

Association for Surgical Education

The impact of aptitude on the learning curve for laparoscopic suturing

Christina E. Buckley, M.B., B.Ch., B.A.O.*, Dara O. Kavanagh, M.Ch., F.R.C.S.I.,
Emmeline Nugent, M.D., M.R.C.S., Donncha Ryan, M.Sc.,
Oscar J. Traynor, M.Ch., F.R.C.S.I., Paul C. Neary, M.D., F.R.C.S.I.

National Surgical Training Centre, Royal College of Surgeons in Ireland, 121 St Stephens Green, Dublin 2, Ireland

KEYWORDS:

Learning curve;
Aptitude;
Laparoscopic suturing;
Simulation;
Proficiency-based
training

Abstract

BACKGROUND: Within surgery, several specialties demand advanced technical skills, specifically in the minimally invasive environment.

METHODS: Two groups of 10 medical students were recruited on the basis of their aptitude (visual-spatial ability, depth perception, and psychomotor ability). All subjects were tested consecutively using the ProMIS III simulator until they reached proficiency performing laparoscopic suturing. Simulator metrics, critical error scores, observed structured assessment of technical skills scores, and Fundamentals of Laparoscopic Surgery scores were recorded.

RESULTS: Group A (high aptitude) achieved proficiency after a mean of 7 attempts (range, 4–10). In group B (low aptitude), 30% achieved proficiency after a mean of 14 attempts (range, 10–16). In group B, 40% demonstrated improvement but did not attain proficiency, and 30% failed to progress.

CONCLUSIONS: Distinct learning curves for laparoscopic suturing can be mapped on the basis of fundamental ability. High aptitude is directly related to earlier completion of the learning curve. A proportion of subjects with low aptitude are unable to reach proficiency despite repeated attempts.

© 2014 Elsevier Inc. All rights reserved.

The technique of laparoscopic suturing was well described by Szabo et al.¹ Laparoscopic suturing is an advanced skill that enables surgeons to broaden the application of laparoscopy.² However, the skill is difficult to acquire and requires specialized training.³ Complex laparoscopic tasks such as laparoscopic suturing and intracorporeal knot tying require a very high level of technical ability. This can be developed using a simulated model.⁴

Dr Buckley was awarded a Covidien Research Fellowship. The remaining authors declare no conflicts of interest.

This study was presented at the 2013 annual meeting of the Association for Surgical Education, Orlando, Florida.

* Corresponding author. Tel.: +353 (1) 402 2704; fax: +353 (1) 402 2459.

E-mail address: bucklece@tcd.ie

Manuscript received May 12, 2013; revised manuscript July 23, 2013

Previous studies have shown that increasing the complexity of a procedure is associated with a progressively steeper learning curve.⁵ In particular, a protracted learning curve has been demonstrated in laparoscopic suturing.⁶ When the learning curve for laparoscopic suturing was examined by Botden et al,⁷ the number of repetitions required to reach the top of the performance curve was 8. We planned to establish if this learning curve differs depending on a subject's aptitude.

Several studies have examined the relationships between specific areas of aptitude, such as visual-spatial and perceptual abilities, and laparoscopic technical skill performance.^{8,9} These studies have concluded that superior laparoscopic performance is demonstrated among novice surgical trainees who possess such attributes.

Table 1 Fundamentals of Laparoscopic Surgery suturing principles

1. Positioning the needle in the needle holder
2. Running the needle through the suturing pad
3. Taking proper bites of the suturing pad while performing the suture
4. Throwing the thread around the needle holder
5. Pulling the thread tightly in the proper direction
6. Tying the correct surgical knot

We have previously shown that aptitude can predict the rate at which a surgical novice achieves proficiency in a basic laparoscopic task, such as laparoscopic appendectomy.¹⁰ It is intuitive that the more complex the laparoscopic procedure, the greater effect that fundamental ability will have on achieving proficiency.

We aimed to compare the rate at which 2 groups of surgical novices became proficient in laparoscopic suturing and intracorporeal knot tying. These 2 groups were at opposite ends of the aptitude spectrum.

Methods

Setting and study participants

Participants were recruited to take part in this study on a voluntary basis. Sixty-two medical students with no prior

surgical experience were tested in 3 different dimensions of aptitude, described below. All participants were asked to sign a consent form allowing the data collected to be used for research purposes. It was made clear to all the subjects that the data were stored and presented in an anonymous format. Ethical approval was granted by the Research Ethics Committee of the Royal College of Surgeons in Ireland.

On the basis of the results of aptitude testing, 2 groups of 10 participants were selected from opposite ends of the aptitude spectrum. Participants in the first group (group A) were considered to have high aptitude, with scores 1 standard deviation higher than the mean score of the study population. Participants in the second group (group B) were considered to have low aptitude, as their scores were 1 standard deviation lower than the mean score of the study population. Five experienced laparoscopic surgeons were also recruited to set benchmark proficiency levels on the ProMIS III simulator (CAE Healthcare, Sarasota, FL). Each of these surgeons had performed >100 complex laparoscopic procedures.

Simulator and materials

The ProMIS III simulator was used for assessment. It facilitates the use of physical models, which ensures tactile feedback, and by tracking the instruments, it provides measurements of performance. Upon completion of a procedure, the simulator generates an immediate profile summary of objective measurements. These include time,

Table 2 Demographic details of the subjects

Variable	High-aptitude group (<i>n</i> = 10)	Low-aptitude group (<i>n</i> = 10)	<i>P</i> (ANOVA)
Age (y)			NS
Range	19–27	19–36	
Mean	21.1	23.5	
Standard deviation	2.6	5.5	
Sex (%)			NS
Male	50	20	
Female	50	80	
Dominant hand (%)			NS
Right	100	100	
Left	0	0	
Corrected vision (%)			NS
Yes	70	50	
No	30	50	
Video games (%)			.001
Yes (≥ 1 h/wk)	90	10	
No	10	90	
Music (%)			NS
Yes (achieved distinction)	70	50	
No	30	50	
Sports (%)			NS
Yes (intercollegiate level)	80	40	
No	20	60	

ANOVA = analysis of variance.

path length, and economy of movement. Numerous studies have provided construct validity for this hybrid simulator.^{11–14}

A 10 × 12 cm piece of synthetic suturing skin (The Chamberlain Group, Great Barrington, MA) was placed in the simulator tray. The laparoscopic suturing task was performed according to Fundamentals of Laparoscopic Surgery (FLS) principles (Table 1) using 3/0 silk sutures and 2 laparoscopic needle holders. Three knots were thrown to complete the task.

Aptitude testing

Visual-spatial aptitude is the ability to generate, transform, and retain structured visual images. It represents one's ability to mentally manipulate 2-dimensional and 3-dimensional figures. Four visual-spatial paper-based tests were selected from the kit of factor-referenced cognitive tests (developed in 1976), which have been previously validated.¹⁵ These include the card rotation test, cube comparison test, map planning test, and surface development test.

Psychomotor aptitude is the ability to perform motor tasks with precision and coordination. In this study, we measured manual and finger dexterity and hand-eye coordination. This was assessed using a grooved pegboard. It has been previously validated and is a well-recognized assessment tool.¹⁶

Depth perception is one's visual ability to perceive the world in 3 dimensions and to assess the distance of an object. Pictorial surface orientation testing was developed to assess a subject's perceptual ability in laparoscopic surgery.¹⁷

Performance assessment

Before performance assessment, each candidate received didactic teaching. Each candidate was sent a stepwise approach detailing how to perform the task and a video link to a live recording of a specific part of a laparoscopic rectopexy before the experiment commenced. When the candidates attended the first session, a simulated laparoscopic suturing demonstration was conducted. They were allocated time to ask questions before they attempted to complete a

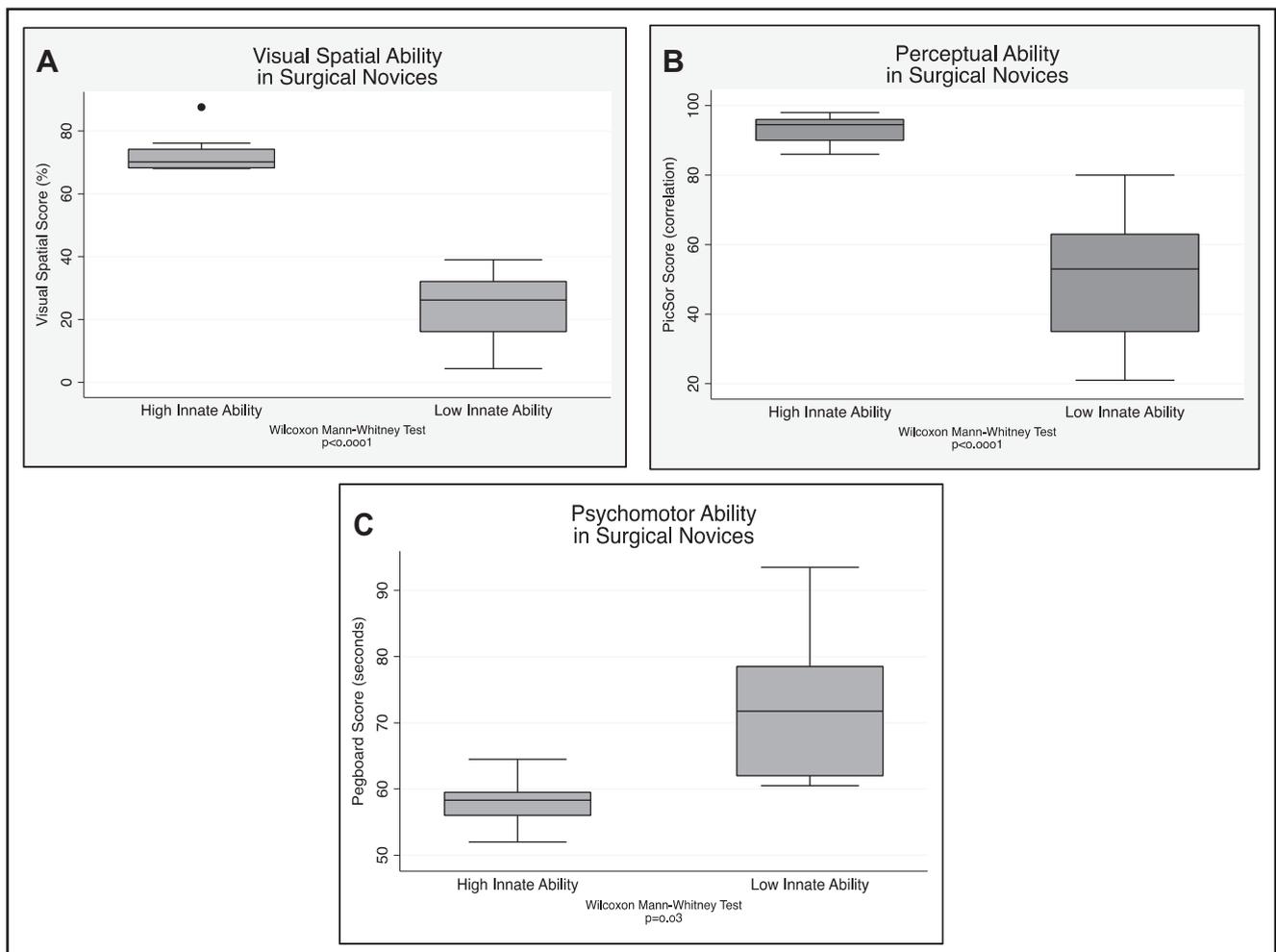


Figure 1 Comparison of (A) visual-spatial scores, (B) depth perception scores, and (C) psychomotor scores.

mandatory multiple-choice questionnaire to ensure thorough comprehension of the procedure. Before their first assessments, candidates had the opportunity to familiarize themselves with the testing equipment by completing a basic laparoscopic task.

Participants were asked to perform the suturing task consecutively until they reached the proficiency scores. An interval practice curriculum rather than massed practice was implemented.^{18,19} Candidates were allowed to perform a maximum of 4 tasks per session to avoid fatigue.^{20,21} Sessions

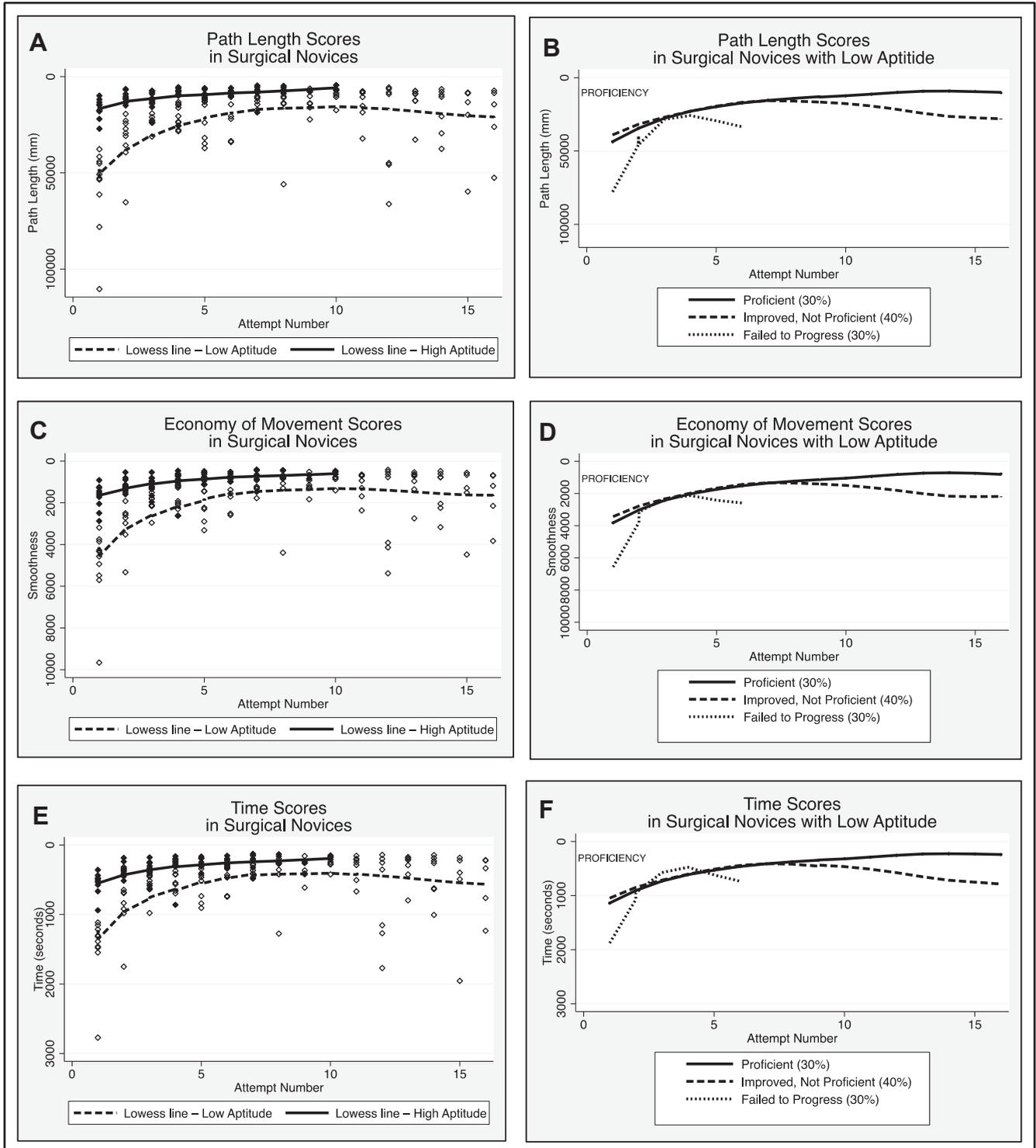


Figure 2 (A) Comparison of path length scores in surgical novices and (B) path length scores for all attempts in those with low aptitude. (C) Comparison of economy of movement scores in surgical novices and (D) economy of movement scores for all attempts in those with low aptitude. (E) Comparison of time scores in surgical novices and (F) time scores for all attempts in those with low aptitude.

Table 3 Metric and subjective scores of the initial attempt

Variable	High-aptitude group (<i>n</i> = 10)	Low-aptitude group (<i>n</i> = 10)	<i>P</i> (Mann-Whitney test)
Time (s)	551	1,475	<.0001
Path length (mm)	57,542	16,635	<.0001
Smoothness	4978	1,721	<.0001
OSATS score	12	7	<.0001
FLS score	13	9	.0006
Error score	4.7	2.2	<.0001

FLS = Fundamentals of Laparoscopic Surgery; OSATS = objective structured assessment of technical skills.

were carried out at a maximum interval of 2 weeks.²² Candidates were supervised by a senior surgeon at all times, and if a subject needed guidance, instructions were given. The senior surgeon did not take over the task at any point during the performance assessment. The amount of prompting per case was not specifically quantified. Upon completion of each procedure, the simulator provided a summary score report, which was relayed to the candidate as a means of assessing progress throughout the experiment.

Each performance was recorded and subsequently assessed by 2 reviewers, blinded to the status of the surgical novice, using the observed structured assessment of technical skills (OSATS) scoring system and the FLS rating scale. The quality of each knot was assessed after task completion. This information was relayed to the candidate after each performance.

Data analysis

Statistical analysis was performed using Stata version 12.0 (StataCorp LP, College Station, TX). The aptitude, metric, and proficiency scores of the 2 groups were compared using the Mann-Whitney test. *P* values <.05 were considered statistically significant. Nonparametric testing was performed, as none of the data were shown to be normally distributed using the Shapiro-Wilk test.

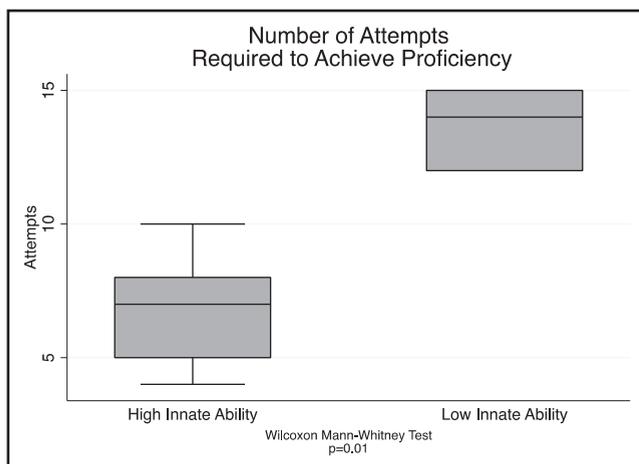


Figure 3 Difference in the number of attempts required to achieve proficiency.

Interrater reliability was determined using Cronbach's α coefficient.

Results

Participant demographics

Of the 20 subjects who participated, 13 were women and 7 were men, and the mean age was 22.3 years (range, 18–36 years). Further demographics are shown in Table 2.

Aptitude scores

The high-aptitude group (group A) achieved significantly higher scores than the low-aptitude group (group B) in all 3 areas of aptitude tested, as illustrated in Fig. 1A–C. Group A scored 72% for visual-spatial ability compared with 24% in group B (*P* < .0001). Depth perception scores were 93% in group A compared with 50% in group B (*P* < .0001), while group A demonstrated improved psychomotor ability by performing the pegboard task in 58 seconds compared with 73 seconds in group B (*P* = .03).

Metric scores

The baseline metric scores for both groups are shown in Table 3; these are the scores from the first attempts of all candidates. Group A achieved better scores than group B in all parameters (*P* < .0001).

Path length scores are illustrated in Fig. 2A. Group A achieved proficiency faster (*P* < .0001) than group B. The learning curve for group A can be seen in Fig. 2B. Within group B, 30% achieved proficiency after a mean of 14 attempts, 40% demonstrated improvement but did not attain proficiency despite 16 attempts, and 30% failed to progress and were unable to progress along the learning curve (Fig. 2B).

Economy of movement and time scores for both groups for all attempts are displayed in Fig. 2C, E, respectively. Group A achieved proficiency in a shorter time frame for these 2 parameters than group B (*P* < .0001). group B can be further divided into 3 subgroups for economy of movement and time scores: 30% attained proficiency, 40% showed improvement but did not attain proficiency,

and 30% failed to progress, as illustrated in Fig. 2D, F, respectively.

Attainment of proficiency

The mean number of attempts to achieve proficiency for group A was 7 (range, 4–10), compared with 14 (range,

10–16) for group B ($P = .01$; Fig. 3). In the low-aptitude group, 30% achieved proficiency after a mean of 14 attempts, 40% demonstrated improvement but did not attain proficiency, and 30% failed to progress and dropped out of the study. They dropped out by personal choice, as they were unable to complete the task after an average of 5 attempts.

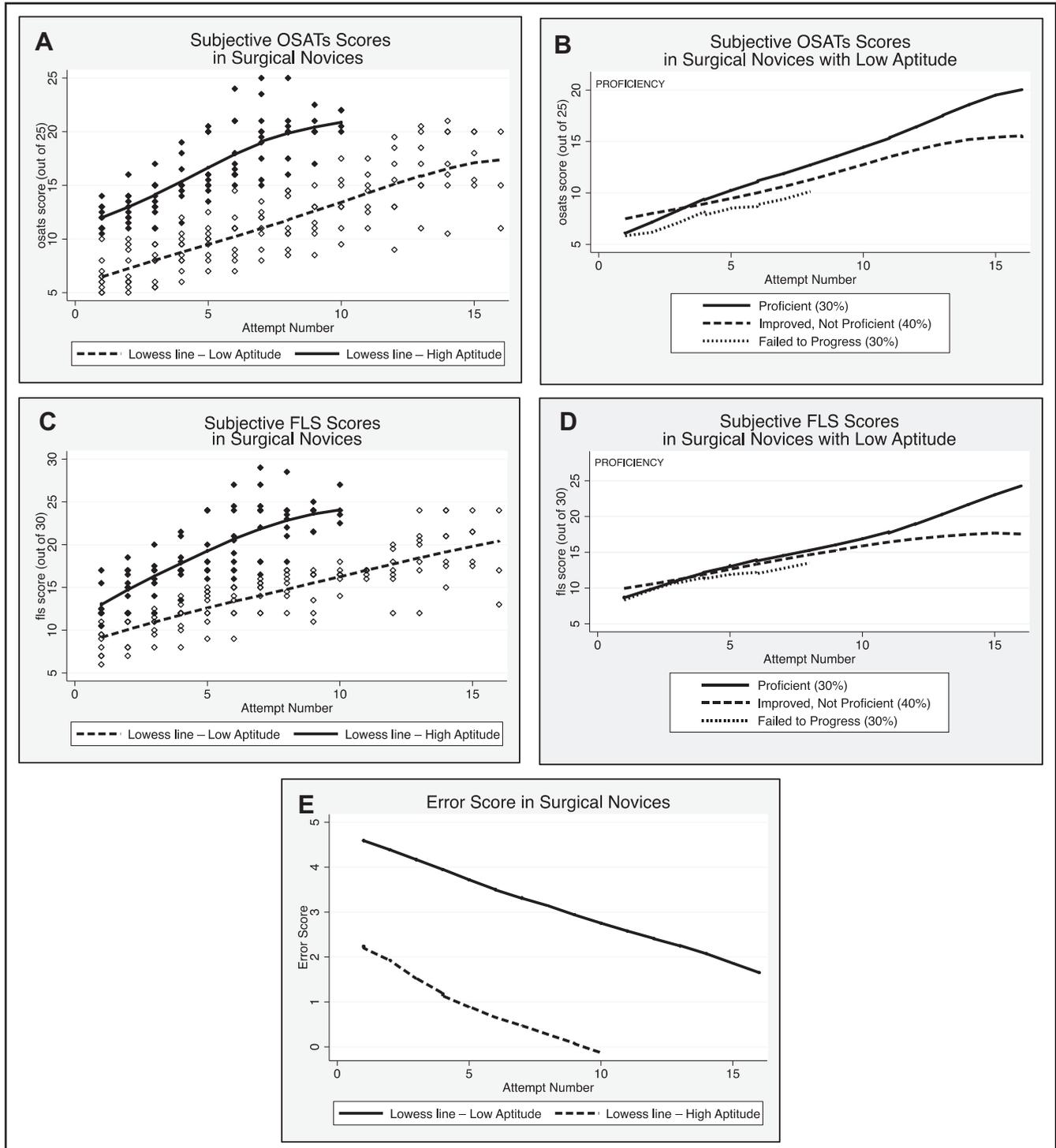


Figure 4 (A) Comparison of OSATS scores in surgical novices and (B) OSATS scores for all attempts in those with low aptitude. (C) Comparison of FLS scores in surgical novices and (D) FLS scores for all attempts in those with low aptitude. (E) Comparison of error scores in surgical novices.

Subjective scores

The baseline subjective scores (OSATS, FLS, and error scores) for both groups are shown in Table 3; these are the scores from the first attempts of all candidates. Group A achieved significantly better scores compared with group B in all parameters ($P < .0001$).

OSATS scores for both groups are shown in Fig. 4A, and FLS scores are shown in Fig. 4C. Group A achieved proficiency with fewer attempts ($P < .001$) than group B. The consistent separation in learning curves among group B was again demonstrated with regard to OSATS and FLS scores, as depicted in Fig. 4B, D, respectively. Interrater reliability between the 2 assessors was determined using Cronbach's α coefficient and was found to be .98 and .95 for FLS and OSATS scores, respectively.

The error scores for both groups are shown in Fig. 4E. The baseline mean error score was 2.2 in group A compared with 4.7 in group B ($P < .001$). Interrater reliability using Cronbach's α coefficient was .86.

Comments

It is clear that distinct learning curves for laparoscopic suturing can be mapped on the basis of fundamental ability. This study has shown that there is a wide disparity in attaining proficiency in groups with differing levels of aptitude.

Surgical training bodies have many objectives, and one of their most important aims is to ensure that candidates excel in their chosen fields. Several specialties demand advanced technical skills specifically in the minimally invasive environment. On the basis of our study findings, candidates who possess good fundamental ability are more likely to succeed in their training pathways within a given time frame.

The current literature shows that residents with higher visual-spatial scores perform significantly better than those with lower scores.^{23,24} Our study supports these findings, as we have shown that candidates with high aptitude scores have a superior baseline in all parameters and attain proficiency quicker.

Grantcharov et al²⁵ previously identified 4 types of learning curves, which varied on the basis of psychomotor ability. Our data strongly support these findings, and we have specifically defined these learning pathways. We also found that a proportion of students fail to progress or follow any upward learning curve.

Previous work carried out at our institution showed that 25% of candidates with low aptitude were unable to achieve proficiency in laparoscopic appendectomy despite repeated attempts.¹⁰ This study shows that the proportion is higher when a complex task such as laparoscopic suturing is being attempted. Only 30% of the candidates with low aptitude were able to achieve proficiency in the laparoscopic suturing task, implying that aptitude plays an important role in learning advanced laparoscopic skills.

Limitations

These findings have been demonstrated in a simulated laparoscopic environment. There is conflicting evidence to support the transfer of skills from a simulated environment to the live operating room.²⁶ We cannot guarantee that these specific findings would be reproducible in a live setting. Furthermore, we have stated that those with higher aptitude have a faster learning curve and can achieve proficiency at a faster rate, but this is somewhat of an artificial learning curve. The initial part of the learning has been shown to be the period of time when most errors are committed. Although the candidates were penalized if they committed any predefined errors, it was not an environment in which patient safety was an issue, so perhaps it is difficult to truly establish whether candidates overcame the learning curve.

Conclusions

High aptitude predicts a faster learning curve and improved performance in laparoscopic suturing. A significant number of candidates with low innate ability are unable to reach proficiency despite repeated practice. This study supports the concept of using objective selection processes based on aptitude to select suitable trainees who are likely to flourish in the challenging field of surgery if selected.

References

1. Szabo Z, Hunter J, Berci G, et al. Analysis of surgical movements during suturing in laparoscopy. *Endosc Surg Allied Technol* 1994;2: 55–61.
2. Allen JW, Rivas H, Cocchione RN, et al. Intracorporeal suturing and knot tying broadens the clinical applicability of laparoscopy. *JLS* 2003;7:137–40.
3. Stefanidis D, Hope WW, Korndorffer Jr JR, et al. Initial laparoscopic basic skills training shortens the learning curve of laparoscopic suturing and is cost-effective. *J Am Coll Surg* 2010;210:436–40.
4. Korndorffer Jr JR, Dunne JB, Sierra R, et al. Simulator training for laparoscopic suturing using performance goals translates to the operating room. *J Am Coll Surg* 2005;201:23–9.
5. Tekkis P, Senagore A. Evaluation of the learning curve in laparoscopic colorectal surgery: comparison of right sided and left sided resections. *Ann Surg* 2005;242:83–91.
6. Van Bruwaene S, De Win G, Miserez M. How much do we need experts during laparoscopic suturing training? *Surg Endosc* 2009;23: 2755–61.
7. Botden SM, de Hingh IH, Jakimowicz JJ. Suturing training in augmented reality: gaining proficiency in suturing skills faster. *Surg Endosc* 2009;23:2131–7.
8. Gallagher AG, Cowie R, Crothers I, et al. PicSOR: an objective test of perceptual skill that predicts laparoscopic technical skill in three initial studies of laparoscopic performance. *Surg Endosc* 2003;17: 1468–71.
9. Hassan I, Gerdes B, Koller M, et al. Spatial perception predicts laparoscopic skills on virtual reality laparoscopy simulator. *Childs Nerv Syst* 2007;23:685–9.
10. Buckley CE, Kavanagh DO, Traynor O, et al. Does aptitude matter? *J Am Coll Surg* 2012;215(suppl):S116.
11. Broe D, Ridgway PF, Johnson S, et al. Construct validation of a novel hybrid surgical simulator. *Surg Endosc* 2006;20:900–4.

12. Gilliam AD. Construct validity of the ProMIS laparoscopic simulator. *Surg Endosc* 2009;23:1150.
13. Neary PC, Boyle E, Delaney CP, et al. Construct validation of a novel hybrid virtual-reality simulator for training and assessing laparoscopic colectomy; results from the first course for experienced senior laparoscopic surgeons. *Surg Endosc* 2008;22:230–9.
14. Ritter EM, Kindelan TW, Michael C, et al. Concurrent validity of augmented reality metrics applied to the Fundamentals of Laparoscopic Surgery (FLS). *Surg Endosc* 2007;21:1441–5.
15. Carroll JB. *Human Cognitive Abilities: A Survey of Factor Analytic Studies*. Cambridge, UK: Cambridge University Press; 1993.
16. Dikmen SS, Heaton RK, Grant I, et al. Test-retest reliability and practice effects of expanded Halstead-Reitan Neuropsychological Test Battery. *J Int Neuropsychol Soc* 1999;5:346–56.
17. Cowie R. Measurement and modelling of perceived slant in surfaces represented by freely viewed line drawings. *Perception* 1998;27:505–40.
18. Gallagher AG, Ritter EM, Champion H, et al. Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. *Ann Surg* 2005;241:364–72.
19. Metalis S. Effects of massed versus distributed practice on acquisition of video game skill. *Percept Motor Skills* 1985;61:457–8.
20. Verdaasdonk EG, Stassen LP, van Wijk RP, et al. The influence of different training schedules on the learning of psychomotor skills for endoscopic surgery. *Surg Endosc* 2007;21:214–9.
21. Van Dongen KW, Ahlberg G, Bonavina L, et al. European consensus on a competency-based virtual reality training program for basic endoscopic surgical psychomotor skills. *Surg Endosc* 2011;25:166–71.
22. Stefanidis D, Acker C, Heniford BT. Proficiency-based laparoscopic simulator training leads to improved operating room skill that is resistant to decay. *Surg Innov* 2008;15:69–73.
23. Wanzel KR, Hamstra SJ, Anastakis DJ, et al. Effect of visual-spatial ability on learning of spatially-complex surgical skills. *Lancet* 2002;359:230–1.
24. Wanzel KR, Hamstra SJ, Caminiti MF, et al. Visual-spatial ability correlates with efficiency of hand motion and successful surgical performance. *Surgery* 2003;134:750–7.
25. Grantcharov TP, Funch-Jensen P. Can everyone achieve proficiency with the laparoscopic technique? Learning curve patterns in technical skills acquisition. *Am J Surg* 2009;197:447–9.
26. Buckley CE, Kavanagh DO, Traynor O, et al. Is the skillset obtained in surgical simulation transferable to the operating theatre. *Am J Surg* 2014;207:146–57.