# Does Aptitude Influence the Rate at which Proficiency Is Achieved for Laparoscopic Appendectomy?

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**BACKGROUND:** The attainment of technical competence for surgical procedures is fundamental to a proficiency-based surgical training program. We hypothesized that aptitude may directly affect one's ability to successfully complete the learning curve for minimally invasive procedures. The aim was to assess whether aptitude has an impact on ability to achieve proficiency in completing a simulated minimally invasive surgical procedure. The index procedure chosen was a laparoscopic appendectomy.

**STUDY DESIGN:** Two groups of medical students with disparate aptitude were selected. Aptitude (visual-spatial, depth perception, and psychomotor ability) was measured by previously validated tests. Indicators of technical proficiency for laparoscopic appendectomy were established by trained surgeons with an individual case volume of more than 150. All subjects were tested consecutively on the ProMIS III (Haptica) until they reached predefined proficiency in this procedure. Simulator metrics, critical error scores, and Objective Structured Assessment of Technical Skills (OSATS) scores were recorded.

**RESULTS:** The mean numbers of attempts to achieve proficiency in performing a laparoscopic appendectomy for group A (high aptitude) and B (low aptitude) were 6 (range 4 to 7) and 14 (range 10 to 18), respectively ($p < 0.0001$). Significant differences were found between the 2 groups for path length ($p = 0.014$), error score ($p = 0.021$), and OSATS score ($p < 0.0001$) at the initial attempt.

**CONCLUSIONS:** High aptitude is directly related to a rapid attainment of proficiency. These findings suggest that resource allocation for proficiency-based technical training in surgery may need to be tailored according to a trainee's natural ability. (J Am Coll Surg 2013;217:1020–1027. © 2013 by the American College of Surgeons)

The various challenges currently facing surgical training programs have led to numerous changes in the way surgical training is being delivered. These challenges include reduced working hours, emphasis on minimally invasive techniques (which reduce the afforded opportunities for trainees to perform index procedures), and changing patient expectations, with emphasis on consultant-delivered services. Although advantageous for the patient, the widespread application of minimally invasive techniques combined with the aforementioned challenges has created barriers to the traditional apprentice-model of surgical technical training. The skill set required in laparoscopy is very different compared with that in open conventional surgery.[1] This is due to lack of tactile feedback, precise hand-eye coordination, a change from 3-dimensional (3-D) to 2-dimensional (2-D) visualization, and adaption to the fulcrum effect.[2,3] Furthermore, the early part of the learning curve is associated with a higher complication rate.[4]

The widespread use of simulators has changed surgical training over the last decade.[5-8] There has been a shift toward implementing proficiency-based programs for surgical residents whereby one must demonstrate proficiency before progression.[9-11] The attainment of technical competence is based on completing the learning curve to a pre-established threshold set by surgical experts.

Aptitude is defined as a set of attributes that determine potential for a given activity. This potential may be developed into skilled behavior with training and practice. There are 3 main areas of aptitude that are considered relevant in

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minimally invasive procedures. These are visual spatial aptitude, psychomotor aptitude, and depth perception.

Several studies have examined the relationship between specific areas of aptitude, such as visual-spatial and perceptual ability, and laparoscopic technical skill performance.[12,13] These studies concluded that superior laparoscopic performance is demonstrated among novice surgical trainees who possess such attributes.

In 2009, Grantcharov and Funch-Jensen[14] assessed the learning curve patterns in acquiring laparoscopic skills. This study concluded that the familiarization rate of laparoscopic techniques varies according to psychomotor ability, and 4 types of learning curves were identified. Prior work in our institution demonstrated that there is an association between aptitude and simulator performance of basic laparoscopic tasks and laparoscopic colectomy.[15]

We hypothesized that aptitude may have direct implications on ability to complete the learning curve for a minimally invasive index procedure. Our study was intended to identify subjects who may not improve with repeated attempts and fail to complete the learning curve for an index laparoscopic procedure such as laparoscopic appendectomy, thereby providing objective measures to refine the selection process for future surgical trainees.

## METHODS

### Setting and study participants

Participants were recruited to take part in this study on a voluntary basis. Eighty medical students with no previous surgical experience were tested in the 3 different aptitudes described below. All participants were in years 1 to 3 of a 5-year medical school program and were asked to sign a consent form allowing data collected to be used for research purposes. It was made clear to all subjects that the data were stored and presented in an anonymous format.

Based on the results of the aptitude tests, 2 groups of 12 were selected from opposite ends of the aptitude spectrum. The first group of 12 students (group A) were considered to have high aptitude, with a score 1 standard deviation higher than the mean score of the study population. The second group of 12 students selected (group B) were considered to have low aptitude because their score was 1 standard deviation lower than the mean score of the study population. The students were blinded to which group they were in. Five experienced laparoscopic surgeons were also recruited in order to set benchmark proficiency levels on the ProMIS simulator (Haptica). Each of these surgeons had previously performed more than 150 laparoscopic appendectomies.

### Simulator and materials

The ProMIS III simulator was used for assessment. It facilitates the use of physical models, which ensures appropriate tactile feedback. Also, by tracking the instruments, it gives measurement and feedback on performance. On completion of a procedure, the simulator generates an immediate profile summary of objective measurements. These include time, path length, and economy of movement. Operative time is the length of the procedure, measured in seconds. Path length is the distance travelled by the instrument or the sum of deviations from a fixed point and is measured in millimeters. Economy of movement is a measurement of smoothness and is detected by changes in instrument velocity. It has no units and is purely a numeric value. These metrics are recorded for each instrument (right and left

**Table 1.** Operative Steps of a Laparoscopic Appendectomy

1. Check to ensure that the equipment is available and working.
2. Umbilical port is inserted using Hassan technique.
3. The 5-mm ports are introduced under vision (left iliac fossa and suprapubic areas).
4. The cecum, terminal ileum, and appendix are identified by touching them with a closed grasping forceps and naming them.
5. The tip of the appendix is grasped with the nondominant hand and it is drawn anteriorly and inferiorly to create tension on the overlying peritoneum.
6. The peritoneum is divided with the scissors.
7. Put further tension on the appendix with the grasper in the nondominant hand toward the right anterior superior iliac spine; this creates tension on the mesoappendix.
8. A space is created in the mesoappendix between the mesoappendicular artery and the appendix using the dissecting forceps in the dominant hand.
9. 3 x clips are applied with the clip applier in the dominant hand to the vessels, and the artery is divided between the more distal 2 clips.
10. An endoloop is introduced and the appendix is released from the grasper and then picked up through the endoloop with the nondominant hand.
11. The appendix is drawn toward the anterior abdominal wall with the grasper and the endoloop is opened and deployed close to the junction with the cecum.
12. The endoloop is then cut with the scissors in the dominant hand.
13. A second endoloop is then deployed (and cut) and the appendix is divided with a scissors distal to the 2 loops. It is removed through the trocar. (In the interest of cost we will not use the third endoloop of a specimen retrieval bag.)

**Table 2.** Critical Steps that Mean Failure

1. Incorrect placement of ports
2. Cutting the terminal ileum
3. Cutting the cecum
4. Incorrect placement of clips/incorrect division of artery between clips 2 and 3 such that there are 2 clips on the specimen at the end
5. Failure to place 2 endoloops on the appendix
6. Failure to cut the appendix distal to the 2 endoloops

hand) during simulation. So, one can determine the contribution of the dominant and nondominant hand to the procedure. Numerous studies have provided construct validity for this hybrid simulator.[16-19]

A synthetic appendix model (Limbs & Things) was inserted into the ProMIS simulator tray. A new model was used for each attempt. The laparoscopic appendectomy was performed in a conventional way using titanium clips to ligate the mesoappendicular vessels and endoloops to secure and transect the appendix base.

## Aptitude testing

Visual-spatial aptitude is the ability to generate, transform, and retain structured visual images. It represents ability to mentally manipulate 2-D and 3-D figures. The specific domains that are useful in laparoscopic performance are spatial visualization, spatial scanning, and spatial orientation. The kit of factor-referenced cognitive tests (1976) contains 72 marker tests that are used to identify 23 aptitude factors.[20] Four visual-spatial paper-based tests, which were previously validated,[21] were selected from this kit. These included the card rotations 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 were interested in measuring manual and finger dexterity and hand-eye coordination. This was assessed using a Grooved Pegboard (Lafayette Instrument). It has been previously validated and is a well-recognized assessment tool.[22] Test-retest reliability for the Grooved Pegboard has been reported as $r > 0.82$.

Depth perception is the visual ability to perceive the world in 3 dimensions and to assess the distance of an object. PicSOr (Pictorial Surface Orientation) testing was developed to assess perceptual ability in laparoscopic surgery.[23] It is the first objective psychometric test of perception to be used in minimally invasive surgery.[12]

## Performance assessment

Before performance assessment, each subject received didactic teaching. Each subject was sent a stepwise approach detailing how to perform the procedure (Table 1) and

**Table 3.** Demographic Details of Subjects

| Demographic | High innate ability | Low innate ability | p Value |
|---|---|---|---|
| Age, y | | | |
| Range | 18–28 | 18–25 | NS |
| Mean | 20.9 | 20.7 | |
| SD | 2.7 | 2.2 | |
| Sex, % | | | |
| Male | 50 | 8 | 0.02 |
| Female | 50 | 92 | |
| Dominant hand, % | | | |
| Right | 100 | 100 | NS |
| Left | 0 | 0 | |
| Corrected vision, % | | | |
| Yes | 67 | 50 | NS |
| No | 33 | 50 | |
| Video games, % | | | |
| Yes (at least 1 h/wk) | 50 | 42 | NS |
| No | 50 | 58 | |
| Music, % | | | |
| Yes (achieved distinction) | 100 | 58 | 0.003 |
| No | 0 | 42 | |
| Sport, % | | | |
| Yes (intercollegiate level) | 33 | 42 | NS |
| No | 67 | 58 | |

a video-link to a live recording of a laparoscopic appendectomy before the experiment commenced. When the subjects attended the first session, a simulated laparoscopic appendectomy was demonstrated. They were allocated time to ask questions before they attempted a mandatory multiple-choice questionnaire to ensure complete comprehension of the procedure. Before their first assessement, they had an opportunity to familiarize themselves with the testing equipment by completing a basic laparoscopic task. They were required to point to various items on the appendix model using the laparoscopic grasper.

Participants were asked to perform the procedure consecutively until they reached the proficiency scores. An interval practice curriculum, as opposed to massed practice, was implemented.[10,24] Subjects were allowed to perform a maximum of 3 procedures per session to avoid fatigue,[25,26] and sessions were spaced at maximum of 2 weeks apart.[27] The subjects were supervised by a senior surgeon at all times and if they needed guidance, instructions were given. However at no stage during any of the performance assessments did the senior surgeon take over the task. On completion of each procedure, the simulator provided a summary report of the metric scores, which were relayed to the candidates so that they were aware of their progress throughout the experiment.

Each performance was recorded and subsequently assessed by 2 reviewers, blinded to the status of the surgical novice, using the OSATS scoring system.[28] Each tray was examined after procedure completion for 6 predefined errors (Table 2), and this was also relayed to the candidates after each performance.

### Data analysis

Statistical analysis was performed using Stata 12.0. The aptitude, metric, and proficiency scores of the 2 groups were compared using the Mann Whitney test. A p value $< 0.05$ was considered statistically significant. Nonparametric testing was performed because none of the data were shown to have a normal distribution using the Shapiro Wilk test.

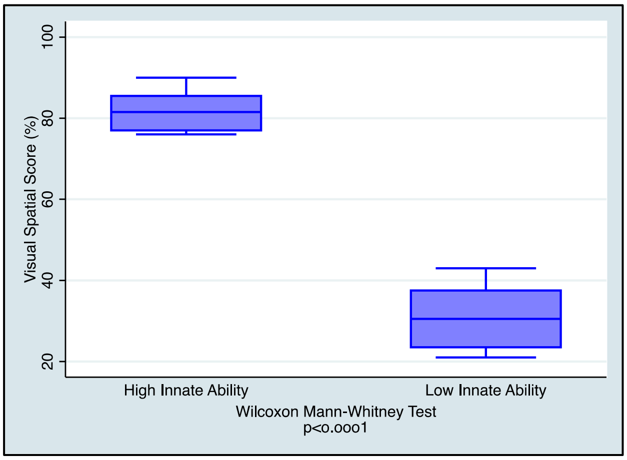


**Figure 1.** Comparison of visual spatial scores in surgical novices.

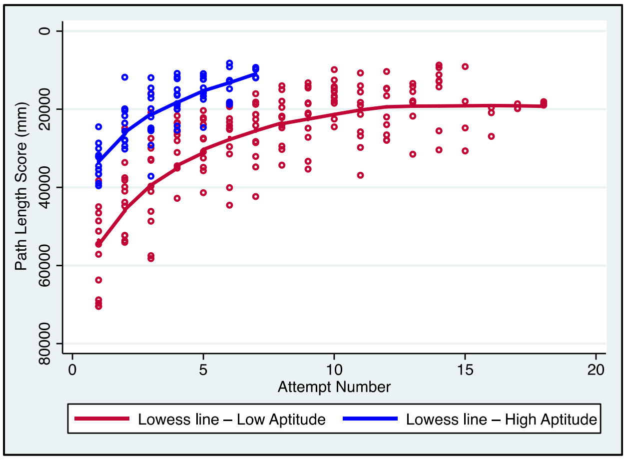


**Figure 2.** Comparison of path length scores in surgical novices.

## RESULTS

### Participant demographics

There were 17 female and 7 male subjects, and all were between 18 and 24 years old. Further demographic details of the subjects can be found in Table 3.

### Aptitude scores

There was a significant difference in the mean aptitude scores of group A and group B in all areas of aptitude. For visual-spatial aptitude, the mean score was 82% for group A compared with 30% in group B ($p < 0.0001$) (Fig. 1). The mean scores for depth perception for group A and B were 90% and 54%, respectively ($p = 0.028$). For psychomotor ability, group A had a mean score of 57 seconds compared with 71 seconds for group B ($p = 0.049$). A faster time implied a higher aptitude for psychomotor ability.

**Table 4.** Metric and Subjective Scores of the Initial Attempt in Both Groups

| Attempt 1 | High innate ability | Low innate ability | p Value (Mann-Whitney test) |
|---|---|---|---|
| Time, s | 1,126 | 1,223 | 0.4 |
| Path length, mm | 33,419 | 57,034 | 0.014 |
| Smoothness | 5,518 | 6,124 | 0.37 |
| Error score, % | 14% | 57% | 0.012 |
| OSATS score (out of 30) | 17 | 8 | <0.0001 |

OSATS, Objective Structured Assessment of Technical Skills.

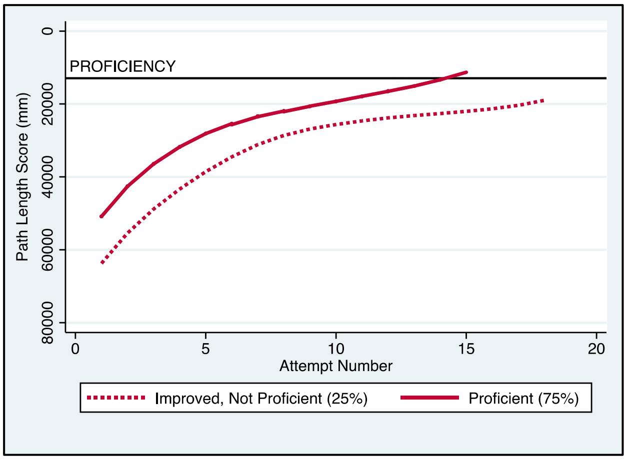


**Figure 3.** Path length scores in surgical novices with low aptitude.

### Metric scores

The metric scores of both groups for their initial attempt are shown in Table 4. The path length scores for all attempts in both groups are depicted in Figure 2. Group A had a higher score at baseline ($p = 0.014$), and they achieved proficiency faster ($p < 0.0001$) than group B. Group B can be divided into 2 subgroups based on the mean number of attempts: 75% of this group achieved proficiency at a mean of 12 attempts but 25% failed to progress after 18 attempts (Fig. 3).

Economy of movement and time scores for both groups are displayed in Figures 4 and 5, respectively. Scores for both groups in these 2 parameters were equal at the initial attempt, but group A achieved proficient levels at a faster rate ($p < 0.0001$). Again, group B can be further divided into 2 subgroups for economy of movement and time scores with 75% achieving proficiency and 25% failing to progress, which is shown in Figures 6 and 7, respectively.

### Attainment of proficiency

There was a significant difference in the number of attempts required to achieve proficiency between the 2 groups, which is demonstrated in Figure 8. Group A achieved proficiency after a mean of 6 attempts. However, group B did not achieve proficiency until a mean of 12 attempts ($p < 0.0001$). Within group B, 3 candidates (25%) failed to achieve proficiency after 18 attempts.

### Subjective scores

The error scores for both groups are shown in Figure 9. Group A committed fewer errors during their initial attempt ($p = 0.012$) and achieved an error score of 0% at a faster rate than those in group B ($p < 0.0001$).

The OSATS scores for both groups are shown in Figure 10. Group A showed superior performance at baseline ($p < 0.0001$) and achieved proficiency with fewer attempts ($p < 0.0010$) compared with group B.

## DISCUSSION

Training a surgeon involves considerable time commitments and has significant financial implications. The aim of a surgical training program is to provide a medium to train candidates efficiently, while ensuring that they are proficient in their chosen field at completion of training. As we strive to improve surgical training to ensure minimal attrition rates and achieve technical proficiency on completion of the program in a time-efficient manner, we should select those with the appropriate aptitude. The results of this study confirm that subjects with high aptitude achieve proficiency significantly earlier than those

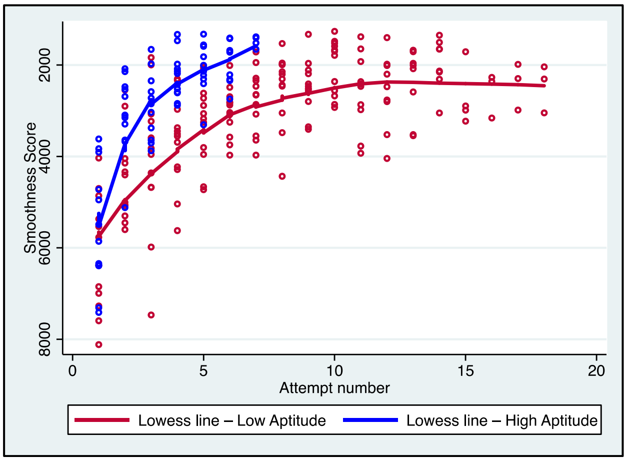


**Figure 4.** Comparison of economy of movement scores in surgical novices.

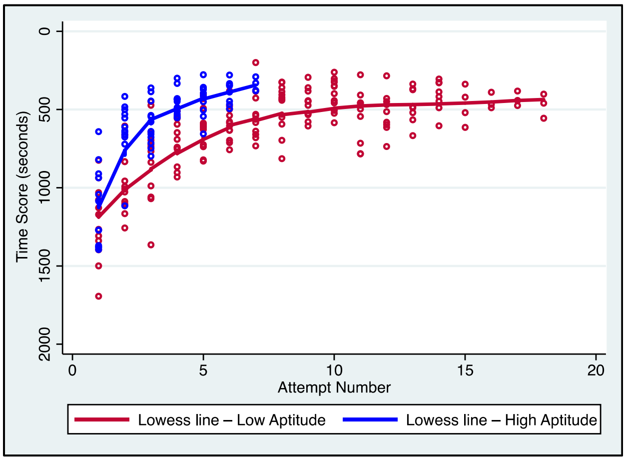


**Figure 5.** Comparison of time scores in surgical novices.

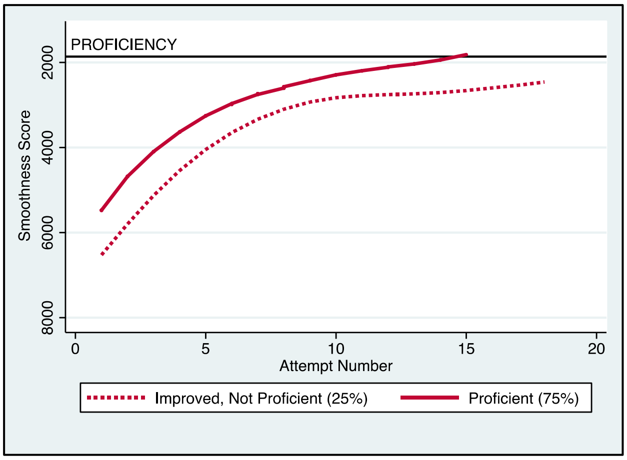


**Figure 6.** Economy of movement scores in surgical novices with low aptitude.

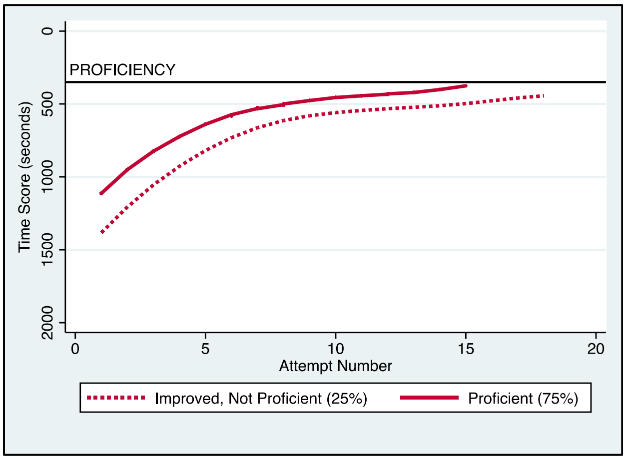


**Figure 7.** Time scores in surgical novices with low aptitude.

with inferior aptitude. Not all candidates with low aptitude can achieve proficiency despite multiple attempts. One in 4 candidates in the group with low aptitude was unable to achieve proficiency in laparoscopic appendectomy despite 18 attempts of the procedure. These findings have significant resource implications.

Work previously carried out by Stefanidis and colleagues[29] concluded that the importance of psychomotor testing lies within the prediction of how rapidly one can acquire a laparoscopic skill. Our work specifically aimed at determining the exact difference in rate of skill acquisition between those with contrasting aptitude. We have demonstrated that previously validated aptitude tests can be used to predict those who will demonstrate the technical ability and learning facility to achieve proficiency from a "novice phase." Current literature shows that residents with higher visual-spatial scores performed significantly better than did those with lower scores.[30,31] Our study strongly supports these findings because we showed that those with high aptitude scores had a reduced error score, superior baseline path length, and quicker attainment of proficiency. Our findings also support previous work that demonstrated that not all surgical candidates could achieve proficiency. Grantcharov and Funch-Jensen's study[14] found that 8.1% of their population group was unable to learn the laparoscopic technique.

This study is not intended to challenge the belief that "practice makes perfect." Instead, it is intended to identify candidates who would require a significant amount of additional training and would struggle in a highly competitive field. We are in a time of dramatic change in the surgical training environment. These findings

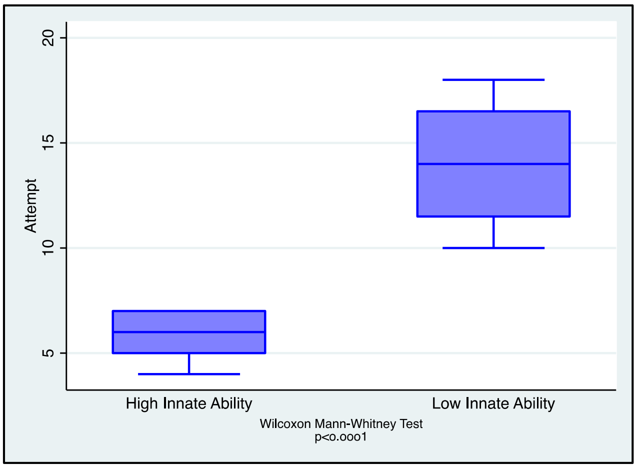


**Figure 8.** Difference in number of attempts required to achieve proficiency.

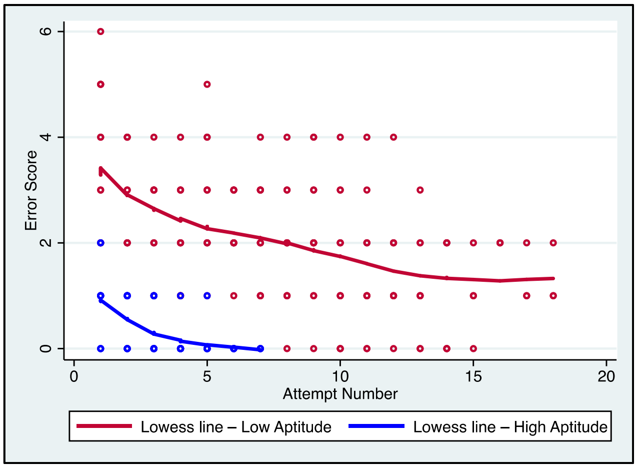


**Figure 9.** Comparison of error scores in surgical novices.

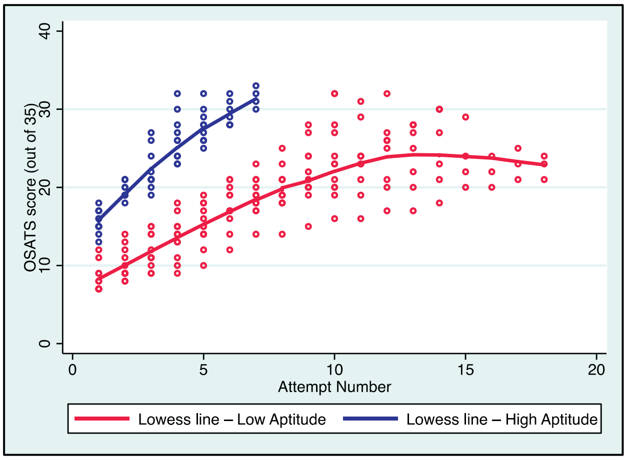


**Figure 10.** Comparison of Objective Structured Assessment of Technical Skills (OSATS) scores in surgical novices.

have significant implications in terms of surgical candidate selection and competency-based progression.

### Limitations

These findings have been demonstrated in a simulated laparoscopic environment. There is conflicting evidence to support the transfer of skill from a simulated environment to the live operating room.[32] We cannot guarantee that these specific findings would be reproducible in a live setting. In addition, we have stated that those with a 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 is not an environment in which patient safety is an issue. Therefore, perhaps it is difficult to truly establish if they have overcome the learning curve.

## CONCLUSIONS

Candidates with high innate ability became proficient at completing a laparoscopic appendectomy at a faster rate than those with lesser innate ability. Our data provide compelling support for an objective multifaceted selection process to select suitable trainees for future training programs.

### Author Contributions

Study conception and design: Buckley, Kavanagh, Gallagher, Traynor, Neary
Acquisition of data: Buckley, Kavanagh
Analysis and interpretation of data: Buckley, Kavanagh, Gallagher, Conroy
Drafting of manuscript: Buckley, Kavanagh
Critical revision: Buckley, Kavanagh, Gallagher, Traynor, Neary

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