Mental Rotation: Cross-Task Training and Generalization

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It is well established that performance on standard mental rotation tasks improves with training (Peters et al., 1995), but thus far there is little consensus regarding the degree of transfer to other tasks which also involve mental rotation. In Experiment 1, we assessed the effect of mental rotation training on participants’ Mental Rotation Test (MRT) scores. Twenty-eight participants were randomly assigned to one of three groups: a “One-Day Training,” “Spaced Training,” or “No Training” group. Participants who received training achieved higher scores on the MRT, an advantage that was still evident after 1 week. Distribution of training did not affect performance. Experiment 2 assessed generalization of mental rotation training to a more complex mental rotation task, laparoscopic surgery. Laparoscopic surgical skills were assessed using Fundamentals of Laparoscopic Surgery (FLS) tasks. Thirty-four participants were randomly assigned to a “Full Mental Rotation Training, MRT and FLS,” “MRT and FLS,” or “FLS-only” group. MRT results from Experiment 1 were replicated and mental rotation training was found to elicit higher scores on the MRT. Further, mental rotation training was found to generalize to certain laparoscopic surgical tasks. Participants who obtained mental rotation training performed significantly better on mental-rotation dependent surgical tasks than participants who did not receive training. Therefore, surgical training programs can use simple computer or paper-based mental rotation training instead of more expensive materials to enhance certain aspects of surgical performance of trainees.

Keywords: mental rotation, training, laparoscopy, surgical skill acquisition, FLS, spatial ability

Humans can accurately gauge whether multiple examples of two-dimensional (2-D) images of a three-dimensional (3-D) object represent the same 3-D shape despite changes in the 2-D object’s orientation. In their seminal study, Shepard and Metzler (1971) presented research participants with two objects that differed in orientation in steps of 20°. They demonstrated that reaction time to determine whether two stimuli represent the same 3-D object increases linearly with the angle of rotation from the original position. Subsequently it has been shown that reaction time for such tasks increases with stimulus complexity for novel stimuli and that this relationship does not appear given sufficient practice with the specific mental rotation task (Bethell-Fox and Shepard, 1988). Furthermore, Kail and Park (1990) demonstrated that with mental rotation training, both children and adults achieve significantly shorter reaction times on mental rotation tasks. In their study, adults initially performed the task more quickly than children, but these differences were eliminated with training.

An important question raised by this work is whether observers are improving their mental rotation skills in general or if learning is task-specific: can mental rotation training on one task lead to improvement on tasks that require similar rotation skills, but differ in their spatial layout and specific task demands? Some studies have attempted to show generalization, but instead have found that the task is performed from memory and solving a different mental rotation task does not evoke the appropriate mental algorithm or apply the strategy used in a previous encounter. This type of learning has been called instance-based (Heil, Rosler, Link, & Bajric, 1998). For example, Kail and Park (1990) presented pattern stimuli at different orientations and participants had to determine whether they were letters or mirror images of letters. They found that performance improved with practice, but when asked to perform transfer tasks, the initial improvement was not maintained. Other studies have demonstrated transfer of improvement of mental rotation, which can be described as process-based (Heil et al., 1998). Sanz de Acedo and Garcia (2003) used the Spatial Relations-Differential Aptitude Test (SR-DAT) to assess the mental rotation ability of children before and after mental rotation training, which consisted of visualization tasks and haptic manipulative material. They found that with mental rotation training and feedback, participants improved their mental rotation ability and transferred this learning to the visualization task.

Mental Rotation Improves Professional Skills

The ability to rotate objects and scenes is essential for many professional skills, including veterinary medicine (Provo, Lamar, & Newby, 2002) and dentistry (Hegarty, Keehner, Khooshabeh, & Montello, 2009). Mental rotation practice has been shown to help veterinary students visualize anatomical 3-D structures (Provo et al., 2002). A qualitative analysis suggested that asking students to supplement their learning by identifying anatomical structures from cross sections elicited better spatial learning than students who just performed a dissection. Being able to see structures from multiple viewpoints helped students integrate and understand the anatomy being
studied and provided a 3-D mental image of the cadaver. This form of learning provided students with a better understanding of the spatial arrangement of structures in the head, which was not available from the dissection alone.

Mental rotation ability has also been correlated with performance on dental tasks. Hegarty and colleagues (2009) conducted a study with 234 dental students that looked at the relationship between scores on spatial ability tests and students’ performance in dental school. Hegarty et al. (2009) found that high scores on the spatial ability tests correlated with better performance in dental school. More specifically, spatial ability, including mental rotation ability, correlated with students’ ability to imagine a cross-section of a 3-D tooth and enhanced performance in restorative dentistry tasks.

Generalization to Laparoscopic Surgery

There is evidence that mental rotation plays an important role in many professional and recreational activities, and researchers have used spatial training to directly improve such skills. For instance, a number of studies have shown that mental rotation abilities are sensitive to training on the same, or a similar task (Shepard & Metzler, 1971; Bethell-Fox and Sheppard, 1988; Peters et al., 1995). However, it is unclear whether mental rotation training transfers to tasks that are different in structure, but require similar mental rotation processing. Researchers have investigated how mental rotation ability correlates with a novice’s performance in fields such as dentistry, laparoscopic surgery, and sports. However, the literature investigating the role of mental rotation ability in surgical skills has reported only a correlational relationship and has not evaluated if mental rotation training improves surgical ability (Wanzel, Hamstra, Anastakis, Matsumoto, and Cusimano, 2002; Wanzel et al., 2003; Hedman et al., 2006).

The main goal of this study is to fill this gap in the literature and determine if mental rotation training transfers to dissimilar skills that are also dependent on mental rotation. We have two objectives in Experiment 1. First, we will verify that training improves performance on a set of mental rotation tasks, some of which have not been used in empirical studies of mental rotation. Second, we will determine if the expected improvement in performance is restricted to the specific mental rotation task used, or if it generalizes to a different mental rotation task. Our goal in Experiment 2 is to determine if the improvement obtained from mental rotation training transfers to a professional task that relies critically on mental rotation—laparoscopic surgical skills training.

General Methods

Participants

Participants included both undergraduate and graduate York University students. Undergraduate students were recruited through signage and the Undergraduate Research Participant Pool (URPP). Participants ranged from 18 to 27 years of age. Sixty-two students participated in this study, 28 in Experiment 1 and 34 in Experiment 2. American Psychological Association guidelines on ethical treatment of participants were followed throughout.

Apparatus and Materials

Participants completed the experiment using a PC computer, pen and paper and, in Experiment 2, a laparoscopic bench model. For surgical tasks, a 27” TV screen was positioned 85 cm from the observer. The bench model was placed on a desk (height = 75 cm) in front of the participant and had a built-in camera that projected the unseen work area onto the screen. Participants used 32 cm long graspers (measured from handle to tip) and 33 cm long scissors to perform the surgical tasks.

Mental Rotation Test (MRT). The Mental Rotation Test (MRT) was first introduced by Vandenberg and Kuse (1978), who constructed the test from figures similar to those used by Shepard and Metzler (1971). Here, we used the redrawn test, MRT-A by Peters et al. (1995), who also provided three additional versions of the test that differed in order and/or level of difficulty. The MRT was administered as follows: participants were asked to view four 3-D figures and decide which two figures were the same as the target object (Figure 1, top). There were 24 items and participants were awarded one point per correct item, for a maximum possible score of 24. The MRT was timed in two parts: the participant was given 4 minutes to complete the first 12 items and 4 minutes to complete the last 12 items.

Mental rotation training tasks. The training tasks used in this study were intended to provide broad experience with mental rotation operations using a variety of stimuli. The visualization tasks had different spatial layouts and, importantly they were spatially different from the MRT. Unlike most other studies of mental rotation, this study relied upon interactive mental rotation training sessions. That is, training consisted of a PC-based game called 3D Blocks (Figure 1, bottom) as well as a number of paper-based mental rotation tasks (Figure 1, middle). Using 3D Blocks, participants were able to rotate blocks around the x, y, and z axes as the blocks fell into a pit. The pit gradually filled and eventually no new blocks would fit, at which point the game provided feedback by terminating that session and starting a new one. The 3-D information was provided via the shading, perspective, and sizes of the blocks. Participants were also able to rotate the side view to obtain multiple viewpoint information.

Paper-based mental rotation training activities were obtained from Dental Admission Test (DAT) practice materials. Examples of the three paper-based training tasks are illustrated in Figure 1 (middle). Figure 1a shows the hole-punch task, in which a piece of paper has been folded two or more times and then hole-punched. The subject must mentally unfold the paper and determine which of a set of five alternatives depicts the correct pattern of hole punches in the original unfolded sheet. In the pattern-folding task (1b), observers must mentally fold the pattern into a 3-D figure and decide which option represents the correctly folded object. In the keyhole task (1c), subjects imagine how a target object looks from every side and decide which hole the object would pass through. Subjects did not receive feedback on their performance during paper-based training.

Data analysis. Heteroscedasticity was assessed using the Levene’s test and distribution normality was assessed using the Shapiro-Wilk test. Since our data was homoscedastic, but violated normality, we used a nonparametric test to analyze our data instead of a conventional analysis of variance (ANOVA).

Experiment 1

Experiment 1 was designed to determine if significant improvement on the MRT is observed following training on a variety of
mental rotation tasks, and if that improvement is retained over time. In addition, while previous studies (Shepard & Metzler, 1971; Bethell-Fox and Shepard, 1988; Kail & Park, 1990) have shown that there is an improvement in mental rotation when participants repeat a specific mental rotation task, it remains unclear how much practice is required to obtain significant improvement. Furthermore, there is evidence that training on certain tasks is enhanced when learning is distributed over a number of training sessions (Bourne & Archer, 1956; Mackay, Morgan, Datta, Chang, & Darzi, 2002; and Moulton et al., 2006). Our experimental design will allow us to compare the effects of limited practice within and across days.

Methods

Twenty-eight participants were randomly assigned to one of three groups: “One-Day Training,” “Spaced-Training,” and “No-Training” groups. The following summarizes the procedure followed by each group.

One-day training. Ten participants (five male and five female) completed the experiment in 1 day. The One-Day Training group initially completed the MRT to obtain a baseline score and then underwent the first of two 40-min training sessions. As outlined in the General Methods section, training consisted of the PC 3D Blocks game (10 minutes), and the three paper-based mental rotation tasks (30 minutes). Participants completed all three types of the paper-based tasks and if there was time remaining they did additional ones so that training always lasted 40 minutes. After the first training session, participants completed the MRT for a second time. Next, participants completed the second training session, and then the MRT for a third time. One week later, participants completed the MRT for a fourth time to assess retention.

Day 1: MRT 1 → Training 1 (40 min) → MRT 2 → Training 2 (40 min) → MRT 3
Day 8: MRT 4

Spaced-training. Ten participants (five male and five female) were randomly assigned to the Spaced-Training group. These participants underwent the same experiment as the One-Day Training group, but the experiment was split into two sessions completed on two consecutive days. This group completed the first MRT and training session on Day 1, and the second MRT, the second training session and the third MRT on Day 2. One week later, participants completed MRT 4.

Day 1: MRT 1 → Training 1 (40 min)
Day 2: MRT 2 → Training 2 (40 min) → MRT 3
Day 9: MRT 4

No-training. Eight participants (4 male and 4 female) were randomly assigned to the No-Training group. This group served as a control to assess the effects of simply repeating the MRT. This group did not undergo any additional training, but completed the MRT three times in 1 day, and again 1 week later.

Day 1: MRT 1 → MRT 2 → MRT 3
Day 8: MRT 4

Results

Mental rotation assessment. Nonparametric tests were performed with an alpha level of 0.05 and predictions were a priori. Figure 2 shows results for MRT performance in Experiment 1. A Kruskal-Wallis analysis of variance showed a significant main group effect, \( \chi^2(2) = 9.605, p < .01 \).

As expected, a Wilcoxon signed-ranks test revealed an improvement of MRT scores for all groups from MRT 1 to MRT 4 (One-Day Training, \( Z = -2.81, p = .005 \); Spaced-Training, \( Z = -2.73, p < .01 \); No-Training, \( Z = -2.54, p = .01 \)). The Mann–Whitney test was used to assess differences between the individual groups. Association strength was assessed using Glass’ rank biserial correlation coefficient (Glass, 1965). The Mann–Whitney test
indicated that the One-Day Training and Spaced-Training groups performed similarly on all MRT sessions. All three groups performed similarly on MRT 1 (Spaced Training compared with No-Training, \( U = 25, p = .20 \)) and MRT 2 (Spaced Training compared with No-Training, \( U = 28, p = .32 \)), so any differences seen between groups by the end of training was likely due to the treatment and not preexisting group differences. This analysis indicated that the Spaced-Training group performed significantly differently from, and better than, the No-Training group on MRT 3 (\( U = 14, p = .01, r_g = 0.64 \) large effect) and MRT 4 (\( U = 21.5, p = .05, r_g = 0.46 \) medium effect).

Since we did not find a significant difference between the One-Day Training and Spaced-Training groups, we collapsed these two training groups to see if there was a difference between the performance of men (\( n = 10 \)) and women (\( n = 10 \)) on the MRT. Overall, males performed significantly better than females (\( U = 18, p < .01, r_g = 0.64 \) large effect). This difference is illustrated in Figure 3.

Figure 2. Experiment 1 MRT Results. The solid black line represents the One Day Training group (\( N = 10 \)), the black dashed line represent the Spaced Training group (\( N = 10 \)), and gray dashed lines represent the No Training group (\( N = 8 \)). The error bars represent the standard error of the mean.

Figure 3. Sex differences in MRT scores. The black solid line represents 10 males, and black dashed line represent 10 females collapsed across the One Day and Spaced Training groups. The error bars represent the standard error of the mean.
Experiment 1 showed that training on a set of various mental rotation tasks led to improvement on the MRT. In previous studies that documented improvement in mental rotation, investigators used mental rotation tasks that were identical (or similar) to the mental rotation task being used for assessment (Bethell-Fox and Shepard, 1988; Kail & Park, 1990; Peters et al., 1995; and Heil et al., 1998) and also found strong training effects. Like other investigators (Peters et al., 1995), we have found sex differences in performance on the MRT. Overall, Experiment 1 demonstrated that training need not be performed on the same task; it is possible to improve performance on different mental rotation tasks while training on another.

Peters and colleagues (1995) found that individuals who completed the MRT after completing a different version of the MRT test benefited significantly from the prior exposure. Similarly, our No-Training group, which repeated the MRT test multiple times, shows improvement due to practice alone. This improvement may have been partly due to the fact that in this study observers were assessed using the MRT test with items in the same order (though the same procedure was used for all groups). However, it is important to note that our One-Day Training and Spaced-Training groups improved significantly more than the No-Training group, thus revealing the added benefit of mental rotation training over and above simple repetition.

Experiment 2

In Experiment 1, we confirmed that mental rotation training significantly improves performance on a different mental rotation task, the MRT. The question remains whether this training transfers to a professional task that relies on mental rotation. In Experiment 2, we answer this question by directly testing skills involved in laparoscopic surgery.

Laparoscopic surgery requires that a surgeon perform a surgical procedure inside a person’s abdomen by inserting surgical instruments and a scope with a video camera that projects the image onto a 2-D screen. New surgeons in many residency programs practice surgical skills using a synthetic model of the laparoscopic environment and Fundamentals of Laparoscopic Surgery (FLS) tasks that mimic surgical skills. FLS tasks have been extensively tested to ensure that they reflect the technical skills that are fundamental to the performance of laparoscopic surgery (Peters et al., 2003; Fried et al., 2004).

Certain FLS tasks require a significant amount of mental rotation. Further, several studies have demonstrated that individuals who achieve high scores on tests of mental rotation and perceptual abilities perform better on simulated surgical tasks (Wanzel et al., 2002; Wanzel et al., 2003; Brandt, & Davies, 2006). Fortunately, individuals who initially exhibit low mental rotation ability and poor surgical performance can improve if given additional practice and feedback on surgical tasks (Wanzel et al., 2002). The results of these studies indicate that there is a correlation between mental rotation and surgical ability. However, no one has assessed the causal nature of this relationship, that is, does training on mental rotation tasks lead to improvements in surgical performance? We ask this question in the study described below.

Methods

The training tasks and MRT tests were essentially the same as described in Experiment 1, except that the standard MRT used in Experiment 1 was reordered prior to each test session for each individual to avoid possible effects of memorization. Experiment 2 also included a surgical skills assessment component. Prior to testing, subjects were randomly assigned to one of three groups: “Full MR Training, MRT & FLS,” “MRT & FLS,” and “FLS-only.” Since Experiment 1 revealed no advantage of distributing training over 2 days, all testing was completed in one day, with the exception of the retention test.

Full MR training, MRT & FLS. Ten participants (five males and five females) initially completed the MRT and two FLS tasks to obtain baseline surgical performance and mental rotation ability scores. They then underwent the first 40-min training session in which they completed the tasks described in the General Methods section. After training, this group completed the MRT for a second time followed by another training session. They then completed the MRT and the FLS tasks again. One week later, participants in this group completed the MRT and FLS retention test.

Day 1: MRT 1 → FLS 1 → Training 1 (40 min) → MRT 2 → Training 2 (40 min) → MRT 3 → FLS 2
Day 8: MRT 4 → FLS 3

MRT & FLS. Thirteen participants (six males and seven females) completed the same set of MRT and FLS tasks as the “Full MR Training MRT and FLS” group, without any intervening training. A comparison between these two groups will reveal benefits to surgical skills simply as a result of repetition of the MRT.

Day 1: MRT 1 → FLS 1 → MRT 2 → MRT 3 → FLS 2
Day 8: MRT 4 → FLS 3

FLS-only. Eleven participants (six males and five females) repeated the FLS tasks twice to assess the amount of improvement in surgical skills tasks that was due to simply repeating the surgical task without any additional mental rotation experience.

Day 1: FLS 1 → FLS 2
Day 8: FLS 3

Assessment of surgical performance. Surgical performance was assessed using a laparoscopic bench model, identical to that widely used in surgical training facilities, and two FLS tasks. Laparoscopic bench models simulate real surgical settings and are used to train resident surgeons before they enter the operating room. Our aim was to choose two tasks that were part of the standard FLS protocol: one that clearly involved mental rotation and would be expected to improve with our battery of mental rotation training tasks, and another that was less influenced by mental rotation ability and would not be expected to improve as a result of training. While there is no “rating” for the FLS tasks in terms of the degree of mental rotation needed, upon close inspection we identified two appropriate candidates: the peg transfer and circle cutting tasks (see Figure 4). By comparing the effects of mental rotation training on these two FLS tasks, we can assess whether improvements are specific to mental rotation or are related to improvements in motor-coordination. As in surgical training, both tasks were performed with camera feedback only, and direct viewing was not permitted.

As described by Fried et al. (2004), the peg transfer task was designed to develop the coordination of both hands and to improve depth and visual-spatial perception in a monocular viewing system. Further, this task gave participants clear visual markers and required primarily lateral motor movements. The peg-transfer task required that subjects pick up a rubber object from a 10.0 × 6.5 cm peg board with a grasper in their dominant hand, transfer it to a

Discussion

were randomly assigned to one of three groups: “Full MR Training, MRT & FLS,” “MRT & FLS,” and “FLS-only.” Since Experiment 1 revealed no advantage of distributing training over 2 days, all testing was completed in one day, with the exception of the retention test.
grasper held in their nondominant hand, and then place it on a peg on the opposite side of the board. The rubber objects had a diameter of 9 mm, while the pegs had a diameter of 3 mm. This task required considerable lateral movement and manual dexterity.

The circle cutting task was developed to teach visual spatial skills, precision, bimanual dexterity, and required the use of the nondominant hand to provide traction and reposition the paper to the appropriate cutting angle (Fried et al., 2004). However, this task requires multiple manual rotational manipulations, which necessitates some premediated mental rotation in 3-D space. In the cutting task subjects were asked to cut around a circle that was outlined in black, with a diameter of 6.5 cm, from a 10 × 14 cm square piece of paper. A red dot was drawn on the paper 1.5 cm away from the circle to indicate where the subject should start cutting. The dominant hand held a long scissor instrument that was used to cut the paper while the other hand grasped a grasper that was used to secure the paper and rotate the paper into the best position for cutting along the circle. This task relied heavily on observers’ ability to mentally rotate the circle, and thereby anticipate the correct cutting angle.

Scoring of surgical tasks. The surgical tasks were timed and limited to 5 minutes. The number of errors was recorded in the peg transfer task. In addition to limiting time, the circle-cutting task is typically assessed by the number of deviations from the circle and the distance cut around the circle (length of cut). However these measures do not fully reflect the precision of the participant’s cutting. For instance, a jagged cut profile that remains close to the circle might well be longer than a smoother profile, which is evident in the MRT & FLS group but were apparent in the MRT & FLS group (U = 83, p < .01, r_g = 0.75 large effect). Males in both groups performed similarly on all MRT sessions, while females in the Full MR Training, MRT & FLS group performed significantly better by the end of testing (MRT 4) that females in the MRT & FLS group (U = 3, p = .02, r_g = 0.82 large effect; see Figure 7).

Surgical skills assessment. For the cutting task (high mental rotation), a precision ratio was computed as described in the Methods section for Experiment 2; a perfect cut had a precision ratio of 0.1641. As seen in the graph in Figure 8, the Full MR Training MRT & FLS group and the MRT & FLS group performed similarly in all three assessments. These two groups performed significantly better than the FLS-only group in the retention session (Session 3; U = 31, p = .04, r_g = 0.42 medium effect, and U = 62, p = .04, r_g = 0.42 medium effect).

As described in the Methods section, we also measured the length of the cut. The “ideal” length was equal to the perimeter of the circle, 19 cm. As seen in Figure 9, the Full MR Training, MRT & FLS group showed the most improvement according to this measure and performed significantly better than the MRT & FLS group in the retention Session 3 (U = 37, p = .04, r_g = 0.43 medium effect), and significantly better than the FLS-only group in both Session 2 (U = 30.5, p = .04, r_g = 0.44 medium effect) and retention Session 3 (U = 29, p = .03, r_g = 0.47 medium effect). In terms of cutting time, all groups improved as a function of practice but there were no significant differences found between groups (see Figure 10).

For the peg transfer task (see Figure 11), there was a small but significant difference in error rates between Full MR Training MRT & FLS and MRT & FLS groups in Session 1 (U = 35.5, p = .03, r_g = 0.45 medium effect) and Session 3 (U = 39, p = .044,
Discussion

**MRT assessment.** In this study we replicated the MRT results of Experiment 1 and confirmed that an improvement in MRT scores was obtained after training on a different set of mental rotation tasks. Further, the Full MR Training, MRT & FLS group performed significantly better on the MRT than the MRT & FLS group and this is clear evidence of generalization of improvement in mental rotation ability. Experiment 2 also showed that the MRT improvement in our first experiment was not due to repetition of the same MRT sequence; the data are comparable across the two studies.

**Surgical skills assessment.** Experiment 2 was designed to assess if training on mental rotation tasks leads to improvement in a professional skill that relies in part on mental rotation. We did not find significant effects for the peg transfer task and therefore our data do not reflect simply an improvement in motor skills. Our main finding was that mental rotation training enhanced performance on certain FLS tasks, specifically the cutting task which was assumed to be dependant upon mental rotation.

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**Figure 6.** MRT Results from Experiment 2. The black solid line represents the Full MR Training, MRT & FLS group (\(N = 10\)), and black dashed line represents the MRT & FLS group (\(N = 13\)). The error bars represent the standard error of the mean.

**Figure 7.** Sex differences on MRT scores in Experiment 2. The left graph shows males’ performance on the MRT and the right graph shows female’s performance. Solid lines represent participants from the Full MR Training, MRT & FLS group, dashed lines represent participants from the MRT & FLS group. The error bars represent the standard error of the mean.
The FLS tasks have primarily been evaluated using the evaluation sheet distributed with the FLS training kit, which are based on time to completion (maximum of 5 min), number of errors or deviations and length of cut. Clearly these measures do not fully capture all aspects of performance and due to task difficulty, ceiling effects are common resulting in small differences in completion time between groups. Therefore we created an additional measure to quantify performance on the cutting task, a ratio describing the precision of the cut and accuracy defined by the length of the cut.

In terms of the length of cut measure, the Full MR Training MRT & FLS group retained their improvement 1 week after training while the MRT & FLS group lost their initial improvement 1 week later. The FLS-only group showed no improvement between sessions. In terms of the precision measure, the Full MR Training, MRT & FLS and MRT & FLS groups performed simi-

![Figure 8](image1.png)  
*Figure 8.* Experiment 2 surgical precision ratios. The black solid line represents the Full MR Training, MRT & FLS group ($N = 10$), black dashed line represents the MRT & FLS group ($N = 13$), and gray dashed lines represent the FLS-only group ($N = 11$). The black lines with open squares represent the ideal precision ratio. The error bars represent the standard error of the mean.

![Figure 9](image2.png)  
*Figure 9.* Experiment 2 length of cut. The black solid line represents the Full MR Training, MRT & FLS group ($N = 10$), and black dashed line represents the MRT & FLS group ($N = 13$) and gray dashed lines represent the FLS-only group ($N = 11$). The black lines with open squares represent the ideal precision ratio. The error bars represent the standard error of the mean.
larly, and both performed better than the FLS-only group. This suggests that any exposure to mental rotation practice can improve surgical performance.

There are several implications of these data. First, our new performance measure gives additional insight into the improvement of surgical skills, and how they might best be quantified. A limitation of this study is the lack of a more precise evaluation measure for the peg transfer task, and a global measure to compare performance among the different FLS tasks. Furthermore, this study supports previous findings that mental rotation ability is involved in certain laparoscopic tasks (Wanzel et al., 2002; Wanzel et al., 2003; Brandt & Davies, 2006). More significantly, we have shown that training on a variety of mental rotation tasks leads to improvements in FLS performance. Thus, Experiment 2 demonstrates that practice with simple paper or computer-based mental rotation exercises can be used to free costly laparoscopic training equipment for focused training procedures, thus reducing the time demands on expert surgeons.

**Figure 10.** Experiment 2 cutting time results. The black solid line represents the Full MR Training, MRT & FLS group \((N = 10)\), and black dashed line represents the MRT & FLS group \((N = 13)\) and gray dashed lines represent the FLS-only group \((N = 11)\). The black lines with open squares represent the ideal precision ratio. The error bars represent the standard error of the mean.

**Figure 11.** Experiment 2 number of errors in the peg transfer task. The black solid line represents the Full MR Training, MRT & FLS group \((N = 10)\), and black dashed line represents the MRT & FLS group \((N = 13)\) and gray dashed lines represent the FLS-only group \((N = 11)\). The black lines with open squares represent the ideal precision ratio. The error bars represent the standard error of the mean.
General Discussion

MRT Assessment

The experiments reported here confirm that MRT performance is sensitive to practice (Hampson, 1990; Peters et al., 1995). However, our experiments differ from previous work in that participants also underwent training on a variety of nonstandard paper and computer-based mental rotation tasks. These tasks were structurally different but yet involved similar rotation of the given object. Participants who were given this training showed significant and steady improvement on the MRT and retained this improvement over time. This data provides strong evidence that mental rotation can be considered a high-level skill in which improvement can be generalized across tasks. Our results are consistent with a growing body of work. For instance, Richards et al. (2002) showed that teaching subjects specific mental rotation strategies significantly improved performance on different mental rotation exercises. Subjects learned how to develop new strategies to solve different three-dimensional ambiguities, and these skills remained for up to 30 days later. Also, Hedman et al. (2006) found that high-level visual spatial skills, such as mental rotation generalize to surgical skills in the early stages of training.

Furthermore, there is evidence that video gaming improves spatial abilities, as well as reducing sex differences in performance on such tasks (Feng, Spence, & Pratt, 2007). In our experiment, we observed that individuals who performed poorly on the 3D Blocks game, or simply did not understand the concept of the game, also exhibited poor performance on our training tasks and MRT assessment.

Surgical Skills Assessment

The goal of Experiment 2 was to determine if improvements in mental rotation generalize to a different and more complex mental rotation task. Previous studies have reported that laparoscopic skills rely on mental rotation (Wanzel et al., 2002, 2003), but to date, researchers have only reported a correlational relationship between these skills. Our experiments demonstrate that there is a causal link between mental rotation and laparoscopic skills. We conclude that mental rotation experience provides significant improvements in performance on certain laparoscopic surgical skills. This holds practical significance for surgical education because training on simple paper and computer-based tasks can be used as an alternative to more expensive high fidelity lessons with an expert.

Performance on tasks that rely on multiple mental and manual rotations, such as the cutting task, benefited more from mental rotation training than tasks that did not involve much mental rotation, such as the peg transfer task. Both of these tasks required bimanual movement and coordination to control the instruments and complete the task. However there were a number of important differences between these tasks. The peg transfer task required mostly lateral movements and the participant was able to complete the task by simply moving the peg across a straight line and using haptic feedback to decide where it should be placed. On the other hand, the cutting task was more complex in nature and had both spatial and cognitive components. To complete this task successfully, participants used spatial visualization and cognitive planning as they had to imagine the paper in different orientations and decide where to place the graspers to rotate the paper around and cut it appropriately. Therefore it is possible that spatial ability, or mental rotation in particular, was not the only ability that was being trained and used in these tasks. Cognitive abilities have been shown to be important in the learning stages of spatial skills (Keehner, Lippa, Montello, Hegarty, & Tendick, 2006) and as such cognitive planning and execution, along with mental rotation, are likely to be important in performance on the training tasks, MRT and the cutting task.
This study is consistent with previous literature showing that video game experience facilitates faster improvement on surgical tasks. Shane, Pettitt, Morgenthal, and Smith (2007) investigated the ability for gamers and nongamers to become proficient on simulated surgical tasks. They found that all participants eventually achieved proficiency, but gamers required less time to reach this goal. Other studies have also shown that there is an advantage to using video game training to improve a professional skill. For example, Gopher, Weil, and Bareket (1994) compared the flight performance of participants who either did or did not previously undergo 10 hours of video game experience. They found a transfer of skills from the video game to flight performance. Further, individuals that had video game training performed significantly better in test flights, which agrees with our conclusions regarding mental rotation training and surgical performance.

Sex Differences

Our experiments confirm the reports from Peters and colleagues (Peters et al., 1995; Peters, Manning, and Reimers, 2007) of sex differences in performance on the MRT. This difference was evident even after both sexes underwent mental rotation training in Experiment 1; females consistently achieved lower scores on the MRT. In our second study, sex differences in performance on the surgical tasks within our Full MR Training, MRT & FLS group were initially observed; however, they disappeared by the end of testing. This is consistent with studies that have shown that females benefit more than males from spatial training (Alington, Leaf, & Monaghan, 1992; Provo et al., 2002). An implication of this work is that sex differences in performance can be eliminated by using a hands-on training approach.

Peters and Battista (2008) offered an explanation for why sex differences are prevalent in performance of the MRT. They argued that the format of test presentation is important, and sex differences in performance are reduced if the test is presented in the Shepard and Metzler (1971) format, which presents a reference and only one target. This assertion is confirmed by functional magnetic resonance imaging research showing that although males and females perform similarly on the Shepard and Metzler task, they exhibited different cerebral activation patterns, reflecting different mental rotation strategies (Jordan, Wustenberg, Heinze, Peters, and Jancke, 2002). Thus the real basis for the original difference may be the type of assessment task used.

Conclusion

This study contributes to the growing body of work that points to mental rotation as an ability that can be improved generally and shows that the effects of mental rotation training transfers to different mental rotation tasks. In addition to the significant theoretical implications of this finding, it could have important consequences for training novices to perform mental rotation intensive tasks. Specifically it should be possible to provide significant mental rotation training to surgical residents using low cost training tasks, which will reduce the time spent on expensive surgical skills apparatus.

References


veterinary students to visualize anatomical structures in three di-
Richards, J. T., Oman, C. M., Shebilske, W. L., Beall, A. C., Liu, A., & Natapoff, A. (2002). Training, transfer, and retention of three-
dimensional spatial memory in virtual environments. *Journal of Vestib-
ular Research-Equilibrium and Orientation*, 12, 223–238.
Sanz de Acedo Lizarraga, M. L., & Garcia Ganuza, J. M. (2003). Improve-
Should surgical novices trade their retractors for joysticks? Videogame
experience decreases the time needed to acquire surgical skills. *Surgical
Endoscopy*, 22, 1294–1297.
Shepard, R., & Metzler, J. (1971). Mental rotation of three dimensional
Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of
3-dimensional spatial visualization. *Perceptual and Motor Skills*, 47(2),
599–604.
Wanzel, K. R., Hamstra, S. J., Anastakis, D. J., Matsumoto, E. D., &
Cusimano, M. D. (2002). Effect of visual-spatial ability on learning of
Wanzel, K. R., Hamstra, S. J., Canini, M. F., Anastakis, D. J., Grober, E. D., &

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The Publications and Communications Board of the American Psychological Association an-
nounces the appointment of 9 new editors for 6-year terms beginning in 2012. As of January 1,
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