BRAIN LATERALIZATION AS A PREDICTOR OF SEX DIFFERENCES IN PERFORMANCE ON SPATIAL TASKS

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ABSTRACT

Sex differences in spatial cognition are considered among the largest sex differences in all cognitive ability (Coluccia & Louse, 2004). One relatively new approach to explain these differences is the lateralization of function hypothesis. The general basis of this approach is that the more lateralized the brain is while completing a task, the more efficient the processing. Research suggests that male brains tend to use the right hemisphere more than the left hemisphere (i.e., are more lateralized) for spatial tasks while women's brains use both the left and right hemispheres (i.e., are more symmetrical) (Rilea, 2008). This study attempted to address the claims that laterality could be a factor in the male advantage in certain spatial tasks.

The main objective of the present study addressed the generalizability of the lateralization of function hypothesis to other tasks. Another goal of this project was to collect data for a new test--the Test of Visuospatial Construction (TVSC)--in a typical adult sample.

Participants completed a variety of tasks known to recruit one hemisphere more than the other (i.e., were lateralized to the right or left hemispheres) as well as other typical spatial tasks (e.g., mental rotation). The performance (i.e., proportion correct and reaction times) on the experimental tasks (i.e., mental rotation and spatial visualization) were correlated with performance on the left- and right-hemisphere lateralized tasks. We found that the right hemisphere tasks correlated with the mental rotation task more strongly with men than women. Additionally, it was found that more right hemisphere lateralization predicted better performance on right hemisphere tasks. Therefore, the results of this study provide support for the notion that brain organization might be a factor for the male advantage in certain spatial tasks.

LIST OF ABBREVIATIONS AND SYMBOLS

M	Mean: the sum of a set of measurements divided by the number of measurements in the set; arithmetic average
MR	Mental Rotation
ms	Milliseconds
N	Sample size
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
PF	Paper-Folding
r	Pearson product-moment correlation
RH	Right Hemisphere
RVF	Right Visual Field
LH	Left Hemisphere
LVF	Left Visual Field
SD	Standard deviation: value of variation from the mean
SV	Spatial Visualization
t	The number of standard deviations in a t-distribution that the sample mean deviates from the mean stated in the null hypothesis
TVSC	Test of Visuospatial Construction
WMT	Word Memory Test
<	Less than

>	Greater than
=	Equal to

DEDICATION

For my family and friends.

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INTRODUCTION

Defined broadly, spatial ability refers to a skill in generating, representing and recalling spatial information (Coluccia & Louse, 2004). A variety of tasks tap into spatial ability which can include: mental rotation, wayfinding, spatial orientation, and remembering locations of objects. The cognitive mechanisms used with these tasks are associated with one area of research, spatial cognition.

Gender differences in spatial cognition are considered among the largest sex differences in all cognitive ability (Coluccia & Louse, 2004). In traditional tests of basic spatial abilities men perform better than women (Coluccia & Louse, 2004). Furthermore, male superiority in spatial processing appears to be present in most cultures (Bowers & LaBarbra, 1988).

Research has identified three important categories of spatial cognition in which sex differences have been extensively studied: spatial perception, mental rotation and spatial visualization (Voyer & Bryden, 1995). Spatial perception refers to determining spatial relations of objects. There are moderate sex differences in this area of spatial cognition that show a male advantage (Voyer & Bryden, 1995). Mental rotation is the ability to rotate a two or three dimensional figure using imagination. Research suggests that sex differences in this category are extremely robust and they consistently appear in the spatial cognition literature (Voyer & Bryden, 1995). The last category, spatial visualization, is the ability to manipulate complex spatial information. There is little evidence that significant sex differences exist in this spatial category. Additionally, research suggests that sex differences in spatial tasks increases when the task/process is more complex (Lawton, 1996). In short, sex differences appear consistently throughout the literature on certain spatial tasks (Voyer & Bryden, 1995). Although these differences exist, there is still debate on the underlying reason for them.

One possible reason behind these differences is that men and women employ different strategies while completing spatial tasks (Lawton, 1994). For instance, men generally rely on a survey perspective when they imagine moving through an environment. Survey knowledge focuses on the relationships between locations and typically utilizes NSEW directions (Chen, Chang & Chang, 2009). In contrast, women generally rely on landmarks and maintain a route perspective that focuses on a sequence of memory about how to get from a starting location to the next place. It appears that men can swap strategies when needed and use landmarks when required. Women on the other hand have more difficulty in changing strategies. Thus, it is possible that men perform better in certain spatial tasks because they can change their strategies based on the available information (Coluccia & Louse, 2004). Along with employing different strategies, there are also several theories that can help explain these sex differences.

The current literature suggests that there are biological explanations, in particular hormone levels, which can have an effect on spatial cognition (Coluccia & Louse, 2004). The natural fluctuations of hormones results in changes in cognitive patterns (Kimura, 1999). In both sexes, such hormonal changes are associated with certain cognitive strengths (Kimura, 1999). For instance, there is a known correlation between testosterone levels and visuospatial ability (Coluccia & Louse, 2004). One study directly tested this hypothesis on rats (Dawson, Cheung & Lau, 1975). The results of this study showed that the administration of testosterone to female rats improved performance in maze learning. On the other hand, castration at birth of male rats impaired their ability to choose the correct direction in a radial maze. These results support the notion that men perform better than women in spatial tasks partly due to their increased level of testosterone.

There is also research that suggests that spatial ability is highly heritable and that there are genetic factors that play a role in producing these sex differences (Linn & Peterson, 1985). The proposed X-linked hypothesis was initially suggested by Bock and Kolakwski (1973) and suggests that the spatial gene is carried on the X chromosome. However, there is little evidence that this gene exists and more research is still needed in this area (Linn & Peterson, 1985).

Some also theorize that there are environmental factors that contribute to the male advantage in overall spatial ability (Gaulin & Hoffman, 1988). Men typically have more experience in activities that enhance the development of spatial skills such as playing video games and engaging in team sports. Therefore, participation in such activities might help develop spatial skills.

However, it is not environmental factors alone that cause these significant sex differences. Research also suggests that it is a combination of both biological and environmental factors (Sherman, 1978). This interactionist approach asserts that sex differences in spatial cognition are due to a combination of experience and natural predispositions. Essentially, the innate predisposition could influence the choice of activities.

Research also suggests that certain personality characteristics also play an important role in shaping spatial ability. Men typically report higher confidence in wayfinding than women and about their own sense of direction (Lawton, 1996). Women on the contrary typically report higher spatial anxiety and have a fear of getting lost. This high spatial anxiety can prevent the exploration of unfamiliar places, thus having a harmful effect on female's confidence in navigating a novel environment and performance of spatial tasks (Coluccia & Louse, 2004).

Although the previously mentioned explanations do provide an important contribution to the field of sex differences in spatial cognition, there is one more possible explanation that deserves mention.

The explanation focuses on cerebral lateralization. In general, lateralization refers to the idea that each hemisphere of the brain is specialized for certain functions (McGlone, 1980). It was once believed that one hemisphere dominated all specific areas of intellect (Vogel, Bowers & Vogel, 2003). However, research now suggests that neither is completely dominant but instead both hemispheres are specialized for separate tasks. Research suggests that the left hemisphere is specialized for language functions whereas the right hemisphere is used more for perception of non-verbal stimuli and expression of intense emotions (Mutha, Haaland, & Sainburg, 2012). Until recently, brain lateralization was once thought to be a unique feature of humans; however, more research has found lateralization in both birds and some invertebrates (Lust, Geuze, Groothuis, & Bouma, 2011). It is therefore likely that lateralization appeared early in evolution and its occurrence is thought to indicate an advantage to the individual.

There are a few theoretical reasons behind the causes of lateralization (Boles, Barth & Merrill, 2008). The "control hypothesis" suggests that lateralization developed to resolve conflict between the hemispheres over the control of certain functions (Orton, 1937). Another reason is the "representational capacity hypothesis", which proposed that lateralization arose to eliminate duplications between the two hemispheres (Doty & Overman, 1977). Additionally, the "multi-tasking hypothesis" suggests that lateralization developed to allow the two hemispheres to have different processes (Wickens, 1984). All of these hypotheses have received various levels of support throughout the literature.

Several techniques can be used to study brain lateralization. These techniques typically include: EEG, fMRI, and Lateral Eye Movements (Vogel, Bowers & Vogel, 2003). Most of these techniques use electrochemical communication between individual neurons and their communication substances called neurotransmitters (Vogel et al., 2003). By using these techniques, researchers can gain a better understanding of how the brain is organized.

Numerous studies have examined brain lateralization across several different domains. One study supported the notion that hemispheric lateralization is beneficial to functioning (Gotts, Jo, Wallace, Saad, Cox & Martin, 2013). They found that the left hemisphere was involved with language and fine motor coordination. In contrast, the right hemisphere is involved with visual-spatial and attentional processing. Gotts and colleagues (2013) further argue that lateralization is associated with enhanced cognitive ability.

Boles (1992) conducted a factor analysis to determine lateralized processes believed to draw on processes localized to temporal, frontal, and occipital lobes. Boles (1992) provided convincing evidence that certain independent lateralized functions do exist. The tasks that seem to be related to spatial ability are occlusions, onsets, locations and crosslines among others. An occlusion task asks participants to determine which line on a pair of perpendicular bars occludes the other. In the occlusions task, participants are shown two different colored lines, with one line overlapping the other. The participant must then decide which color line occluded the other. In an onset task, participants are shown two “O’s” on a computer screen. Participants are then asked to determine which “O” was presented first. A locations task asks participants to view a lateralized dot and subsequently locate on it a grid on the computer screen. Last, a crosslines task asks participants to determine whether a line was above or below a target image. Furthermore, Boles' research dovetails with other research that suggests that spatial ability is usually right hemisphere specific (Boles, 2002).

Vogel and colleagues (2003) conducted a meta-analysis and found that their results also yielded a strong right hemisphere advantage for most spatial tasks. Additionally, the analysis found that men showed a strong preference for the right hemisphere while women did not have a hemisphere preference. Vogel and colleagues (2003) hypothesized that women tend to use language to talk through spatial tasks whereas men think in terms of the shapes themselves. Therefore, since language is located in the left hemisphere, it makes sense that women would use their left hemisphere along with their right to solve spatial tasks. Conversely, men would favor the right hemisphere. In any case, although there are differences between men and women in their lateralization of processing spatial information, the sex differences in lateralization are very small (Boles, 2005; Hiscock, Israelian, Inch, & Jacek, 1995).

As a specific example of sex differences in lateralized processed on spatial information, Rilea, Roskos-Ewoldsen, & Boles (2004) found that the male brain is organized more asymmetrically so that perceptual and spatial tasks tend to be processed in the right hemisphere. In contrast, the female brain is structured more symmetrically, with both hemispheres processing spatial information. Therefore, in general, men appear to be more lateralized than women in terms of spatial processing, and it can be argued that lateralized processes are more efficient (Rilea et al., 2004). This concept is referred to as the lateralization of function approach and provides some explanation of why men typically outperform women on certain spatial tasks (Rilea et al., 2004). However, there seems to be some uncertainty to this notion.

More recent data of Boles, Barth, & Merrill (2008) indicate that the direction of the correlation between performance and lateralization depends on the process. They argued that lateralization and performance relations are more complex than originally thought. Boles and colleagues (2008) found that being highly lateralized does not always provide an advantage in performance. Strong laterality is associated with increased performance in some processes such as spatial positional and auditory linguistic tasks. However, for other processes, strong laterality is related to a decrease in performance: For example, their study found that greater right hemisphere lateralization in an occlusions task was significantly related to slower reaction times on the task (Boles et al., 2008). Boles' (2008) research therefore supports a neurodevelopmental theory of lateralization, in that very early and very late lateralizing processes produce positive correlations between asymmetry and performance, while processes that lateralize at intermediate ages show negative correlations in adults. Therefore, the direction of the correlation depends on the nature of the process that is lateralized. These data demonstrate that further research is necessary to investigate the lateralization of function approach in regards to spatial ability. In any case, it is important to note that although laterality might not always be related to increased performance, it is still relevant.

Rilea and colleagues (2004) tested the lateralization of function approach using three different spatial tasks: mental rotation, spatial perception, and spatial visualization. The purpose of the study was to test whether the pattern of sex differences across three types of spatial ability were related to the amount of right hemisphere processing used for the task. The tasks for the study included a mental rotation, a Paper-Folding and a water-level task, representing the spatial abilities of mental rotation, spatial visualization, and spatial perception. All of the tasks were computer administered and presented bilaterally to both the left visual field (right hemisphere) and the right visual field (left hemisphere). On the mental rotation task, men showed a right-hemisphere advantage, whereas women showed bilateral processing. This was expected because men are considered to be lateralized to the right hemisphere and women are considered less lateralized for spatial ability. There was also no sex differences observed, presumably because the stimuli were simple stick figures rather than the more complex 3-D block stimuli. On the water level task, men outperformed women, and both men and women showed a right hemisphere advantage. Lastly, on the Paper-Folding task, no hemispheric differences were observed for either men or women. These findings support the idea that hemispheric processing of the task and the extent to which a person is right-hemisphere lateralized for processing spatial information are important factors that could contribute to sex differences in spatial cognition. In short, these results suggest that the male advantage in spatial tasks may be determined by the extent to which the task is right hemisphere dependent.

Since there is relatively little data on this issue, the main objective of the current study was to test the generalizability of the lateralization of function approach as a way to explain sex differences in spatial tasks. The present study incorporated a new spatial task as well as other lateralized tasks. Previous factor analyses have identified certain lateralized spatial processes that can be measured with certain tasks (Boles, 2002). The lateralized tasks used in this study have been used in previous research and have consistently shown to be lateralized to either the left or right hemispheres (Boles, 2002). By only showing the stimuli for a short amount of time, there is a high probability that the stimuli will only be processed in a certain hemisphere (Rilea et al., 2004). Using tasks that have been shown to demonstrate cerebral lateralization, we then correlated performance on these tasks to the other spatial tasks.

Aside from testing the lateralization of function approach, this study also collected normative data on a modified block design task known as the Test of Visuospatial Construction (TVSC), which is considered to be a spatial visualization task (McDermott, 2010). Block design tasks are frequently used in measures of intelligence and in the diagnoses of brain damage (Rozencwag & Corroyer, 2001). Originally created in 2008, it has undergone two revisions. The current version of the TVSC was created as a motor-free assessment of visuospatial construction and has been shown to discriminate between healthy participants and individuals with certain neurological disorders such as Alzheimer's, Parkinson's and MS (Fuchs, McDermott, Odell & Manning, 2012). The TVSC can assess visuospatial construction without the need for physical manipulation of test materials. This is important because limited dexterity can confound performance on measures such as Block Design in individuals with neurological conditions. By only needing a verbal response, participants who are physically unable to manipulate the materials will now be able to complete the task. Thus, this revised measure is a great improvement on the original block design task. In the current study, we investigated the relation between performance on the TVSC and performance on the Paper-Folding task to establish construct validity.

Another secondary objective of this study was to obtain reliability values for the mental rotation and Paper-Folding tasks. It was important to obtain these values in order to compare performance on other lateralized spatial tasks. Therefore, the present study aimed to obtain the reliability information for the previously mentioned tasks.

Furthermore, in order to ensure participants were putting forth effort, a simple memory test was used. Research suggests that poor effort by participants during testing can have profound effects on test performance (An, Zakzanis, & Joordens, 2012). The cognitive effort task known as the Word Memory Test (WMT) has been shown to be a reliable indicator of effort (Green, Allen, & Astner, 1996). Therefore, the present study included the WMT to ensure all participants were putting forth sufficient effort. Additionally, a mental health questionnaire was administered to ensure that all participants were mentally fit enough to participate.

In short, the present study addressed the generalizability of the lateralization of function approach. This study was based on the notion that men's brains are more lateralized than women's in terms of spatial processing and that more lateralization in turn leads to more efficient spatial performance. Therefore, the more efficient the processing in the right hemisphere, the more likely performance will be enhanced in right hemisphere tasks. The specific hypotheses were:

Hypothesis 1: Sex Differences in Performance.

H1a: Performance on the mental rotation task will be higher for men than for women because research suggests that men outperform women in mental rotation tasks (Coluccia & Louse, 2004).

H1b: Performance on the spatial visualization tasks (i.e., Paper-Folding and Block Design tasks) will be the same for men and women because research suggests that there are typically no sex differences in spatial visualization tasks (Coluccia & Louse, 2004).

H1c: Performance on the hemispheric lateralized tasks will be the same for men and women because no sex differences have been reported in previous research.

Hypothesis 2: Correlations between Experimental and Hemispheric Tasks

H2a: Performance on the right hemisphere tasks will correlate with performance on both the Mental Rotation task (presented to the right hemisphere) and the Paper-Folding Task (presented to the right hemisphere).

H2b: Performance on the left hemisphere tasks will correlate with performance on both the Mental Rotation task (presented to the left hemisphere) and the Paper-Folding task (presented to the left hemisphere).

Hypothesis 3: Correlations between the Spatial Visualization Tasks

H3: There will be a positive correlation with performance on the TVSC and the Paper-Folding task because they both are considered to be spatial visualization tasks.

METHODOLOGY

Participants

126 undergraduate students (45 men and 81 women) were recruited using the online sign-up method implemented by the psychology department. The age of the participants ranged from 18 to 46 years old (*M* = 19.6, *SD* = 3.6). A chi square analysis revealed that there were significantly more women in the sample then men χ^2 (1, N = 126) = 10.28, $p < .01$. Participants received credit toward an introduction to psychology course requirement for participating in this study. There was minimal risk to participants and no deception was involved. Participants cannot be identified on any forms or in any data files.

Apparatus

Lateralized tasks were presented randomly on a Macintosh computer using Super Lab software. Additionally, the experimental tasks and the effort task were all presented randomly on a Dell PC, also using Super Lab software.

Measures

Cognitive effort: The Word Memory Test (Green, Allen, & Astner, 1996). The Word Memory Test (WMT) was a computer-administered test. The WMT is a symptom validity test embedded within symptom and ability batteries in neuropsychological testing to detect malingering or symptom exaggeration. Respondents were shown 20 word pairs (e.g., hat-mitten, cold-snow) twice. Next, the participant completed an immediate recognition (IR) task in which they were asked to choose which words from the original pairs were presented previously (e.g., choose hat or coat, winter or snow). After a 30-min delay, respondents were asked to complete a delayed recognition (DR) task in which they were asked to identify previously presented words. Finally, the WMT utilized a Consistency score (CNS) that was automatically calculated. If the participants failed it, then it was constituted as poor/inconsistent effort. If one of the IR, DR, or CNS scores was below the recommended cut score, the WMT manual suggested that respondents should be considered suspect for putting forth insufficient effort during testing. According to the test manual, a clear pass was one in which the IR or DR scores are above 90% correct. A clear fail was one in which any of these scores is at or below 82.5% correct. The WMT software program automatically calculated a consistency score for each participant. This score reflects the consistency of responses from the Immediate Recognition and Delayed Recognition test of the WMT. The participant received one point if the correct response was chosen both times or the incorrect response was chosen both times. A score of zero was given if the person was inconsistent for a given item, scoring incorrectly on one trial and correctly on the other trial. The consistency score was expressed as a percentage. The total WMT test time was approximately 15 minutes. The WMT shows extremely high test-retest reliability (.97) and is considered a valid measure.

Mental Health Questionnaire (McDermott, 2010). (See Appendix C). This was a paper and pencil questionnaire designed to evaluate participant's previous medical and psychiatric history. This questionnaire was important to screen for mental illness that could affect reaction time and performance. This questionnaire was needed to validate the results and eliminate any confounding variables contributing to performance. Information on this sheet remains confidential. Participants had the option for their questionnaire to be destroyed after they finish the testing session. This questionnaire took approximately five minutes to complete. No participants chose to have their questionnaire destroyed.

Mental Rotation Task (Rilea, Roskos-Ewoldsen, & Boles, 2004). (See Appendix F). This task required participants to determine whether a stick figure that has been rotated is the same as or a mirror image of a prototype stick figure previously observed. To increase the likelihood that the stick figure was processed in only one hemisphere, two stick figures were presented simultaneously, one on either side of center of the screen. In the center, an arrow appeared indicating which stick figure will be the target figure. Participants completed 10 practice trials. In the practice trials, two trials were presented at each of five orientations. Half of the trials were "yes" responses and half of the trials were "no" responses. Half of the target figures were presented to the left visual field (right hemisphere) and half of the target figures were presented to the right visual field (left hemisphere). Each practice trial began with the prototype stick figure in the center of the computer screen, which remained on the screen for 500 *ms*. The prototype stick figure was always upright and holding the ball in the left hand. The participant was instructed to learn the prototype stick figure during the practice trials. This display was replaced by a small fixation cross appearing in the center of the computer screen for 500 *ms*. Following the fixation cross, an arrow appeared in the center of the screen pointing to the left or right side. Simultaneously, rotated stick figures appeared for 100 *ms*. The stick figures are rotated either 0°, 45°, 90°, 135°, or 180° from upright. The participant decided whether the target figure was the same as the prototype (yes), or a mirror image of it (no). The test trials were identical except that the prototype stick figure no longer appeared. Participants completed 40 test trials with eight trials at each orientation. In half of the trials, the stimuli were the same and half of the trials the stimuli were different. Half of the target figures were presented to the left visual field (right hemisphere) and half of the target figures were presented to the right visual field (left hemisphere). Finally, half of the trials at 45°, 90°, and 135° had stick figures tilted to the left of upright, and half had the stick figures tilted to the right of upright.

Spatial Visualization Tasks.

Paper-Folding Task (Rilea, Roskos-Ewoldsen & Boles, 2004). (See Appendix F). This was a computer-administered task that asked participants to mentally unfold a piece of paper that had been folded one to three times and then had a hole punched in it. Each trial began with a fixation cross presented at the center of the computer screen for 500 *ms*. Next, a square representing a piece of paper appeared in the center of the screen. This was followed by a display of a series of folds in the paper. Each display remained on the screen for 750 *ms*. The final display of the folded piece of paper contained a small circle to represent a hole being punched through it. After the last display, two unfolded pieces of paper with several holes punch them were presented for 100 *ms* on either side of the centrally located arrow. Participants then completed 8 practice trials and 32 test trials. Half of the trials were presented to the left hemisphere and half of the trials were presented to the right hemisphere. The dependent variables from this measure were reaction time on correct trials and proportion of correct responses.

Test of Visuospatial Construction (TVSC) (McDermott, 2010). (See Appendix D). This was a paper and pencil version of the Block Design task adapted from the WAIS- IV and was specifically designed to assess spatial visualization. It was individually presented with a face-to-face format. For this task participants completed a total of 32 trials. In all of the trials participants were shown two sets of blocks with designs on them. However, the second set was missing a block. Participants were then shown four blocks with different designs on them. The participants then chose the block that made the second set look exactly like the first set. Participants were then instructed to complete all of the trials as fast as they could without making any mistakes. Trials 6-32 were timed to the nearest second with a stopwatch, while trials 1-5 were untimed. The purpose of the first five trials was to familiarize participants with the task. Trials 6-17 had a 45 second time limit for a response while trials 18-32 had an 80 second time limit. The level of difficulty increased with the number of blocks and with the time limits. The participants were allowed to self-correct if he or she did so within 1-2 seconds after the initial answer. All responses were recorded on a response sheet. The dependent variables from this measure were reaction time and proportion of correct responses. The TVSC task took approximately 10 minutes. This test is considered to have good discriminant and convergent validity (McDermott & Donnell, 2010).

Left Hemisphere Tasks.

Onsets (Boles, 1996). (See Appendix E). An identical "O" was presented in each quadrant of the visual field with an arrowhead pointing to the side to be considered. On each side, one of the 'O's preceded the other by a brief delay. The participant's task was to decide which "O" had been presented first, and to press either the top or bottom key on an external keyboard. A trial involved presentation of a fixation cross for 750 *ms*, followed by a 100 *ms* blank period, and the presentation of the first "O". Following a delay of 50, 67, or 83 *ms*, the second "O" was then presented. Both remained on the screen until the participant responded. No practice feedback was given. There were 144 experimental trials. The dependent variables from this measure were reaction time on correct trials and proportion of correct responses. This task typically favors the left hemisphere and took approximately 12 minutes to complete. This task has a reported Spearman-Brown corrected split-half reliability of +.27 (Boles, 2002).

Crosslines (Boles, 2002). (See Appendix E). Crosslines was a computer-administered task. Following a 750 *ms* central fixation cross and a 100 *ms* blank period, a small horizontal line was presented for 100 *ms* in the right and left visual fields either above or below the center of the cross. Between the fields, up-down placement was random (i.e. both could be “up”, both “down”, or one could be “up” and the other “down”). Along with the horizontal line, a central arrowhead (“<”or “>”) indicated which side of the fixation point to respond to. The participant responded by pressing one of two keys labeled “TOP” and “BOTTOM” to indicate either the “up” or “down” position. Following a 24-trial practice block, three blocks of 48 trials (144 total) were given. The dependent variables from this measure were reaction time on correct trials and proportion of correct responses. Previous results indicated a left hemisphere advantage in performing this categorical spatial task. This task took approximately 15 minutes to complete. This task has a reported reliability of +.44 (Boles, 2002).

Right Hemisphere Tasks.

*Occlusions (Boles, 2002). (*See Appendix E). The Occlusions task was computer administered. After a 750 *ms* fixation cross and a100 *ms* blank, a pair of perpendicular bars were presented in each visual field for 100 *ms*, simultaneously with an arrowhead at fixation indicating the pair to attend to. One bar (selected at random) was blue while the other was red; and one (also selected at random) occluded the other, thereby appearing to be in the foreground. The participant pressed one of two keys labeled “BLUE” or “RED” to indicate the bar appearing to be in the foreground. A block of 24 practice trials were used, followed by three blocks of 48 trials each (144 total). The dependent variables measured were reaction time as well as proportion of correct responses. This task is typically shown to have a right hemisphere advantage and took approximately 14 minutes to complete. This task has a reported reliability of +.43 (Boles, 2002).

Locations (Boles, 2002). (See Appendix E). The Locations task was computer administered. The participants watched a fixation cross in the center of the screen, followed by two dots, one on each side of the fixation point. At the same time an arrow head appeared in the center, pointing to one of them. The task was to recognize the position of the dot represented on the side the arrowhead pointed to. Next, an array of letters appeared on the center of the screen. The task was to select the position the dot appeared in. For example, if the dot was shown in the left right corner, the participant would select the letter that corresponded to that position, and type the letter on the computer. The dependent variables for this task were reaction time and proportion correct. This task is shown to have a right hemisphere advantage and took approximately 15 minutes to complete. This task has a reported reliability of +.50 (Boles, 2002).

For IRB approval document, please see Appendix G.

Procedures

Participants entered the lab and were given an information sheet regarding the procedures of the study (Appendix A). As per testing protocol, participants completed the confidential mental health questionnaire. This questionnaire assessed for any previous or current mental illness and took approximately five minutes to complete. The first portion on this study included the computerized administration of the WMT. For the WMT, the participant first completed an immediate recognition task. After a 30-minute delay, participants completed the delayed recognition task.

During the 30 minute delay of the WMT, participants were asked to complete the TVSC task (McDermott, 2010). After the TVSC task was completed, participants completed the delayed recognition task of the WMT. After the delayed WMT task was completed, participants then completed the four lateralized task; Onsets, Occlusions, Locations, and Crosslines. These four tasks were administered consecutively in random order on a Macintosh computer. Participants were seated approximately 20" in front of the computer monitor with their index and middle finger placed on the appropriate response keys. Prior to each task, participants were instructed that while it was important to both quickly and accurately, the experimenter emphasized that accuracy was most important. Additionally, the experimenter emphasized that participants should not move their head or eyes during the tasks, and that they should maintain their focus on the center of the computer monitor. After completing the lateralized tasks, participants then completed the computer administered Mental Rotation task and the Paper-Folding task in random order on a Dell PC. Finally, participants received a debriefing form (Appendix B) and left the study.

RESULTS

Before analyzing the main data set, we wanted to make sure that participants were making an effort at completing the tasks. We used the Word Memory Test (WMT) to do this. As stated in the WMT test manual, participants needed to meet a consistency score of at least 82.5% to demonstrate effort. Two participants did not meet the criteria because their consistency scores were 78% each. However, their data were still included because their performance on the other tasks was relatively high. When we do remove them from the data analyses, we find the results do not change.

Additionally, a reliability analysis was conducted in order to determine the internal consistency of the Paper-Folding and mental rotation task. Up until now, reliability for these measures has not been analyzed, to my knowledge. Therefore, it was crucial to establish the reliability of these measures for this study. The mental rotation task had a Spearman Brown corrected split-half reliability of .95. The Paper-Folding task had a Spearman Brown corrected split-half reliability of .84. The Paper-Folding task had a lower internal consistency probably due to the reduced number of trials. Therefore, the reliability analysis indicated that both measures were reliable for the purposes of this study.

Overall Performance on the Tasks

Next, we calculated the means and standard deviations of each of the main variables to ensure that the assumption of normality was met (Tables 1 and 2). We also checked skewness and kurtosis levels for each main variable to ensure the data were normally distributed. Skewness and kurtosis values were generally less than two except for the Crosslines task. The Crosslines tasks had the highest skewness value of -2.66. Based on these statistics, it was decided that the variables were close enough to normal to continue further testing. Also, the sample size was well over 30, so the sampling distribution would be nearly normal anyway.

Overall, the difficulty of the tasks varied. For proportion correct, performance on the experimental tasks (Mental Rotation, Paper-Folding & the TVSC) was lowest (M = .65), while performance on the hemisphere tasks (Crosslines, Occlusions, Locations & Onsets) was the highest (M = .71), with the exception of the Locations Task (M = .25). Performance on this task might have been lower due to the increased difficulty; there were more answer options available to participants and this might have made the task harder for them. In terms of sex differences in proportion correct, the same tasks were averaged and men outperformed women on both the experimental tasks (Men M = .68; Women M = .62 p =.02) and hemispheric tasks (Men M = .72; Women M = .69 p =.29), although the difference was not significant for the hemispheric tasks.

For reaction times, performance was fastest for the hemisphere tasks (M = 981 ms), while the slowest reaction times were during the experimental tasks (M = 1483 ms). In terms of sex differences, there were no sex differences in reaction times for the experimental tasks (Women M = 2141 ms; Men M = 2079 ms; p =.49). Men, however, had faster reaction times than women on the hemisphere tasks (Men M = 914 ms; Women M = 1012 ms p = 01).

Table 1:

Proportion Correct for all Tasks

	Overall	Men	Women
	M,SD	*M,SD*	*M,SD*
	n=126	*n*=45	*n*=81
Experimental Tasks			
TVSC-Block design	.81, .13	.81, .14	.82, .11
MR Overall *	.68, .20	.73, .22	.65, .19
MR--LVF	.67, .21	.72, .22	.65, .20
MR—RVF*	.68, .21	.75, .23	.66, .19
SV--Overall	.61, .15	.63, .15	.59, .15
SV—LVF*	.59, .17	.64, .15	.56, .18
SV--RVF	.62, .17	.63, .18	.61, .16
Left Hemisphere tasks			
Onsets Overall	.83, .16	.86, .13	.81, .16
Onsets LVF	.83, .16	.87, .14	.81, .17
Onsets RVF	.83, .17	.86, .14	.82, .18
Crosslines Overall	.89, .18	.88, .21	.90, .16
Crosslines LVF	.89, .18	.88, .21	.91, .16
Crosslines RVF	.89, .18	.88, .21	.89, .16
Right Hemisphere Tasks			
Locations Overall*	.25, .08	.27, .10	.24, .06
Locations LVF	.25, .08	.27, .10	.24, .07
Locations RVF*	.24, .09	.27, .13	.22, .06
Occlusions Overall	.85, .12	.87, .13	.84, .11
Occlusions LVF	.85, .15	.87, .14	.84, .15
Occlusion RVF	.86, .13	.87, .13	.85, .12

Note. LVF = Stimuli were presented to the Left Visual Field (Right Hemisphere), RVF = Stimuli were presented to the Right Visual Field (Left Hemisphere), MR = Mental Rotation, SV = Spatial Visualization

* indicates sex difference, $p < .05$

Table 2:

Reaction Times (ms) For All Tasks (Correct Trials Only)

	Overall	Men	Women
	M, SD	*M, SD*	*M, SD*
	n=126	*n*=45	*n*=81
Experimental Tasks			
TVSC-Block design*	6150, 175	5550, 160	6480, 175
MR Overall	1443, 634	1430, 863	1450, 470
MR--LVF	1400, 657	1384, 872	1409, 502
MR--RVF	1457, 667	1454, 926	1459, 483
SV--Overall	1496, 886	1626, 1223	1424, 624
SV-LVF	1452, 825	1524, 1073	1411, 651
SV- RVF	1439, 1117	1587, 1681	1356, 610
Left Hemisphere Tasks			
Onsets Overall*	1068, 360	982, 354	1116, 356
Onsets LVF	1060, 410	981, 391	1103, 416
Onsets RVF*	1028, 341	941, 342	1076, 332
Crosslines Overall*	545, 153	474, 125	586, 152
Crosslines LVF*	548, 158	486, 161	583, 145
Crosslines RVF*	533, 150	458, 119	576, 151
Right Hemisphere Tasks			
Locations Overall	1498, 365	1450, 357	1525, 369
Locations LVF	1471, 444	1444, 529	1486, 389
Locations RVF	1501, 407	1444, 366	1533, 428
Occlusions Overall*	785, 198	733, 211	814, 184
Occlusions LVF	766, 199	720, 207	792, 191
Occlusion RVF*	784, 191	729, 202	816, 177

Note. LVF = Stimuli were presented to the Left Visual Field (Right Hemisphere), RVF = Stimuli were presented to the Right Visual Field (Left Hemisphere), MR = Mental Rotation, SV = Spatial Visualization

* indicates sex differences, $p < .05$

Lateralization Coefficients

Next, lateralization coefficients (LC's) were calculated for each lateralized task (Boles, et al., 2008) (Tables 3 &4). A lateralization coefficient is a measure of laterality. In particular, a lateralization coefficient is considered to be an index of asymmetry that takes into account ceiling and floor effects and is very common in the literature. Basically, performance on a task recruiting or presented to one hemisphere is subtracted from performance recruiting or presented to the other hemisphere. The larger the number, the more lateralization there is on that task. A LC = 0 means that there was no lateralization. A positive number generally represents a right hemisphere advantage, whereas a negative number represents a left hemisphere advantage. The formulas for LC take into account floor and ceiling effects. If overall accuracy was less than 50%, the following formula was used: (Rcorrect-Lcorrect)/(Rcorrect+LCorrect) *100, where Rcorrect is the proportion correct when the stimuli were presented to the right hemisphere and Lcorrect is the proportion correct when the stimuli were presented to the left hemisphere. When overall accuracy was greater than 50%, the following formula was used (Rcorrect-Lcorrect)/ RErrors+LErrors) * 100, where RErrors and LErrors represent the proportion of errors when stimuli were presented to the right and left hemispheres, respectively. These formulas essentially define asymmetry as a proportion of the maximum difference that can be obtained at any given level of accuracy (Boles, et al., 2008).

A laterality difference score was calculated for reaction times for each task. This was done by the formula: LRT-RRT. This can also be expressed as RVF RT- LVF RT, where RVF and LVF refer to Right- and Left-Visual Field, respectively. Therefore, a positive number represents a right hemisphere advantage (i.e., the RTs were faster when stimuli were presented to the right hemisphere) whereas a negative number represents a left hemisphere advantage (i.e., the RTs were slower for the right hemisphere).

Table 3 shows that for proportion correct, the tasks were not lateralized in a coherent way. The finding for proportion correct LCs was unexpected and will be discussed further in the discussion section. However, Table 4 indicates that participants were noticeably lateralized for reaction times. The lateralization coefficients for reaction times on the hemispheric tasks aligned in the expected direction (i.e., right hemisphere tasks showed a right hemisphere advantage, and left hemisphere tasks showed a left hemisphere advantage). For the experimental tasks, the lateralization differed by sex. The Mental Rotation Task showed the expected right hemisphere advantage. On the Spatial Visualization Task, men had a right hemisphere advantage and women had a left hemisphere advantage. This unexpected difference will be discussed further in the discussion. There were no significant sex differences in lateralization coefficients for proportion correct or reaction time. Lateralization coefficients were not calculated for the TVSC because it was not displayed bilaterally to the participants.

Table 3:

Lateralization Coefficients for Proportion Correct

	Overall	Men	Women	Advantage	Expected Advantage
Experimental Tasks					
Mental Rotation	.56	-.05	.89	LH-men RH-women	RH
Spatial Visualization	-4.67*	-1.06	-6.68*	LH	None
Left Hemisphere Tasks					
Onsets	-5.51	.68	-8.81*	RH-men, LH-women	LH
Crosslines	-4.33	-1.68	-6.03	LH	LH
Right Hemisphere Tasks					
Locations	2.14	.31	3.17*	RH	RH
Occlusions	-7.67*	-17.39*	-1.99	LH	RH

Note. Positive numbers indicate a right hemisphere (Left Visual Field, LVF) advantage and negative numbers indicate a left hemisphere (Right Visual Field, RVF) advantage. RH = Right Hemisphere, LH=Left Hemisphere.
*LC is significantly different from zero, $p < .05$ (two-tailed)

Table 4

Lateralization Coefficients for Reaction Times

	Overall	Men	Women	Advantage	Expected Advantage
Experimental Tasks					
Mental Rotation	39.56*	49.2	38.12	RH	RH
Spatial Visualization	-12.88	63.11	-55.1	RH-men; LH-women	None
Left Hemisphere Tasks					
Onsets	-31.66	-40.22	-26.87	LH	LH
Crosslines	-15.10*	-27.29	-7.98	LH	LH
Right Hemisphere Tasks					
Locations	30.19	.56	47.28	RH	RH
Occlusion	18.07*	8.46	23.69*	RH	RH

Note. Positive numbers indicate a right hemisphere (Left Visual Field, LVF) advantage and negative numbers indicate a left hemisphere (Right Visual Field, RVF) advantage. RH = Right Hemisphere, LH=Left Hemisphere.
*LC is significantly different from zero, $p < .05$ (two-tailed)

Correlations among the Experimental and Hemispheric Tasks

A correlation matrix was created to show the relationships between performance on the experimental and hemispheric tasks for proportion correct (Table 5) and reaction times (Table 6). Tables 5 and 6 can be interpreted as showing which hemisphere was recruited for each task. Specifically, the stronger the correlation of performance on the experimental task with performance on the right hemisphere (LVF) tasks, the more the right hemisphere is recruited for the experimental task. On the other hand, the stronger the correlation of performance on the experimental task with performance on the left hemisphere (RVF) tasks, the more the left hemisphere is recruited for the experimental task. At the very least, the stronger the correlation, the more the cognitive processing overlaps.

Proportion correct. Mental Rotation Task. Table 5 shows that, for men, mental rotation shared cognitive processes with all four hemispheric tasks: Onsets (LH, r = .56), Crosslines (LH, r = .40), Locations (RH, r = .38), and Occlusions (RH, r = .71). For women, mental rotation shared cognitive processes with only Onsets (LH, r = .42); the remaining correlations were less than r = .24, *ns*.

Spatial Visualization Task. For men, the results for the Spatial Visualization Task are similar to those from the Mental Rotation Task. Specifically, spatial visualization shared cognitive processes with Onsets (LH, r = .43), Locations (RH, r = .41), and Occlusions (RH, r = .43). However the correlation was not significant for Crosslines (LH, r = .20, *ns*). Women showed the same pattern of correlations as men for the spatial visualization task, but the women's' pattern differs from their own pattern for the mental rotation task. For women, spatial visualization shared cognitive processes with Onsets (LH, r = .36), Locations (RH, r = .34), and Occlusions (RH, r = .40), but not for Crosslines (LH, r = .26, *ns*)

The TVSC. For men, the TVSC shared cognitive processes with Onsets (LH, *r* =.55), Crosslines (LH, *r* =.48), and Occlusions (RH, *r*=.60), but not for Locations (RH, *r* =.34). For women, the TVSC shared cognitive processes with Onsets, (LH, *r* =.46), Occlusions (RH, *r* =.39) but not for crosslines (LH, *r* =.15, *ns*) or Locations (RH, *r* =.25, *ns*).

Reaction times.

Mental Rotation Task. The results show that men generally relied on both their left and right hemispheres for the mental rotation task (Table 6). For men, correlations of overall mental rotation with the left hemisphere tasks were *r* = .51 (Onsets) and *r* = .42 (Crosslines), and for the right hemisphere tasks they were *r* = .37 (Locations) and *r* = .53 (Occlusions). For women, there was recruitment of both the right and left hemispheres for the mental rotation task, but the correlations depended on the hemispheric task. The correlation between overall mental rotation reaction times and left hemisphere performance for women were *r* = .46 (Onsets) and *r* = .25, *ns* (Crosslines). The correlations with the right hemisphere tasks were *r* = .05, *ns* (Locations) and *r* = .41 (Occlusions). Despite the differences in patterns of correlations between men and women, the difference in correlations between men and women on each task did not differ significantly, using Fisher r to z transformations. The only exception was for the Locations (right hemisphere) task, $z = 1.77$, $p = .04$ (one-tailed), where the correlation between mental rotation RT and locations RT was stronger for men than for women.

Spatial Visualization Task. In contrast to the mental rotation task, reaction times on the spatial visualization task were generally clearer (Table 6). Spatial visualization reaction times correlated with performance on three of the four hemispheric tasks for men, but there were no significant correlations with any of the hemispheric tasks for women. Specifically, the correlations between men's overall spatial visualization and the left hemispheric tasks were *r* =

.43 (Onsets) and r = .21, *ns* (Crosslines); for the right hemisphere tasks the correlations were r = .39 (Locations) and r = .51 (Occlusions). For women, the correlations with the left hemisphere tasks were r = .10, *ns* (Onsets) and r = .09, *ns* (Crosslines); and the correlations with the right hemisphere tasks were r = .02, *ns* (Locations) and r = .21, *ns* (Occlusions). There was a significant difference between men and women in the strength of the correlation between spatial visualization RT and the other hemispheric tasks, except for Crosslines, using r to z transformation, $p < .04$ (one-tailed).

The TVSC. For men, the TVSC correlated with Onsets (LH r =.46), Crosslines (LH r =.40), and Occlusions (RH r =.37), but not for Locations (RH r =.30, *ns*) and for women, the TVSC only correlated with Crosslines (LH r =.23). All other correlations for women were not significant.

Table 5

Correlations among Hemispheric and Experimental Tasks (Proportion Correct)

Task	Men	Women	Overall
	n=45	*n*=81	*n*=126
Onsets (LH)			
MR_LH	.55***	.40***	.46***
MR_RH	.52***	.39***	.45***
MR Overall	.56***	.42***	.48***
SV_LH	.49***	.33**	.39***
SV_RH	.27	.27**	.29***
SV Overall	.43**	.36**	.39***
TVSC	.55***	.45***	.46***
Crosslines (LH)			
MR_LH	.41**	.16	.26**
MR_RH	.35	.11	.20
MR Overall	.40**	.14	.24**
SV_LH	.23	.29**	.26**
SV_RH	.13	.14	.17
SV Overall	.20	.26	.22
TVSC	.48***	.15	.32***
Locations (RH)			
MR_LH	.35*	.12	.26**
MR_RH	.38*	.05	.23**
MR Overall	.38*	.09	.26**
SV_LH	.42**	.25	.33***
SV_RH	.33**	.31**	.34***
SV Overall	.41**	.34**	.38***
TVSC	.34	.25	.27**
Occlusions (RH)			
MR_LH	.70***	.21	.43***
MR_RH	.67***	.22	.41***
MR Overall	.71***	.23	.44***
SV_LH	.43**	.32**	.37***
SV_RH	.35	.35**	.36***
SV Overall	.43**	.40***	.41***
TVSC	.60***	.39**	.48***

Note. MR = Mental Rotation, SV = Spatial Visualization, LH = Stimuli were presented to the Left Hemisphere (Right Visual Field, RVF), RH = Stimuli were presented to the Right Hemisphere (Left Visual Field, LVF)
**$p < .01$, ***$p < .001$

Table 6

Correlations among Experimental and Hemispheric Tasks (Reaction Time)

Task	Men	Women	Overall
	n=45	*n*=81	*n*=126
Onsets (LH)			
MR_LH	.49**	.44***	.43***
MR_RH	.51**	.45***	.46***
MR Overall	.51*	.46**	.46**
SV_LH	.44**	.10	.25**
SV RH	.41**	.11	.24
SV Overall	.43**	.11	.24**
TVSC	.46**	.15	.28**
Crosslines (LH)			
MR_LH	.40**	.24	.28**
MR_RH	.41**	.25	.30**
MR Overall	.42*	.25	.29*
SV_LH	.21	.09	.09
SV RH	.23	.12	.14
SV Overall	.21	.09	.09
TVSC*	.40**	.23*	.34***
Locations (RH)			
MR_LH	.32	.01	.16
MR_RH	.35***	.10	.22***
MR Overall	.37***	.05	.20
SV_LH	.34	-.04	.16
SV_RH	.36***	.03	.17
SV Overall	.39***	.02	.20
TVSC*	.30	.07	.17
Occlusion(RH)			
MR_LH	.52***	.32**	.41***
MR_RH	.51***	.43***	.46***
MR Overall	.53***	.41***	.46***
SV_LH	.49**	.17	.32***
SV RH	.49**	.26	.36***
SV Overall	.51***	.21	.34***
TVSC	.37**	.20	.30**

Note. MR = Mental Rotation, SV = Spatial Visualization, LH = Stimuli were presented to the Left Hemisphere (Right Visual Field, RVF), RH = Stimuli were presented to the Right Hemisphere (Left Visual Field, LVF)
**p < .01, *** p < .001

Tests of Hypotheses

The main hypotheses were tested individually. The specific analyses were dictated by the hypotheses.

Hypothesis 1: Sex Differences in Performance.

Hypothesis 1 involves sex differences in performance on all the tasks (see Tables 1 and 2 for means). Hypothesis 1a stated that performance on the mental rotation task would be higher for men than for women. Two independent samples t-tests, one for proportion correct and one for reaction time, were conducted to determine if performance on the mental rotation task was higher for men than for women. The results indicated that men performed better than women, as measured by percent correct [t (123) = 2.10, p =.03] but not reaction time [t (123) = -.171, p =.86]. However, it is common for sex differences to show up in one measure but not the other (Rilea, 2004); therefore, Hypothesis 1a is supported.

Hypothesis 1b stated that performance on the spatial visualization tasks would be equivalent for men and women. For the Paper-Folding task, two independent samples t-tests were conducted to determine if proportion correct and reaction time were the same for men and women. The results indicated that there were no sex differences in either proportion correct [t (124) =1.55, p =.12] or reaction time [t (124) =1.225, p =.22]. An additional two independent samples t-tests were conducted to determine if there were sex differences on the TVSC. The results indicated that there were no sex differences in proportion correct [t (124) =-.675, p =.50]. However, there was a clear male advantage for reaction time [t (124) = -2.942, p =.004]. This male advantage was unexpected and indicates that this new task may involve processes other than those involved in the Paper-Folding task. As a consequence, the results with the more traditional measure of spatial visualization (Paper-Folding) support Hypothesis 1b.

Hypothesis1c stated that performance on the lateralized tasks would be the same for men and women because the tasks we considered to be simple. Independent samples t-tests were conducted to determine if performance on the four lateralized tasks would be similar for both men and women. For proportion correct, there were no sex differences on the left hemisphere tasks: Onsets, t (118) =1.638, p =.10, and Crosslines, t (120) = -.613, p=.54. For the right hemisphere tasks, there was not a significant sex difference for the Occlusions task, t (120) =.996, p =.32, but there was a significant male advantage on the Locations task, t (121) = 2.408, p =.02. For reaction times, men generally outperformed women on all of the tasks: For the left hemisphere tasks, Onsets [t (118) =-1.975, p =.05] and Crosslines [t (120) = 4.166, p < .001], and for the right hemisphere tasks, Locations [t (121) = -1.106, p= .27] and Occlusions [t (120) =-2.219, p = .028]. These results appear not to support Hypothesis 1c.

Additionally, there were no significant sex differences found in lateralization coefficients for either proportion correct or reaction time (refer to Tables 3 and 4 for coefficients). This is in line with some previous research (Boles, 2005).

Hypothesis 2: Correlations among Experimental and Hemispheric Tasks.

Hypothesis 2 involved testing whether there was a correspondence between performance on the hemisphere tasks and performance on the experimental tasks (see Tables 5 and 6 for correlations). Specifically, Hypothesis 2a stated that performance on the right hemisphere tasks would be correlated with performance on both the mental rotation task (when presented to the right hemisphere) and the spatial visualization (i.e., Paper-Folding) task (when presented to the right hemisphere). Pearson correlations were conducted to test this hypothesis. For proportion correct (Table 5), all of the relevant correlations (e.g., MR_RH and SV_RH with Locations), were significantly different than zero, ranging from r = .23 to r = .41. For reaction times (Table

6), three out of the four correlations were significant and the significant correlations ranged from *r* = .22 to *r* = .46. Thus, the results support Hypothesis 2a overall.

Hypothesis 2b stated that the left hemisphere tasks would be correlated with the Mental Rotation task (when presented to the left hemisphere) and the spatial visualization task (when presented to the left hemisphere). Pearson correlations were conducted and the results paralleled those for Hypothesis 2a. For proportion correct (Table 5), all of the relevant correlations (e.g., MR_LH and SV_LH with Onsets), were significantly different than zero, ranging from *r* = .26 to *r* = .46. For reaction times (Table 6), three out of the four correlations were significant and the significant correlations ranged from *r* = .25 to *r* = .43. Thus, the results support Hypothesis 2b overall.

It should be noted, however, that the opposite comparisons (e.g., correlations between performance on the left hemisphere tasks and performance on the experimental tasks when they were presented to the right hemisphere) also tended to be significant. For proportion correct, six out of the eight relevant correlations (e.g., MR_RH and Onsets, which is a left hemisphere task, *r* = .45) were significant. For reaction time, only four out of the eight relevant correlations (e.g., MR_LH and Occlusions, which is a right hemisphere task, *r* = .41) were significant.

Hypothesis 3: Correlations among the Spatial Visualization Tasks.

Lastly, Hypothesis 3 stated that there would be a positive correlation between performance on the TVSC and the Paper-Folding task because they both are considered to tap into the construct of spatial visualization. For proportion correct, the results indicated a positive correlation between the two tasks, $r = .30$, $n = 126$, $p < .01$. For reaction time, the results indicated a positive correlation between the two tasks, however it was not significant, $r = .14$, $n = 126$, $p = .12$. It is important to note that the shared variance between the two tasks is only 9%

(proportion correct) and 2% (reaction time), which indicates that, although they share some cognitive processes, they could possibly rely on different cognitive processes. Therefore, hypothesis 3 was partially supported.

DISCUSSION

The primary objective of this study was to test the generalizability of the lateralization of function hypothesis. The hypothesis states that when the brain is more lateralized for specific types of spatial processing, such as mental rotation, performance on the task will be higher than when the brain is less lateralized for the task. Further, the hypothesis has been used to explain at least in part the reason for sex differences on certain spatial tasks, although sex differences are not necessary for the hypothesis; the relation between degree of lateralization and performance should occur for both men and women.

Lateralization of Function Hypothesis

There were three kinds of evidence to test the generalizability of this hypothesis. First, we needed to show that men outperformed women on the on the mental rotation task but not necessarily the spatial visualization task, and this is what was found. These results are also in line with the current research on sex differences favoring males on mental rotation tasks (Coluccia & Louse, 2004). Second, we needed to show the right hemisphere tasks would correlate with both the mental rotation and Paper-Folding task when presented to the right hemisphere. Additionally, we needed to show that the left hemisphere tasks would correlate with the mental rotation and Paper-Folding task when presented to the left hemisphere. The results showed support for all of these main hypotheses.

For the mental rotation task, men outperformed women in proportion correct. This is consistent with pervious research (Coluccia & Louse, 2004). We also found that men's performance on the mental rotation task was correlated with the hemispheric tasks that have a right hemisphere advantage, whereas women's performance was not, or at least not as strongly as men. As a more direct test, the more the mental rotation task was lateralized to the right hemisphere, the greater the performance on the mental rotation task.

For the spatial visualization task, there were no sex differences in proportion correct or reaction times. This is in line with previous research that little sex differences exist in spatial visualization tasks (Coluccia & Louse, 2004). This supports the lateralization of function hypothesis since the task is not considered a lateralized task; therefore, we would not expect to find sex differences. Additionally, we found that more right hemisphere lateralization did not predict better performance for the spatial visualization task.

In terms of sex differences, men outperformed women in proportion correct for the mental rotation task. This advantage may be due to brain organization; however, there are still some other reasons that should be mentioned. Men and women employ different strategies when completing certain spatial tasks (Coluccia & Louse, 2004). Therefore, it is possible that men use more efficient strategies than women do. Women may also have more difficulty in changing strategies thus decreasing their performance (Chen et al., 2009). Another possible explanation could be due to the interaction of biological and environmental factors (Sherman, 1978). Alternatively, maybe it could be due to personality characteristics (i.e. anxiety levels) (Lawton, 1996). The results from the current study do not fully rule out these possibilities; however, it is important to recognize that the lateralization of function hypothesis certainly is a strong one, given the data.

Despite the evidence supporting the lateralization of function hypothesis, there were some other findings that were unexpected. First, the lateralization coefficients for proportion correct did not match up clearly with the expected advantage. One might think this would be due to possible ceiling effects since proportion correct on the hemispheric tasks were relatively high. However, the lateralization coefficient formula was used specifically to account for ceiling and floor effects. Therefore, it is unclear as to why some of the lateralization coefficients did not align in the expected direction for proportion correct.

Additionally, when the stimuli from the mental rotation were presented to the left hemisphere, RT performance correlated with RT performance on the left hemisphere tasks, as expected, but they also correlated with the right hemisphere tasks. Along the same lines, when the mental rotation stimuli were presented to the right hemisphere, RT performance also correlated with RT performance on the left hemisphere tasks, not just the right hemisphere tasks. That is, it did not matter which hemisphere stimuli were presented to. It is possible that the nature of the tasks was too similar and thus we found correlations regardless of which hemisphere stimuli were presented to.

We found that, for men, the mental rotation task recruited the left and right hemisphere. Although not completely unexpected, this does not perfectly align with previous literature (Rilea et al, 2004). Rilea and colleagues (2004) found a right hemisphere advantage for both men and women; however, this does not mean they did not recruit from the left hemisphere at all. Their results only demonstrated that performance was higher when the stimuli were presented to the right hemisphere. It is important to keep in mind however that Rilea and colleagues only included data from participants whose performance was above 50%.

For women, the pattern for mental rotation was not as clear because their performance correlated with one LH task and one RH task, and did not correlate with the other LH and RH tasks. This may indicate that they were relying on both hemispheres, but only some parts of the hemispheres. In turn, this may indicate that they were using different strategies to complete the task. The results do not provide direct evidence of that, however, and if they were using different strategies, the results would not tell us whether these strategies were above or below the threshold of awareness.

We also found that the spatial visualization task recruited both the left and right hemispheres, but for men only. For women, our results suggest that neither the left nor the right hemispheres were engaged when they completed the spatial visualization task. More important, it seems ludicrous to suggest that they used neither hemisphere when completing the spatial visualization task. More likely, the hemispheric tasks used in the current study did not tap into areas that women use to complete the task. This leads to question, which part of the hemispheres are women using to complete the task? Answering this question requires further research.

Spatial Visualization Tasks: Paper-Folding versus The TVSC

A secondary goal was to compare the two spatial visualization tasks. The more traditional spatial visualization task—Paper-Folding—had its own unique findings. The results for the Paper-Folding task suggested that there were no significant sex differences in either proportion correct or reaction time. This is consistent with previous literature (Coluccia & Louse, 2004). For the TVSC, there were no significant sex differences for proportion correct; however, there was a sex difference for reaction time, with men responding more quickly than women. This difference in reaction time was unexpected. However, although rarely observed in spatial visualization tasks, it is still possible for sex differences to show up in one measure but not the other (Rilea, et al., 2004).

Another main objective of this project was to collect normative data on the TVSC; to date; the TVSC has mostly been used for participants who have a disabling condition such as MS (Fuchs et al., 2012). The TVSC had some similarities with the Paper-Folding task as well as some differences. There were both positively correlated for proportion correct and reaction time; however, only the proportion correct correlation was significant. This result indicates that they may be recruiting different cognitive processes or requiring different strategies. Another difference between these two tasks was that the TVSC has a 3-D aspect to it, whereas the Paper-Folding task was a 2-D presentation. Additionally, although these tasks might seem to tap into spatial visualization, previous factor analyses have pointed out that similar spatial tasks might in fact be relying on different underlying cognitive processes (Boles, 2002). This might account for the lower than expected correlation between the two tasks.

Reliability of Experimental Tasks

Another objective of this study was to conduct reliability analyses for both the mental rotation and Paper-Folding task. As with any measure, it is important that they be considered reliable. After conducting reliability analyses, the results suggested that both the mental rotation and Paper-Folding task were considered reliable measures. The mental rotation had slightly higher reliability than the Paper-Folding task. This might be due to the fact there were more trials in this task than in the Paper-Folding. Additionally, a Spearman Brown corrected split-half reliability analysis was conducted to test the reliability of the lateralization coefficients (LC) of the hemispheric tasks. Most LC's of the lateralized tasks met the suggested minimum .30 requirement and were considered reliable, except for Locations RT (.19) and Occlusions RT (.20). Additionally, the reliability of the LC's were consistent with previous research (Boles, 2002). The LC's for the experimental tasks were also checked for reliability. The results were not as clear (Paper-Folding correct= .22, Paper-Folding RT= .41, Mental Rotation correct= .10, Mental Rotation RT=.20).

Limitations

It is important to note that this study is not without its limitations. There were several unexpected results and this might be due to a lack of power. However, the number of subjects recruited was based on a power analysis with a medium effect size. Future research might want to consider conducting a similar study using a larger sample, but only if one wishes to search for a small effect size. Another limitation that might be worth mentioning is that strategy usage was not surveyed from the participants. Recent research suggests that certain strategies might mediate which hemisphere is used for processing (Rilea, 2008). Specifically, research suggests that a left hemisphere advantage would be observed when using a self-based approach (egocentric) and right hemisphere advantage would be observed when using an object-based approach (exocentric). More research should look into ascertaining strategy use while engaging in such lateralized tasks.

Future Directions

Although it may seem that the lateralization of function hypothesis has relatively strong support, there are still some future directions that warrant research. One way to improve this research might be to incorporate imaging studies using fMRI technology. By conducting these imaging studies on brain lateralization, we might be able to gain a better understanding on actual areas of activation during certain spatial tasks. Another way to improve the research is to incorporate more types of tasks instead of the ones used in this project. In particular, additional hemispheric tasks need to be devised to tap into the areas of the brain that women may be using in the spatial visualization task. Additionally, it might be of great interest to include a verbal measure that is presented bilaterally and, presumably, lateralized to the left hemisphere. By including this verbal measure, we might find a stronger correlation for women in the left hemisphere performance over men. This would provide some support for the notion that lateralization leads to better performance in certain domains.

Conclusion

The findings from this study suggest that hemisphere organization might be a factor in explaining the different pattern of performance for men and women across different types of spatial tasks; however, there may be other contributing factors. Based on these results, it is safe to assume that more research would be beneficial in this area.

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APPENDICES

Appendix A

INFORMATION SHEET

In this study you will be asked to complete a memory test and several visual-spatial tasks. Instructions are given before the tasks. The procedures in this study are experimental in nature. You should ask questions if you do not understand them.

No risk or discomfort is expected in this study. A benefit you can expect is knowledge about research methods in psychology. Your participation is voluntary and without obligation. You are free to decide whether you participate or not. You may withdraw at any time during the experiment.

All data are confidential. No individual will be identified in reports of the results. You will have the option to destroy your data once the study is complete.

The entire study should last approximately two hours. You will receive 2 research credits towards your PY 101 course requirement. You will receive a debriefing at the end of your participation. This will explain the specific hypotheses of this study.

Contact Person Name: Beverly Roskos
Phone Number: (205)-348-7942

If you have any questions about your rights as a research participant, you may contact, Carpantato Myles, The University of Alabama Research Compliance Officer, at 205-348-846

Appendix B

DEBRIEFING FOR "A Lateralization of Function Approach to Understand Sex Differences in a New Spatial Task"

Experimenter: Sara Steele
Faculty Sponsor: Dr. Beverley Roskos
Hours: 2

The purpose of this study was to find support for the notion that men and women have different brain organization, and therefore have different levels of certain cognitive abilities. The tasks you have completed assessed your spatial ability as well as hemispheric preference for these tasks.

Research suggests that since men typically outperform women on spatial tasks, it is due to their brain organization. Male brains are considered more asymmetrical whereas female brains are considered more symmetrical. In, men, spatial ability is considered to be more lateralized to the right hemisphere. However, women use both hemispheres to process spatial tasks. The premise of the approach used in this study was that the male advantage could be explained by how much the task is a right hemisphere task.

Please note that participants in this study should be "naïve". In other words, they should not know in detail what it is about, since this might influence their results. We would appreciate you not speaking about the study in any detail with friends who might participate. Thanks!

Further Reading

You can read about spatial cognition in the following sources:

Boles, D. B. (2002). Lateralized spatial processes and their lexical implications. *Neuropsychologia*, *40*(12), 2125-2135

Rilea, S. L. (2008). A lateralization of function approach to sex differences in spatial ability: A reexamination. *Brain and Cognition*, *67*(2), 168-182.

Rilea, S. L., Roskos-Ewoldsen, B., & Boles, D. (2004). Sex differences in spatial ability: A lateralization of function approach. *Brain and Cognition*, *56*(3), 332-343.

Primary Investigator: Beverly Roskos
Phone Number: (205)-348-7942

Appendix C

HISTORY QUESTIONNAIRE

Confidential

Please answer all questions as completely as possible. We respect your right to decline to answer some questions.

Today's Date: _________ Examiner's initials: _______

Sex: ___ Female___ Male Current Age: ______

Handedness: ___ Right ___ Left ___ Both

Ethnicity: ___ African-American ___ Hispanic ___ White
___ American Indian ___ Asian ___ Other: ____________

Education: _____ Less than High School (____ # years) _____ GED
_____ Completed High School _____ Some College (____ # years
_____ AA degree _____ Bachelor's degree
_____ Some graduate school(____ # years)
_____ Master's degree
_____ PhD, MD, JD or other (____ total # years)

Is English your primary language? ___ Yes ___ No

Did you have difficulty with any school subjects? ___ Yes ___ No
If Yes, which ones:
____

Did you ever have any special tutoring or special classes? ___ Yes ___ No
If Yes, explain:
____

Did you ever repeat any grades? ___ Yes ___ No
If Yes, list which ones:
____

Your current occupational status:

___ Full-time___ Part-time___ Unemployed___ Retired___

Disability___Volunteer ___ Student

MEDICAL HISTORY

Do you have any neurologic or other chronic medical conditions?___ Yes___ No

If Yes, please list: ____

Have you ever experienced a head injury **with** loss of consciousness **or** sense of being "dazed"?
___ Yes ___ No

If Yes, please describe: ____

Please list your current medications:

Medication	Amount	Reason

Do you now drink or have you ever regularly drunk alcohol products? ___ Yes ___ No

If Yes, please describe (amount, frequency): ___________________________________

PSYCHIATRIC HISTORY

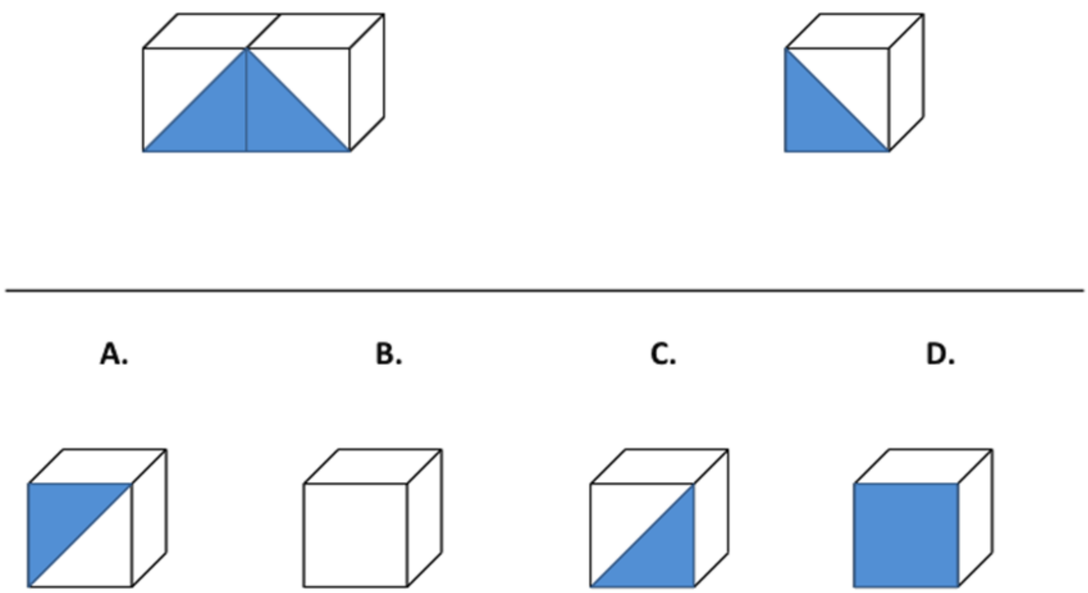
Have you ever been treated or diagnosed with depression, anxiety, or other psychological disorder? __ Yes __ No

If Yes, please explain: ____

Are you **currently** being treated for one of these disorders? ___ Yes ___ No

Appendix D

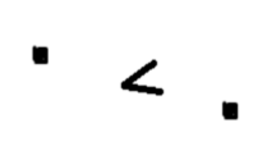
Test of Visuospatial Construction (TVSC) (McDermott, 2010)



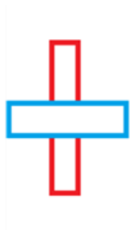
Participants indicated which block (A,B,C,D) would complete the block on the right to match the blocks on the left. The correct answer in this example is C. This task only required a verbal response.

Appendix E

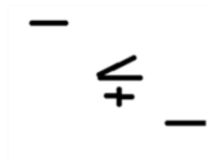
LATERALIZED TASKS



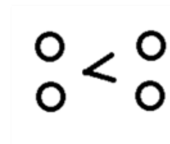
Locations



Occlusions



Crosslines



Onsets

These four tasks were administered on a computer in the lab*

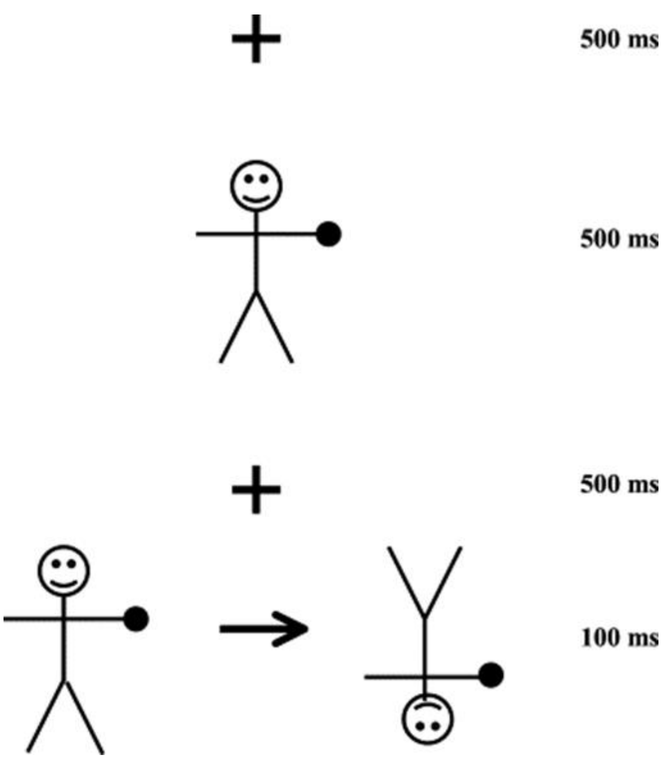
- *Locations task*- Participants remembered the location of the dot that the sign is pointing to
- *Occlusion task*- Participants determined which bar occluded the other
- *Crosslines task*- Participants indicated whether the horizontal line was either above or below the fixation point.
- *Onsets*- Participant indicated which circle appeared first on the screen.

*All responses were recorded on a keyboard.

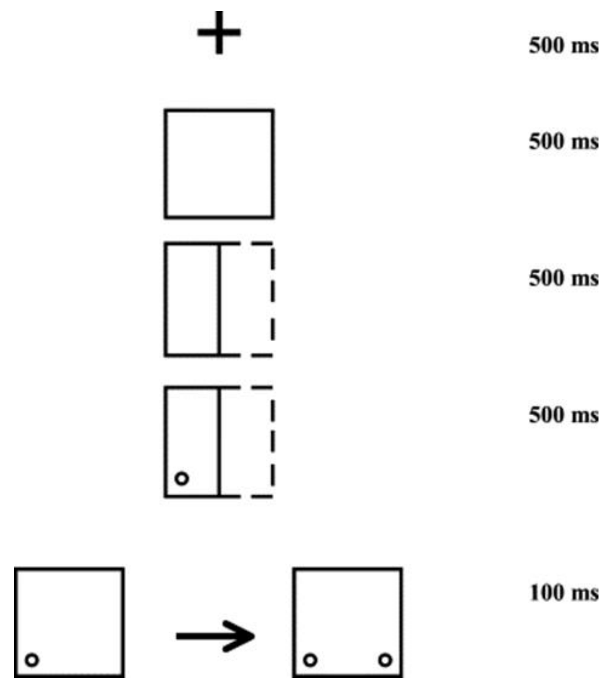
Appendix F

MENTAL ROTATION TASK and PAPER_FOLDING TASK-
SCREENSHOT EXAMPLE

Mental Rotation Task



Paper-Folding Task



These tasks were administered on a computer in the lab*

Mental Rotation task: Participants indicated if the stick figure is the same or the mirror image of the target stick figure.

Paper-Folding Task: Participants mentally unfolded a piece of paper that had been folded one to three times and then had a hole punched in it

*All responses were recorded on a keyboard

Appendix G

January 10, 2013

Office for Research

Institutional Review Board for the Protection of Human Subjects

THE UNIVERSITY OF ALABAMA RESEARCH

Sara Steele
Department of Psychology
College of Arts and Sciences
Box 870348

Re: IRB # 13-OR-013: "A Lateralization of Brain Function Approach to Understanding Sex Differences in Spatial Ability"

Dear Ms. Steele,

The University of Alabama Institutional Review Board has granted approval for your proposed research.

Your application has been given expedited approval according to 45 CFR part 46. You have also been granted a waiver/alteration of informed consent. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your application will expire on January 9, 2014. If the study continues beyond that date, you must complete the IRB Renewal Application. If you modify the application, please complete the Modification of an Approved Protocol form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, please complete the Request for Study Closure (Investigator) form.

Please use reproductions of the IRB-stamped information and debriefing sheets.

Should you need to submit any further correspondence regarding this application, please include the assigned IRB application number.

Good luck with your research.

Sincerely,

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Office for Research Compliance
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