJ. Effects of Repetition and Inactivity on Laparoscopic Skills Training. *J Minim Invasive Gynecol*. 2016;23:194–197.

SUPPLEMENTARY INFORMATION

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jsurg.2019.04.006.