Sex Differences on a Mental Rotation Task: Variations in Hemispheric Activation Between Children and College Students

Jonathan E. Roberts

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Martha Ann Bell, Ph.D., Chair
Robin Panneton Cooper, Ph.D.
Helen J. Crawford, Ph.D.

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SEX DIFFERENCES ON A MENTAL ROTATION TASK: VARIATIONS IN HEMISPHERIC ACTIVATION BETWEEN CHILDREN AND COLLEGE STUDENTS

By Jonathan E. Roberts
Martha Ann Bell, Ph.D., Chair
Psychology

(ABSTRACT)

The area of cognitive research that has produced the most consistent sex differences is the area of spatial ability. Particularly, males usually perform better on mental rotation tasks than do females. One argument for these differences is that experience with spatial activity drives these differences, such that traditionally more masculine activities require more practice of spatial abilities. Another argument is biological in nature, such that there is either 1) a critical period of development that leads to differential lateralization of the brain, or 2) differential activation of the brain by circulating hormones. Performance on mental rotation tasks has been associated with right parietal activation levels, both during task performance and prior to performance during baseline recordings. The present study examined the relations among sex, age, EEG hemispheric activation (at the 10.5-13.5Hz. frequency band), and 2-dimensional mental rotation task ability. Nineteen eight-year-olds (10 boys) and 20 college students (10 men), had EEG recorded at baseline and while performing a mental rotation task. Men performed better on the mental rotation task than women, while there were no differences between boys and girls. After covarying for baseline EEG high alpha power values, EEG results during the mental rotation task indicated an interaction, with men exhibiting more activation (lower EEG power values at 10.5-13.5Hz) than women in the parietal and posterior temporal regions, while boys' and girls' power values 10.5-13.5Hz did not differ in the parietal or posterior temporal regions. Furthermore, during the baseline condition, men generally exhibited more activation (lower EEG power values at 10.5-13.5Hz) throughout all regions of the scalp. Results support the hypothesis that hormones, or hormonal influence, may result in a biological change which affects both brain activation and performance on mental rotation tasks.

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The study of sex differences has been both a popular and a controversial topic among researchers. While many cognitive tasks have purportedly favored one sex or the other, the area of cognitive research that has more consistently shown sex differences is the area of spatial ability. Spatial ability can be generally defined as the skills of generating, transforming, representing, and recalling symbolic, nonlinguistic information (Linn & Petersen, 1985). Although the individual tests used in the area of spatial abilities are numerous, recent meta-analyses (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995) have broken the tasks into three different factors: mental rotation, spatial perception, and spatial visualization. Sex differences on tests of spatial visualization have been the least replicable, while sex differences on tests of spatial perception have been more reliable. Tests of mental rotation in adult populations, however, have more consistently shown a sex difference in favor of men (Linn & Petersen, 1985: Voyer et al., 1995 [see tables 1 and 2]). Mental rotation tasks are broadly characterized as exercises that require the mental repositioning of a 2- or 3-dimensional object. Specifically, participants are typically presented with an object that is to be turned in the imagination and matched with one of two or more choices.

Two general lines of research are discussed. First, theories concerning sex differences on spatial tasks are reviewed. Next is a review of the psychobiological evidence that suggests that spatial functioning is localized to the parietal lobe. Due to the large number of different tasks which are used to assess spatial ability, the theory section will generally refer to *spatial abilities*. Because this study is concerned with the localization of spatial ability to the parietal lobe during a mental rotation task, the psychobiological data will primarily focus on mental rotation tasks. However, EEG studies that are concerned with other spatial tasks will be included.

Explanations of Sex Differences in Spatial Abilities

As soon as researchers began finding sex differences on mental rotation and other tests of spatial abilities, they also began searching for explanations as to how these differences might arise. Two main arguments have emerged: 1) that sex differences on spatial tasks are largely due to differential experience, and 2) that sex differences on spatial tasks are related to hormonal influx. The hormonal influx argument can be further subdivided into a “critical period” argument, stating that hormone influx at critical periods, such as the neonatal period or the timing of puberty, have a direct effect on the brain mechanisms which contribute to spatial task performance, and an “activation” argument, stating that hormone levels at the time of spatial testing contribute to the spatial task performance. While the present paper will focus on hormonal and experiential causes of the sex differences in spatial performance, Vandenberg and his colleagues (Vandenberg, 1980) have contributed research which also indicates a genetic influence on spatial abilities.

Spatial Experience

One explanation of the sex differences found on spatial tasks has been put forth by Newcombe and her colleagues, who argue that these differences are driven by an individual’s experience within the environment. Newcombe, Bandura, and Taylor (1983) used a spatial experience questionnaire to find that male college students participated in more spatially related tasks than did the female college students. For example, they compiled a list of 81 adolescent activities which they claimed involved spatial abilities. On the basis of male/female responses, 41 of the activities were classified as masculine (i.e. football, darts, carpentry), while 21 were classified as feminine (i.e. figure skating, gymnastics, interior decorating), and 20 were considered sex neutral (i.e. bowling, diving, sculpting). Not only were more spatial activities classified as masculine, but males also reported more overall participation in these activities.

Nash (1975) found that spatial task performance is positively related to masculinity scales for both boys and girls. Likewise, in a longitudinal study, 11-year-old girls who rated high on a measure of the masculinity of the ideal self, or who said they wanted to be a boy at age 11, performed better on spatial ability tasks at 16 years of age (Newcombe & Dubas, 1992). Conversely, high self-ratings on feminine expressivity in girls at 11 years of age were negatively related to spatial ability tasks at age 16. In the study by Newcombe and Dubas (1992), however, 11-year-old girls' spatial activity was not found to be related to spatial ability at either 11 or 16 years of age.

Furthermore, in a meta-analysis, Baenninger and Newcombe (1989) found a reliable relation between spatial activity participation and spatial ability, such that participation in spatial activities was positively correlated with spatial ability among both boys and girls. Using only studies that incorporated the Newcombe et al. (1983) spatial experience questionnaire, Baenninger and Newcombe (1989) found a weak but reliable relation between spatial participation and spatial ability. Baenninger and Newcombe (1989) conceded that, for both sexes, all of the effect sizes were small, with spatial experience only accounting for about a 9% improvement rate on test scores.

Hormones: Critical Periods vs. Activation

One argument as to why sex differences are found in mental rotation tasks is that the presence of hormones at a critical period in development may affect the development of specific brain regions and/or brain lateralization. One of the first theories addressing sex differences on spatial tasks was a "critical period" theory put forth by Waber (1977). Waber reported that late maturing females performed better on spatial ability tasks than did early maturing females. Based on this finding, she suggested that late maturing females had brains that were more laterally specialized than early maturers, meaning that there was more right hemisphere engagement in activities, and that this specialization was associated with better performance on right-hemisphere tasks. This finding is intuitive because males, who are more laterally specialized than females, are also later maturers (Waber, 1977). Thus, later maturing females' brain lateralization may look more like that of a male. However, there have been failures to replicate the finding that late maturing females perform better on spatial tasks than do early maturing females (e.g., Newcombe & Bandura, 1983; Newcombe & Dubas, 1989).

Another argument for a critical period was made by Resnick, Berenbaum, Gottesman, and Bouchard (1986), in a study of children with congenital adrenal hyperplasia (CAH), a disorder associated with elevated prenatal androgen levels. Resnick et al. (1986) found that females who had CAH performed better on tests of spatial ability than unaffected relatives, suggesting that prenatal hormones may have had an effect on spatial ability. In a different study, Jacklin, Wilcox, and Maccoby (1988) assessed umbilical cord hormone levels at birth and then tested cognitive abilities at six years of age. They reported finding that high testosterone and androstenedione levels were associated with poor performance on spatial tasks at six years of age. This is the opposite finding from the one reported by Resnick et al. (1986), and more research is needed in this area. Surprisingly, in both of these studies hormones levels were not assessed at the time of spatial testing. Particularly in the case of the females with CAH, this leaves open the possibility that there were still hormonal effects from the disorder. Thus, information concerning hormone levels coincident with the testing situation may be more valuable than information about prenatal or birth hormone levels.

Another hormonal hypothesis regarding the sex differences in spatial ability is an activation argument, stating that hormone levels at the time of spatial testing contribute to the spatial task performance. This idea is supported by several different lines of reasoning. First, sex differences on spatial ability tasks are inconsistently found until after puberty (Linn & Petersen, 1985; Waber, 1977). Until the end of the first year of life, testosterone levels are higher in males than in females, but from the end of the first year until just before the onset of puberty, testosterone levels are low among both sexes (Stahl, Gotz, Poppe, Amendt, & Dorner, 1978). This, coupled with the inconsistent data between pre-pubescent boys and girls on mental rotation tasks, supports a hormone activation argument for the sex differences in spatial ability tasks (Linn & Petersen, 1985; Waber, 1977).

Perhaps even more compelling evidence for hormone activation differences in spatial abilities has come from studies which directly manipulate hormone levels. In a compelling series of studies by Van Goozen and colleagues (Van Goozen, Cohen-Kettenis, Gooren, Fridja, & Van de Poll, 1994,1995) groups of male-to-female and female-to-male transsexuals were studied before and after hormone therapy. The female-to-male group showed enhanced performance on spatial tests after treatment, while the male-to-female group's performance showed deteriorated performance on tasks of spatial ability. Likewise, a study by Janowsky, Oviatt, and Orwoll (1994) found that men ages 65-70 who were supplemented with testosterone to 150% of their baseline rate performed better than a double-blind control group on spatial cognition tasks. There were no differences in non-spatial cognitive performance between treatment and control groups. Janowsky et al. (1994) suggested that testosterone's inhibiting effect on estradiol may be linked to the spatial performance enhancement. This is in agreement with other reports drawing on the level of estradiol and spatial performance across the menstrual cycle and the finding that increased levels of estradiol are related to decreased performance of spatial abilities (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Silverman & Phillips, 1993).

Evidence for the effects of spatial experience and the effects of hormones on spatial tasks are both quite compelling. There may be two separate routes leading to a developmental pathway which results in increased performance on spatial tasks. The evidence of the hormonal activation argument, which states that circulating hormones affect spatial performance, however, cannot be ignored. In an attempt to replicate the studies which directly manipulate hormone levels, this study "manipulated" hormonal levels by using two different age groups as participants: eight-year-olds, who should be at least two or three years away from puberty (and its hormonal influx), and college students, who should have adult-levels of male and female hormones.

Parietal Lobe Involvement in Mental Rotation

In the quest to find which area of the brain is involved in spatial task performance, researchers have studied monkeys. In the non-human primate literature, it is accepted that damage to the parietal lobe causes deficits in performance on spatial tasks. The spatial task which has been most studied in monkeys is landmark discrimination, which is severely affected by parietal damage (Brody & Pribram, 1978; Pohl, 1973; Ungerleider & Brody, 1977). Likewise, monkeys with damage to the parietal lobe have shown deficits on other spatial tasks, including patterned strings (Ungerleider & Brody, 1977), route-following (Petrides & Iverson, 1979), cage-finding (Sugishita, Etlinger, & Ridley, 1978) and the stylus maze (Milner, Ockleford, & Dewar, 1977).

In humans, there is also a great deal of evidence to support the hypothesis that spatial tasks are associated with the parietal (and particularly the right parietal) lobe. In a clinical population, Ratliff (1979) found that individuals with damage to the right posterior area of the brain made more errors than individuals with damage to the left posterior area of the brain on a spatial task that required mental rotation to an inverted position. This suggests that the right posterior area is specifically involved in the mental rotation of part of the task. In another study, Ditunno and Mann (1990) also found that patients with damage to the right parietal area made more errors and took longer to respond on a mental rotation task than either patients with damage to the left parietal lobe or control participants. Likewise, Vingerhoets, Lannoo, and Bauwens (1996) found that subjects with parietal lesions made more errors on a mental rotation task than patients with frontal lesions. A caveat about using neurological patients is that often damage to one area of the brain can affect an entire brain system, rendering difficulty in localizing the diffuse aspects of behavior which may have been compromised by the damage.

A non-invasive way of localizing brain function has been with the use of the electroencephalogram (EEG). Typically, adult EEG recordings made in a state of cognitive functioning exhibit reduced alpha power values at the scalp recording site associated with the area of the brain most involved in the task. This is sometimes referred to as *alpha suppression*, and is considered to exemplify activation of that particular brain area. When recording EEG data, alpha is EEG activity between 8-13 Hz and is the classic band associated with cognitive functioning in adults (Hugdahl, 1995). For instance, if alpha suppression were seen in the scalp electrodes associated with the right parietal cortex during mental rotation tasks, researchers would interpret the data to indicate right parietal activation (alpha suppression), meaning that the right parietal area is involved in mental rotation performance.

In fact it is the case that EEG, as well as other brain measures, have found activation of the right parietal lobe during spatial tasks. In a study by Davidson, Chapman, Chapman, and Henriques (1990), psychometrically matched verbal and spatial cognitive tasks were compared. In a group of college students, the verbal task produced relatively more left central 8-13 Hz EEG alpha suppression (indicating more left central activation) than right central suppression, while the spatial task produced relatively more right parietal 8-13 Hz EEG suppression (indicating more right parietal activation) than left parietal suppression. In a study using the dual measures of EEG evoked potentials (EPs) and regional cerebral blood flow (rCBF), Papanicolaou, Deutsch, Bourbon, Will, Loring, and Eisenberg (1987) found that during mental rotation tasks there was greater activation in the right parietal than the left parietal regions. Michel, Kaufman, and Williamson (1994) found that alpha suppression increased with angle in a mental rotation task. In this task, subjects were asked if an abstract probe figure was the same as a memory figure which was presented earlier at a different orientation. As the angle of the figure rotated further from the original position, there was an increase in alpha suppression, as well as an increase in reaction time. Using a functional magnetic resonance imaging procedure (fMRI), Cohen and colleagues (Cohen et al., 1996) compared brain functioning while participants were determining if two figures were the same. The figures were in either a rotation or a non-rotation condition, allowing for the use of a subtraction technique. Using this procedure, Cohen et al. concluded that the areas most activated during the rotation condition (as compared to the non-rotation condition) were the superior parietal and frontal eye field areas. Likewise, in a different fMRI study, Tagaris et al. (1998) found that both the left and right precentral gyrus, as well as the right superior parietal lobule, were the areas most activated in a visual mental rotation task.

Despite these general findings of activation of the right parietal area during spatial tasks, there is some evidence that EEG activation may also be moderated by sex. Ray, Newcombe, Semon, and Cole (1981) used EEG measures to report that high spatial ability among males was associated with greater relative right parietal alpha suppression during a spatial task than during baseline. Ray et al. also reported that among low spatial ability males there was greater left parietal alpha suppression, while there was no systematic suppression patterns among either high or low spatial ability females during spatial tasks. This suggested that mastery of the task is associated with right parietal suppression, but only in males. Results of greater right parietal suppression by high ability males during spatial tasks were replicated by Berfield, Ray, and Newcombe (1986), who likewise found no consistent relations among either high or low ability females and right or left alpha suppression during the spatial tasks. In another study, Corsi-Cabrera, Ramos, Guevara, Arce, & Gutierrez, (1993) found alpha suppression for males, but not for females, during a spatial task. The data from these EEG studies suggests that males and females have electrophysiological differences in their processing of spatial material.

Baseline EEG, or the EEG taken while the research participant is in a resting state, has also been correlated with spatial ability. Furst (1976) found that high spatial ability males had greater right parietal alpha suppression at baseline. Likewise, Berfield et al. (1986) and Ray et al. (1981) in the two studies described above, also found greater right parietal alpha suppression at baseline to be related to males' spatial ability performance. Ray et al. (1981) proposed that these baseline differences not only indicate a greater use of the right but also less intrusion from the left when solving spatial tasks. It is interesting to note that these studies have shown no associations with either baseline EEG measures or EEG measures during task performance for females.

Longitudinal and cross-sectional studies examining the relationship between age, sex, and EEG power values indicate several types of findings. First, there is a general finding that interindividual variability in EEG recordings is much greater in children than in adults (Benninger, Matthis, & Scheffner, 1984; Gasser, Verleger, Bacher, & Sroka, 1988; Matsuura et al., 1985). Next, research indicates that women exhibit greater overall EEG alpha power than men both during baseline measures and during performance of different types of tasks (Benninger et al., 1984; Gasser et al., 1988; Matsuura et al., 1985). Such findings have been replicated in studies dealing with mental rotation task performance by Cosi-Cabrera and her colleagues, who have found a pattern of greater EEG alpha power among women both during a baseline condition and while performing mental rotation tasks (Arce, Ramos, Guevara, & Corsi-Cabrera, 1995; Corsi-Cabrera et al., 1993). Finally, there is an indication that while adolescents 14 - 17 years of age may show adult like sex differences in EEG, after 6 years of age but before 11-12 years of age there is no indication of a sex difference in the alpha band (Benninger et al., 1984; Matsuura et al., 1985). In light of these data, it would be important to account for any baseline EEG sex differences when examining EEG sex differences during any type of task performance.

Traditionally, psychophysiological tests of spatial abilities, and particularly mental rotation tasks, have focused on the parietal lobe. With a more recent focus on the brain as a system, as opposed to a collection of independent lobes, it is important to acknowledge that brain areas are interconnected. Research with non-human primates has indicated that the parietal cortex has many connections to the prefrontal cortex (Selemon & Goldman-Rakic, 1988). West and Bell (1997) found frontal *as well as* parietal EEG activation in subjects performing a Stroop task, which has long been considered a pre-frontal task. While the literature on EEG activation during spatial tasks has focused exclusively on parietal activity (to the extreme of only recording from the parietal lobe in some instances; e.g. Ray et al, 1981), it may be that a brain systems approach could more accurately reflect the dynamics of brain activation during a mental rotation task.

Purpose and Hypotheses

The purpose of this study was to examine the effects of sex, age, mental rotation ability on brain wave activity. This study proposed to measure baseline EEG and EEG during mental rotation task performance in males and females in two age groups: eight-year olds and college students. Because all of the previous EEG studies of spatial abilities have been with college age or older (adult) populations, there are no data in the literature of EEG measures during spatial task performance in a population of children. The use of a college age group assured that the mental rotation task is indeed replicating the activation findings listed above. Furthermore, a mental rotation task appropriate for both the eight-year-old group and the college-age group was used. Finally, in order to assure that right parietal activation was a function of the mental rotation task, and not just activation related to general cognition, participants were also tested on a reading (verbal) task. Previous literature has associated verbal tasks with left frontal (Kraft, Mitchell, Langus, & Wheatly, 1980; Mattson, Sheer, & Fletcher, 1992) or left central activation (Davidson et al., 1990).

Recent studies have indicated that the standard 8-13 Hz alpha band may actually may be comprised of two distinct (high and low) bands (Crawford, Clarke, & Kitner-Triolo, 1996;

Crawford & Vasilescu, 1995; Klimesch, 1996). Particularly, studies have found that the lower alpha band (7.5-10.5 Hz) may be associated with states of alertness and emotions while, the high alpha band (10.5-13.5 Hz) has been associated with cognitive workloads (Crawford et al., 1996; Klimesch, Schimke, Ladurner, & Pfurtscheller, 1990). In light of this research, the high (10.5-13.5 Hz) alpha band was of interest to this study. Because both of the tasks used were cognitively demanding, it was expected that EEG activation during both tasks would be found in the high alpha band.

There were four hypothesis addressed in this study:

Behavior

1) It was hypothesized that there would be an interaction on mental rotation task performance such that male college students would perform at a higher level than female college students, but that there would be no sex difference between the eight-year-old boys and girls. Although null findings are difficult to interpret, the eight-year-old group had several factors working against a sex difference in performance. If puberty, pubertal timing, or hormone differences do have an effect on spatial ability, then there should be no differences between the eight-year-old boys and girls. However, if a sex difference was found at such a young age, this would provide a problem for the argument that sex differences are mediated by pubertal onset or hormonal influx. However, it could provide some support for the argument that sex differences in spatial ability are mediated primarily by experience. Finally, if the hypothesized difference in the college students were found, it would make the findings with the eight-year-olds more interpretable, even if they were null.

Baseline EEG

2) Within the college students, it was hypothesized that there would be an interaction such that men would exhibit generally lower EEG alpha power values (at 10.5-13.5 Hz) than women throughout all scalp locations, while there would be no baseline EEG alpha power value

differences (at 10.5-13.5 Hz) between the eight-year-old boys and girls at any recording site. This hypothesis was consistent with the literature on developmental sex differences in EEG power values in the alpha band.

Task EEG

3) While assessing the task EEG, baseline EEG measures were covaried for in all conditions. It was hypothesized that, for male and female college students, as well as for boys and girls, there would be lower EEG alpha power values (indicating greater activation) of the right parietal area (at 10.5-13.5 Hz) during mental rotation task performance. In addition, it was it was further specified that there would be a sex by age interaction in the task EEG data at the parietal scalp locations. Within the college students, it was hypothesized that there would be task EEG differences between men and women, with men exhibiting more right parietal activation (lower power values) at 10.5-13.5 Hz than women during the mental rotation task. Within the eight-year-old group, it was hypothesized that there would be no task EEG alpha power differences between boys or girls at any recording site. As noted in the literature review, however, there are many interconnections between prefrontal and parietal cortices. Because of these interconnections, right parietal activation during task performance may be associated with some level of frontal activation. Lesion studies in humans and non-human primates have highlighted the importance of the parietal area in mental rotation task performance. Therefore, the present study made hypotheses for the right parietal area. Analyses examined frontal activation, as well as activation of other scalp sites.

Methods

Participants

Eight-year-olds. Twenty-eight 8-year-old participants (14 male, 14 female) were recruited for this study. Participants were recruited through an existing database of families which have previously participated in psychological research at Virginia Tech. All participants were screened for handedness using The Edinburgh Inventory (Oldfield, 1971) for handedness (see Appendix A). Additionally, a questionnaire was given to the parent of each child to assure there were no known neurological problems (see Appendix B). Also, parents were given the Tanner (Marshall & Tanner; 1969,1970) body-type questionnaire to complete concerning their child to assure that pubertal influx of hormones had not begun. Participants were within three months of their eighth birthday. For their participation, the children were rewarded with a single trip to a "treasure chest" of small toys at the end of the session.

Nine of the eight-year-old participants had to be dropped from final analysis for various reasons: three participants were excluded due to left handedness, as this may have an effect on laterality, two due to consumption of cough or cold medications on the day of testing, one due to excess artifact in the EEG recording, one due to a medical condition which caused difficulty seeing the computer screen, one due to an equipment failure, and one due to experimenter error. Therefore, a total of 19 participants (10 male, 9 female) were included in the final analysis.

College students. Twenty three right-handed college students (12 male, 11 female) were recruited through the Introductory Psychology extra credit pool to participate in this study. Subjects were compensated for their participation by extra credit in their Introductory Psychology class. Four participants (2 male, 1 female) were excluded from final analysis, two due to excess artifact and one due to consumption of cough or cold medications on the day of testing. Therefore, reported results include 20 participants (10 male, 10 female).

Procedure

Upon entering the lab, both age groups were given an informed consent form to read and sign (see Appendices C & D). In addition, parents of the 8-year-olds also signed a consent form (see Appendix E). Both age groups were also assessed for neurological problems with a questionnaire (see Appendix B). Potential participants were dropped if there were any "yes" answers to this questionnaire, or if they had consumed more than two caffinated beverages on the day of testing. One 8-year-old participant had to be dropped from analysis due to a neurological condition that caused difficulty with sight, while no participants were dropped to due excess caffeine consumption. Both age groups were given a questionnaire to assess the types of sports- and computer-related activities in which each participant was involved (see Appendices F & G). The data from this questionnaire were used for post-hoc analyses.

EEG recording. Participants had the Electro-Cap EEG recording device, as well as EOG electrodes, applied. After the cap was in place, Omni-Prep abrasive gel and Electro-Gel conductive gel were inserted in 16 electrodes associated with the international 10/20 system (Jasper, 1958): Fp1, Fp2 (frontal pole), F3, F4 (medial frontal), F7, F8 (lateral frontal), C3, C4 (central), T3, T4 (anterior temporal), T5, T6 (posterior temporal), P3, P4 (parietal), and O1, O2 (occipital). Electrodes were referenced to Cz and grounded anterior to Fz electrode on the Electro-Cap.

In addition, Electro-Cap ear electrodes (Omni-Prep abrasive gel and Synapse conductive gel) were attached to the earlobes and recordings for each ear were made referenced to Cz. This allowed an off-line transformation of the EEG data to an average-ears configuration. The ears reference (either linked or averaged) is the montage of choice in the EEG research literature (Hugdahl, 1995).

SensorMedics miniature electrodes (Synapse conductive cream) were applied to the supra orbit and outer canthus of the right eye after the skin had been wiped with an alcohol pad. This allowed monitoring of the EOG and eyeblinks for later artifact scoring of the EEG data.

For all electrodes (EEG, ears, EOG), impedances were less than 5K ohms and less than 500 ohms separated homologous electrode pairs.

EEG recordings were made with custom-made SA Instrumentation Bio-Amps at a sampling rate of 512 Hz to prevent aliasing. The high pass filter setting was set at 1 Hz and the low pass filter setting was set at 100 Hz, with a gain of 20K for the adults, and 10K for the children. The gain was set higher for the adults because, physiologically, children have greater amplitude in their EEG (Thatcher, 1997). Data were collected on a Pentium computer using Snap/Shot acquisition software.

Baseline EEG consisted first of one minute with eyes open. During the eyes open recording, participants were be instructed to look at a blank computer screen and to think about a "walk in the woods" and were instructed to sit quietly without motor movements. After baseline EEG had been recorded, the computer-based mental rotation task began.

Mental Rotation Task. Participants were seated in front of a computer and were shown the Overman Mental Rotation Task (Epting, Barbour, & Overman, 1996; Epting & Overman, 1998). This mental rotation task consisted of a "gingerbread man" (later referred to as "figure") presented at the top of the computer screen, with two choices, one of which matched the original, presented at the bottom of the screen. Figures, original and choices, were computer-generated in such a manner so that each had the same amount of area within its borders. The figure had four possible positions. While either the left or right arm was extended straight out, the opposite arm was either in an "up" or "down" position. During task performance, the participant was asked to match the original figure at the top to one of two figures at the bottom. The original figure was always in an upright position, while the subsequent "choice" figures at the bottom were rotated 90° to the left, 90° to the right, or 180° (see Figure 1). Participants were asked to choose which "choice" figure was the same as the "original" figure. The entire keyboard was covered except for two keys, one on the right side of the keyboard and one on the left side of the keyboard, which the participants used to choose the figure which correctly matches the original. Additionally, the space bar was used to let participants self-pace time between trials. In order to minimize motor movements, hands were rested in such a manner that only finger movements were required. All trials were randomized in such a manner that correct responses were equally divided between the right and left choices, and that the choice figures were turned equally to each side.

In order to control for general attentional and/or reaction time differences, a match-to-sample task utilizing the same stimuli was randomly mixed within the testing session. These trials were the same as above except that the figures at the bottom of the page were not rotated, as if they were in a 0° rotation condition. This match-to-sample task assured that differences in rotation ability were due specifically to the ability to mentally rotate objects. Likewise, if there were general or reaction time differences in the match-to-sample task, the 0° latency data would allow transformation of the trial latency values. For example, latency to respond during the match to sample can be considered baseline response for reaction time. It was expected that participants would take longer to respond at 90° than during the match to sample task (0°) and longer at 180° than at 90°.

After 2 familiarization pre-trials the testing phase was begun. Participants were given two blocks of 16 trials. Only 32 total trials were given because data have shown that after 30-40 trials, the task becomes one of memory, rather than a rotation (Epting et al, 1996; Epting & Overman, 1998). Performance was measured by percentage of correct trials, as well as mean latency to respond. Participants' responses were recorded automatically by the computer and saved for later analysis. The computer program was set up in such a manner that the participant could respond any time after the "choice" figures were displayed on the screen. However, the figures disappeared after 2 seconds, displaying the message "please make a choice now" to the participant. After making their choice, the computer screen displayed feedback to the participant to let them know if they were correct or incorrect. The participant was then allowed to start the next trial at their own pace by pressing the space bar. Most participants completed the mental rotation task in two to three minutes.

Reading Task. In addition to the mental rotation task, a reading task was also given. The present study hypothesized that differences in mental rotation task performance would be related to right parietal activation. In order to assure that right parietal activation was a function of the mental rotation task, and not just activation related to general cognition, participants were also tested on a reading (verbal) task. Previous literature has found verbal tasks are related to left frontal (Kraft et al., 1980; Mattson et al., 1992) or left central activation (Davidson et al., 1990).

During the verbal task, participants were asked to read a paragraph and then to answer questions regarding this paragraph (as consistent with Kraft et al., 1980). The material was at the second grade reading level and taken from a reading textbook. The participants were asked a total of four questions about the reading. Two questions were factual and two were inferential (see Appendix H). Most participants finished the reading task in two to three minutes.

EEG Analysis

Using software developed by the James Long Company, the EEG data were re-referenced via software to average ears configuration. Data were artifact scored using EOG as a guide, with gross motor and muscle movements removed through artifact scoring. The visual representation of gross motor and muscle artifact was obvious to the eye because artifact occurs at frequencies greater than 90Hz. Artifact free EEG data were analyzed with a discrete Fourier transform (DFT) using a Hanning window of one-second width and 50% overlap. Mean voltage was subtracted from each data point prior to analysis to eliminate any power results due to DC offset, and power was calculated for 10.5-13.5 Hz. In a review of the ontogeny of EEG during childhood, Bell (1998) has noted that spectral power values of 8-year-old children are within the adult range. Adult and child EEG data sets were separately normalized using natural log transformation.

Results

Behavior

It was hypothesized that male college students would perform better than female college students on the mental rotation task, while there would be no sex differences in performance in the eight-year-olds on the mental rotation task. Performance on mental rotation tasks has traditionally been examined both in terms of correct responses and reaction time (for a meta-analysis including mental rotation tasks see Voyer et al., 1995).

Mental Rotation: Total Number of Correct Responses

In order to assess the effects of sex on the number correct trials of the mental rotation task a repeated measures ANOVA was performed. The independent variables were sex, age, and angle of rotation (0°, 90°, 270°, 180°), and the dependent variable was the total number of correct responses. All participants completed a total of 32 trials, with 8 trials at each angle of rotation.

Analyses revealed a main effect for age [$F(1, 38) = 71.034$, $p < .001$], with adult participants answering more responses correctly than children. Also, there was a main effect of angle of rotation [$F(3, 36) = 12.557$, $p < .001$]. Post hoc analyses revealed that the total number of correct responses was higher in the 0° condition than the 90° condition [$t(38) = 3.413$, $p = .002$] and the 270° condition [$t(38) = 3.620$, $p = .001$], and that there were more correct responses in the the 90° condition [$t(38) = 3.636$, $p = .001$] and the 270° condition [$t(38) = 3.010$, $p = .005$] than in the 180° condition. There were no other main effects or interactions (see figure 2 for a summary of these data).

Mental Rotation: Reaction Time

In order to assess the effects of age, sex, and angle of rotation on the reaction time on the mental rotation task data were analyzed as a mixed linear model treating the subjects effects as random, and the sex, age, and angle of rotation effects as fixed. Analyses included only those trials in which a correct response was made by the participant. For each age group, analyses were first completed on the 0° (reaction time) condition. These analyses revealed that men's reaction times were faster than women's in the 0° condition [$F(1, 18) = 4.77$, $p = .04$], but that boys' and girls' reaction times did not differ in the 0° condition [$F(1, 17) = .73$, $p = .40$]. In order to control for reaction time, data from each correct trial at the 90°, 270°, and 180° conditions were adjusted by subtracting each individual's mean reaction time from the 0° condition. This insured that any differences in reaction time at other rotation angles were specific to the rotation, rather than simply differences in overall reaction time.

Analyses revealed a main effect for angle of rotation [$F(1, 35) = 8.70$, $p < .001$] with reaction times being slower in the 180° than either in the 90° [$t(160) = 4.319$, $p < .001$], or 270° [$t(169) = 2.740$, $p = .007$], conditions. Also, analyses revealed a sex by angle of rotation interaction [$F(1, 617) = 3.03$, $p = .048$], driven by males responding faster than females at the 180° [$F(1, 194) = 8.272$, $p = .004$] but not at the 90° or 270° condition. Further analyses at the 180° condition revealed that men were faster than women [$F(1, 18) = 7.52$, $p = .01$], but that there were no differences between boys' and girls' reaction times [$F(1, 18) = .47$, $p = .50$] at the 180° condition. There were no other main effects or interactions in the reaction time data (see figure 3 for a summary of these data).

<u>Summary and discussion of mental rotation findings</u>. It was hypothesized that there would be a sex difference interaction on mental rotation task performance such that male college students would perform at a higher level than female college students, while there would be no sex difference on mental rotation task performance between the eight-year-old boys and girls. While there was no significant age by sex by angle of rotation interaction, main effect testing revealed that, when reaction time was partialled out, college-aged men performed better on the

mental rotation task than the college-aged women, but only at the 180° condition. There were no differences between the eight-year-old boys and girls at any condition. Furthermore, there were no differences between either men and women or girls and boys on the number of correct responses. Previous literature using the same gingerbreadman task within an adult populations also found that the sex difference was only significant in the 180° condition (Epting & Overman, 1998). This data supports the hypothesis that some process occurs between childhood and adulthood which causes sex differences on the mental rotation task.

EEG Activation

In light of research indicating that the high (10.5-13.5 Hz) alpha band may be associated with cognitive workload (e.g., Crawford, Clark, & Kitner-Triolo, 1996; Klimesch, 1996), all hypotheses were analyzed using high alpha (10.5-13.5 Hz) frequency band. The analyses were accomplished on baseline EEG and mental rotation task and reading task EEG controlling for baseline EEG. Within each one of these analyses, the overall MANOVA (or MANCOVA) will not be interpreted independently, but rather will be used for justification for separate MANOVAs (or MANCOVAs) performed on the EEG for each individual region (i.e., each homologous pair of recording sites).

Exploratory analyses were also performed on both the traditional (7.5-13.5 Hz) and the low (7.5-10.5 Hz) alpha frequency bands. Those results will not be discussed in relation to the present findings.

Baseline EEG

It was hypothesized that there would be an interaction such that, within the college students, there would be baseline EEG differences between males and females, with males exhibiting generally lower EEG power values than females throughout all scalp locations, while within the eight-year-old group there would be no baseline EEG differences between males or females at any recording site

A repeated measures MANOVA was used to assess the effects of sex and age on region/hemispheric activation at baseline. The within groups independent variables were region (frontal pole, medial frontal, lateral frontal, central, anterior temporal, posterior temporal, parietal, occipital) and hemisphere (right, left) and the between groups independent variables were sex and age. The dependent variable was baseline EEG ln power values at 10.5-13.5 Hz. There were main effects for age [$F(1, 35) = 38.354$, $p < .001$], sex [$F(1, 35) = 11.661$, $p = .002$], and region [Wilks = .093, approximate $F(7, 29) = 40.435$, $p < .001$]. Interactions included age X sex [$F(1, 35) = 9.352$, $p = .004$], and region X age [Wilks = .524, approximate $F(7, 29) = 3.758$, $p = .005$]. There were no other main effects or interactions.

To examine these interactions, separate MANOVAs were performed on the EEG power values for each region. This also allowed for interpretation of the main effects of age, sex, and region that were reported in the overall MANOVA analysis noted above. For the MANOVAs done for each region, age and sex were the between subjects factors and hemisphere was the within subjects factor. The dependent variable was EEG power at 10.5-13.5 Hz.

In all regions, there was a main effect for age [all F's > 16; all p's < .001], with the college students exhibiting lower EEG power values than the children. Likewise, for all regions there was a main effect for sex [all F's > 5; all p's < .026], with the male participants exhibiting lower EEG power values than female participants. Furthermore, in all regions there was an age X sex interaction [all F's > 6; all p's < .016], with men exhibiting lower power values (more activation) than women [all t's < -2.5 , all p's < .023], while boys' and girls' power values did not differ [all t's < -1.45, all p's > .166].

<u>Summary and discussion of baseline findings</u>. In all regions there was a main effect for age, with the college students exhibiting lower EEG power values than the children. Likewise, in all regions there was a main effect for sex, with male participants exhibiting lower EEG power values (more activation) than female participants. Finally, in all regions there was an age X sex

interaction, such that men exhibited lower high alpha power values (more activation) than women, but boys' and girls' power values did not differ.

In the baseline condition, college-age men exhibited lower power values than college-age women throughout the entire scalp. This pattern was not specific to the right parietal area. Previous work had indicated that right parietal activation at baseline may be associated with enhanced spatial performance, particularly among high ability males (Furst, 1976; Ray et al., 1981). Interestingly, these studies recorded from considerably less sites than the present study, and may have missed the fact that their findings were not specific to the parietal area, but caused by generalized activation at baseline. Furthermore, the present study did not screen for either spatial ability prior to spatial testing and right parietal activation at baseline may be associated specifically with high ability males. Because the current study relied on randomized sampling, and did not focus on high ability males or females, this may have caused the lack of baseline findings specific to the right parietal area or it may be that males just have naturally lower power values at baseline. As mentioned earlier, Corsi-Cabrera and her colleagues (Arce, Ramos, Guevara, & Corsi-Cabrera, 1995; Corsi-Cabrera et al., 1993) have also found that men exhibit generally lower alpha power values than women in a baseline state. These data, along with the present findings, indicate that both high spatial ability men and adult men who have not been chosen on the basis of spatial ability have lower alpha band power values (at 10.5 - 13.5 Hz) than females at a baseline state.

Consistent with previous literature suggesting that children younger than 11-12 years of age exhibited no sex differences in alpha power, no sex difference between boys and girls was hypothesized in the baseline condition. Supporting this hypothesis, there was no difference between girls' and boys' power values in the baseline condition. Also in the baseline condition, children exhibited higher power values than adults throughout all regions of the scalp. There are three different explanations for why this may have occurred. First, because the eight-year-olds have not finished growing, it may be that their skulls are much thinner than the adults' skulls, resulting in more activity being transmitted to the recording sites. Secondly, the brain of an eight year old may still be "pruning" toward adult-like levels. Finally, it may be that generally higher power values are seen throughout the entire scalp of the eight-year-old because the brain is not as specialized as the adult brain, and the higher power values are the result of generally less specialized, less efficient brain (Thatcher, 1997).

Task EEG Covaried for Baseline EEG

It was hypothesized that, for male and female college students, as well as for boys and girls, there would be greater EEG activation of the parietal area (10.5-13.5 Hz) during mental rotation task performance. In addition, it was hypothesized that there would be a sex by age interaction in the mental rotation task EEG data at the parietal scalp locations. Within the college students, it was hypothesized that there would be task EEG differences between men and women with men exhibiting more right parietal activation at 10.5-13.5 Hz than women. Within the eight-year-old group, it was hypothesized that there would be no task EEG differences between boys and girls at any recording site.

In order to assure that the age and sex effects found during task performance were specific to task performance, and not due to the influence of the sex difference in the baseline EEG measures, a MANCOVA was used to control for baseline EEG power values. Likewise, in order to ensure that the effects found during the mental rotation task were specific to cognition associated with mental rotation task performance, and not due to generalized effects of cognition, EEG data were collected during a reading task thought to activate the left frontal and central areas.

Before the MANCOVA was performed, regression analyses were performed to assure that the relationship of baseline EEG with mental rotation and reading task EEG did not vary as a level of age, sex, or age X sex interactions. These analyses assured that there were no response-covariate interactions which could have created spurious interactions. Analyses required that a regression equation be performed for each scalp location two times, once using the mental rotation task EEG as the dependent variable and once using reading task EEG as the dependent variable. In both cases the independent variables were baseline power values at each scalp location, age, sex, and age X sex. This resulted in a total of 32 regression equations (16 sites and two tasks) with 96 p values (age, sex, and age X sex for each equation). Of the 96 values, only two reached significance at the .05 level. Statistical calculations established that if 96 independent tests were run on non-significant data, there would be 95.6% likelihood that two would reach significance at the .05 level. Thus, it was concluded that there were no interactions between the either the mental rotation EEG or reading task EEG and the baseline EEG as a function of age, sex, or age X sex.

After the regression analyses were completed the MANCOVA was performed. The within groups independent variables were region (frontal pole, medial frontal, lateral frontal, central, anterior temporal, posterior temporal, parietal, occipital), hemisphere (right, left), and task (mental rotation, reading), and the between groups independent variables were sex and age. The dependent variable was task performance EEG ln power values at 10.5-13.5 Hz, and the covariate was baseline EEG ln power values at 10.5-13.5 Hz. There were main effects for age [$F(1, 19) = 11.315$, $p = .003$] and sex [$F(1, 19) = 6.018$, $p = .024$]. Interactions included region X age X sex [Wilks = .327, approximate $F(7, 13) = 3.828$, $p = .018$], task X age X sex [Wilks = .799, approximate $F(7, 13) = 4.780$, $p = .042$], region X task X hemisphere X age [Wilks = .227, approximate $F(7, 13) = 6.331$, $p = .002$], region X task X hemisphere X sex [Wilks = .377, approximate $F(7, 13) = 3.066$, $p = .039$], and region X task X hemisphere X age X sex [Wilks = .402, approximate $F(7, 13) = 2.757$, $p = .054$].

To examine the interactions among age, sex, region, hemisphere, and task type while controlling for baseline activation, separate MANCOVAs were performed on the EEG power values for each region. For the MANCOVAs done for each region, age and sex were the between subjects factors. Hemisphere and task type were the within subjects factors. The dependent variable was EEG ln power values at 10.5-13.5 Hz and the covariate was baseline EEG ln power values at 10.5-13.5 Hz.

In the cases of significant interactions involving task type, separate MANCOVA tests using mental rotation task covaried with baseline and reading task covaried with baseline were accomplished. The main goal of the reading task was to ensure that the age and sex effects found during the rotation task were specific to rotation, and not due to the influence of general cognition. While the interactions involving task type denote that the two tasks were associated with differential electrical patterns at the scalp locations, performing separate MANCOVAs on the mental rotation EEG and reading EEG allowed for assessment of these interactions. In each of these task-separated MANCOVAs, age and sex were the between subjects factors and hemisphere was the within subjects factor. The dependent variable was EEG ln power values at 10.5-13.5 Hz, and the covariate was baseline EEG ln power values at 10.5-13.5 Hz.

For the <u>frontal pole (Fp1, Fp2)</u> data, there was a main effect for age [$F(1, 33) = 11.322$, $p < .001$], with the college students exhibiting lower EEG power values than the children. Likewise, there was a main effect for task [$F(1, 33) = 17.757$, $p < .001$], with lower power values (more activation) being exhibited during the reading task than during the mental rotation task. There were no other main effects or interactions in the frontal pole data.

For the <u>medial frontal (F3, F4)</u> data, there was a main effect for age [$F(1, 33) = 15.364$, $p < .001$], with the college students exhibiting lower EEG power values than the children. There were no other main effects or interactions in the medial frontal data.

For the <u>lateral frontal (F7, F8)</u> data, there was a main effect for hemisphere [$F(1, 33) = 4.226$, $p = .048$], with the right hemisphere exhibiting lower power values than the left hemisphere. Furthermore, there was a task X hemisphere interaction [Wilks = .643, approximate

$F(1, 33) = 18.316$, $p < .001$]. Further MANCOVA testing revealed that the task X hemisphere interaction was driven by the mental rotation task condition. During the mental rotation task the right lateral frontal area exhibited lower power values (more activation) than the left lateral frontal area [$F(1, 33) = 17.724$, $p < .001$], while during reading task there was no difference between the left and right lateral frontal power values [$F(1, 33) = 1.001$, $p = .324$]. Furthermore, participants exhibited lower power values (more activation) in left lateral frontal area during the reading task than during the mental rotation task [$t(38) = 4.098$, $p < .001$], but there was no difference between the reading and mental rotation tasks at the right lateral frontal area task [$t(38) = .904$, $p = .372$].

For the <u>central (C3, C4)</u> data, there was a main effect for age [$F(1, 33) = 20.987$, $p < .001$], with the college students exhibiting lower EEG power values than the children. Likewise, there was a main effect for sex [$F(1, 33) = 5.072$, $p = .031$], with male participants exhibiting lower EEG power values (more activation) than female participants.

For the <u>anterior temporal (T3, T4)</u> data, there was a main effect for age [$F(1, 33) = 6.263$, $p = .017$], with the college students exhibiting lower EEG power values than the children. Likewise, there was a main effect for hemisphere [$F(1, 33) = 8.231$, $p = .007$], with the right hemisphere exhibiting lower power values than the left hemisphere. Also, there was a main effect for task [$F(1, 33) = 22.252$, $p < .001$], with the reading task exhibiting lower EEG power values (more activation) than rotation task. Finally, there was a task X hemisphere interaction [Wilks = .796, approximate $F(1, 33) = 8.451$, $p = .006$].

Further MANCOVA testing revealed that task X hemisphere interaction was driven by the mental rotation task condition. During the mental rotation task the right anterior temporal area exhibited lower power values (more activation) than the left anterior temporal area [$F(1, 33) = 14.405$, $p = .001$], while during the reading task there was no difference between the left and right hemisphere anterior temporal power values [$F(1, 33) = .059$, $p = .810$]. Furthermore, participants exhibited lower power values (more activation) in left anterior temporal area during the reading task than during the mental rotation task [t (38) = 4.982, p < .001], but there was no difference between the reading and mental rotation tasks at the right anterior temporal area task [t (38) = 1.493, p = .144].

For the posterior temporal (T5, T6) data, there was a main effect for age [F(1, 33) = 27.544, p < .001], with the college students exhibiting lower EEG power values than the children. Likewise, there was a main effect for sex [F(1, 33) = 7.015, p = .012], with male participants exhibiting lower EEG power values (more activation) than female participants. Interactions included task X hemisphere X age [F(1, 33) = 10.215, p = .003], task X hemisphere X sex [F(1, 33) = 16.850 p < .001], and task X age X sex X hemisphere [F(1, 33) = 19.748, p < .001].

Further MANCOVA testing revealed that the posterior temporal task X age X sex X hemisphere interaction was driven by the mental rotation task condition (see figure 4). Within the mental rotation task condition, there were significant interactions for hemisphere X age [F(1, 33) = 4.316, p = .046], hemisphere X sex [F(1, 33) = 10.776, p = .002], and age X sex X hemisphere [F(1, 33) = 10.062, p = .003]. Post hoc analyses revealed that these interactions were driven specifically by men having lower left [t (18) = -2.67, p < .01] than right posterior temporal power values (indicating greater left activation), while women's', boys', and girls' left and right posterior temporal power values did not differ. Within the reading task condition, however, there were no significant hemisphere X age, hemisphere X sex, or age X sex X hemisphere interactions.

For the parietal (P3, P4) data, there was a main effect for age [F(1, 33) = 16.178, p < .001], with the college students exhibiting lower EEG power values than the children. Likewise, there was a main effect for sex [F(1, 33) = 6.023, p = .020], with male participants exhibiting lower EEG power values (more activation) than female participants. Furthermore, interactions included a hemisphere X sex [F(1, 33) = 4.608, p = .039] and a task X age X sex X hemisphere [F(1, 33) = 6.367, p = .017].

Further MANCOVA testing revealed that the parietal task X age X sex X hemisphere interactions were driven by the mental rotation task condition. Within the mental rotation task condition, there were significant interactions for hemisphere X sex [F(1, 33) = 8.176, p = .007] and age X sex X hemisphere [F(1, 33) = 4.529, p = .041] (see figure 5). Post hoc analyses revealed that these interactions were driven specifically by men having lower left [t (18) = -1.91, p < .05] than right parietal power values (indicating greater left activation), while women's, boys', and girls' left and right parietal power values did not differ. Within the reading task condition there were no significant hemisphere X age, hemisphere X sex, or age X sex X hemisphere interactions.

For the <u>occipital (O1, O2)</u> data, there was a main effect for age [F(1, 33) = 9.363, p = .004], with the college students exhibiting lower EEG power values than the children. Likewise, there was a main effect for sex [F(1, 33) = 5.719, p = .023], with male participants exhibiting lower EEG power values (more activation) than female participants. Also, there was task X age interaction [F(1, 33) = 7.423, p = .010], Furthermore, there was a task X sex X hemisphere interaction [F(1, 33) = 8.220, p = .007].

Further MANCOVA testing revealed that the occipital task X sex X hemisphere interaction was driven by the mental rotation task condition. Within the mental rotation task condition, there was a significant interaction for sex X hemisphere [F(1, 33) = 10.776, p = .002] (see figure 6). Post hoc analyses revealed that these interactions were driven by males having lower left [t (37) = 3.82, p < .001] occipital power values than females (indicating greater left activation), while male and female right occipital power values did not differ. Within the reading task condition there were no significant hemisphere X age, sex X hemisphere, or hemisphere X age X sex interactions.

Summary and discussion of task EEG. In all regions *except* the lateral frontal region there was a main effect for age, with the college students exhibiting lower EEG power values than the children. In the posterior temporal, parietal, and occipital regions there was a main effect for sex, with male participants exhibiting lower EEG power values (more activation) than female participants.

During the mental rotation task the right lateral frontal and right anterior temporal regions exhibited lower EEG power values (more activation) throughout all participants. Also, among adult males, the left posterior temporal and left parietal areas of the scalp were activated specifically by the mental rotation task. Finally, male participants exhibited lower left occipital power values than female participants during the mental rotation task.

The MANCOVA with task EEG as the dependent measure and baseline EEG as the covariate assured that findings from the task EEG were specific to mental rotation task performance, and not a product of baseline activation or general cognition.

Post-Hoc Analyses of Extra Curricular Spatial Activities and Spatial Performance

In order to investigate whether males and females were differentially involved in activities that may have improved performance on the spatial task, analysis was performed on answers to a questionnaire that the participants were given during their lab visit. Specifically, this questionnaire assessed the type of sports and computer activities the participants had performed, as well as the amount of time spent on these activities (for details, see Appendices F & G), similar to the assessments made by Baenninger and Newcombe, 1989)

Adults. There were no differences between men and women on their reported total number of hours spent per week playing computer games [$F(1, 18) = 3.039$, $p = .098$]. Likewise, there were no differences between men and women on their reported total number of spatial activities that they had been involved in [$F(1, 18) = 2.647$, $p = .121$], total number of hours spent per week playing sports [F(1, 18) = 1.835, p = .192], or of the total number of hours spent playing Tetris in their lifetime [F(1, 18) = .692, p = .416] (see table 3).

Children. There were no differences between boys and girls on their reported total number of hours spent per week playing computer games [F(1, 18) = .269 , p = .611]. Likewise, there were no differences between boys and girls on their reported total number of spatial activities that they had been involved in [F(1, 18) = .252, p = .636], total number of hours spent per week playing sports [F(1, 18) = .452, p = .511], or of the total number of hours spent playing Tetris in their lifetime [F(1, 19) = 1.238 = .611] (see table 4).

General Discussion

This study was designed to examine the relations among mental rotation ability, sex, and EEG activation within two different age groups: 8-year-olds and college students. In order to assess these relations, both age groups had EEG recordings accomplished in a baseline state, during a computerized mental rotation task, and during a computerized reading task. While the EEG recordings during baseline and during the mental rotation task were of greatest interest, the recordings during the reading task were important because they allowed for assurance that findings during the mental rotation task were specific to mental rotation performance, and not just general cognition.

Behavior

Researchers have indicated that a male advantage on mental rotation tasks is most evident after puberty (Linn & Petersen, 1985; Voyer et al., 1995). One explanation of such findings is that circulating body hormones, particularly testosterone, contribute to facilitated performance on spatial tasks (Janowsky et al., 1994; Van Goozen et al., 1994, 1995). Consistent with this literature, the current hypothesis was that, among college students, males would outperform females on computerized mental rotation task performance, but among the eight-year-olds, there would be no sex difference on the task. In the present study, boys and girls did not differ on either number correct or reaction time on the mental rotation task. While men and women did not significantly differ on the number correct on the mental rotation task, males did respond faster than females at the 180° rotation condition. It should be noted that the adult male advantage in reaction time on the mental rotation task was due to rotation ability, and not just a general reaction time quickness. After partialling out reaction time at 0° men were still faster at the 180° rotation condition, the condition in which the greatest amount of rotation is required. Using this same gingerbread man task, Epting and Overman (1998) also found that sex difference were significant only in the 180° rotation condition.

These data supported the hypothesis that adults, but not children, would exhibit sex differences on the mental rotation task. While these results could be due to biological or hormonal influences, some researchers would argue that they are the result of spatial experience. Specifically, Baenninger and Newcombe (1989) present a compelling argument that there is a relation between spatial activity participation and increased spatial ability regardless of sex. In order to test for such differences in spatial experience, both males and females were given open-ended questionnaires about their participation in sports and computerized spatial activities. From these questionnaires, the number of spatial activities in which each participant had participated (from the list complied by Baenninger & Newcombe, 1989), as well the number of hours per week spent playing sports, was computed. Additionally, the total number of hours each subject had spent playing Tetris, a popular computerized 2-dimensional rotation game, was also computed. In the present sample, there were no sex differences on the total number of spatial activities, the total hours spent playing sports per week, or the total number of hours playing Tetris for both children and adults. It should be noted that there appeared to be mean differences in these data, particularly in the adult sample. However, as can be seen in the standard deviations, there was considerable variance in these data. While the means appeared to be different, they did not reach significance because the means were greatly affected by a few outliers, not necessarily by differences between the two groups. Though not conclusive, these data would indicate that while spatial experience may lead to enhanced performance on spatial tasks, at least within the present sample, biological (and not experiential) differences may be driving the sex difference in reaction time within the adults.

EEG

If, in fact, there are biological differences between men and women which contribute to a sex difference on mental rotation tasks, there may be brain activation differences during baseline as well as during task performance. In order to assess possible brain differences between males and females, EEG recordings were performed during a baseline condition and during the computerized mental rotation task. Much of the adult literature using spatial tasks (e.g. Davidson et al, 1990) has used the traditional alpha (8-13 Hz) alpha band. Recent research has indicated that that traditional alpha (8-13 Hz) may be divided into a low frequency band (7.5-10.5 Hz), which has been related to states of alertness and mood, and high frequency band (10.5-13.5 Hz), which has been related to higher cognitive functions (Crawford, Clark, & Kitner-Triolo, 1996; Klimesch, 1996). Because both the mental rotation task and the reading task involved higher cognitive functioning, the high rhythmic band was chosen for analyses. The present findings support the hypothesis that higher cognitive functioning is associated with the high frequency band (10.5-13.5 Hz). However, researchers such as West and Bell (1997) found age related Stroop-task EEG differences at 8 -10 Hz, suggesting that some types of cognition may be associated with this low rhythmic component of the alpha band.

Consistent with previous literature, it was hypothesized that college-age men would exhibit generally lower high alpha power values during baseline, while eight-year-old boys' and girls' high alpha power values would not differ. This hypothesis was supported. Within children, longitudinal and cross-sectional studies have suggested that while there is a great deal of interindividual variability in baseline EEG alpha band, there do not appear to be sex differences before 11-12 years of age (Benninger et al., 1984; Gasser et al., 1988; Matsuura et al., 1985). Within adults, however, research indicates that men exhibit lower EEG power than men both during baseline measures (Arce et al., 1995; Benninger et al., 1984; Gasser et al., 1988; Matsuura et al., 1985).

Likewise, it was hypothesized that men would exhibit lower right parietal EEG power values than women during mental rotation task performance, but that boys' and girls' right parietal power values during mental rotation task performance than would not differ. As noted, the results of the EEG analysis did not support these hypotheses, as men exhibited left parietal activation during the mental rotation task.

It is generally accepted in brain research that the parietal (and particularly the right parietal) area is responsible for spatial tasks. For example, studies by Ratliff (1979), Dittuno and Mann (1990), and Vingerhoets et al. (1996) have all found that damage to the right parietal area affects performance on mental rotation tasks more than damage to either the left parietal or frontal areas. Likewise, EEG, ERP, and rCBF studies have all found that rotation of 3-dimensional block-type complex stimuli produce activation in the right parietal area (e.g. Berfield et al. (1986); Michel et al. (1994); Papanicoloueau et al. (1987)).

However, there is in the literature a suggestion that rotation of simple stimuli can lead to activation of the left parietal area. In a PET study performed by Alivisatos and Petrides (1997), participants were required to discriminate whether alphanumeric stimuli were "normal" or "mirror image" at various angles. While the task required mental rotation, the stimuli were simple rather than complex, resulting in a "simpler" rotation task. The task elicited activation of the left parietal and right frontal areas. In the present study while rotating the "gingerbread men", all subjects exhibited activation in the right frontal area, while only the college-age men exhibited activation in the left parietal area. Because all of the participants in the Alivisatos and Petrides (1997) study were male, the present study replicates their findings left parietal and right frontal activation. Finally, Fischer & Pellegrino (1988) found a left hemisphere advantage for the rotation of both alphanumeric characters and figures from the Primary Mental Abilities test. In that study, participants were presented with figures and had to decide if they were identical to, or mirror images of, a centrally presented figure. Participants were significantly faster when the stimuli were presented in the right visual field, indicating a left hemisphere advantage for the task. It could be argued, then, that the use of simple stimuli, or a simple task, would result in left hemisphere activation. If it were the case that simple (or alphanumeric) stimuli lead to activation of the left parietal area, then one would have to conclude that this would be for both sexes. The results of the present study, however, suggest that a simple 2-dimensional rotation task leads to left parietal activation for adult males.

It may be the case, then, that adult male left parietal activation during the present mental rotation task is the result of using a simple, rather than a more complex, rotation task. Conversely, in the adult females, the lack of activation in the left parietal lobe could be the result of <u>more</u> use of the right parietal area, which would be indicative of a more complex rotation task. Each of these statements fits with the reaction time data. Adult males had faster reaction times, and activation patterns that are more indicative of a simple rotation task. Females had slower reaction times and exhibited brain patterns that are indicative of a more difficult type of rotation task. The end result, then, could be that males and females were actually performing two different types of tasks. For the males, the task was somewhat easier and did not require the use of the limited resources of the right posterior region of the brain, while for females, the lack of left hemisphere activation (and the presence of right hemisphere activation), suggests that the posterior right region of the brain is needed to perform what was perceived to be a difficult rotation task.

The behavioral and EEG results taken together suggest that there may a biological difference between males and females on the mental rotation task. This sex difference was absent among the eight-year-old children on both the rotation task and the EEG measures, suggesting that there is some process occurring between childhood and adulthood which is contributing to these differences. One possible explanation of the behavioral and EEG differences could lie in brain plasticity, with a malleable brain forming to the needs of the body. For example, as male children begin to differentially participate in activities which require the use of spatial skills, their brains may become adapted to the tasks, and specialization to spatial tasks may occur within the brain. However, in the present study there were no differences in spatial activity experience between males and females, suggesting that these differences were not entirely the cause of spatial activity experience. Another explanation for the differences in rotation task ability and EEG could be the onset of puberty and the resulting hormonal changes (e.g. Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Silverman & Phillips, 1993; Van Goozen, Cohen-Kettenis, Gooren, Fridja, & Van de Poll, 1994,1995). The body of evidence to suggest that hormonal factors influence spatial abilities is growing, and this “natural” manipulation of hormones should add to the evidence of the hormonal influences on spatial ability.

Future Research

Directly leading from the present study are two research ideas. First, a within subjects study is needed to test the hypothesis that simple rotation leads to left parietal activation while complex rotation leads to right parietal activation. While this idea has face validity, all of the research comparisons have been post-hoc and not only between subjects, but between studies. Such a study could support the hypothesis that males and females are using different areas of the brain because of the differential difficulty of the task.

An issue with the present study is that hormonal level is inferred from age, not measured. Between the two age groups used in the current study (8-year-olds and college students), however, the measurement of hormones would probably not be very useful. According to the literature, it is highly likely that the eight-year-old males and females have very similar levels of hormones (Stahl, Gotz, Poppe, Amendt, & Dorner, 1978), while the male and female college students have hormone levels that are characteristic of adult levels. Instead of inferring (or even measuring) hormones, it would be advantageous for animal research to be done to manipulate the circulating hormone levels. The use of animal subjects would allow for both a between and within subjects design to test for spatial abilities corresponding with circulating hormone levels.

Conclusion

This study contributes to the literature in two ways. To begin with, this is the first study to directly compare the mental rotation task performance and EEG recordings among both children and adults. By using a task which could be performed by both children and adults, it allowed for comparison of EEG recordings between children and adults.

Second and more importantly, the present study made use of the baseline EEG data as a covariant in examining task EEG. By covarying for baseline data both for mental rotation-related and reading-related EEG analysis, any observed activation effects were specific to the tasks which were being performed.

In conclusion, the results from this study suggest that age and sex behavioral and EEG differences on a mental rotation task may be the result of some biological difference between childhood and adulthood. That difference may be hormonal, with the physiological changes associated with biological maturation affecting performance on spatial tasks.

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Table 1

Effect Sizes for Sex Differences in Spatial Abilities as a Function of Category of Test

Category of test	N	Weighted Estimator of Effect Size	Test of Significance for Effect Size (Z)
Mental rotation	78	0.56	4.63*
Spatial perception	92	0.44	2.25*
Spatial visualization	116	0.19	1.43

*$p<.05$

Note. From a meta-analysis of sex differences in spatial abilities by Voyer, Voyer, & Bryden (1995, Table 4, p. 258).

Table 2

Number of Studies Favoring Each Gender as a Function of Category of Test

Category of Test	Favor Males	No Gender Diff	Favor Females	Total
Mental rotation	34	16	0	50
Spatial perception	40	18	0	58
Spatial visualization	38	41	3	82

Note. Summary of Tables 1, 2, and 3 from a meta-analysis of sex differences in spatial abilities by Voyer, Voyer, & Bryden (1995). Includes only studies not reported in a meta-analysis by Linn and Petersen (1985).

Table 3

Means (and SD's) of Adult's Self-Reported Spatial Experience Questionnaire

Spatial Category	Men	Women
Hours Per Week Playing Sports	5.60 (6.34)	2.70 (2.37)
Number of Different Spatial Activities	2.00 (.67)	1.50 (.70)
Hours Per Week Playing Computer Games	2.55 (3.51)	.55 (.92)
Total Tetris Hours	49.00 (48.47)	28.55 (60.78)

Note: all p's > .05.

Table 4

Means (and SD's) of Children's Self-Reported Spatial Experience Questionnaire

Spatial Category	Boys	Girls
Hours Per Week Playing Sports	2.42 (1.20)	3.08 (2.83)
Number of Different Spatial Activities	2.10 (.99)	2.33 (1.12)
Hours Per Week Playing Computer Games	1.72 (1.98)	2.51 (4.34)
Total Tetris Hours	2.02 (4.67)	.28 (.44)

Note: all p's > .05.

Figure Captions

Figure 1. Samples of the Overman Mental Rotation task in conditions rotated 90° to the left, 90° to the right, and 180°.

Figure 2. Correct Responses on Mental Rotation Task

Figure 3. Reaction Time on Correct Trials of the Mental Rotation Task

Figure 4. Mental Rotation Task Covaried with Baseline: Posterior Temporal Age X Sex X Hemisphere Interaction

Figure 5. Mental Rotation Task Covaried with Baseline: Parietal Age X Sex X Hemisphere Interaction

Figure 6. Mental Rotation Task Covaried With Baseline: Occipital Region Sex X Hemisphere Interaction

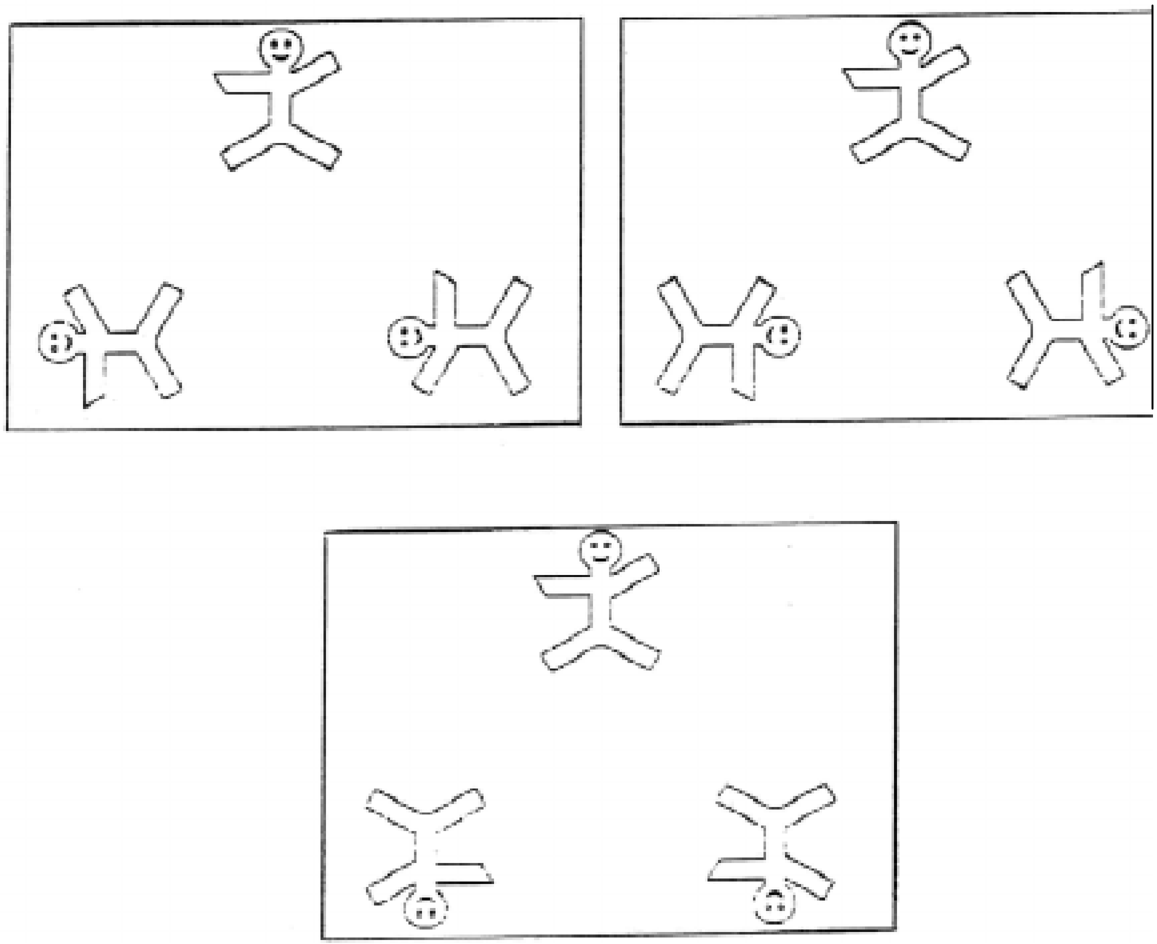

Figure 1.
Samples of the Overman Mental Rotation task in conditions rotated 90° to the left, 90° to the right, and 180°

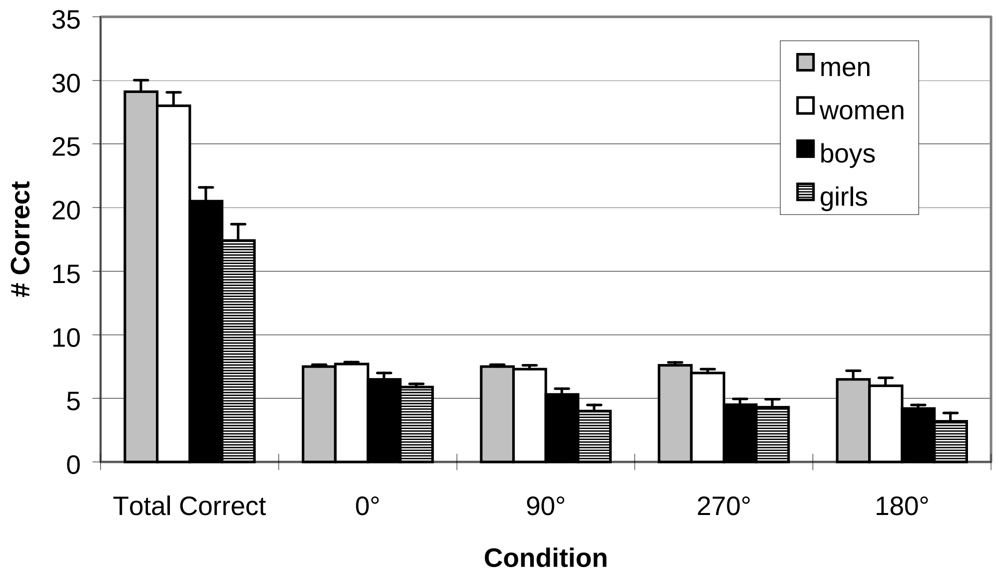

Figure 2.
Correct Responses on Mental Rotation Task

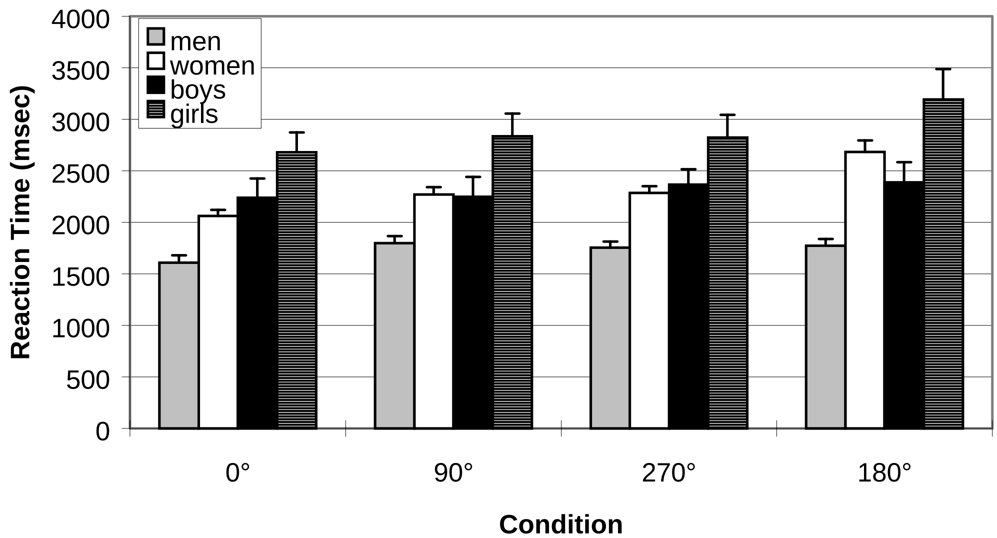

Figure 3.
Reaction Time on Correct Trials of the Mental Rotation Task

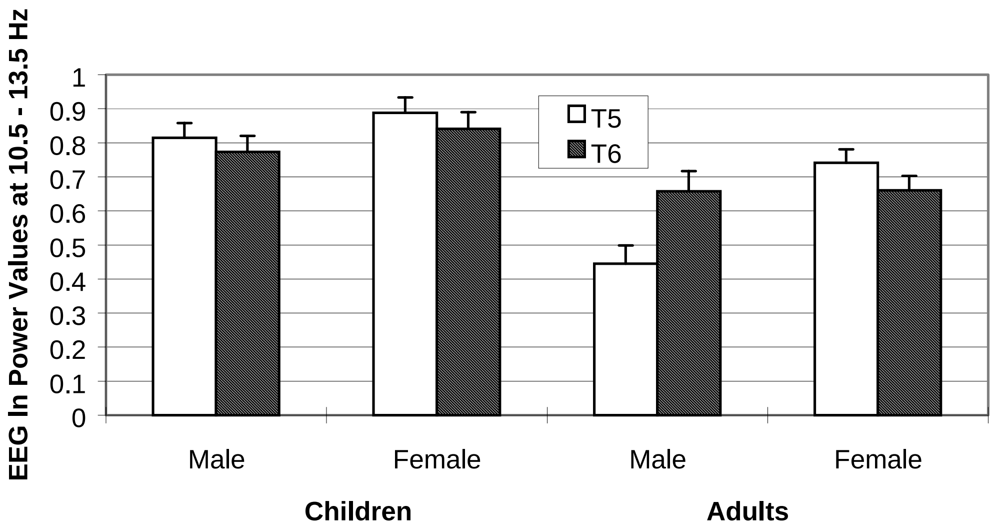

Figure 4.
Mental Rotation Task Covaried with Baseline
Posterior Temporal Age X Sex X Hemisphere Interaction

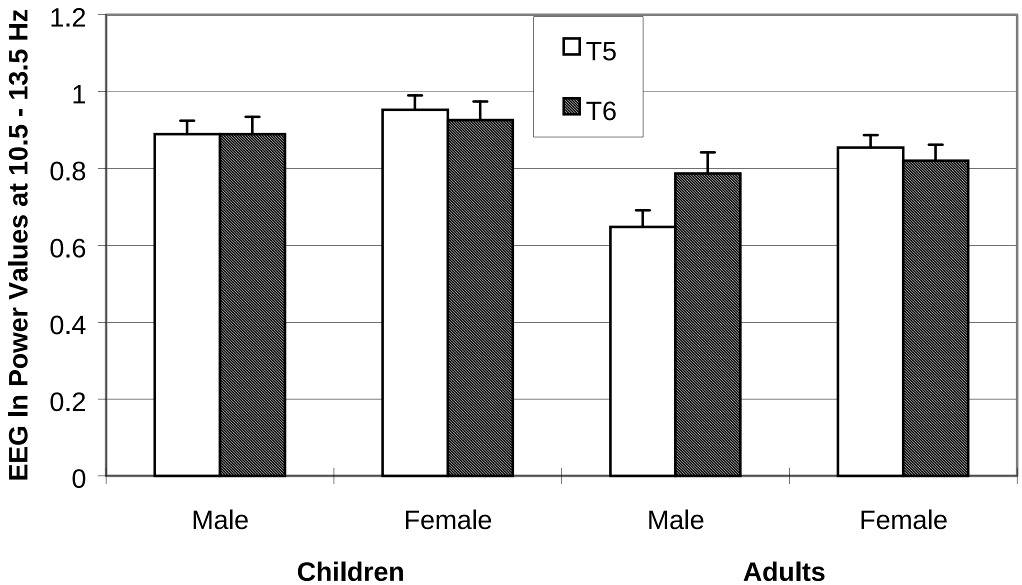

Figure 5.
Mental Rotation Task Covaried with Baseline
Parietal Age X Sex X Hemisphere Interaction

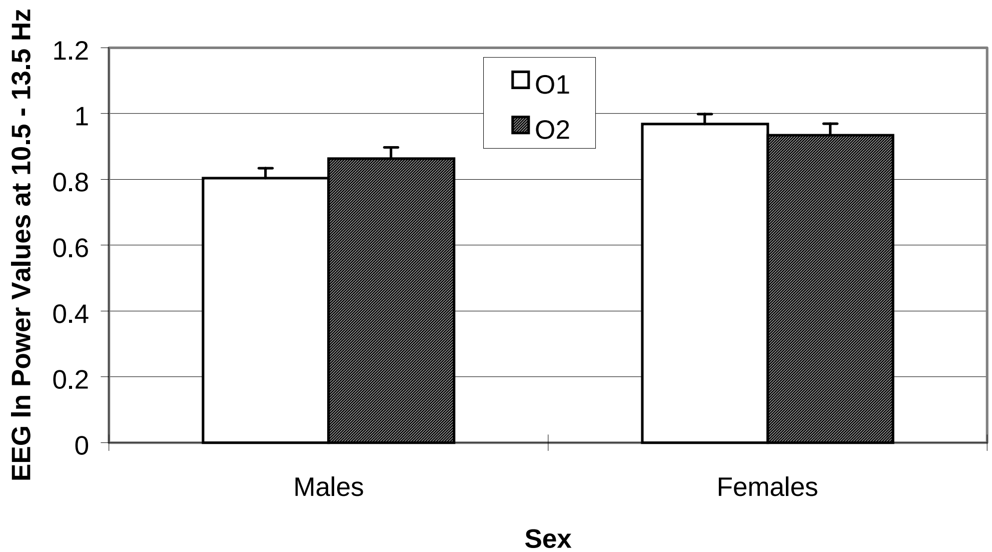

Figure 6.
Mental Rotation Task Covaried With Baseline Occipital Region Sex X Hemiphere Interaction

Appendix A

Edinburgh Inventory for Handedness

EDINBURGH HANDEDNESS INVENTORY

Surname ____________ Given Names ____________

Date of Birth ____________ Sex ____________

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put* ++. If in any case you are really indifferent *put* + *in both columns*.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

Appendix B

Neurological Questionnaire

1) Have you ever had a concussion or lost consciousness as the result of a blow to the head?

2) Did you go under general anesthesia before one year of age?

3) Have you been diagnosed for ADD or ADHD?

4) Are you currently taking any Medications?

If so, what type?

5) Have you ever experienced a seizure?

6) How many drinks of coffee, tea, or cola have you had today?

Appendix C
For College Students

VIRGINIA POLYTECHNIC AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: "Mental Rotation Ability Related to Age and EEG Power Values"
Investigator: Jonathan Roberts
Faculty Advisor: Martha Ann Bell, PhD.

I. Purpose of this Research

You have been invited to participate in a research project investigating the development of spatial skills. Specifically, we are examining how brain-wave activity and age are related to the ability to "mentally rotate" objects.

II. Procedures

This study involves a 45-minute visit to the Developmental Cognitive Neuroscience Section (Derring 5076-F) of the Development Labs at Virginia Tech. This study involves 3 Questionnaires (Handedness Questionnaire, Body-Type Questionnaire, and Neurological Questionnaire) that will be completed in our research lab. It will take approximately 15 minutes to complete these 3 questionnaires.

First, we will ask you for your informed consent that details information concerning the questionnaires and the visit you will make to our research lab. Then you will fill out the three questionnaires mentioned above.

Next, you will have a cap that helps us collect brain-wave activity placed on your head. The cap looks and fits like a swim cap. In order to collect brain-wave activity, gel will be applied to your head through little holes in the cap. In addition, we will be placing two small stickers near one eye to monitor eye movements and one small sticker on the back to ensure high quality brain-wave activity recording. These procedures are similar to ones used in a doctor's office and will cause no harm. While brain-wave activity is being recorded you will be asked to sit quietly with your eyes closed for one minute and then to sit quietly with your eyes open for one minute. Brain wave activity will also be recorded while playing a game on a computer. The game that you will play is a matching game where you are asked to tell which two figures look alike. This game takes about 5-7 minutes to play. After the game with the figures, we will ask you to read a paragraph and answer four questions about that paragraph. After this procedure, the cap and sticky patches will be removed and the gel will be washed from your head with warm water and a wash cloth.

III. Risks

There is minimal risk associated with this research project. The brain-wave procedures are similar to that done in a doctor's office and are not harmful. The researcher who will apply the brain-wave cap will wear disposable latex gloves. The EEG gel could cause an allergic reaction, but the chance of this is extremely rare. Other researchers in our laboratory have used Omni-Prep over 500 infants, children, and adults and none have had a reaction to the gel. In the rare chance that a reaction does occur, the skin will be cleansed with rubbing alcohol, the company manufacturing the gel will be called immediately, and the Chair of the Virginia Tech Institutional Review Board will be notified.

IV. Benefits of this Research

There are no tangible benefits to you. No promise or guarantee of benefits have been made to encourage you to participate in this study. In a scientific sense, however, this research study will give developmental specialists more information about the development of particular brain areas and the corresponding correlation with problem solving abilities.

V. Extent of Confidentiality

Information gathered for this study will be confidential and the information from each individual will be identified by code number only. We will not ask for social security numbers. Only the code number will be entered into the computer with data from your visit. Information linking name and code number will be kept in a file drawer and locked. Only Jonathan Roberts and Dr. Martha Ann Bell will have access to the card file.

VI. Compensation

You will be given extra credit in your psychology class for participation in this study.

VII. Freedom to Withdraw

You may withdraw from participation in this lab visit at any time without penalty. You will still receive the extra credit in your psychology class.

VIII. Approval of Research

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at VPI&SU and by the Department of Psychology at Virginia Tech.

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I will be asked to have EEG recording equipment applied. I will also be asked to sit quietly for one minute with my eyes open and one minute with my closed. I will play the computer game to the best of my ability.

X. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdrawal at any time without penalty. I agree to abide by the rules of this project.

_______________________________ _______________
Signature Date

Should I have any questions about this study, I may contact:

___________________________________	231-2320
Jonathan Roberts	Office Phone
Investigator	
___________________________________	231-2546
Martha Ann Bell, PhD	Office Phone
Faculty Advisor	
___________________________________	231-6581
R.J. Harvey, PhD	Office Phone
Chair, Psychology Ethics Committee	
___________________________________	231-5281
Tom Hurd, Chair	Phone
IRB Research Division	

Appendix D
For Eight-Year-Olds

VIRGINIA POLYTECHNIC AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: "Mental Rotation Ability Related to Age and EEG Power Values"
Investigator: Jonathan Roberts
Faculty Advisor: Martha Ann Bell, PhD.

I. Purpose of this Research

You are going to get to help us with a research project about the way brain waves are related to the way you play games.

II. Procedures

First, you will have a cap that looks like a swim cap put on your head. Then, we will put some gel through some little holes that are on the cap. This allows us to measure your brain waves. After that, you will be asked to sit quietly and still for one minute with your eyes closed and one minute with your eyes open. Then, you will play one game on a computer, and then read a paragraph and answer four questions about that paragraph. Finally, we will wash the gel off your head.

III. Risks

We are going to get some gel in your hair, but we will wash it out when you are done playing the games.

IV. Benefits of this Research

You will get to help us understand the way that different brain waves are related to the different ways that people think.

V. Extent of Confidentiality

We won't use your name when we report the results of this study.

VI. Compensation

We will give you a trip to a treasure chest of small prizes.

VII. Freedom to Withdraw

We don't think you will, but if you really feel like you don't want to do this anymore then you don't have to.

VIII. Approval of Research

Virginia Tech approved this project.

IX. Participant's Responsibilities

We will ask you to sit still with your eyes open for one minute and closed for one minute. Also, we will ask you to play a game on the computer for us.

X. Participant's Permission

I have read and understand this form. I have asked any questions that I have had, and I agree to participate in this experiment. I understand that I can quit at any time I want and I won't be penalized. I understand that I will get a copy of this form.

______________________________ ______________

Signature Date

Should I have any questions about this study, I may contact:

__________________________________ 231-2320

Jonathan Roberts Office Phone

Investigator

__________________________________ 231-2546

Martha Ann Bell, PhD Office Phone

Faculty Advisor

__________________________________ 231-6581

R.J. Harvey, PhD Office Phone

Chair, Psychology Ethics Committee

__________________________________ 231-5281

Tom Hurd, Chair Phone

IRB Research Division

Appendix E
For Parents of Eight-Year-Olds

VIRGINIA POLYTECHNIC AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: “Mental Rotation Ability Related to Age and EEG Power Values”
Investigator: Jonathan Roberts
Faculty Advisor: Martha Ann Bell, PhD.

I. Purpose of this Research

You and your child have been invited to participate in a research project investigating the development of spatial skills. Specifically, we are examining how brain-wave activity and age are related to the ability to “mentally rotate” objects.

II. Procedures

This study involves a 45-minute visit to the Developmental Cognitive Neuroscience Section (Derring 5076-F) of the Development Labs at Virginia Tech. This study involves 3 Questionnaires (Handedness Questionnaire, Body-Type Questionnaire, and Neurological Questionnaire) that will be completed in our research lab. The handedness questionnaire and the neurological questionnaire will have already been given to you over the phone.

Upon arriving at the laboratory, will ask you for your informed consent that details information concerning the questionnaires and the visit you and your child will make to our research lab. Then we will ask you to fill out the Body-Type questionnaire mentioned above.

Next, you child will have a cap that helps us collect brain-wave activity placed on his/her head. The cap looks and fits like a swim cap. In order to collect brain-wave activity, gel will be applied to your child’s head through little holes in the cap. In addition, we will be placing two small stickers near one eye to monitor eye movements and one small sticker on the back to ensure high quality brain-wave activity recording. These procedures are similar to ones used in a doctor’s office and will cause no harm. While brain-wave activity is being recorded your child will be asked to sit quietly with his/her eyes closed for one minute and then to sit quietly with their eyes open for one minute. Brain wave activity will also be recorded while they are playing a game on a computer. The game that your child will play is a matching game where they are asked to tell which two figures look alike. This game takes about 5-7 minutes to play. After the figures game, your child will read a paragraph and answer four questions about that paragraph. After this procedure, the cap and sticky patches will be removed and the gel will be washed from your head with warm water and a wash cloth.

III. Risks

There is minimal risk associated with this research project. The brain-wave procedures are similar to that done in a doctor's office and are not harmful. The researcher who will apply the brain-wave cap will wear disposable latex gloves. The EEG gel could cause an allergic reaction, but the chance of this is extremely rare. Other researchers in our laboratory have used Omni-Prep over 500 infants, children, and adults and none have had a reaction to the gel. In the rare chance that a reaction does occur, the skin will be cleansed with rubbing alcohol, the company manufacturing the gel will be called immediately, and the Chair of the Virginia Tech Institutional Review Board will be notified.

IV. Benefits of this Research

There are no tangible benefits to you or your child. No promise or guarantee of benefits have been made to encourage you and your child to participate in this study. In a scientific sense, however, this research study will give developmental specialists more information about the development of particular brain areas and the corresponding correlation with problem solving abilities.

V. Extent of Confidentiality

Information gathered for this study will be confidential and the information from each individual will be identified by code number only. We will not ask for social security numbers. Only the code number will be entered into the computer with data from your visit. Information linking name and code number will be kept in a file drawer and locked. Only Jonathan Roberts and Dr. Martha Ann Bell will have access to the card file.

VI. Compensation

You will be not be compensated for your participation in this study. Your child, however, will receive trips to a "treasure chest" of toys.

VII. Freedom to Withdraw

You may withdraw from participation in this lab visit at any time.

VIII. Approval of Research

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at VPI&SU and by the Department of Psychology at Virginia Tech.

IX. Parent's Responsibilities

None.

X. Parent's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for my child to participate in this project. I understand that I may withdrawal at any time without penalty. I understand that I will be given a copy of this consent form.

______________________________ _______________
Signature Date

Should I have any questions about this study, I may contact:

__________________________________	231-2320
Jonathan Roberts Investigator	Office Phone
__________________________________	231-2546
Martha Ann Bell, PhD Faculty Advisor	Office Phone
__________________________________	231-6581
R.J. Harvey, PhD Chair, Psychology Ethics Committee	Office Phone
__________________________________	231-5281
Tom Hurd, Chair Irb Research Division	Phone

Appendix F
For College Students

Sports and Computer Experience Questionnaire

1) Are you currently involved in any organized sports?

If so, please list:____

2) Are there any sports not listed above in which you participate at least once a week?

If so, please list:____

3) About how many hours a week do you spend playing sports?_________

4) Describe your sports background from high school and elementary school.

5) Do you have a computer at your residence (or one that you can use regularly)?

If so, what types of things do you use your computer for?
(please check the appropriate boxes and approximate hours per week spent on each activity)

Word Processing: ________________

Internet / email: ________________

Computer games: ________________

If so, what types of games do you play? _____________

6) About how many hours have you spent playing Tetris (or similar games) ? _________

Appendix G
For Eight-Year-Olds

Sports and Computer Experience Questionnaire

1) Do you play on any sports teams?

If so, please list:____

2) Are there any sports you play at home, at school, or with friends?

If so, please list:____

3) About how many hours a week do you spend playing sports?___________

4) Do you have a computer at home?

If so, what types of things do you use your computer for?
(please check the appropriate boxes and approximate hours per week spent on each activity)

School: ________________

Internet / email: ________________

Computer games: ________________

If so, what types of games do you play? _____________

5) About how many hours have you spent playing Tetris (or similar games) ? __________

Appendix H
Copy of the Reading Task

It was raining outside. Inside, Mother and Oliver were sitting in the big chair, having a hug.

"Tell me a secret," said Oliver.

"All right," said Mother. Mother whispered a secret into Oliver's ear: "We are snug as three bugs in a rug."

"Me too," said Amanda.

"First I have to tell my tiger," said Oliver. Oliver whispered the secret into his tiger's ear: "Three bugs are having a hug."

"Now me," said Amanda. Oliver whispered the secret into Amanda's ear: "Three bugs are on the rug."

Was it raining outside?

Did Oliver tell the same secret to Amanda that Mother told to him?

Were Amanda and Oliver sitting in the big chair, having a hug?

Did Oliver tell the secret to his tiger before he told it to Amanda?

Note: all responses were answered with YES or NO keys

JONATHAN E. ROBERTS

CURRENT ADDRESS:

Office: Department of Psychology
Virginia Polytechnic Institute
and State University
Blacksburg, VA 24061-0436
Phone: (540) 231-2320
email: jorober5@vt.edu

Home: 310 Shenandoah Circle
Blacksburg, VA 24060
Phone: (540) 552-2982

EDUCATION:

M.S. **Psychological Science,** anticipated February 1999
Virginia Polytechnic Institute and State University
Thesis Title:
Gender Differences on a Mental Rotation Task: Variations in Hemispheric Activation Between Children and College Students
Committee Chair: Martha Ann Bell, Ph.D.

University of South Carolina
Completed 1995-1996 year of experimental psychology program
Supervisor: Martha Ann Bell, Ph.D.

B.A. **Psychology,** May 1995
University of North Carolina, Wilmington
Wilmington, NC

UNIVERSITY TEACHING EXPERIENCE:

Instructor:
Psychology of Learning
VPI & SU, Blacksburg, VA
Sole lecturer of 3-hour Psychology of Learning class
Developed academic regimen and course syllabus
Spring, 1999

Instructor:
Cognitive Psychology Laboratory
VPI & SU, Blacksburg, VA
Instructed 2 laboratory sessions of Cognitive Psychology
Developed academic regimen and course syllabus
Fall, 1997; Fall 1998

Instructor:

Introductory Psychology Laboratory
VPI & SU, Blacksburg, VA
Instructed a total of 6 laboratory sections of Introductory Psychology
Developed regimen to follow lecture format
Fall 1996, Spring 1997, Spring 1998

RESEARCH EXPERIENCE:

Graduate Research Assistant/Laboratory Manager
VPI & SU, Blacksburg, VA
M.S. Project Related
- Developed a modified version of the Overman Task of Mental Rotation
- Primary investigator responsible for recruiting 40 participants in research project
- Primary investigator responsible for collecting behavioral and electrophysiological data from college students and 8-year-old children

Laboratory Manager Related
- Trained and supervised a team of undergraduate research assistants for a project based in an infant cognitive development laboratory
- Assisted in setting up new psychophysiological laboratory

Supervisor: Martha Ann Bell, Ph.D.
1996-present

Graduate Research Assistant
University of South Carolina
- Participated in collecting object permanence and electrophysiological data from infants ages 5-11 months
- Received training in editing and analyzing EEG data
- Trained undergraduate research assistants

Supervisor: Martha Ann Bell, Ph.D.
1995-1996

Undergraduate Research Assistant
University of North Carolina at Wilmington
- Conducted delayed non-matching to sample (DNMS) task with human children
- Assisted with construction of materials used in task
- Assisted training others to conduct task

Supervisor: William Overman, Ph.D.
1994-1995

HONORS

- *APS Showcase Poster Presentation*--one of the best posters submitted in content area: "Sex differences on a mental rotation task disappear with computer familiarization." Presented at the American Psychological Society 10th Annual Convention, Washington, DC, May 1998

PROFESSIONAL MEMBERSHIPS:

Student Member of:
American Psychological Society
International Society on Infant Studies
Society for Research in Child Development

PAPERS PRESENTED AT SCIENTIFIC MEETINGS:

Roberts, J.E. Gender Differences on a Mental Rotation Task: Variations Hemispheric Activation Between Children and College Students. Accepted to be presented at the Society for Research in Child Development, Albuquerque, NM, April 1999.

Roberts, J.E., Bell, M.A., & Carlsen, R.M. Sex differences on a mental rotation task disappear with computer familiarization. Presented at the American Psychological Society 10th Annual Convention, Washington, DC, May 1998.

Roberts, J.E., Bell, M.A., Pope, S. Infant displacement and table displacement object search skills in infants 8 & 10 months of age. Presented at the International Conference on Infant Studies, Atlanta, GA, April 1998.

Roberts, J.E. Attention and mood are related to 8- and 10-month olds' performance on the A-not-B task. Presented at the Society for Research in Child Development, Washington, DC, April 1997.