# Spatial Abilities of Expert Clinical Anatomists: Comparison of Abilities Between Novices, Intermediates, and Experts in Anatomy

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Spatial ability has been found to be a good predictor of success in learning anatomy. However, little research has explored whether spatial ability can be improved through anatomy education and experience. This study had two aims: (1) to determine if spatial ability is a learned or inherent facet in learning anatomy and (2) to ascertain if there is any difference in spatial ability between experts and novices in anatomy. Fifty participants were indentified: 10 controls, 10 novices, 10 intermediates, and 20 experts. Participants completed four computerized spatial ability tasks, a visual mental rotation task, categorical spatial judgment task, metric spatial task, and an image-scanning task. The findings revealed that experts ($P = 0.007$) and intermediates ($P = 0.016$) were better in the metric spatial task than novices in terms of making more correct spatial judgments. Experts ($P = 0.033$), intermediates ($P = 0.003$), and novices ($P = 0.004$) were better in the categorical spatial task than controls in terms of speed of responses. These results suggest that certain spatial cognitive abilities are especially important and characteristic of work needed in clinical anatomy, and that education and experience contribute to further development of these abilities. Anat Sci Educ 4:1–8. © 2011 American Association of Anatomists.

*Key words:* anatomical sciences; medical education; anatomy education; computers in anatomy education; spatial abilities; mental rotation

## INTRODUCTION

It has been suggested in recent literature that changes in medical training over the years have increasingly neglected anatomy (Ellis, 2002) and that this has, in part, been the cause for the recent increase of medicolegal claims against surgeons in the United Kingdom (Goodwin, 2000). Moreover, new styles in anatomy teaching have taken much criticism (Kaufman, 1997; Hanna and Tang, 2005), especially teaching that focuses on computer and textbook-based learning as opposed to more traditional hands-on dissection techniques (Amadio, 1996; Cahill and Leonard, 1997; Ellis, 2001; von Lüdinghausen, 2001; Korf et al., 2008; Wood et al., 2010). A focus on anatomy teaching during medical training is necessary to identify where practical improvements can be made. Spatial ability has been found to be a good predictor of students' success in learning anatomy and examination performance (Garg et al., 2001). It has also been suggested that spatial ability might be even more important than the type of educational materials that are studied (Garg et al., 2001). Spatial ability has also been related to clinical performance. Wanzel et al. (2003) suggested that through experience, surgical performance increases regardless of individual spatial ability (or manual dexterity) making the case that inherent spatial ability becomes less important as experience takes over.

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Despite its effect on performance, both academically and clinically, spatial learning is poorly understood, and there has been very little research into the various components of spatial abilities and their implications to teaching anatomy.

Studies related to spatial ability and anatomy experience are limited; however, it is evident that experience can improve spatial ability to some extent. Kioumourtzoglou et al. (1998) found that water polo players have significantly better scores than novices on decision making, visual reaction time, and spatial orientation. Furthermore, Dror et al. (1993) found that pilots judged metric spatial relations better than nonpilots, and pilots mentally rotated objects better than nonpilots, again providing evidence for links between spatial ability and experience. With the current concerns over lamentable anatomy knowledge gained at medical school and rising litigation linked to a deficit of anatomical knowledge (Ellis, 2002; Older, 2004), understanding spatial ability with the view to improving anatomy teaching would be valuable.

The aim of this study was to examine spatial ability in experts and novices in anatomy. We used the four experimental paradigms developed by Dror et al. (1993) to objectively test and quantify various components of spatial ability of people with different experience and training in medical anatomy, from total novices to experts.

# MATERIALS AND METHODS

## Study Design

This comparative study gained favorable ethics approval from the University of Southampton, School of Medicine (SOMSEC030.09).

## Participants

Random sampling was used to select 10 controls. Ten novices (first-year medical students), 10 intermediates (fourth- and fifth-year medical students), and 20 experts. Experts for the purpose of this study were defined as university lecturers who had more than five years' experience of teaching anatomy. The demographics of the control population included an age range of 20–50 years, an academic qualification not higher than GCSE and occupations that were not related to spatial ability, e.g., anatomy technicians, architects, and pilots. There were an equal number of males and females for each category as a gender difference may exist (e.g., Voyer et al., 2000; Peters et al., 2007). Informed consent was gained from all participants.

## Methods of Measurement

The method has been designed specifically to explore four components of spatial abilities related to anatomy, components of which had been used previously to study military fighter pilots (Dror et al., 1993). These were administered via computerized experiments: a visual mental rotation task, a scanning task, a categorical spatial relation task, and a metric spatial relation task. The tasks were administered and counterbalanced across participants. Participants first had practice trials to familiarize themselves with the experimental setup and tasks. For the practice trials, participants received feedback. It was confirmed that none of the participants had previous experience with these computerized experiments.

**Rotation task.** The rotation task was selected as it mimics the need for orientation in anatomy. This type of spatial appreciation may take place clinically, for example, when orientating anatomical structures on a CT image.

Participants were presented with two consecutive black and white drawings. The first drawing was always presented upright, whereas the second drawing was either identical or differed slightly from the first presentation (e.g., an additional line was present or absent, or a shape was changed). The second drawing was presented at 0°, 35°, 70°, or 105°. The participants were required to judge whether the two drawings were the same, regardless of orientation. This task consisted of 48 trials. The trials were presented in a fixed pseudo-random order with no more than three consecutive "yes" or "no" trials, no more than three consecutive trials with the second stimuli in the same orientation, and no more than three consecutive trials with the same objects. All participants received the same order of presentation.

**Scanning task.** This task was selected as it tests the ability to scan images and recall positions of objects without the relevant stimuli. In clinical practice, this is used, for example, for image-guided procedures such as angioplasty.

Participants were presented with a circle consisting of 16 segments. Three of these segments were black and the others white. All the segments then turned white and an arrow appeared in the center of the circle. Participants were required to judge whether or not the segment to which the arrow was pointing was previously black. This task consisted of 48 trials in which the arrow pointed to a segment which was previously black in one half of the trials, and the other half pointed to a segment which was previously white. The trials were presented in a fixed pseudo-random order, with no more than three consecutive "yes" or "no" trials, no more than three consecutive trials with the arrow pointing to the same segment, and no more than three consecutive trials with the arrow pointing from the same distance. All participants received the same order of presentation.

**Categorical task.** This task was selected as it tests the ability to judge the categorical relation of one object to another. This is used clinically, for example, when surface anatomical landmarks are used to find underlying structures.

Participants were presented with a dot located above or below a bar and asked to judge whether the dot was above the bar. The dot could appear at one of four distances away from the bar. The bar could appear in one of three locations; centrally and slightly above and below central. Bar-dot stimuli were presented in a fixed pseudo-random order, with no more than three consecutive "above" or "below" trials and no more than three consecutive trials with the dot being a certain distance away from the bar. All participants received the stimuli in the same order.

**Metric task.** The metric task was selected as it tests the ability to judge specific distance. This is used, for example, when surgeons need to appreciate depth of fascial layers or when clinicians take blood.

Participants were presented with a dot located above or below a bar at different distances. For this task, participants were required to estimate the distance between the dot and the bar. Exactly the same stimuli were used in this task as in the categorical task; however, participants were required to make a different type of spatial judgment. Participants made their response by typing in their estimation (in cm) using the number pad on the keyboard with their dominant hand.

## Table 1.

Mean Number of Correct Answers

| Task | Participants | *N* | Mean | 95% Confidence interval for mean |  | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
|  |  |  |  | Lower bound | Upper bound |  |  |
| Metric | Intermediates | 10 | 36.90 | 29.87 | 43.93 | 17 | 47 |
|  | Experts | 20 | 36.55 | 32.33 | 40.77 | 12 | 47 |
|  | Novices | 10 | 25.30 | 15.17 | 35.43 | 3 | 43 |
|  | Control | 10 | 33.40 | 26.92 | 39.88 | 19 | 45 |
|  | Total | 50 | 33.74 | 30.61 | 36.87 | 3 | 47 |
| Scanning | Intermediates | 10 | 43.60 | 40.60 | 46.60 | 33 | 47 |
|  | Experts | 20 | 41.55 | 39.42 | 43.68 | 30 | 48 |
|  | Novices | 10 | 43.30 | 41.11 | 45.49 | 37 | 47 |
|  | Control | 10 | 40.60 | 37.75 | 43.45 | 35 | 48 |
|  | Total | 50 | 42.12 | 40.94 | 43.30 | 30 | 48 |
| Categorical | Intermediates | 10 | 47.00 | 45.99 | 48.01 | 44 | 48 |
|  | Experts | 20 | 47.40 | 46.87 | 47.93 | 44 | 48 |
|  | Novices | 10 | 46.20 | 43.77 | 48.63 | 37 | 48 |
|  | Control | 10 | 47.40 | 46.71 | 48.09 | 45 | 48 |
|  | Total | 50 | 47.08 | 46.56 | 47.60 | 37 | 48 |
| Rotation | Intermediates | 10 | 39.70 | 36.98 | 42.42 | 31 | 44 |
|  | Experts | 20 | 38.55 | 36.53 | 40.57 | 31 | 47 |
|  | Novices | 10 | 37.80 | 34.62 | 40.98 | 31 | 43 |
|  | Control | 10 | 38.10 | 34.19 | 42.01 | 31 | 46 |
|  | Total | 50 | 38.54 | 37.29 | 39.79 | 31 | 47 |

### Statistical Analysis

The numbers of correct answers and the mean response times were subjected to analysis of variance, comparing performance among the control, novice, intermediate, and expert groups on each of the tasks (using a 95% confidence interval). A post hoc test was performed looking at least significant difference (LSD) and pair-wise comparisons between the groups. A Bonferroni correction was performed to counter the effects of multiple testing.

## RESULTS

### Number of Correct Answers

The metric task revealed that experts and intermediates were performing better than the other groups (see Table 1). Results from parametric statistics performed on this data confirmed the statistical differences between groups; $P = 0.04$ (see Table 2). In all the other tasks (scanning, categorical, and rotation), no significant difference was found (see Table 2). A post hoc test was performed on the data from the metric task looking at LSD and pair-wise comparisons between the groups (see Table 3). Significant difference was found between the intermediate and novice groups ($P = 0.016$) and expert and novice groups ($P = 0.007$). The intermediates and experts scored a significantly higher number of correct answers than the novices. A Bonferroni correction test was completed and showed that even when accounting for multiple testing, the mean difference between experts and novices is significant, $P = 0.045$ (see Table 3).

### Response Times

Significant differences were found between groups for the scanning task, $P = 0.05$, and the categorical spatial task, $P = 0.10$ (see Table 4). A post hoc test was performed for a pair-wise comparison between groups (see Table 5). Average response time was found to be significantly faster in the scanning task in the intermediates than experts ($P = 0.027$) and controls ($P = 0.033$). Intermediates ($P = 0.003$), experts ($P = 0.033$), and novices ($P = 0.004$) response times were all found to be significantly faster than controls in the categorical spatial task.

## Table 2.

**Mean Number of Correct Answers—Overall ANOVA**

| Task | Comparison | df | *P* value |
|---|---|---|---|
| Metric | Between groups | 3 | 0.040 |
| | Within groups | 46 | |
| | Total | 49 | |
| Scanning | Between groups | 3 | 0.290 |
| | Within groups | 46 | |
| | Total | 49 | |
| Categorical | Between groups | 3 | 0.368 |
| | Within groups | 46 | |
| | Total | 49 | |
| Rotation | Between groups | 3 | 0.793 |
| | Within groups | 46 | |
| | Total | 49 | |

df, degree of freedom.

## DISCUSSION

For the metric spatial relations task, both the expert and intermediate groups outperformed the novice group, the experts and the intermediates scoring significantly higher than the novices. These results suggest that ability to judge distance may have improved through experience.

Although no significant difference was found in the categorical spatial relations task between groups when examining the number of correct answers, differences were found in response times. Novices, intermediates, and experts all responded significantly faster than the control group. These results suggest that response times in ability to assess spatial relations may have also been improved through experience. The image-scanning task showed no significant differences between groups when looking at the number of correct answers; however, differences were found in response times. Intermediates scored significantly higher than both the control and expert groups. These results suggest that response times in ability to recall positions were better in the student groups. One possible explanation for these results may be

## Table 3.

**Mean Number of Correct Answers: Metric Task: Post Hoc Test: Least Significant Difference (LSD) and Bonferroni Correction (BC)**

| | | | | | 95% Confidence interval | |
|---|---|---|---|---|---|---|
| | (I) Group | (J) Group | Mean difference (I − J) | *P* value | Lower bound | Upper bound |
| LSD | Intermediates | Experts | 0.350 | 0.931 | −7.74 | 8.44 |
| | | Novices | 11.600[a] | 0.016 | 2.25 | 20.95 |
| | | Control | 3.500 | 0.455 | −5.85 | 12.85 |
| | Experts | Novices | 11.250[a] | 0.007 | 3.16 | 19.34 |
| | | Control | 3.150 | 0.437 | −4.94 | 11.24 |
| | Control | Novices | 8.100 | 0.088 | −1.25 | 17.45 |
| BC | Intermediates | Experts | 0.350 | 1.000 | −10.74 | 11.44 |
| | | Novices | 11.600 | 0.097 | −1.20 | 24.40 |
| | | Control | 3.500 | 1.000 | −9.30 | 16.30 |
| | Experts | Novices | 11.250[a] | 0.045 | 0.16 | 22.34 |
| | | Control | 3.150 | 1.000 | −7.94 | 14.24 |
| | Control | Novices | 8.100 | 0.526 | −4.70 | 20.90 |

Comparing (I) group, the control, to (J) group, the comparator (representing intermediates, experts, novices, and control groups, respectively), to see if there is a significant difference in results between these groups.

[a] Significant at *P* value ($<0.05$) showing (J) group to be inferior to (I) group.

## Table 4.

Average Response Times

| Average response time in tasks | Comparison | df | *P* value |
|---|---|---|---|
| Metric | Between groups | 3 | 0.546 |
| | Within groups | 46 | |
| | Total | 49 | |
| Scanning | Between groups | 3 | 0.050 |
| | Within groups | 46 | |
| | Total | 49 | |
| Categorical | Between groups | 3 | 0.010 |
| | Within groups | 46 | |
| | Total | 49 | |
| Rotation | Between groups | 3 | 0.801 |
| | Within groups | 46 | |
| | Total | 49 | |

df, degree of freedom

that student participants are more familiar with computer-based programs than the expert group (because of a generation difference), and, therefore, the student groups were quicker at responding on these computer-based programs. For mental rotation, no significant differences were found between any of the groups in either the number of correct answers or response times. These results suggest that the ability to mentally rotate had not been improved through experience.

In most of the tasks, it was found that expert groups responded faster overall than nonexpert groups (with the exception of image scanning). We found that experts had better ability to judge metric spatial relations. However, in contrast, there was no evidence that the more expert groups have higher ability to scan visual mental images or mentally rotate objects. Thus, there is evidence that experts have selective advantages, not overall superior performance. Reasons for selective advantages in the more experienced groups may be focused on the variable plasticity of different regions of the brain responsible for difference aspects of spatial ability. Evidence suggests that some processes in the brain are more plastic and thus susceptible to change, whereas other processes are less plastic, and one possible reason for such differences is that some processes rely on more primitive, hard-wired brain structures than others do (DeFelipe, 2006).

The metric spatial relations task requires the participant to make precise distance judgments. Such processing relies on accurately making small spatial distinctions, which involves the parietal lobes, particularly right parietal lobe structures (Hellige and Michimata, 1989; Kosslyn et al., 1989). However, no difference was found in the mental rotation task where such processing relies on a set of complex computations that involve parietal and frontal lobe structures (Deutsch et al., 1988).

All groups scanned images at comparable rates finding no significant differences between levels of expertise; image scanning is thought to involve the middle temporal area of the brain, possibly suggesting that image scanning is a less adaptable brain process (Allman et al., 1985).

Overall, the more experienced groups judged metric spatial relations better than the novice group. Other studies have also demonstrated this same finding. For example, Dror et al. (1993) showed that ability to judge metric spatial relations is learnt through experience. Both the expert and intermediate groups outperformed the novices, and this result dovetails well with other research, which suggest that inherent spatial ability becomes less important as experience takes over (Wanzel et al., 2003). It is clear from previous research that spatial ability is a reliable predictor of success in learning anatomy (Rochford, 1985; Garg et al., 2001; Guillot et al., 2006).

This is all a prelude to focusing anatomy teaching on developing those spatial skills that are susceptible to change. If spatial abilities are adaptable in individuals, then improving 3D anatomy teaching, techniques, and materials is paramount in advancing anatomy learning amongst medical students. The review of current teaching techniques enters into the ongoing debate over the advantages and disadvantages of using human cadavers for teaching. The ability to observe the form of 3D structures and the spatial relationship between them are some of the primary advantages of learning anatomy by using human cadavers (Crisp, 1989; Hill and Anderson, 1991; Pabst, 1993; Marks, 1996; Wood et al., 2010).

Evidence also suggests that computer-based teaching materials are associated with a better understanding of spatial anatomy (Silén et al., 2008; Petersson et al., 2009) and improved learning (Lynch et al., 2001; St Aubin, 2001; McNulty et al., 2004, 2009; Sugand et al., 2010). Furthermore, they have proved to be well received by students (Nieder et al., 2000; McNulty et al., 2009). Whether human cadavers have a select advantage over computer-based material is a matter of ongoing debate; however, it is clear that both techniques use spatial ability and could have the potential to improve individual spatial abilities that are susceptible to change. Moreover, measuring the spatial abilities that are not susceptible to change could be used as criteria for screening and selecting medical professionals of which anatomical spatial ability is most relevant, for example, surgeons.

Although it might be thought that interest in applied anatomy may be driven by innate higher spatial ability, evidence suggests that individual interest is actually governed by perceived training needs (Langlois et al., 2009). Therefore, medical trainees may not necessarily be choosing medical professions that compliment their innate skill strengths further highlighting the importance of attempting to introduce more techniques and teaching methods to improve spatial ability where possible.

The authors recognize that the study had some limitations. First, the experimental design used two-dimensional (2D), not three-dimensional (3D) pictures. Anatomical spatial appreciation involves 3D and 2D visualization. As this was the first study of its kind, 2D testing was appropriate and has established a baseline; however a later study could build on the data to include 3D testing. However, the cognitive literature suggests that 2D and 3D image rotations are very similar

## Table 5.

**Average Response Times: Post Hoc Test**

| | | | | 95% Confidence interval | |
|---|---|---|---|---|---|
| **Dependent variable** | **(J) Group** | **(I) Group** | ***P* value** | **Lower bound** | **Upper bound** |
| Metric average response time | Experts | Intermediates | 0.167 | −131.6036 | 737.5856 |
| | | Novices | 0.389 | −246.6606 | 622.5286 |
| | | Control | 0.597 | −319.5736 | 549.6156 |
| | Novices | Intermediates | 0.647 | −386.7696 | 616.8836 |
| | Control | Intermediates | 0.455 | −313.8566 | 689.7966 |
| | | Novices | 0.771 | −428.9136 | 574.7396 |
| Scanning average response time | Experts | Intermediates | 0.027 | 76.0099 | 1219.9681 |
| | | Novices | 0.077 | −57.5881 | 1086.3701 |
| | Novices | Intermediates | 0.686 | −526.8666 | 794.0626 |
| | Control | Intermediates | 0.033 | 59.7944 | 1380.7236 |
| | | Experts | 0.800 | −499.7091 | 644.2491 |
| | | Novices | 0.080 | −73.8036 | 1247.1256 |
| Categorical average response time | Experts | Intermediates | 0.149 | −32.1764 | 205.4974 |
| | | Novices | 0.206 | −43.1644 | 194.5094 |
| | Novices | Intermediates | 0.873 | −126.2330 | 148.2090 |
| | Control | Intermediates | 0.003 | 79.0660 | 353.5080 |
| | | Experts | 0.033 | 10.7896 | 248.4634 |
| | | Novices | 0.004 | 68.0780 | 342.5200 |
| Rotation average response time | Intermediates | Experts | 0.841 | −710.5326 | 868.9756 |
| | | Novices | 0.513 | −613.4274 | 1210.4314 |
| | Experts | Novices | 0.579 | −570.4736 | 1009.0346 |
| | Control | Intermediates | 0.752 | −767.8329 | 1056.0259 |
| | | Experts | 0.572 | −566.4361 | 1013.0721 |
| | | Novices | 0.334 | −469.3309 | 1354.5279 |

Comparing (I) group, the control, to (J) group, the comparator (representing intermediates, experts, novices, and control groups, respectively), to see if there is a significant difference in results between these groups. A significant *P* value ($<0.05$) showing (J) group to be inferior to (I) group.

from a cognitive perspective. Genetic, hormonal, and neurological factors were not controlled and have been found to potentially affect individual spatial ability (McGee, 1979). Environmental factors, such as vocational activities involving spatial intelligence, were also not controlled. Although participants' ages were noted, this factor was not taken into account when analyzing results but has also been shown to potentially influence spatial ability (Salthouse and Mitchell, 1990; Salthouse et al., 1990). It is possible that self-selection bias meant that the participants who volunteered to take part in the study were those who believe that they have good spatial ability and thus introduced self-selection bias. Furthermore, the medical students used for this study were all from the University of Southampton, whereas the anatomy experts had studied in a range of universities. As the Southampton students had received all the same anatomy teaching, it might be that this university may teach spatially relevant anatomy differently compared with other universities, and so these students may score a higher or lower average on the tasks. For the categorical and scanning tasks, the majority of scores are at or near the maximum possible for the test (48), suggesting a possible ceiling effect. This may have limited the ability to measure the different groups by creating values near the ceiling limit. This may have reduced variance, decreasing the sensitivity of the experiment and, therefore, does not determine if the average of one group is significantly different from the average of another group. The control group involved a range of ages 20–50 years; in subsequent tests, it may be possible to improve age matching and have a control group for each participant group, e.g., nonmedical students and nonscience professors.

## CONCLUSION

This study is a step toward understanding spatial abilities required for conducting and understanding anatomy. Spatial ability is a good predictor of successful anatomy learning, and evidence from this study suggests that only certain aspects of spatial ability can be gained through experience. Current educational methods, such as dissection, and more recently 3D computer images, have been shown to produce a better understanding of spatial anatomy (Crisp, 1989; Hill and Anderson, 1991; Pabst, 1993; Marks, 1996; Silén et al., 2008; Petersson et al., 2009). In the light of the results from this study, it may be possible to develop "spatial ability" sessions, which at various points in the curriculum enable students to refine their spatial skills in order to enable more effective learning of anatomy. This would add to current methods of learning through specifically targeting certain components of spatial ability, as this is important in successful anatomy learning (Garg et al., 2001).

## NOTES ON CONTRIBUTORS

RUTH FERNANDEZ, B.Med., B.Sc., is a foundation Year 1 doctor in the Royal Hampshire County Hospital, Winchester, United Kingdom. She undertook part of the experimental work and performed data analysis.

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