Role of Spatial Ability as a Probable Ability Determinant in Skill Acquisition for Sonographic Scanning

Douglas W. Clem, PhD, RDCS, RVT, Joe Donaldson, PhD, Brad Curs, PhD, Sharlette Anderson, MHS, RDMS, RDCS, RVT, Moses Hdeib, MD, RDMS, RVT, RDCS

Objectives—Spatial ability refers to an individual’s capacity to visualize and mentally manipulate 3-dimensional objects. Because sonographers manually manipulate 2- and 3-dimensional sonographic images to generate renderings of anatomic structures, it can be assumed that spatial ability is an ability determinant for understanding and producing these medical images. Using the theory of ability determinants of skilled performance as a conceptual framework, this study explored the relationship of spatial ability and learning sonographic scanning.

Methods—Beginning sonography students from 3 different types of educational institutions were administered a spatial ability test before their initial scanning laboratory course work. The students’ spatial test scores were compared with their scanning competency performance scores after the first scanning competency test and then to the overall average of the competency scores for the 2 semesters. The spatial ability test was again administered after the 2-semester learning period to see whether the students’ spatial ability had increased.

Results—A significant relationship between the students’ spatial ability test scores and their scanning performance scores was found after the first scanning competency (r = 0.46; P < .05), and also when averaging all competency scores throughout the learning period (r = 0.49; P < .05). A moderate increase in the spatial ability of the students was also found (r = 0.32; P < .05). The incoming grade point average was found to be more predictive of the students’ scanning scores than spatial or ACT scores. No relationship was found between spatial ability and student retention.

Conclusions—High spatial test scores as well as a high incoming grade point average appear to be the best ability determinants in skill acquisition for sonographic scanning.

Key Words—sonographic scanning; sonography; spatial ability

Spatial ability is a neurophysiologic aptitude that allows humans to visualize and mentally manipulate objects in space. Spatial images can be thought of as “pictures in the mind,” which are the products of a mental process that constitutes a concrete mental image constructed identically to the object viewed in reality. Recently, numerous studies have linked the role of spatial ability and its importance in learning certain specific skills in medical occupations, especially in general surgery, colonoscopy, laparoscopic surgery, and dentistry. Dental educational programs have included spatial ability testing as part of required admissions criteria since the 1940s.
Research on spatial ability testing in relation to occupational aptitude has been done by a host of researchers since the 1920s. Spatial ability aptitude tests have been shown to be valuable in predicting individual performance and success in occupations such as dentistry, art, engineering, industrial machine operating, drafting, designing, surgery, and many others. Many of these careers require high scores on spatial ability tests before hire or for admission to their educational programs.

Conceptual Framework
The conceptual framework for this study was based on well-established theories derived from scholarly work done regarding human skill acquisition. Ackerman’s theory of skill acquisition was used as the conceptual basis for this study. According to the theory, there are 3 phases through which the learner must progress in skill acquisition, with a specific ability determinant that facilitates task performance.

During the cognitive phase (phase 1), task performance places high demands on general intellectual abilities in verbal, figural, and numeric areas. In the associative phase (phase 2), skill acquisition places demands on perceptual speed abilities, or the rate at which a task can be accomplished. In the autonomous phase (phase 3) of skill acquisition, demands are placed on psychomotor skills (muscular movements resulting from mental processes) to the point whereby performance of the skill becomes automatic and proceeds with little or no concentrated effort.

Ackerman’s theory can be applied to acquiring the skills of sonographic scanning. The cognitive phase of learning sonographic scanning is quite demanding. While one hand is manipulating the probe, the other is operating the machine to optimize the images produced. At the same time, sonographers must visually understand and interpret what they see and make the appropriate corrections with the probe. The associative phase of skill acquisition involves strengthening the associations that the learner has made during the cognitive phase and places demands on perceptual speed abilities. Repetition and deliberate practice hone the skills necessary for task accomplishment in a timely fashion. Finally, the autonomous phase places demands on psychomotor abilities. After completion of this phase, the student scans effortlessly with one hand, operates the machine with the other, and mentally interprets the images throughout the varying protocol of the study quickly and efficiently.

Previous Study
An exploratory study performed previously by the primary investigator found a fairly weak correlation between the beginning sonography students’ spatial test scores and their first 30-hour scanning competency scores ($r = 0.20$). However, a strong correlation ($r = 0.60$) was found between the spatial test scores and their 2-semester averaged competency scores. This study was an extension of the exploratory study and explored spatial ability as an ability determinant in skill acquisition for sonographic scanning.

Research Questions
The following research questions were addressed in this study: (1) what is the range of spatial ability of beginning sonography students; (2) is there a relationship between spatial ability and learning sonographic imaging; and (3) does spatial ability improve throughout the learning period in the sonography program?

Materials and Methods

Research Design
Permission was granted from our Institutional Review Board for the 3 years of study (2008–2011) for exploring the relationship between spatial ability and student performance in learning to scan sonographic images. We conducted a correlational, quantitative study whereby analyses centered largely on the use of descriptive statistics, histograms, correlations, and various forms of regression to answer the 3 research questions. The sample of student sonographers was drawn from 4 sonography programs from different parts of the country.

Data Sources
For this study, student participants in sonography programs from the following types of institutions volunteered to participate: a large Midwestern university, a Midwestern community college, a community college from the Atlantic coastal region, and a proprietary school. The directors of these programs volunteered to participate in the study. True names of the educational institutions are not provided to protect the identities of the participating schools. Instead, regions of origin will be used to identify the programs.

Sample
Eleven abdominal students from the exploratory study were included in this expanded study, for a total number of 79 who contributed data that included the pre instructional spatial test scores, the first 30-hour Sonography Clinical Assessment Notebook (SCAN) scores, and the 2-semester averaged SCAN scores. However, 6 students dropped out of their sonography programs before the study ended, 5 from the Midwestern community college and 1 from the...
Atlantic coast community college, for a total number of 73. Table 1 shows the breakdown of study participants by site, number of students, specialty, and year of study after the 6 students dropped.

**Instrumentation: Revised Minnesota Paper Form Board Test, Independent Variable**

Spatial ability tests are designed to evaluate a person’s ability to mentally manipulate diagrams of objects into alternate formations. The original Revised Minnesota Paper Form Board Test (RMPFBT) was developed in the late 1920s by Likert and Quasha and was the first psychometric test assessing visual-spatial ability. The test measures an ability that predicts performance in jobs requiring the capacity to visualize and mentally manipulate objects in space. The RMPFBT has been used to assess applicants in a wide range of jobs, including electrical and mechanical positions in industrial plants, mechanics at utility companies, draftspersons, industrial machine operators, and many others. The test used for this study was updated in 1995. It is a 65-question, 20-minute, paper-and-pencil test that evaluates spatial relationship abilities. The range of possible scores is 0 to 64.

**Reliability and Validity of the RMPFBT**

The RMPFBT has split-half reliability measuring internal consistency of 0.93 and a test-retest score of 0.85, measuring stability over time. There are 4 alternate forms of the test, with reliability of 0.85. Criterion-related validity, which means to provide an educated guess about an examinee’s potential for future success, has not been established for sonography, but comparatively for a medical occupation that has used spatial ability testing since the 1940s, it is 0.61 for dentistry. Construct validity, or the extent to which a test measures the trait (spatial ability) it was designed to measure, which in this case was visual spatial ability, is 0.75.

**Instrumentation: SCAN, Dependent Variable**

The SCAN was devised by the International Foundation for Sonography Education and Research with initial funding provided by the Society for Diagnostic Medical Sonography Educational Foundation. It is an evaluation tool designed to aid in the assessment of clinical proficiencies of sonography students. It is competency based and designed in such a way that a student’s proficiency for each specialty in sonography can be assessed.

Student achievement, or performance in sonographic imaging for this study, was assessed by the student’s instructor/preceptor at each site using a 1 to 5 Likert scale on the SCAN competency form, with a score of 5 being optimal execution of the specific competency and a score of 1 being nondiagnostic quality of the competency. Scores of 2, 3, and 4 were used for intermediate levels of competency. Inter-rater variability is expected when using a 5-point Likert scale and may be a limitation to the accuracy of assessing individual performance.

All participants in the study had their scanning competency scores recorded for the following competencies: aorta, liver, abdominal Doppler, pancreas, kidneys, gallbladder, and spleen. The pelvis competency scores were available from 2 sites, the Midwestern university and Atlantic coast community college, but were not available from the other 2 sites. Global scores for each competency were totaled and then averaged for a percentage score. The procedure for administering the spatial tests and scoring the competencies and the logistics of handling each follow.

**Procedure**

All students were complete beginners; they had no experience scanning any sonographic images before this time. Each site’s preceptor administered the informed consent, and then the spatial tests were administered twice: before laboratory instruction and after the 2-semester learning period. After signing the informed consent, the students wrote their names on the first page of the test booklet, which was numbered. The preceptor kept the front page with the student’s name and test booklet number. After the student completed the spatial test, the preceptor gathered the test booklets and consent forms and mailed them back to the primary investigator.

<table>
<thead>
<tr>
<th>Table 1. Sample Population</th>
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<tr>
<td><strong>Study</strong></td>
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<tr>
<td>Exploratory</td>
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<tr>
<td>Expanded</td>
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<td>Expanded</td>
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</table>
The primary investigator had only the student’s test booklet number for identification purposes, with no other identifying information. The site preceptor did not have any knowledge of any student’s spatial test scores throughout the 2-semester learning period. A copy of the informed consent and the pre and post spatial scores were returned to the preceptors in sealed envelopes to disseminate to the study participants at the completion of the study.

During the 2-semester learning period, the students’ scanning scores from their sonography laboratory courses were recorded on the appropriate SCAN form for each particular competency for 2 consecutive semesters. When the 2-semester learning period was completed, the completed SCAN forms were mailed back for analysis.

Variables in the Study
The independent variable was the students’ spatial test scores on the RMPFBT. The dependent variable was the students’ scanning scores. For Midwestern university classes, incoming grade point average (GPA) and ACT test scores were also analyzed.

Data Analysis
Data provided by the 4 study sites were imported into IBM SPSS Statistics Version 19 software and analyzed according to the demands of each of the following research questions:

1. What is the range of the spatial ability test scores among the sonography students from the 4 sites? For the quantitative analysis of this question, descriptive statistics, histograms, and 1-way analysis of variance (ANOVA) were used to explore the range of spatial ability before beginning laboratory instruction. Individual percentile normative comparisons were made according to information provided in the RMPFBT manual.

2. What is the relationship between spatial ability and learning sonographic scanning? Using bivariate correlation analysis, the students’ spatial test scores were compared to their scanning competency scores. Simple regression with one independent variable was used, which correlated the spatial test scores with the scanning scores in the 4 categories. Then multiple regression analysis was performed in analyzing spatial and scanning scores with the additional student demographic information.

3. Does spatial ability improve throughout the 2-semester learning period? A repeated measures dependent means $t$ test was used to analyze question 3.

Results

Question 1: What Is the Range of Spatial Ability of Beginning Sonography Students?
Figure 1 shows a histogram for the pre spatial test scores for the remaining 73 study participants after 6 students dropped out. Table 2 provides the descriptive statistics for the pre spatial test scores by site.

Table 2: Descriptive Statistics for Pre Spatial Test Scores by Site

<table>
<thead>
<tr>
<th>Measure</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwestern university class 1</td>
<td>11</td>
<td>44.55</td>
<td>5.429</td>
<td>34</td>
<td>52</td>
</tr>
<tr>
<td>Midwestern university class 2</td>
<td>13</td>
<td>48.08</td>
<td>5.722</td>
<td>39</td>
<td>57</td>
</tr>
<tr>
<td>Midwestern university class 3</td>
<td>19</td>
<td>51.11</td>
<td>7.745</td>
<td>34</td>
<td>64</td>
</tr>
<tr>
<td>Atlantic coast community college</td>
<td>8</td>
<td>52.25</td>
<td>10.264</td>
<td>29</td>
<td>61</td>
</tr>
<tr>
<td>Midwestern community college</td>
<td>11</td>
<td>47.18</td>
<td>8.424</td>
<td>31</td>
<td>58</td>
</tr>
<tr>
<td>Proprietary school</td>
<td>11</td>
<td>40.18</td>
<td>8.256</td>
<td>28</td>
<td>54</td>
</tr>
</tbody>
</table>
Referring to the RMPFBT test manual’s table of normative data for educational groups, the spatial test scores ranged from the 25th to 95th percentiles. The expanded study’s raw scores ranged from 28 to 64 (out of a possible high score of 64), which corresponded to a range from the 10th to 99th percentiles, where \( N = 73 \). The Atlantic coast community college had the highest mean, whereas the proprietary school had the lowest.

A 1-way ANOVA or an \( F \) test was performed with the site as the independent variable to see whether the differences between the means of all the sites were statistically significant. Results indicated that there was a significant difference between the means of the pre spatial test scores between sites (\( F(5,67) = 3.8; P < .05; \omega = 0.47 \)). The \( \omega \) statistic is called “omega squared” and represents the effect size, similar to \( r^2 \) in a regression model. A result of greater than 0.50 represents a large effect size. In this case, at 0.47, it very nearly is. Overall, the descriptive statistics for the expanded study showed a wide range of spatial ability amongst the students, and histogram analysis revealed a normal distribution for the 73 expanded study participants.

**Question 2: Is There a Relationship Between Spatial Ability and Learning Sonographic Imaging?**

Applying Ackerman’s theory of skill acquisition to the study, it was expected that a strong relationship should be seen between spatial ability and the students’ scanning scores after their first scanning competency or after the first 30 hours of instruction. Then, after practice and instruction throughout the semester, a less robust relationship should be seen, as the automaticity of the skill develops during phase 3 and replaces the high cognitive load from phase 1. The results of the relationship after the first scanning competency are shown in Figure 2.

Figure 2 shows a scatterplot after the first 30 hours of laboratory instruction. Regression analysis was done to assess the linearity of the results to the regression model. With a Pearson \( r \) correlation of 0.46, this result indicates a moderate effect. The coefficient of determination, or \( r^2 \), of 0.21 indicates that about 21% of the variance in the scanning competency scores can be attributed the spatial test scores. Then regression analysis was performed for the 2-semester averaged time of measure. A scatterplot for this measure is shown in Figure 3. For the 2-semester averaged time of measurement, Pearson \( r = 0.49 \), and \( r^2 = 0.23 \).

**Multiple Regression Comparing Spatial, ACT, and GPA Data for Midwestern University Classes 1–3**

Demographic information for the age of participants was not available for the Midwestern university, and complete data for ACT scores and incoming GPA were not available from the sites other than the Midwestern university. Therefore, only the 3 Midwestern university classes that supplied spatial test scores, ACT or Graduate Record Examination (GRE) scores, and the incoming GPA could be analyzed to compare which variable was more predictive of the scanning scores. The following are results from multiple regression analysis for Midwestern university class 1–3 undergraduates for the first 30-hour SCAN scores in Table 3 and then the 2-semester averaged SCAN scores in Table 3, comparing the means between their spatial test scores, their ACT scores, and their incoming GPA.

**Figure 2** Scatterplot after 30 hours of laboratory instruction.

![Figure 2](image1)

**Figure 3** Scatterplot of the 2-semester averaged measure of laboratory instruction.

![Figure 3](image2)
Notice that for the 2-semester averaged time of measure, a statistically significant result occurred for incoming GPA ($P < .05$). A $B$ value of 5.41 indicates that as the GPA increases by 1 unit, scanning scores increase by 5.41 units. The units for GPA (eg, 4.0) are measured in tenths. These results mean that the incoming GPA is a more valuable predictor of success in learning sonographic scanning than spatial test scores or ACT scores.

Multiple regression analysis for Midwestern university class 1–3 graduate students for the first 30-hour SCAN scores and then the 2-semester averaged SCAN scores was performed. Interestingly, while the GPA was the best predictor of scanning scores for the undergraduates, the GPA is also seen below as a strong predictor in comparison to GRE and spatial test scores but was not statistically significant.

**Question 3: Does Spatial Ability Improve Throughout the Learning Period in the Sonography Program?**

Question 3 was analyzed by using the data from the expanded study’s 4 sites (Midwestern university class 3, Atlantic coast community college, Midwestern community college, and proprietary school) whose participants completed the pre and post spatial tests ($n = 49$). Repeated measures dependent $t$ tests were performed with the following results: mean = 47.96; SE = 1.34; $t(48) = –2.31; P < .05$; and $r = 0.32$. Histograms of pre and post spatial test scores were also compared, as shown in Figure 4.

The histogram for the pre spatial test scores for the overall category of 49 participants shows a normal distribution, with insignificant values of skew (−1.50) and kurtosis (−0.814), which are less than 1.96. By contrast, the histogram for the post spatial test scores shows a leftward

**Table 3. Multiple Regression Analysis for 2-Semester Averaged SCAN Scores of Midwestern University Undergraduates**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>SE</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre spatial test scores, Midwestern university class 1–3 undergraduates</td>
<td>0.03</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Midwestern university undergraduate ACT scores</td>
<td>0.08</td>
<td>0.14</td>
<td>−0.10</td>
</tr>
<tr>
<td>Undergraduate incoming GPA</td>
<td>5.41</td>
<td>2.07</td>
<td>0.44†</td>
</tr>
</tbody>
</table>

Note: $r = 0.69; r^2 = 0.47$, significant for undergraduate incoming GPA (*$P < .05$).

**Figure 4.** Comparison of pre and post spatial test scores for the 49 expanded study participants.
negative skew of –3.03, significant at \( P < .01 \), with the value of kurtosis (1.80) being insignificant. The \( t \) value of –2.31 can be converted to an \( r \) value, or effect size, of 0.32 (\( P < .05 \)), which indicates a moderate improvement in spatial ability for the expanded study participants.\(^{17}\)

While results of the combined data from all sites indicate a moderate improvement of the students’ spatial ability, when analyzing the data by site, no individual site showed improvement that was statistically significant. Each site, except for Midwestern university class 3, had a small number of participants, well under the usually acceptable number of 15 for statistical evaluation. When aggregated together, the analysis becomes clearer.

Discussion

This expanded study sought to validate the findings of the primary author’s previous exploratory study. It also addressed several limitations of that study by (1) expanding the scope of the sample to include the different types of educational institutions commonly found in sonography education in the United States, (2) increasing the sample size from 17 to 73, (3) adding a post spatial test for additional investigation, and (4) incorporating student demographic information in the analysis. A discussion on each of the 3 research questions follows.

For question 1, the exploratory study found a wide range of spatial ability among the 17 students. The expanded study’s raw scores ranged from 28 to 64, which corresponded to a range from the 10th to 99th percentiles, validating the exploratory study’s finding of having a wide range of spatial ability among the beginning sonographers. Histogram analysis revealed a normal distribution for the original 79 expanded study participants. The results suggest that even with all of the screening practices of the admissions committees who seek to find the best possible candidates by requiring such information, there remain marked differences in spatial ability among beginning sonography students. In other words, there does not appear to be any “weeding out” of students with low spatial ability during the screening process.

Therefore, sonography program admission committees are admitting people with low spatial ability who may be at a disadvantage in learning to scan, compared to those people with high spatial ability. If admission committees are screening for the best possible candidate, then administering a spatial ability test would be appropriate. This procedure may be especially prudent for certificate programs, community colleges, and proprietary schools, which may not have enough time built in their curricula to allow for low–spatial ability learners to catch up to high–spatial ability learners.

Bachelor’s degree programs may believe that they have the time and resources to work with low–spatial ability learners. These types of programs offer multiple specialties over several years of study, which allows all learners time to hone their scanning skills and to choose which sonographic specialty suits them best individually. A spatial ability test for bachelor’s programs may be better used to identify low–spatial ability learners to individualize their course of study and allow them extra practice and instruction.

Ideally, to assess skill acquisition through all 3 phases of Ackerman’s model of skill acquisition,\(^{15}\) the participants would be followed learning to scan one task (one specific organ) throughout the learning period, with all competency testing made at the same time intervals at all sites. The final scan would thus indicate the level of scanning ability attained for that particular organ. A study that includes a repeated measures ANOVA design could then be used for analysis to explore the students’ progress in relation to their spatial ability in all 3 phases of skill acquisition.

In this study, however, different organs were scanned from the onset to the end with an increasing degree of difficulty from start to finish. Competency testing was not done at the same time at all sites, except for the first 30-hour measurements, and there were unequal numbers of competency tests. Most sites started with the aorta scan as the first laboratory competency. The Midwestern community college, however, started with gallbladder competency. It is unknown whether one competency is more difficult than the other.

Therefore, the next best measure of assessing learning throughout the 2-semester period was to average all the competency scanning scores. This measure includes all scanning scores from start to finish, but since the last scan is much more difficult than the first scan, this time of measure may or may not represent the students’ level of skill attainment. For question 2, which explored the relationship between spatial ability and sonographic scanning, the previous exploratory study showed a significant correlation between spatial ability and skill acquisition of scanning (\( r = 0.60 \), not after the initial 30 hours (\( r = 0.26 \)), as expected. In the expanded study, however, both times of measure were significant (\( r = 0.43 \) and 0.49, respectively). In comparison to other similar studies from surgical training, Anastakis et al\(^{18}\) found a correlation of \( r = 0.58 \) between the RMPFBT and general surgery ability. Other examples of spatial ability and skill acquisition included: acquiring colonoscopy skills,\(^{5}\) finding \( r = 0.61 \) correlation with spatial ability; laparoscopy skills,\(^{4}\) \( r = 0.39 \) correlation; and dental skills,\(^{4}\) \( r = 0.50 \) correlation.
For the exploratory study, it was expected that a strong correlation would be seen after the first 30 hours of instruction. Instead, the study found a much weaker correlation (0.26) after the first 30 hours than for the overall 2-semester averaged scores (0.60). It was unclear at the time why this result occurred and was a point of emphasis for the expanded study to validate this finding.

The expanded study’s results for the first 30 hours produced a Pearson correlation of $r = 0.46$, which is much stronger than the $r = 0.26$ correlation found in the exploratory study. For the 2-semester averaged scores, $r = 0.49$, which was not as robust as the $r = 0.60$ from the exploratory study. The expanded study’s initial correlations were similar to the findings from other studies in the medical skill acquisition literature noted above. The 2-semester averaged correlation ($r = 0.49$) concurred with the findings of the other studies that spatial ability may be important in the latter stages of skill acquisition as well.

One possible hypothesis for a lower correlation after the first 30 hours of instruction may be that cognitive overload and/or underdeveloped psychomotor skills are masking the effect of having high spatial ability for the first 30-hour scan scores. But then, why is there such a difference between the two studies for the first 30 hours of measure? The answer remains unclear. Navigating the manipulations of the transducer, operating the machine, and concentrating on image acquisition present a considerable challenge of general ability for beginning sonography students initially to manage all at once. Because psychomotor skills were not assessed in this study, that factor may be a direction for further research.

The exploratory study and the expanded study both showed that spatial ability is a significant ability determinant for skill acquisition in learning sonographic scanning, especially when considering the 2-semester averaged time of measure. The $r^2$ value of 0.24 for the 2-semester averaged scores for the expanded study means that spatial ability accounted for 24% of the variation in the 2-semester averaged scanning scores. This finding is consistent with a study done by Gray and Deem, who found that scores on the Perceptual Ability Test, a spatial visualization test like the RMPFBT used for admission into dental schools, accounted for 25% of the variability of the final grades in the dental preclinical technique courses. This finding may mean that use of a spatial ability test such as the RMPFBT would be appropriate for use in admissions to sonography programs as well.

Using Midwestern university class 1–3 data, multiple regression analysis was performed to compare the incoming GPA, ACT scores for the undergraduates/GRE scores for the graduates, and their preinstructional RMPFBT spatial test scores with their scanning test scores for both periods of measure. Evans and Dirks found that the GPA was the strongest admissions criteria factor in predicting student success: greater than spatial ability, interviews, and other personality measures. In this study, for the Midwestern university class 1–3 undergraduates ($n = 34$), the incoming GPA ($r = 0.44; P < .05$) was confirmed again as being the greatest factor for predicting scanning success for the 2-semester averaged SCAN scores.

Hegarty et al. found no evidence that dental education improved the dental students’ spatial ability throughout a 2-year course of instruction. This study explored the same question within the context of sonography education. The RMPFBT was administered to the participants after the 2-semester learning period was completed. The pre–learning period spatial test scores were compared to the post–learning period spatial test scores, and a statistically significant change in their post spatial test scores was realized. This result was likely due to having practice and instruction over the 2-semester learning period. The result seen in the expanded study, coupled with an obvious increase in spatial scores from beginning to end, may suggest that spatial ability seems to be an important ability determinant in the success for scanning competency throughout all phases of learning.

**Limitations**

Four significant limitations were highlighted in the above discussion. One was that assessment of the participants’ psychomotor skills was not included in the study. Poor transfer of psychomotor skills to image acquisition could mask having high spatial ability as a determinant of skill acquisition.

A second important limitation to the study, as discussed above, was the small numbers of participants for the individual classes when breaking down the analysis by site: Midwestern university class 1 ($n = 11$), Midwestern university class 2 ($n = 13$), Midwestern university class 3 ($n = 19$), Atlantic coast community college ($n = 8$), Midwestern community college ($n = 11$), and proprietary school ($n = 11$). Any size sample of fewer than 15 will have unacceptably low statistical power. Therefore, the small sample sizes from individual classes and sites make it difficult to generalize findings by site to a specific general population, such as for all community colleges or all proprietary schools.

A third limitation to the expanded study was inter-rater variability in deriving the competency SCAN scores. All preceptors at all the sites were sonographers professionally registered by the American Registry for Diagnostic Medical Sonography who understand the expectations set by industry standards. However, the site preceptors had
no common training in scoring the competencies for which a 5-point Likert scale was used. While each level on the scale had distinct qualifications, there will always be some inter-rater discrepancy. Anecdotally, in our experience with subjective ratings using Likert scales, what merits a score of 3 versus a 4 out of 5 points becomes problematic for consistency. Finally, inter-site variability as to the order of anatomic competencies varied somewhat. Midwestern university, Atlantic coast community college, and proprietary school competency tests were given in the same order. The Midwestern community college had a somewhat different order of testing, which may have affected the first 30-hour scanning period of measure. Two of the sites did not include pelvic competency, which resulted in an unequal number of scanning competencies.

Conclusions
In this study, there were 4 results that need to be addressed:
1. Low–spatial ability students are not being weeded out with the use of traditional admissions criteria. Therefore, it appears that high scores on a spatial ability test along with the highest incoming GPA, as well as other traditional admissions measures, would probably be an appropriate addition to admissions criteria for choosing the best candidate for admission.
2. A moderately strong relationship was found between spatial ability and student performance in learning sonographic scanning. In addition, this relationship may exist in all phases of skill acquisition because there was no drop-off in correlation strength with the 2-semester averaged scores. Brief physician fellowships and 18-month certificate programs found in proprietary schools and community colleges may not have the time to allow low–spatial ability learners to catch up to the high–spatial ability learners. Training individuals with high spatial ability, identified through the use of spatial ability tests, may be a priority to these types of training programs.
3. The incoming GPA was a stronger predictor of scanning scores than spatial ability test scores or ACT scores. It appears that the best candidate for admission to a sonography program is one with the highest possible incoming GPA in addition to the highest possible spatial test scores. ACT and GRE test scores seem to be least effective in predicting student performance, even to the point of being irrelevant.
4. Spatial ability did improve throughout the learning period. This finding is a bonus, at least, for low–spatial ability learners who need to improve their spatial ability to keep up with high–spatial ability learners.

Implications for Future Research
The results of this study suggest several directions for future research. This study only included students studying abdominal sonography. Other specialties, such as cardiac sonography, obstetric sonography, vascular sonography, and others, may or may not prove to have the same relationship between spatial ability and learning to scan.

For future research, it may be important to do a repeated measures ANOVA study in which like classes with similar competencies are compared throughout all 3 stages of skill acquisition. Further research is also needed in assessing how spatial ability and psychomotor skills are related to acquiring sonographic scanning skills.

Finally, the relationship between spatial test scores and student retention should be addressed. A longitudinal study following students on a semester-by-semester basis and using logistical regression analysis would be an appropriate method for studying spatial ability and its relationship to student retention.

Implications for Institutional Policy
The findings of this study have two major implications for institutional policy. First, it is well documented that dental schools have been using scores from the Perceptual Ability Test, a subtest of the Dental Admissions Test, since the 1940s in their assessment of candidates for admission into dental school. In view of the fact that the coefficient of determination (0.24) is at least as strong as in dentistry, sonography programs should consider including a spatial ability test, such as the RMPFBT, along with their incoming GPA data to admit the strongest candidates, especially if the program believes that it does not have time for low–spatial ability learners to catch up to high–spatial ability learners.

Second, another potential use for the spatial test would be to identify those students with low spatial ability and view them as students requiring additional practice time and instruction to help them in overcoming their deficiency. Examples of specific teaching methods, computer-aided instructional software, and other specific course work abound in the literature for improving spatial ability are available as well.

In conclusion, at least a moderately strong relationship has been shown between spatial ability and sonographic skill acquisition; therefore, spatial ability is an important ability determinant for student achievement in sonographic scanning. This study has shown that spatial ability testing may be an appropriate additional component of admissions data to be used in selecting candidates for admission to sonographic programs across
the country. It is also appropriate for identifying low–
spatial ability students who may require extra time for
practice and/or additional instruction and remediation
for success.

Inevitably, adding a spatial ability test to admissions
criteria might increase the level of competency of sonog-
raphers graduating from sonography education programs
and entering the workforce. Bringing in highly qualified
individuals with the capacity to learn to scan quickly and
effectively raises the level of competence of the graduates
entering the workforce, which in turn enhances patient
care and the quality of service to the medical community.

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