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ABSTRACT

This research aims to devise an intervention that can enhance three-dimensional anatomical understanding and develop testing instruments that can be used to measure this understanding. First year veterinary medicine students (N=62) participated in a study that explored: (1) whether participants who use a cross section for learning the anatomy of the canine head have a better understanding of the three-dimensional locations and relationships of structures in the head than students who only perform dissection; (2) if those who use a cross section for learning the anatomy of the canine head can better visualize three-dimensional anatomy in other areas of the body; and (3) whether female participants perform as well as their male counterparts on measures designed to assess spatial ability of three-dimensional anatomical understanding. No statistically significant gender or group differences in the means for the anatomical covariates were found in the analysis. (Contains 51 references.) (DDR)

Spatial Ability, Gender, and the Ability to Visualize Anatomy in Three Dimensions.

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Running Head: Visualizing Anatomy in Three Dimensions

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Introduction

During their study of gross anatomy, veterinary students learn to communicate verbally regarding anatomical structures. Knowledge of the anatomy of a live animal also requires understanding the spatial orientation of and three-dimensional relationships between anatomical structures, and being able to adjust this understanding to accommodate changing body positions of the animal. Dissection of a cadaver is the major experience provided to anatomy students, and some aspects of this experience may limit the potential of the cadaver to teach these three-dimensional relationships (Rosse, 1995). Dissection is destructive; successive layers of tissue are removed or reflected to facilitate dissection of deeper structures. In this manner the relationship of structures to the body surface and to each other are permanently destroyed or altered. In addition, students usually assume a standard position relative to the cadaver and thus may not experience varied perspectives on the cadaver while dissecting.

The extent to which students are able to visualize anatomy in three dimensions is not well measured by cadaver examinations, which include a majority of questions that request verbal information about a structure that is visible to the student. Live animal examinations might provide some measure of the ability to visualize the three-dimensional aspect of animal anatomy, due to the need to visualize internal structures. Similarly, written examination questions sometimes require the student to access a mental image of a structure or region in order to answer, or to make a sketch which demonstrates understanding of relationships (Rochford, 1985). However, the remaining questions on these examinations test recognition and recall of verbal information regarding visible structures. It is thus possible that the students who can more easily visualize unseen structures aren't the same students who perform well on examinations (Friedman, et al., 1993). Previous research suggests that some students have more difficulty with either verbal or spatial anatomy information (Rochford, 1985; Keen et al., 1988).

Spatial ability varies among individuals (Salthouse et al., 1990), and may be related to the ability to master the spatial domain of anatomy. A correlation has been demonstrated between spatial ability and performance in anatomy or other disciplines (Lord, 1987; Rochford, 1985; Pribyl & Bodner, 1987; Casey et al., 1995). Rochford (1985) and Keen et al. (1988) measured spatial ability of second-year medical students, and found that those students who performed poorly on a battery of three-dimensional exercises were more likely to also perform poorly on anatomy practical examinations and other anatomy questions judged to be "three-dimensional".

Spatial skills have been shown to improve as a result of being involved in courses such as engineering or physics, or when specific interventions are given to students (Blade & Watson, 1955; Pallrand & Seeber, 1984; Lord, 1985b, 1987; Braukmann & Pedras, 1993; Baartmans & Sorby, 1996; Duesbury & O'Neil, 1996). Training in specific spatial tasks has also been shown to generalize to tasks for which no training was received. Stericker and LeVesconte (1982) trained participants using direct practice with items from three different tests of spatial ability. Included in their post-test were items from a fourth test of spatial ability for which no practice had been given. Spatial ability of experimental groups was increased significantly more than that of control groups for all four tests.

Gender differences complicate the issue of spatial ability. Males have a documented advantage in spatial ability (Linn & Peterson, 1985; Masters & Sanders, 1993; Casey et al., 1995). There is current debate as to whether this difference is innate, or the result of different cultural conditioning and developmental experiences between males and females (Stericker & LeVesconte, 1982; Casey & Brabeck, 1990; Kerns & Berenbaum, 1991; Alington et al., 1992; Newcombe & Dubas, 1992; Grimshaw, Sitarenios & Finegan, 1995; Van Goozen et al., 1995; Snyder & Harris, 1996). The perception by females of a test as spatial in nature may influence female performance on the test (Sharps et al., 1993); when instructions on mental rotations tasks were varied to de-emphasize the spatial nature of the task, the gender difference in performance disappeared. Some evidence exists that women show relatively greater effect than men from interventions designed to improve spatial ability (Stericker & LeVesconte, 1982; Koslow, 1987; Lord, 1987; Alington et al., 1992). There is also some evidence that the gender difference in spatial ability in the general population may be decreasing, although this remains controversial (Voyer, Voyer & Byrden, 1995, Halpern, 1997).

The heavy science background of veterinary students (American Association of Veterinary Medical Colleges, 1996) may provide a means by which they are selected for spatial ability prior to matriculation. Spatial ability of college students in science or math courses is higher than that of students in liberal arts-type courses (Pallrand & Seeber, 1984; Lord, 1985a; Lord, 1987). Females in science and other spatially oriented majors have greater spatial ability than their non-science oriented peers (Casey & Brabeck, 1989; Casey et al., 1993). Lord (1985a) found that first-year undergraduate women majoring in biology were as spatially competent as were their male peers. Such selection for spatial ability should lessen the gender gap in spatial ability among veterinary students. Students entering a Midwestern veterinary school were recently tested on a range of ability measures including visuo-spatial abilities, and gender differences were not observed (Bailey et al., 1995).

In summary, while veterinary students are expected to master the spatial domain of anatomy, these students typically are not provided instruction specifically designed to promote this ability, nor are they tested for mastery in this domain. Extrapolated to gross anatomy, previous research suggests that students might improve their ability to visualize anatomical structures in three dimensions, given appropriate practice experiences. What activities might enhance a student's ability to visualize anatomical structures in three dimensions? How can this ability be measured? What is the contribution of spatial ability to the ability to visualize anatomical structures? Does student gender relate to ability to visualize anatomy in three dimensions? In an attempt to answer these questions, this research investigated the effect of an intervention designed to enhance the ability to visualize the anatomy of the head of the dog in three dimensions.

Objectives

The goals of this research were to devise an intervention that would enhance three-dimensional anatomical understanding; and to develop testing instruments that could be used to measure this understanding. Anatomical cross sections have been used for both teaching and testing for spatial knowledge of anatomy (Friedman et al., 1993; Keen et al., 1988; Lord, 1985b). Because of the increasing use of diagnostic procedures such as magnetic resonance imaging and computed tomography, cross sectional anatomy is also relevant to the veterinary practitioner. For these reasons, identification of structures visible on a cross section of a canine head was chosen as the intervention.

It was anticipated that observation of structures on the cross section would provide the student with a unique perspective, not available from dissection, of the spatial relationships between structures of the head. This would better promote visualization of these structures in three dimensions, and perhaps also promote transfer of three-dimensional thinking to other areas of the canine body. The specific research hypotheses were:

Hypothesis 1: Participants who use a cross section for learning anatomy of the canine head will have a better understanding of the three-dimensional locations and relationships of structures in the head than students who perform dissection only.

Hypothesis 2: Participants who use a cross section for learning anatomy of the canine head will be better able to visualize three-dimensional anatomy in other areas of the body.

Hypothesis 3: Female participants should perform equally as well as their male counterparts on measures designed to assess spatial ability or three-dimensional anatomical understanding.

Participants and Setting

The participants in this study were 62 first-year veterinary students (48 female, 14 male, average age 24.0 years) at Purdue University during the 1994-1995 academic year and 66 first-year veterinary students (45 female, 21 male, average age 23.8 years) at Purdue University during the 1995-1996 academic year. First year students (42 female, 18 male, average age unknown) at another Midwestern veterinary school (School X) during the 1995-1996 academic year served as a control group for testing instruments in this study.

All of the first-year students at Purdue remain together for the entire day. Successive classes of students also communicate due to a formal "big sibling" system. The canine anatomy course in which this study took place occurred in the fall and consisted of twice-weekly lectures, and laboratory sessions three times per week. Students were assigned to dissection pairs, and all pairs of students dissected all areas of their cadaver. Students first learned the muscles and skeleton of the limbs and trunk, followed by thoracic anatomy and vessels and nerves of the front limb, then abdominal/pelvic anatomy and vessels and nerves of the hind limb, and finally the head. Two or three instructors assisted in most laboratory sessions. Other resources included preparations of skeletons and various organs, labeled radiographs for each body region, cadaver sections, and two live palpation dogs. The laboratory was open for students at all times.

The regular examinations normally given in this course were not altered for this research. These consisted of three written and laboratory examinations, three live dog examinations, and written, laboratory and live dog final examinations. The written examinations included short-answer, essay, matching, labeling and sketching questions. The laboratory examinations, which were timed, involved mainly identification of structures tagged on the students' cadavers. Live dog examinations were given in small groups with no time limits, and students had the opportunity to palpate the animal during the examinations. The experimental test given to the students will be described later.

In the spring semester students took a comparative anatomy course very similar to the canine anatomy course. The course instructor for the first trial retired at the end of that year, and the instructor who normally teaches comparative anatomy took his place. This instructor attempted to maintain identical procedures for the second trial, but some changes occurred that will be discussed later.

Methodology

Threats to the internal validity of experiments (Isaac & Michael, 1976; Kirk, 1982) can largely be eliminated through the use of experimental/control group designs and random assignment of participants to groups. Some such threats are resistant to elimination by random assignment (Cook & Campbell, 1979). Provision of "placebo" treatments (Borg, 1984; Adair, Sharpe & Huynh, 1989) was used to minimize these threats to the internal validity of the experiment that existed due to the close communication of the participants.

Participants were randomly assigned to one of two control conditions, or one experimental condition that involved study of a cross section of a canine head. All participants worked on dissection of their canine cadaver throughout the study. Control groups (Groups 1 and 2 in Trial 1, and Groups 4 and 5 in Trial 2) received a placebo assignment involving radiographs of the region they were currently dissecting. Prior to the first placebo assignment, participants were informed that a study of the educational methods used in the course was under way, and were assured that the research would not have a negative impact upon their grade. To help ensure that no participants were deprived of beneficial educational experiences, and that none received unfair advantage, all participants were required to summarize the information from their assignment for classmates at an appropriate time.

For both placebo assignments participants were asked to make labeled tracings of 8-10 structures from the radiographs on a blank overhead transparency. They were asked to make a tracing from both a lateral and a ventrodorsal view, and submit the tracings for grading and feedback. After these assignments, participants were required to summarize the content for classmates who had not had the assignment. The two control groups in each trial were separated temporally, and the contents of their assignments were different, but the formats were identical. The assignment for the first control group involved radiographs of the thorax, and that of the second control group involved radiographs of the abdomen.

Experimental groups (Group 3 in Trial 1 and Group 6 in Trial 2) received the intervention assignment during dissection of the head. This assignment involved a life-size color photograph of a cross section of a canine head. A digitized image of the cross section as well as a schematic showing the level of the section is shown in Figure 1. Participants were given a list of 13 structures that were visible on the cross section. They were asked to make tracings on overhead transparencies of the structures on the list, and submit these tracings for grading and feedback.

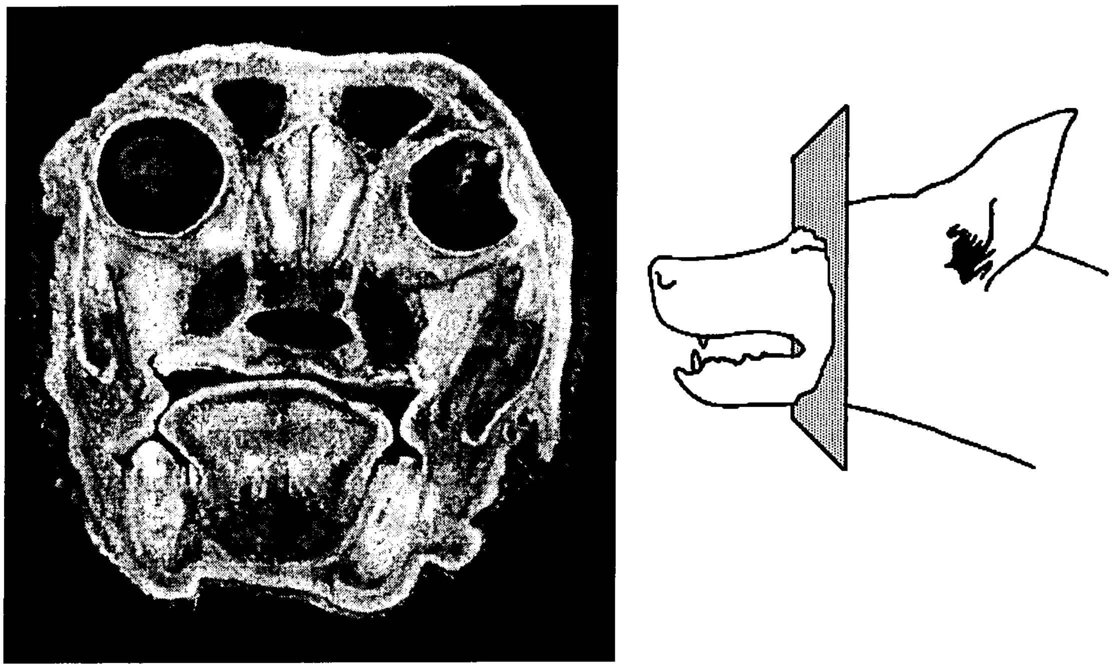


Figure 1. Digitized image of the cross section photograph (not to scale) and schematic showing level of the cross section.

Approximately 10 days were allowed to complete both the placebo and the experimental assignments, during which time all necessary materials were continuously available in the laboratory. No record was kept of time spent in use of these materials. After the experimental assignment, all participants were given the opportunity to take an experimental paper-and-pencil test of anatomy of the head, for which they received extra credit. Following data collection, the experimental groups were required to summarize their assignment for the control groups. The test was repeated in April, again on a voluntary basis.

The test consisted of 3 parts, each intended to measure three-dimensional knowledge of structures of the head in a slightly different way. Parts A and B of the test were directly related to one another. At the top of the page, a diagram of a canine head with a plane bisecting it indicated the location of a cross section. This diagram is shown in Figure 2. For Part A, participants were asked to circle from a list of possible structures all structures they believed would be included in the indicated section. There were 8 correct structures, determined from an actual cross section at that level. The score (A) for this part was obtained by awarding 2 points for each correct structure chosen, and subtracting 2 points for each incorrect structure and for each omission of a correct structure. The possible range of scores for this section was –20 to 15 points.

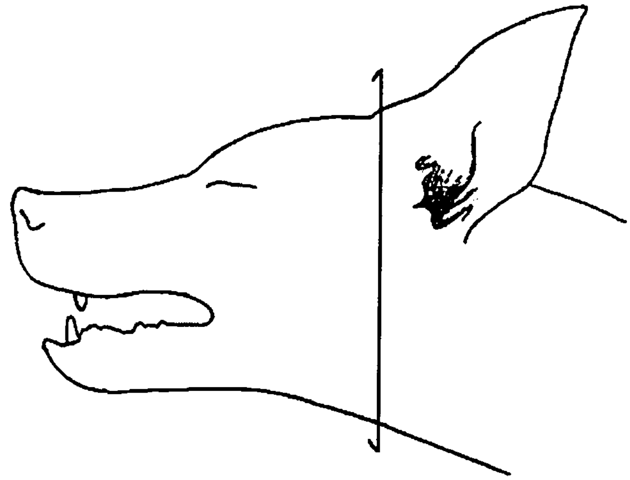


Figure 2. Diagram for Part A (not to scale) of the head test.

Part B of the test provided an outline of the cross section depicted in Part A. This outline is shown in Figure 3. Participants were instructed to place the structures chosen in Part A in their correct location within the outline in Part B. Part B was scored with an overhead transparency with the structures drawn on it; and 0, 0.5, 1.0, 1.5 or 2 points were given for each structure, depending on the degree of proximity to the correct location. The score was converted to a percentage (B) by dividing the points earned by the total points possible for that participant, based on structures circled in Part A.

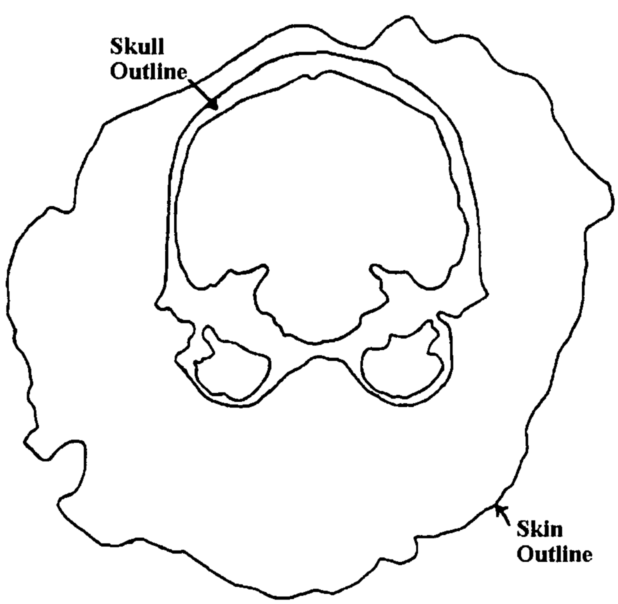
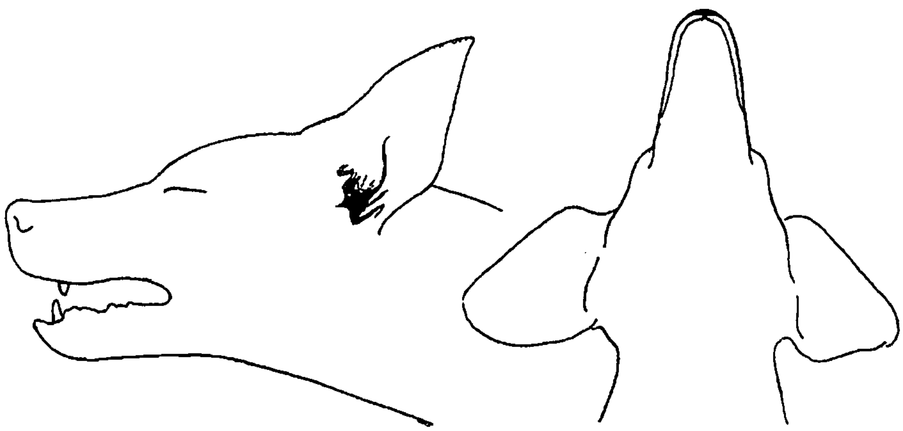


Figure 3. Diagram for Part B (not to scale) of the head test.

Part C involved the sketching of 8 structures onto ventral and lateral views of the head. The participant was instructed to place each of the 8 structures on both outlines. Figure 4 shows the diagrams used for Part C of the test. Part C was also scored with an overhead transparency containing correct structures and generated three scores. One score (CI) resulted from placement of individual structures, with up to 2 points awarded for each structure in the same manner as described above. The total possible for this score was 32 points.



Lateral **Ventral**

Figure 4. Diagrams for Part C (not to scale) of the head test.

The other two scores for Part C were designed to measure understanding of relative position of pairs of structures. From a lateral perspective one can judge relationships between structures on the rostral-caudal and dorsal-ventral axes; from a ventral perspective one can judge relationships between structures on the rostral-caudal and medial-lateral axes. The experimenter chose pairs of structures for each axis, and structure pairs placed in correct relationship to each other were awarded up to 2 points as described above. Table 1 lists pairs of structures used for this purpose.

Table 1. Pairs of structures chosen to measure understanding of spatial relationships between structures of the head, lateral and ventral views.

Lateral View	
Rostral-Caudal Axis	Dorsal-Ventral Axis
retractor bulbi & 4th premolar	frontal sinus & retractor bulbi
retractor bulbi & ramus of mandible	zygomatic arch & tympanic bulla
zygomatic arch & tympanic bulla	ear canal & tympanic bulla
ramus of mandible & tympanic bulla	retractor bulbi & tympanic bulla
retractor bulbi & tympanic bulla	frontal sinus & zygomatic arch
frontal sinus & tympanic bulla	
Ventral View	
Rostral-Caudal Axis	Medial-Lateral Axis
retractor bulbi & 4th premolar	zygomatic arch & ramus of mandible
retractor bulbi & ramus of mandible	frontal sinus & retractor bulbi
zygomatic arch & tympanic bulla	frontal sinus & zygomatic arch
ramus of mandible & tympanic bulla	ear canal & tympanic bulla
retractor bulbi & tympanic bulla	zygomatic arch & tympanic bulla
frontal sinus & tympanic bulla	

A rostral-caudal score (ROS) was obtained by adding the total for pairs of structures on the rostral-caudal axis on the lateral view to that for pairs of structures on the rostral-caudal axis on the ventral view.

The other score (DOVMEL) was computed by adding totals for pairs of structures on the dorsal-ventral axis on the lateral view to totals for pairs of structures on the medial-lateral axis on the ventral view.

Procedures were included to validate the use of this test for this research. A field trial of the test was conducted with 5 volunteer second-year veterinary students. On the basis of their feedback, minor modifications were made. The test was sent to 2 other veterinary anatomists, who were asked to evaluate the extent to which this test would measure spatial understanding of structures of the head. Trial 1 and 2 participants also provided feedback regarding the content validity of the test during interviews. Inter-rater reliability was determined using a random sample of 10 tests, which were photocopied before scoring and given to another instructor, with an explanation of the scoring methods used. This second instructor's scores were then compared to those obtained by the researcher. The test-retest reliability over a time interval of 3.5 months was calculated. Finally, students at School X also took the test to compare their performance to that of participants at Purdue.

Two administrations of the head test thus contributed 10 of the 11 dependent variables; A1 & A2; B1 & B2; CI1 & CI2; ROS1 & ROS2; and DOVMEL1 & DOVMEL2. The final dependent variable was derived from the live dog final examination. The performance on questions from this examination that were judged to require visualization of anatomical structures was used to create a score (VISUAL%) for each participant.

Analysis of covariance (ANCOVA) was used to test for treatment effects on each of the 11 dependent variables. To control for the effect of anatomy performance on the dependent variables, performance on live dog examinations and performance on written and laboratory examinations were used as covariates. Because of the potential relationship between spatial ability and performance in anatomy, the Purdue Visualization of Rotations (Carter et al., 1987), a test of mental rotation ability, was added to Trial 2 as an additional covariate. This test is a 10-minute, 20-item test, and was given once in August and again in April. Figure 5 shows an example item from this test.

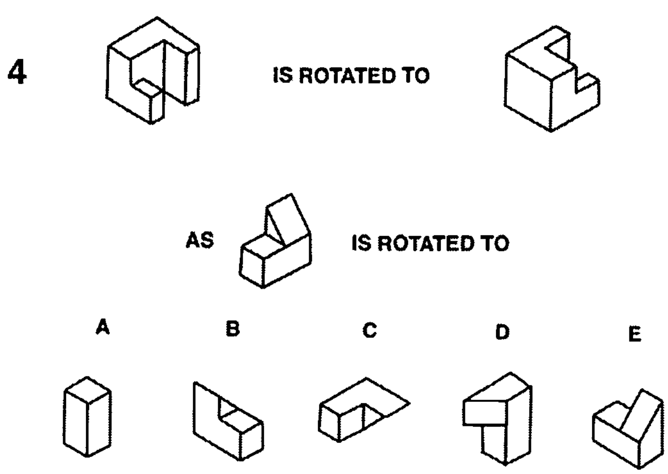


Figure 5. Example item from Purdue Visualization of Rotations.

Qualitative Methods

A qualitative analysis was also included in this research design. This was an attempt to determine the effect of variables which could not be ethically controlled in this setting, and to estimate the degree to which the experimental methods were implemented as intended (Harden, 1986; Irby, 1990; Patton, 1990; Marshall & Rossman, 1995). It was also intended to illuminate the meaning of the experience to the participants. Following the head test, all participants were requested to complete a survey regarding the head cross section assignment and the drawing test. Most participants in both trials completed surveys.

Participants were asked for their comments in several areas: the personal effect of studying a cross section; the relative difficulty of visualizing anatomical structures in a live dog; and whether the head test actually measured their knowledge of anatomical structures in three dimensions. Finally, seven participants in Trial 1 and 8 in Trial 2 were randomly chosen from a pool of volunteers for interviews. Interviews were constructed after the participants in the first trial completed the surveys, and were intended to explore the survey topics in greater detail.

Statistical Results

There were no statistically significant gender or group differences in the means for the anatomical covariates in this analysis. Table 2 displays the group means and standard deviations for scores on examinations (EXAM%) and live dog quizzes (QUIZ).

Table 2. Group means and standard deviations (stdev) for EXAM% and QUIZ.

Group	**Sample Size**	**EXAM% (stdev)**	**QUIZ (stdev)**
1	24	91.1 (3.8)	80.6 (4.6)
2	18	91.8 (3.5)	80.6 (3.8)
3	20	88.8 (6.4)	79.9 (5.3)
Groups 1-3	female 47	90.7 (5.2)	80.6 (4.7)
	male 15	90.2 (3.7)	79.6 (4.2)
4	22	84.7 (7.3)	72.1 (7.7)
5	22	85.4 (6.9)	75.3 (6.6)
6	22	84.3 (7.4)	73.8 (6.2)
Groups 4-6	female 46	84.6 (7.0)	73.6 (6.6)
	male 20	85.2 (7.6)	74.1 (7.7)

Group means and standard deviations for the spatial ability measurements are presented in Table 3. The group mean for spatial ability increased for all groups between August and April, with Group 6 making the largest gain. Overall, men improved by 0.4 points; women improved by 2.7 points. The difference between the male and female means for spatial ability at the beginning of the year (SPAT) was statistically significant ($p < 0.05$); this gender difference had disappeared by the end of the year (SPAT2).

Group means and standard deviations for the dependent variables are summarized in Tables 4 through 9. Table 10 shows the reliability coefficients for the head test. There were no group differences noted for performance on visualization of anatomical structures on a live dog as measured by VISUAL%. Neither were there any consistent group differences on performance on Parts A or B of the head test (A1, A2, B1 and B2). The experimental group (Group 3) in Trial 1 scored significantly higher than the control groups on measures derived from Part C of the head test (CI1, CI2, ROS1, ROS2, DOVMEL1 and DOVMEL2). However, the experimental group in Trial 2 (Group 6) scored lower than the control groups on these measures. Men tended to perform better than women on scores derived from Part C of the test, while women tended to perform better than men on Parts A and B.

Table 3. Group means and standard deviations by gender for spatial ability.

		August		**April**
Group	**Sample Size**	**SPAT (stdev)**	**Sample Size**	**SPAT2 (stdev)**
4	22	13.8 (3.2)	21	15.4 (2.9)
5	22	12.9 (4.0)	19	14.9 (4.0)
6	22	12.8 (3.2)	22	15.3 (2.6)
Groups 4-6	female 46	12.4 (3.6)	female 43	15.1 (3.3)
	male 20	14.9 (2.9)	male 19	15.3 (2.9)

Table 4. Group means and standard deviations for variable VISUAL%.

	Trial 1			Trial 2	
Group	**Sample Size**	**Mean (stdev)**	**Group**	**Sample Size**	**Mean (stdev)**
1	24	85.4 (15.4)	**4**	22	71.0 (14.8)
2	18	88.4 (10.1)	**5**	22	73.3 (12.4)
3	20	84.0 (12.6)	**6**	22	72.7 (11.0)
Groups 1-3	female 47	85.8 (13.4)	**Groups 4-6**	female 46	72.9 (12.7)
	male 15	85.8 (13.1)		male 20	71.1 (12.9)

Table 5. Group means and standard deviations for variables A1 and A2.

	December		March	
Group	**Sample Size**	**A1 (stdev)**	**Sample Size**	**A2 (stdev)**
1	24	4.4 (6.3)	15	2.4 (6.7)
2	18	-0.1 (4.0)	12	2.2 (5.8)
3	20	3.0 (6.8)	11	0.0 (5.7)
Groups 1-3	female 47	3.0 (5.5)	female 27	1.9 (5.4)
	male 15	1.5 (7.7)	male 11	1.1 (7.8)
4	20	4.2 (4.9)	17	3.9 (4.5)
5	20	3.1 (5.3)	20	2.6 (5.4)
6	20	4.7 (4.6)	19	2.7 (5.2)
Groups 4-6	female 44	4.0 (4.7)	female 43	3.1 (5.2)
	male 18	4.0 (5.6)	male 13	2.8 (4.6)

Table 6. Group means and standard deviations for variables B1 and B2.

	December		March	
Group	**Sample Size**	**B1 (stdev)**	**Sample Size**	**B2 (stdev)**
1	24	57.1 (25.4)	15	52.2 (25.3)
2	18	52.5 (22.8)	12	62.0 (19.3)
3	20	48.9 (25.3)	11	58.1 (13.7)
Groups 1-3	female 47	50.9 (24.7)	female 27	55.4 (18.0)
	male 15	60.1 (23.2)	male 11	60.1 (26.4)
4	20	43.6 (21.0)	17	58.4 (20.7)
5	22	52.1 (22.8)	20	71.0 (14.2)
6	20	54.6 (21.0)	19	62.8 (18.1)
Groups 4-6	female 44	51.8 (22.2)	female 43	66.8 (16.2)
	male 18	46.2 (20.8)	male 13	56.7 (22.5)

Table 7. Group means and standard deviations by gender for variables CI1 and CI2.

	December		March	
Group	**Sample Size**	**CI1 (stdev)**	**Sample Size**	**CI2 (stdev)**
1	24	14.9 (5.6)	15	15.2 (4.1)
2	18	12.3 (4.7)	12	13.6 (4.0)
3	20	16.4 (4.7)	11	16.7 (4.4)
Groups 1-3	female 47	14.2 (5.6)	female 27	15.3 (3.9)
	male 15	15.9 (3.8)	male 11	14.7 (5.3)
4	20	16.1 (3.7)	17	18.2 (4.4)
5	22	16.5 (4.2)	20	18.3 (4.8)
6	20	14.5 (3.8)	19	15.7 (2.8)
Groups 4-6	female 44	15.7 (3.8)	female 43	16.7 (4.3)
	male 18	15.9 (4.4)	male 13	19.4 (3.2)

Table 8. Group means and standard deviations by gender for variables ROS1 and ROS2.

	December		March	
Group	**Sample Size**	**ROS1 (stdev)**	**Sample Size**	**ROS2 (stdev)**
1	24	14.7 (5.1)	15	13.3 (4.9)
2	18	12.4 (4.8)	12	14.8 (3.4)
3	20	14.9 (5.4)	11	14.7 (4.5)
Groups 1-3	female 47	14.1 (5.2)	female 27	14.1 (4.0)
	male 15	14.0 (5.0)	male 11	14.4 (5.3)
4	20	15.1 (4.2)	17	15.7 (4.6)
5	22	15.9 (2.6)	20	15.1 (4.9)
6	20	14.8 (4.0)	19	13.7 (4.7)
Groups 4-6	female 44	15.1 (3.5)	female 43	14.2 (5.0)
	male 18	15.8 (3.9)	male 13	16.8 (3.0)

Table 9. Group means and standard deviations by gender for DOVMEL1 and DOVMEL2.

	December		March	
Group	**Sample Size**	**DOVMEL1 (stdev)**	**Sample Size**	**DOVMEL2 (stdev)**
1	24	11.8 (4.1)	15	11.1 (3.4)
2	18	10.6 (4.3)	12	11.4 (2.4)
3	20	14.0 (4.4)	11	12.3 (3.9)
Groups 1-3	female 47	11.6 (4.4)	female 27	11.1 (2.9)
	male 15	13.9 (3.8)	male 11	12.7 (3.8)
4	20	13.1 (3.2)	17	12.6 (3.8)
5	22	13.9 (3.1)	20	12.7 (4.2)
6	20	12.8 (3.3)	19	11.4 (3.5)
Groups 4-6	female 44	13.1 (3.1)	female 43	11.8 (4.1)
	male 18	13.7 (3.4)	male 13	13.7 (2.2)

Table 10. Test-retest and inter-rater reliability of the head test.

Score	Test-Retest Reliability Trial 1 (n=38)	Test-Retest Reliability Trial 2 (n=54)	Inter-Rater Reliability n=10
A	0.61*	0.14	N/A
B	0.51*	0.58*	0.77*
CI	0.36*	0.57*	0.90*
ROS	0.42*	0.37*	0.59
DOVMEL	0.30	0.45*	0.64*

* = $p < 0.05$

Two content experts judged the test to be valid for the purpose of measuring three-dimensional anatomical knowledge, given the obvious limitation of the paper-an-pencil format. Participants also responded on surveys and during interviews that they felt the test accurately measured their three-dimensional knowledge of structures of the head, as will be discussed later.

The data were analyzed using the SAS software (Version 6, SAS Institute, Cary, NC). Because the variables were chosen to assess three-dimensional knowledge in different ways, a separate analysis was done for each dependent variable. The analysis was designed to test for main effects on each dependent variable of group membership (GROUP, representing the treatment effect of the intervention), gender (GEN), examination performance (EXAM%), and quiz performance (QUIZ). For Trial 2, the analysis was also designed to test for an effect of spatial ability (SPAT) on each dependent variable. Data from each trial was analyzed separately, due to differences that occurred between Trial 1 and Trial 2, which are discussed later. In order to make comparisons between Trial 1 and Trial 2 more valid, Trial 2 data were analyzed both with and without spatial ability as a covariate. Results are summarized in Table 11.

Table 11. Statistically significant effects for dependent variables in Trial 1 and Trial 2.

	Statistically Significant Effects ($p < 0.05$)		
Variable	**Trial 1**	**Trial 2 (spatial ability)**	**Trial 2 (no spatial ability)**
VISUAL%	QUIZ	QUIZ	QUIZ
A1	GROUP, EXAM%	none	none
A2	none	none	none
B1	EXAM%	none	none
B2	EXAM%, QUIZ	SPAT, GEN	none
CI1	none	EXAM%	EXAM%
CI2	none	none	none
ROS1	none	SPAT	none
ROS2	EXAM%	SPAT	none
DOVMEL1	none	none	EXAM%
DOVMEL2	EXAM%	none	none

Performance on live dog quizzes had a significant effect on ability to visualize anatomical structures on a live dog, as measured by VISUAL%. There were no other consistent significant effects between the two trials. There was no significant group effect for any of the dependent variables, with the exception of Part A in Trial 1. In this case the experimental group was intermediate in performance between the two control groups. There was a significant effect of spatial ability on performance on Part B and one of the scores from Part C in Trial 2; and spatial ability was significantly correlated with both performance on Parts B and C of the experimental test, and performance on anatomy examinations. The effect of gender was significant for only Part B, and in this case women scored better than did men.

Qualitative Results

Control participants were asked whether they had heard about or studied the head cross section photograph prior to data collection. In Trial 1, only 11 of the 38 control participants answered these questions due to an error in the survey directions. All of these said that they had not studied the cross section assignment photograph prior to the head test. In Trial 2, 36 of the 40 control participants said they had not studied the cross section photograph prior to the test. Of these, 16 said they were aware or somewhat aware of the content of the assignment before the head test. One commented:

> "I think somehow I knew what they were doing, but I don't remember how I came by that information. I had studied the head from our dissection guide, but I hadn't looked at all at what they were doing."

Most of the control participants in Trial 1 and slightly more than half of those in Trial 2 indicated that they had not thought about structures of the head in cross section prior to the head test. Of those who indicated that they had previously thought about the head in cross section, pictures in the book were most frequently mentioned as the reason.

The head test was present in some of the test files of participants in Trial 2. When specifically asked during interviews and on surveys, Trial 2 participants indicated that they had not studied this test prior to the first time it was given to them in December. They also indicated that participants from Trial 1 had not given them any information about the head test.

The Trial 2 interviewees were asked what effect the spatial ability test had on their approach to anatomy learning. The spatial ability test apparently sensitized them to the need to visualize in three dimensions. One commented, "it made me think about, OK, you gotta think of everything in three dimensions". Another said, "to an extent it kind of brought forth the idea, you know, that you have to deal with spatial relationships, but it didn't really have a major effect, I don't think."

The spatial ability test may have had an effect on participants of which they were not aware, however, as was evidenced by these two comments:

> "My lab partner, she never got her grade from the spatial thing because her social security number was all mixed up, so she <u>thinks</u> she has a spatial problem whether she does or not....I liked the spatial test though cause it kind of told you...if you <u>had</u> trouble with it then you could spend more time working on it."

> "I think that I have a better understanding now that, at least for me anyway, that it takes time to really turn something around in your head, and imagine how it looks differently from different perspectives."

Some participants affirmed the value of dissection over other forms of study for learning three-dimensional relationships. When asked how they had learned to visualize structures within the head of the live dog, these participants responded:

> "Doing the actual dissection has been <u>very</u> helpful for me. Books can <u>not</u> duplicate the learning that occurs during dissection. The 3D arrangement, size, location, etc. are understood by doing the dissection."

> "I think the way I saw them on the actual head took over more of the way I view it, so I kind of put the cross section aside and saw it the way we were seeing it in lab every day."

"To me, I think the dissection's better. I mean, I learn a lot from looking at a whole head and seeing where everything is."

However, several participants explained the difficulty they experience in mentally rotating the image of the dog cadaver from the position in which they dissected it, to a new orientation:

"....you know how you go to the test, and you're like, 'Well, I'll get at least two right, cause they'll put it on my dog, and I know my dog.' And I come to one of the questions that you'd tagged on our dog, and it was a vessel that we had taken out on the other side, and you had dissected it from the other side, and I had no idea for like half a second. It's funny, cause we always talk about, how, you know, 'that's on your side and that's on my side.' And heaven forbid if you turn the dog around, and you don't know what's going on. That's one of the biggest problems in large animal anatomy. It's like, 'Geez, this thing is standing up!' We're used to looking at it from ventral to dorsal. It's like, 'Wait a minute--we're looking at it from the other side now.'"

"I get stuck in the mindset of the dissected dog—if it is in a certain position all semester (like on its back), I don't even learn what it would be like on an upright, living dog."

Dissection was described by some as a destructive process, which alters relationships between the structures being dissected. One participant explained, "...once we dissected our dog you don't get it back the same way to see all of the relationships." Or, as another commented, "It is difficult to gain a good understanding of relative position of parts during dissection because you have to cut through and remove some things to find the next thing." Participants also thought their focus was too narrow during dissection. One explained, "When we learn them we must learn each structure individually and then often lose sight of the big picture," and another commented, "In dissection we focus so much on finding structures I neglect to observe their relative positions."

Using the cross-section of the head as a learning tool was recognized as a way to integrate relationship information. Comments such as the following illustrate this perceived benefit:

"It gave me a different perspective on how I viewed the head (i.e. separate entities--muscle, bone, etc.) this put it all together and helped me to integrate."

"..a cross section really gives a distinctive understanding of how all the structures are related."

"I mean, getting to think like that (in cross section) is very important...a lot of the things we'll see, especially with this book, the dissection guide, you'll see: skeleton--'OK, that's how the skeleton is.' You'll see: vessels--'OK, that's how the vessels are.' But you never see them interposed."

"... working with cross sections...we have to do those things. As much as I hate doing it, to really start from the beginning and get people thinking in that mode. I wish I had started doing that earlier, cause I feel I would have gotten a much earlier picture of what was going on."

Participants were asked to comment on whether they felt identification of structures on the cross section of the head had an effect on their ability to visualize structures on a live dog. Most felt that the assignment had a positive impact on these abilities:

"From the side, you know, you're just kinda taking the layers off, and you're visualizing them in layers. With a cross section, you're like, 'Oh, that's where that went?'"

"Yes, because once you see the whole picture...the spatial arrangement of things and the spatial organization makes more sense."

"I think it helped some. It made it...a little easier to see, especially the more medial structures, how they related to everything else."

Although cross sections were seen as beneficial by most, they were difficult for some participants to interpret without guidance, and some failed altogether to appreciate their benefits:

> "...with the assignment we kind of had someone explain to us how to do a cross section...how to put all the cross sections together and figure things out, and I think that was helpful...if you just look at a cross section, sometimes it's intimidating..."

> "I don't think cross sections are a very good learning tool since they don't let you orient yourself spatially concerning the entire head. Without being able to turn the head and view it as a whole, cross sections are difficult to work with."

> "Cross sections are harder to visualize because I can't see the entire muscle (artery, etc.). I guess it's harder to get my bearings."

Participants were asked for their assessment of the experimental test as a measure of their three-dimensional anatomical knowledge of structures of the head, and most felt the test was a fair assessment of this knowledge. This was particularly so because they had not known they were going to take the test, and "what I was doing on that test is what I had learned, not what I had memorized for a test, so it was accurate."

The head test was also perceived as a learning experience. One control participant said that the cross section quiz was "the beginning of my understanding. Prior to this I had never really thought much about the importance of it." Another commented, "I sat there and looked at it on the longitudinal section, and would go to the cross section, and as I was drawing it, 'no, that isn't right,' and...comparing the two as I was doing the test really made a difference. It was a really good way to learn it."

Participants were asked to rate the ease or difficulty of visualizing the structures that would be included in the cross section indicated on Part A of the head test. Experimental participants were less likely to think of this as "very difficult" or "somewhat difficult", and more likely to say that it was an "easy" activity. However, the reverse pattern was noted for drawing the structures in Part C; experimental participants were more likely to describe this as difficult than were control participants. Some participants found the test to be quite difficult--one wrote the following comment next to Part B: "Oh my God, you have GOT to be kidding!" Most participants appreciated the experience, however, in spite of its difficulty. They viewed the experience as "eye-opening" in terms of areas that needed more study. Some mentioned that they were more motivated to think about the spatial arrangement of the head after the head test:

> "...up until they presented the assignment, and up until we had the quiz in lecture, I hadn't really looked at it all that closely, so, um, it kinda kicked into my head, that, 'OK, I better look at this and make sure I know it.'

> "...so when you gave me the quiz, at first I was like, 'I'm not gonna be able to answer these things. I don't know where this stuff is.' But as I thought about it, it helped me realize where they were, and it certainly made me go back and look at it on the cadaver..."

> "I know I went home and really hit the head hard, because I hadn't realized that I didn't know the whole arrangement of everything. So yeah, I think it was important. I think it was a good eye-opener."

One limitation of the test mentioned by participants was the 2-dimensional format: "I had to take slices of the head off in my own head. It was difficult to turn a 3D image into a 2D image." The format did not provide any surface 3-dimensional cues that could have been used to figure out structure locations. One participant explained "...when you just have the outline of the head, you don't have other things to help you: 'OK, this bump, and that prominence, and they fit in between the two.'"

Some participants indicated that they had trouble with the test because they couldn't draw the structures. For some this meant lack of ability to communicate on paper about the orientation of the structure: "overlapping of structures makes actually sketching structures difficult even if you know where they are". Others were referring to a deficiency in drawing ability in general. Most, however, felt that their score on the head test was actually related to what they knew about those structures.

Participants felt that one cross section was helpful, but several sequential ones would have been more instructive. As explained by one experimental group participant: "...it was limiting in that it was only a partial development; had more sections been used, would have developed a more complete 3-D image, which would have done more for me." Another commented that the assignment had not been extensive enough to make a lasting impact: "...it helped, but because it was only one small assignment, I don't know how much stuck with me." One felt that more interaction with the cross section image would have aided in processing the information:

> "I would have done better if I had done this (the head test) after we presented it. Because we did have a little bit of discussion about it, with, you know, the people we were presenting to. And if maybe we had a few questions...if we had thought of a few questions to ask them, that might have helped with the whole processing thing."

Discussion

Reliability and Validity of the Test Instruments

The Kuder-Richardson and split-half reliabilities of the Purdue Visualization of Rotations measure have previously been demonstrated to be high, in the range of 0.78 to 0.85, with samples of undergraduate chemistry students (Bodner & Guay, 1995). The content validity of this instrument has also been shown to be good (Bodner & Guay, 1995), in that there is a high degree of correlation of scores on this test with scores on other tests of spatial ability.

For this study, the test-retest reliability of the Purdue Visualization of Rotations was 0.63, which was statistically significant. The test-retest interval of 7.5 months was longer than the appropriate "several months" (McMillan & Schumacher, 1984), but the test-retest reliability was slightly less than the acceptable range for reliability coefficients of 0.70 to 0.90. The test-retest interval was chosen to measure spatial ability at the beginning and end of Trial 2; had a shorter interval been used, the reliability might have higher.

The test-retest reliabilities of the different parts of the head test were statistically significant in most cases for both trials, but they were not consistent from Trial 1 to Trial 2. The highest reliability coefficient which was obtained was 0.61 for Part A in Trial 1; this did not reach the acceptable level defined by McMillan and Schumacher (1984).

According to McMillan and Schumacher, reliability coefficients are affected by the type of test, the degree of heterogeneity of participants, the number of test items; the range of scores; and the discrimination of the items. Factors which must be taken into account when determining if a test instrument is reliable include the type and purpose of the test, whether other test instruments are in existence that could have been chosen, and whether the participants are similar enough to those used to establish reliability of the instrument. To the researcher's knowledge, no other test instrument existed with which to measure three-dimensional knowledge of anatomy of the head. Therefore, a more reliable instrument could not have been chosen. Because this research was the first use of this test instrument, no norm group existed to provide an estimate of the reliability of this instrument prior to the present study, and to which this sample of participants could be compared.

The parts of this test all had a large range of scores, which should increase reliability. All parts of the test were judged to be difficult by participants, which should increase the discriminatory power of the test and therefore increase its reliability. The fact that the test-retest reliability was statistically significant in 8 of the 10 cases further supports the reliability of this test for its intended purpose. The moderate to high inter-rater reliability for Parts B and C of the head test gives credence to the reliability of the scoring methods used.

The least reliable part of the test appeared to be Part A, and it also did not generally correlate well with other scores or with the covariates. This could mean that Part A was not measuring the same knowledge as other parts of the head test. Because of the multiple-choice nature of this part of the test, it is possible that participants guessed to a higher degree, which could decrease the reliability of this score. Guessing was in fact mentioned on surveys as a strategy to solve this part of the test.

The argument could be made that participants had difficulty with the test not because they could not "see" the location of the structures, but because they did not have the ability to draw them on the test. However, it is more likely that they could not imagine the appearance of the structures from a perspective with which they were unfamiliar. In one study (Rock, Wheeler & Tudor, 1989), participants who were unable to reliably draw images of objects from an imagined viewpoint were still able to adequately draw them from the perspective from which they were viewing them. This would indicate that deficiency in drawing skills should not be a problem, although in this research participants still had to rely on memory of the image of the structures to draw them.

The participants themselves did not feel that drawing ability had any effect on their scores on the head test. With only a few exceptions, even those who described their drawing skills as poor, felt that they were able to represent the location of the object well enough for it to be counted as correct. Nevertheless, the format of the test might be improved by providing the outlines of the structures as they would be seen from the given perspective, and asking the participant to place them in their correct location. This would eliminate the need to draw the structure, and also the possible influence of gender on drawing ability (Sappington et. al., 1996), but would still measure whether the participant could visualize its location. An assessment of this kind could best be designed for computer application, in which the participant could click and drag a structure to its intended location.

The above considerations taken together indicate that the use of the head test for this research was valid. Its use to measure three-dimensional knowledge was considered acceptable by two content experts. Participants for the most part felt that this test was an accurate assessment of the degree of their three-dimensional anatomical knowledge. More investigation of this test instrument with other samples of participants would be necessary to establish this as a valid and reliable test format for measuring three-dimensional anatomical knowledge.

<u>Lack of Treatment Effect</u>

> "All statistical data are based on *someone's* definition of what to measure and how to measure it." M. Quinn Patton (1990), *Qualitative Evaluation and Research Methods*, p. 480.

> "We need to be reminded that in our desire to find out what is effective systematic intervention (from an experimental research point of view), we tend to forget that the change we aim for may have different significance for different persons." M. Van Manen (1990), *Researching Lived Experience,* p. 7.

When the statistical results are considered in isolation, there appears to be no effect on understanding spatial relationships of structures of the head from the limited intervention in this experiment. One possible reason for the lack of treatment effect is the limited nature of the experimental intervention in comparison to the total experience gained in the anatomy laboratory. Because of the spatial nature of the anatomy course itself, any intervention that would be expected to cause a difference in the experimental group would have to be a strong one. Participants did not spend very much time (30 – 60 minutes) in study of the cross section. The primary drawback to the design of this research was failure to design an intervention that was powerful enough to place the experimental group beyond the control groups in terms of spatial practice in anatomy.

Another factor in the interpretation of the experimental results is the use of placebo exercises. In retrospect, the specific placebo exercises that were chosen were a kind of spatial training in themselves, and may have been as beneficial as the intervention. Experimental and control group participants spent equal amounts of time on their respective assignments. Participants in the control groups were required to identify, trace and label structures in two radiographic images made at perpendicular orientations to each other. In addition, control group participants explained their assignment before data collection; experimental group participants did not realize the extra benefit from verbalization of the assignment until after data collection. The spatial training control participants received from these assignments may have affected their ability to visualize structures of the head. Placebo activities more different from the intervention should have been used in this study.

Treatment diffusion could be a potential problem due to the fact that all participants were in the class together at all times. There was, however, no evidence of widespread awareness by the control groups of the content of the intervention assignment during either trial, and no evidence that control students spent significant time in the study of the cross section used in the intervention.

Trial 2 participants performed better on the head test than did those of Trial 1. This difference in performance could be due to communication between participants in the two trials. It could also relate to differences that existed between the two trials, including:

1) The possibility that Trial 2 participants had more overall exposure to cross-sections than participants in Trial 1. The instructor for gross anatomy for Trial 2 was different than that for Trial 1. The instructor for Trial 2 routinely used cross sectional images during lecture and involved the students in discussions about structures on those images. Participants in Trial 2 made more references to these types of images during interviews than did those of Trial 1.

2) Participants in Trial 2 were tested for spatial ability at the beginning of the trial. This measure was justified to them on the grounds that spatial ability may be related to performance in anatomy class, and that anatomy requires spatial thinking. These participants may have been more aware of the need to visualize anatomical structures in three dimensions, and may have practiced this more than participants in Trial 1.

3) The two samples of veterinary students might have been different on some variable not measured in this research. Although the average age, GRE and GPA data appears similar between the two classes, spatial ability was not measured in Trial 1.

4) The researcher was not able to be present for the first administration of the head test in Trial 1. Another instructor, who did not explain how to complete the test, gave the test. For Trial 2, the researcher was present and was able to summarize what was expected for the different parts of the test. This may have contributed to the higher scores in Trial 2.

The head is recognized as a difficult area for students to visualize, and cross sections of the head have previously been used for the purpose of teaching three-dimensional relationships of structures of the head. Other anatomists have recognized the usefulness of cross sectional anatomy to teach and test understanding of spatial relationships in the body (Farnum & Beck, 1990; Berman et al., 1993; Friedman et al., 1993). Farnum and Beck (1990) used cross sections as part of a multi-media unit that included an actual cross section, computed tomography (CT) images, radiographic images and a skull. Students were allowed 1/2 hour in which to interact with the instructional materials and to answer provided study questions. No evaluation of the effectiveness of this intervention was made; however, some of its components could have improved the intervention reported here. A more powerful intervention using cross sections could have included more than one section so that participants could follow structures of the head rather than observe their positions at one level of section only. The use of an actual cross section specimen instead of the photograph of the section would also have been an improvement. Requiring participants to have more interaction with the cross section (such as through the use of study questions about the image), or having participants produce their own cross sectional image given a certain level of section through the head, would both have increased processing of the information. In particular, the use of a series of cross sections was mentioned by participants in this study as providing a possible improvement in their understanding.

One of the unknown factors in this research is the degree of background exposure of participants to cross sectional images in their textbooks and other study materials. The dissection guide used by these participants contains two cross sectional images of the head, and the extent to which control-group participants studied these or similar images in other texts can never be determined. One of the reasons cross sections were chosen for this research was the perception that most students tend to overlook a cross section when they encounter it in a textbook. Comments from control-group participants tend to validate this perception; most said they had not used cross sections prior to the test, and some said that a cross section is such an unfamiliar perspective on anatomical structures that it is disorienting. Using more cross sectional images in the intervention would have served to increase the exposure of the experimental group to cross-sections as compared to that of the control group.

Spatial Ability and the Head Test

Spatial ability as measured in this study correlated significantly with performance on Part C of the head test only. While it was expected that spatial ability would be required to successfully complete all parts of the test, Part C was felt to be the most related to the specific mental ability measured by the Purdue Visualization of Rotations test. The ability to imagine the appearance of an object if it were rotated (Purdue Visualization of Rotations) is similar to the ability to imagine the appearance of an anatomical structure from multiple points of view as in Part C.

Spatial ability did not have a statistically significant effect on the dependent variables generated from Part C in this trial, except for ROS. It did have a significant effect on the dependent variable B2 in Trial 2. This effect is difficult to interpret; spatial ability was not correlated significantly with scores on Part B, and gender also was a significant effect for this variable. Women outscored men on this variable, but the opposite would be expected considering spatial ability alone, because men had a higher spatial ability score than women.

Spatial Ability and Anatomy Performance

Spatial ability in this study correlated significantly with examination performance. Some questions on the written examinations required making sketches to illustrate the position of organs or structures within the body. Other questions on written examinations also might require recall and visualization of spatial relationships. Most questions on laboratory examinations are identification only, but the cadaver may be presented in an unfamiliar orientation, requiring that the student first rotate either the visual stimulus, or her- or himself, in order to recognize the structure. Thus, the finding that spatial ability was significantly related to performance on examinations is not surprising, and is in agreement with previous research suggesting that students with low spatial ability are at academic risk in anatomy (Rochford, 1985; Keen et al., 1988).

Performance on live dog quizzes had no relationship to spatial ability for women, and for men the score for live dog quizzes was only slightly positively related to spatial ability. No analysis of the type of questions included on the live dog quizzes was performed. The possibility exists that the majority of questions on these assessments required factual rather than spatial information. This research could have been improved if the proportion of spatial and non-spatial questions included on each of the live dog quizzes had been assessed.

There are several components of spatial ability (McGee, 1979). The test of mental rotation ability used for this research, the Purdue Visualization of Rotations, might not measure the same aspect of spatial ability required to visualize the placement of structures within the live animal. Mental rotation ability was chosen because it seems intuitive that in order to answer questions on a live dog examination, a student would rotate her or his mental image of the cadaver to the upright dog. However, this may not be the kind of mental manipulation performed, or it may be performed in conjunction with additional mental manipulations.

An attempt was made with the surveys and interviews to determine how participants visualized the location of structures of the head within a live animal. A frequent reference was to trying to "picture the cadaver", indicating that they do rely on the image of their cadaver when confronted with the live animal. Others, however, said they had learned this through practice with the live dog and reference to the skull at the same time--they attempted to visualize the skull and other structures inside the head.

Spatial ability increased from the beginning to the end of the year. This was to be expected, because the type of thinking required for successful performance in an anatomy course could be considered as spatial training, and because spatial ability has been shown to increase as a result of involvement in other courses (Blade & Watson, 1955; Pallrand & Seeber, 1984). Mental exercises such as those required for the head test, for visualization of structures on radiographs, and for palpating the live dog, are all similar to exercises which have been used specifically to improve spatial ability (Stericker & LeVesconte, 1982; Ferrini-Mundy, 1987; Braukman & Pedras, 1993; Baartmans & Sorby, 1996).

Spatial Ability and Gender

The gender difference in spatial ability for this population was unexpected in light of previous research which suggests that women entering veterinary medicine should have high spatial ability because of their academic background (Pallrand & Seeber, 1984; Lord, 1985a; Casey et al., 1993). In addition, women veterinary students were recently found to be equal to men in spatial reasoning (Bailey et al., 1995). The finding that spatial ability of women increased more than that of men is in agreement with research suggesting that women might benefit more than men from spatial training (Koslow, 1987; Lord, 1987; Allington, et al., 1992). The possibility exists that women were influenced both by the knowledge that the test was a test of spatial ability (Stericker & LeVesconte, 1982), and by an expectation to increase their spatial ability score over the year. Discussions took place with the participants regarding the possibility of increases in spatial ability as a result of participation in anatomy. These discussions about increases in spatial ability as a result of practice were not gender-specific. If expectations, or motivation to perform better, caused an increase in spatial ability for women in the class, this should also have been the case for men. The fact that no statistically significant gender difference in spatial ability existed at School X also points to the need to investigate this ability further among veterinary students. Perhaps women at Purdue were indeed influenced by the expectations of the researcher that women might score lower than men, although every effort was made not to discuss this issue during the study.

Because spatial ability is related to at least some measures of performance in anatomy, the equal performance of the women and men in anatomy in this study despite lower mean spatial ability of the women deserves comment. Voyer (1997) suggests that the magnitude of the gender difference in mental rotations is reduced when a ratio score, which measures the number correct out of the number attempted, rather than a raw score is used. It may be that women have the same ability as do men to perform mental rotations of objects, but can not do so as quickly. The amount of time given for answering questions on anatomy examinations may not be small enough to detect this difference.

Both verbal and spatial knowledge domains must be mastered while learning anatomy (Rochford, 1985; Friedman et al., 1993; Rosse, 1995). Another interpretation of the current findings is that women may compensate for lower spatial ability in anatomy with well-developed verbal anatomy ability. Alternately, the test of spatial ability (mental rotation ability) used in this research may not measure the type of spatial ability necessary to perform well in anatomy, or it may measure only one of many necessary skills. Women may have a different kind of spatial aptitude than men that helps them succeed in gross anatomy. Halpern (1997) has stated that women are more skilled than men at tasks that require access to spatial information in long-term memory, while men are more skilled at tasks that require transformation in visual working memory.

In summary, there is no evidence from this research that women can not attain the same level of performance as can men on measures of spatial thinking in anatomy. There is however, evidence from this research that female veterinary students have more room to improve in spatial ability than their male peers. Gender differences in this study must be interpreted with caution, however, because of the disproportionate number of women in the study.

Conclusions

The qualitative analysis demonstrates that, although the use of one cross section did not result in measurable gains in three-dimensional anatomical understanding, participants did gain new insights into spatial relationships as a result of their experience with the cross section. The qualitative analysis supported the hypothesis that spatial thinking in anatomy is difficult for some students. Individuals described the difficulty they experienced in transferring the knowledge gained from dissection to the live animal. The qualitative data also indicated that for some participants there were intangible benefits of the intervention, which were not detected by the statistical analysis. Most participants felt the cross section assignment did have a positive impact on their ability to visualize the spatial arrangement of structures of the head. Participants were able to see structures from a perspective that was unavailable during dissection, and thus added to their complete understanding of the arrangement of structures of the head. In addition, the cross section reinforced information about spatial relationships that had been observed but lost due to the destructive nature of dissection. Most participants offered strong support for both the cross section assignment and the test used in this research, and felt that their use in the class should be continued.

Some participants expressed differing opinions on the value of cross sections in increasing their spatial anatomical knowledge; some felt that the dissection experience was more beneficial, while others indicated that cross sections were too difficult to interpret, or that they just could not think in that manner.

Participants reported greater ability and motivation to visualize structures of the head, and greater appreciation of relationships between structures of the head, as a result of viewing cross sections and taking the experimental test. One of the unexpected benefits of the head test was that it made participants re-consider what they were learning about structures of the head, and realize where their deficiencies were. The comments they made about the test indicated that for them it had as powerful an effect as the cross section assignment in terms of learning to visualize anatomy in three dimensions.

In conclusion, the words of one participant illustrate the insight she gained from her experience of this research:

> "I think it [the study] was definitely valid. We're so focused on the test, and the exam. And as long as I can tell what is on the exam, I'm happy. Well, that's all nice, cause you pass anatomy and you get a good grade, but like you said, when there's a dog standing in front of you, it's like, 'Does the spleen come out that far forward?' Cause you could identify the spleen, that's not a problem, but where is it in the animal that you are gonna treat? That's the most important part. That should be the gist of why we're learning anatomy."

Future Directions

The most promising future direction for research in this area would be to design an intervention that is more three-dimensional in nature. This could be done using physical sections from a cadaver as opposed to a photograph. With multiple actual sections, students could rotate the specimens, and follow given structures from one section to the next. A physical specimen would also include the color, texture and contrast information which students feel helps distinguish structures from one another.

Future directions also include further analysis of the relationship between spatial ability and performance in anatomy. Spatial ability might be used to identify students who would have particular difficulty with visualizing anatomical structures in three dimensions, and these students could be offered extra help in developing this ability. Previous research into the relationship between spatial ability and anatomy performance did not address the gender issue. Research along these lines would be interesting, especially in regards to the ability to think in three dimensions. In this sample the women appeared to perform at equal levels with the men on anatomical tests and on the experimental test, despite the fact that they began the year with less spatial ability than the men. It is possible that women compensate for poorer performance on spatial anatomical questions with better performance on non-spatial questions. Is the gender difference in spatial ability true for all populations of veterinary students? If so, did the spatial ability of the women in this study increase because of the discussion regarding the spatial nature of anatomy study, or would their spatial ability have increased without this intervention? How quickly do women attain the same levels of spatial ability as men? These questions should be of interest to the profession because of its large female population.

A possible alternative approach to spatial training in anatomy would be one using the computer to visualize anatomical structures. With possibilities such as virtual reality (Wright, Rolland & Kancherla, 1995), three-dimensional imaging, rotational capability, and successive revelation of obscured structures, students could be prompted to visualize structures from a variety of perspectives, which should improve spatial visualization skills (McCracken & Spurgeon, 1991; Sundsten, Kastella & Conley, 1991; Richter et al., 1994; Schubert et al., 1994). Computers could also be fruitfully used to test three-dimensional anatomical knowledge (Friedman et al., 1993). A drawback to this approach is the expense of the computer equipment and software necessary to support such applications.

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