THE RELATIONSHIP BETWEEN GONADAL HORMONES AND THE EMERGENCE OF COGNITIVE SEX DIFFERENCES: YEAR FOUR OF A LONGITUDINAL STUDY

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ABSTRACT

Cognitive sex differences among adults have been consistently acknowledged in the scientific literature. Males typically perform better than females on various tests of spatial abilities. Females typically perform better than males on tests of fine motor dexterity, object and location memory tasks, and tests of verbal fluency. However, data have shown that these sex differences typically do not appear before puberty. There is compelling evidence from adult studies that at least some of these sex specific behaviors are correlated with levels of circulating testosterone, estradiol, and progesterone. The present study is in the 4th year of a longitudinal study in which adolescents were tested in their 7th, 8th, 9th, and now 10th grade years. Adolescents completed six cognitive tasks that have shown sex differences in adults. Performance on these tasks was correlated with circulating levels of estradiol, progesterone, and testosterone and compared with performance in the previous three years.

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Thank you to my family and friends, especially Mr. Steven Klem, for your continuing support, encouragement, and that extra “push” when I needed it. I could not have done this without you.

DEDICATION

This thesis is dedicated to my grandparents, George and Mary Hennick. I would never have made it this far without you.

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INTRODUCTION

There is compelling evidence that cognitive sex differences occur in adults, however, studies have shown that these sex differences do not appear before puberty. These cognitive sex differences include a male advantage on spatial visualization, spatial perception and mental rotation, and a female advantage on fine motor coordination, verbal fluency and object and location memory (Halpern, 1992; Maccoby & Jacklin, 1974). The cause of these sex differences, whether social or biological factors or some combination of the two, has been highly debated. There is evidence that at least some of these cognitive sex specific behaviors are correlated with circulating hormones. Research on this topic has included studies of cognitive sex differences in adults, studies of natural hormone changes, and hormone manipulation studies.

Implications for Sex Differences

For the past 20 years, college bound males have had a Quantitative Scholastic Aptitude Test (SAT) score that is on average 50 points higher than that of college bound females (College Entrance Examination Board and Educational Testing Service, 1996). Despite popular notions that these sex differences have lessened due to the practice of recentering the SAT scores, these scores favor males and the male advantage has not declined in the last 30 years. Anderson (1990) concluded that measures of mathematical ability tend to be strongly correlated with spatial ability. Many of the advanced topics in mathematics such as, geometry, trigonometry and calculus, require spatial skills. When spatial ability is statistically controlled, sex differences in quantitative ability become nonsignificant (Burnette, Lane, & Dratt, 1979). Spatial concepts are necessary in the fields of dentistry, engineering, architecture, and airplane piloting. These are fields in which females are underrepresented. Supportive evidence that some cognitive sex differences exist may aid in the development of sex specific educational, testing, and training techniques.

This study will examine the current literature on cognitive sex differences and test the hypothesis that these differences are correlated with circulating hormones.

Terminology

Spatial ability is a general term used to describe skills that involve representing, transforming, generating, and recalling symbolic, nonlinguistic information (Linn & Peterson, 1985). Spatial tasks can be more specifically categorized into tests of spatial perception, spatial visualization and mental rotation. Spatial perception requires subjects to locate the horizontal or the vertical while ignoring distracting information (Linn & Peterson, 1985). These types of tests include the Rod and Frame Task and the Water Level Task.

Mental rotation is defined as the ability to imagine how objects will appear when they are rotated, how a solid object will appear when unfolded or how a flat object will appear if it is folded (Linn & Peterson, 1985). Examples of these types of tests include the Spatial Relations subtest of the Primary Mental Abilities Test (PMA), the Cards Rotation Test, the Shepard and Metzler Mental Rotation Task and the Ratcliff Mannequin Task.

Spatial visualization refers to complex analytic multi-step processing of spatial information. These tasks may involve the same processes as spatial perception and mental rotation but require multiple problem-solving strategies. (Linn & Peterson, 1985). Examples of these tasks include the Embedded Figures Test, Paper Folding, Paper Form Board, Hidden Figures, and the Block Design from the Wechsler Adult Intelligence Scale (WAIS).

The term verbal ability refers to all of the components of language. It can include verbal or word fluency, associational fluency, oral comprehension, verbal analogies and vocabulary (Halpern, 1992). Examples of tests of verbal abilities include the Word Fluency subtest of the PMA, Figures of Speech, Word Beginnings and Endings, and the Vocabulary, Similarities, and Information subtests of the WAIS.

Evidence of Cognitive Sex Differences

Linn and Peterson (1985) conducted a meta-analysis of the literature on the magnitude, nature, and age of first occurrence of cognitive sex differences. Several different measures of spatial abilities were included in this analysis including the Rod and Frame Test and the Water Level Task to assess spatial perception abilities, the Shepard-Metzler Mental Rotation Test and the Spatial Relations subtest of the PMA to assess mental rotation abilities, and Hidden Figures, Paper Folding, Paper Form Board and Block Design to assess spatial visualization abilities. Large sex differences were found for mental rotation, medium differences for spatial perception and small sex differences for spatial visualization. Effect sizes for spatial perception sex differences were only statistically significant for those over 18 years old. For mental rotation, males outperformed females on at any age where measurement is possible (age 10 or 11). No significant sex differences were found for spatial visualization at any point in the life span. The authors suggest that timing of maturation may be involved with sex differences in spatial ability, but more research with appropriate measures is needed.

Voyer, Voyer, and Bryden (1995) conducted a meta-analysis of the literature on sex differences in different kinds of spatial ability from 1974-1993. This study provided an extension of Linn and Peterson's (1985) findings. Tests of spatial ability used in this analysis included the Cards Rotation Test, the Water Level Test, the Embedded Figures Test, the Rod and Frame Test, Paper Form Board, Paper Folding, and the Block Design subtest of the WAIS. This overall analysis of 286 studies demonstrated that sex differences in spatial abilities favoring males are significant. They found that, on average, males outperformed females by 0.6 standard deviation units on mental rotation tasks, by 0.4 standard deviation units on spatial perception and by 0.2 standard deviation units in spatial visualization tasks. Interestingly, the authors found an increase in the magnitude of sex differences with an increase in age. Participants below age 13 did not show significant sex differences in any of the categories of spatial tests, participants above age 18 always showed sex differences, and those between the ages of 13 and 18 showed significant sex differences in the spatial perception and mental rotation tests.

Waber (1976), proposed a relationship between spatial ability and the timing of pubertal maturation. She hypothesized that the brain becomes more laterally specialized for spatial ability for later maturers than for early maturers. Waber argued that sex differences in mental abilities reflect differences in the organization of cortical function that are related to differential rates of physical maturation. She measured maturation by ratings on the Tanner criteria for staging secondary sexual characteristics. Bodily measures of degree of masculinity or femininity include anthropometric size estimations, examination of the distribution of pubertal hair and body fat, and estimation of total body water (Nyborg, 1983). Early maturers were defined as having scores at least 1 standard deviation below the mean age for their stage of sexual development, and defined as late maturers if their chronological age was at least 1 standard deviation above the mean. Waber used the Word Fluency subtest of the PMA, the Digit Symbol subtest of the Wechsler Intelligence Scale for Children (WISC), and the Color-Naming subtest of the Stroop Color Word test to assess verbal ability. The Block Design subtest of the WISC, the Embedded

Figures test, and the Spatial Abilities subtest of the PMA were used to measure spatial ability. Within individuals, regardless of sex, early maturers scored better on verbal tasks and late maturers scored better on spatial tasks. This laterality hypothesis might explain sex differences in spatial ability since boys mature 1-2 years later than girls, on average.

Nyborg (1983), conducted a literature review on spatial abilities and found trends related to the rate of hormonal change. Spatial ability tests used in Nyborg's analysis included the Rod and Frame test, the Embedded Figures test and Money's Road Map Test for direction sense. In early post-pubescence, physically early maturing adolescents showed higher spatial ability than did late maturing adolescents, regardless of sex. However, after pubescence, spatial ability in the late maturers increased and surpassed that of the early maturers. This increase in spatial ability by the late maturers continued into adulthood. Nyborg proposed the "Optimal Estrogen Range" (OER) Theory. This theory states that there is an optimal range of cerebral estrogen values for the maximal expression of spatial ability. In other words, either too high or too low levels of estrogen minimizes the expression of spatial ability. This theory may be used to explain low spatial ability before puberty and high spatial ability after puberty in late maturing girls, as well as changes in spatial performance during the menstrual cycle.

These studies provide evidence that the hormonal changes that occur during pubescence may play a role in the performance of certain cognitive tasks.

Studies of Natural Hormonal Changes

There is a natural fluctuation of gonadal hormones with age as well as across the menstrual cycle. Several studies have examined the relationship between these fluctuations and cognitive abilities.

Hampson (1990) studied performance on manual coordination, verbal fluency, perceptual speed, and spatial ability in females in different phases of their menstrual cycle. Serum estradiol levels were assayed to ensure that the females were on their self-reported phase. Spatial tasks included the Rod and Frame task, the Embedded Figures task, Paper Folding, and the Minnesota Paper Form Board (MPFB). Perceptual speed and accuracy was measured using the Identical Pictures Test and the Matching Familiar Figures Test. Manual coordination was assessed using the Manual Sequence Box. Females performed significantly better on spatial tasks during the menstrual phase of their cycle when estrogen and progesterone are low. Females performed significantly worse on manual coordination during this same time. Females performed better on manual coordination and verbal fluency during the midluteal phase of their cycle when estrogen and progesterone are high. In a similar study, post-menopausal women performed significantly better on manual sequencing, speed articulation, and perceptual speed tasks when on estrogen replacement therapy than when off estrogen replacement therapy (Kimura & Hampson, 1994). The spatial tasks included the Card Rotations task and the Hidden Patterns test. Speed Articulation was measured by Tongue Twister tasks manual sequencing was measured using the Manual Sequence Box. These tasks appear to be more sensitive to fluctuations in estrogen than the spatial tasks, indicating that the spatial tasks may be more influenced by testosterone levels, however, testosterone levels were not analyzed in these female subjects.

Epting and Overman (1998) found sex differences in the expected direction on visual-spatial tasks and on a manual dexterity task, however, they did not find an effect due to menstrual phase in a within-subject design. Spatial tasks used in this study included a mental rotations task similar to the Ratcliff Manequin Task, the Rod and Frame task, and the Water Level task. Manual dexterity was measured using the Purdue Pegboard and the Finger Tap task.

The study used ovulation detection kits to define menstrual cycle phase. Ovulation kits are more reliable than day count techniques or measuring basal body temperature (BBT), however, they are not as reliable as direct hormonal assays. The authors state that these negative findings do not mean there are no effects of menstrual phase on cognition. This study raises more questions on how hormones influence cognition in humans.

Hier and Crowly (1982) studied spatial ability in a group of males with idiopathic hypogonadotropic hypogonadism. Men with this disorder constitute a rare group in which to examine the effect of androgen deficiency at puberty on the development of human cognitive skills. The androgen levels in these males are similar to those of normal females. Spatial ability was measured using the Block Design subtest of the WAIS, the Embedded Figures test, and Space Relations subtest of the Differential Aptitude Test (DAT). These men exhibited impaired spatial ability in comparison to men with normal gonadal function.

Resnick, Berenbaum, Gottesman, and Bouchard (1986) administered a battery of cognitive tests to females with congenital adrenal hyperplasia (CAH). CAH is an autosomal recessive disorder associated with elevated prenatal adrenal androgen levels. The androgen levels in these females are similar to those of normal males. The Paper Form Board, Hidden Patterns and Paper Folding task were used to measure spatial ability. Mental Rotations and Card Rotations were used to measure spatial orientation. The CAH group of females performed significantly better than normal females on three measures of spatial ability and two measures of spatial orientation. The largest difference score in the two groups was observed in the measurement of three-dimensional mental rotation. These results are consistent with an effect of prenatal hormones on the development of spatial ability.

Hormone Manipulation Studies

Direct manipulation is the ideal way to determine the relationship between hormones and cognitive abilities. However, experiments of this type are rare due to various ethical limitations. Two studies have accomplished this difficult task.

Van Goozen, Cohen-Kettenis, Gooren, and Van de Poll (1995) studied cognitive functions before and after cross-sex hormone treatment in male-to-female and female-to-male transsexuals. Anti-androgen and estrogen treatment was administered to the male-to-female transsexuals and testosterone was administered to the female-to-male transsexuals. The Card Rotations task was used in this study as a measure of spatial ability. Both groups performed consistently with their biological sex on certain cognitive tasks, before treatment. In the male-to-female group, the deprivation of androgens and administration of estrogen resulted in increased verbal fluency and decreased visual-spatial abilities. In the female-to-male group, the administration of testosterone improved performance on a visual-spatial task and decreased performance on the verbal fluency task.

Janowsky, Oviatt, and Orwoll (1994) studied verbal and visual memory, spatial cognition, motor speed, and cognitive flexibility in a double-blind study in which a group of healthy older men were administered testosterone for three months. The Block Design subtest of the WAIS-R was used as a measure of spatial cognition. The California Verbal Learning Test and the Visual Reproduction subtest of the Wechsler Memory Scale were administered to assess short and long term memory for verbal and visual information. The Grooved Pegboard Test was administered to assess fine motor dexterity and speed and the Trail Making Test was used to assess speeded cognitive flexibility. The increase in testosterone levels to 150% baseline resulted in significant improvement on spatial tasks, but no significant difference for memory and fine motor dexterity. Treatment was found to have a curvilinear effect on spatial cognition, with moderate levels of testosterone resulting in increased performance, and the lowest and highest levels resulting in decreased performance. This finding leads to the conclusion that optimal levels of testosterone may be needed for maximum performance on spatial cognition.

These studies provide evidence that the fluctuation of androgens can *quickly* alter performance on cognitive tasks and that these differences are not due to socialization.

Research on sex differences indicates that there are consistent differences in performance on several cognitive tasks. Furthermore, these cognitive sex differences are correlated with differences in circulating gonadal hormones and the rate of hormonal change.

The present study attempts to determine the relationship between sex specific cognitive tasks and circulating levels of testosterone, estradiol, and progesterone in a population of adolescents undergoing substantial but normal hormonal changes. These adolescents were studied in a longitudinal, within-subjects design.

METHOD

Participants

Letters were sent home with children currently attending public school in the New Hanover county school system requesting parents' permission to participate in the study. (See Appendix A). Upon return of the permission slip to UNCW, parents were contacted and an appointment for testing was scheduled. Each child was tested within two weeks of their test date in the previous years and at the same time of day as the previous years.

The study began with 150 adolescents (75 males and 75 females) and by the end of this fourth year of the study, there were approximately 90 remaining subjects (approximately 45 males and 45 females). Attrition was not found to be due to poor performance, ethnicity, or gender. Ninety three percent of subjects were Caucasian, 5% African American, and 1% Hispanic. The ethnic diversity did not resemble that of the normal population, however, we did not pre-select or exclude participants according to ethnic background. The parents received a $15 gift certificate to Harris Teeter for bringing the students to the university for testing and the adolescents receive a $15 gift certificate to Millennium Music, as well as various coupons to local businesses for participating in the study.

Procedure

The University of North Carolina at Wilmington institutional review board approved all procedures. Informed consent was obtained by both parent and child prior to each testing session (See Appendix B). Each subject completed an information sheet concerning their gender, ethnicity, handedness, and medications currently using (See Appendix C). Females completed an additional section concerning information about their menstrual cycle and birth control being used. Parents completed a brief questionnaire regarding socio-economic status and occupations (See Appendix D). Each subject was administered a battery of six cognitive tasks known to show sex differences in adults. Three of these tasks have been shown to have a female advantage and three of these tasks have been shown to have a male advantage. Each subject sustained a finger stick after each testing session and blood was assayed for testosterone, estradiol, and progesterone. The administration of these tasks required approximately one hour to complete and were given in the order that follows.

Task 1: Water Level Task. The subjects were shown a picture of a rectangular jar with a rubber stopper (that does not let the water spill out) and a line drawn across the middle of the jar to represent where the water level would be if the jar were half full of water. Below the jar is a line representing a flat table on which the jar sits (See Figure 1). The subjects were given seven different pictures of this jar titled at 45, 90, 135, 225, 270, 315, and 360 degree angles. The subjects were given a pencil and ruler and asked to draw a line where the water level should be at the given angles when the jar is half full.

The correct answer is always a horizontal line. The dependent measure is the degrees of the participant drawn line from the correct horizontal line. The concepts measured are spatial perception, spatial visualization, and mental rotation. This task has been shown in several previous studies to have a distinct male advantage (Piaget & Inhelder,1956; Halpern, 1992).

Task 2: The Flags Task (Two-Dimensional Mental Rotation). The subjects were shown a pair of American flags side by side and asked to determine if the flags shown are mirror images of each other (if they are seeing the same sides of the flags or different sides of the flags). Subjects were given 48 pairs of flags, 24 were mirror images and 24 were the same side (See Figure 2). Adolescents were given a brief demonstration with "cut-out" flags to show that the flags could be rotated to match or not match. Participants were asked to put a (+) in the box provided if they are seeing the same sides of the flags or a (-) in the box if they are seeing opposite sides of the flags. The subjects had three minutes to complete the task. The dependent measure is the number of trials correct over number of trial attempted in the three minutes. Mental rotation tasks of this kind have been shown to have a male advantage (Eals & Silverman, 1994).

Task 3: Ratcliff Mannequin Task (Basketball Man Task). This task is a computerized version of a paper and pencil task developed by Ratcliff (1979). Subjects were shown a picture of “Basketball Man” in which the man is

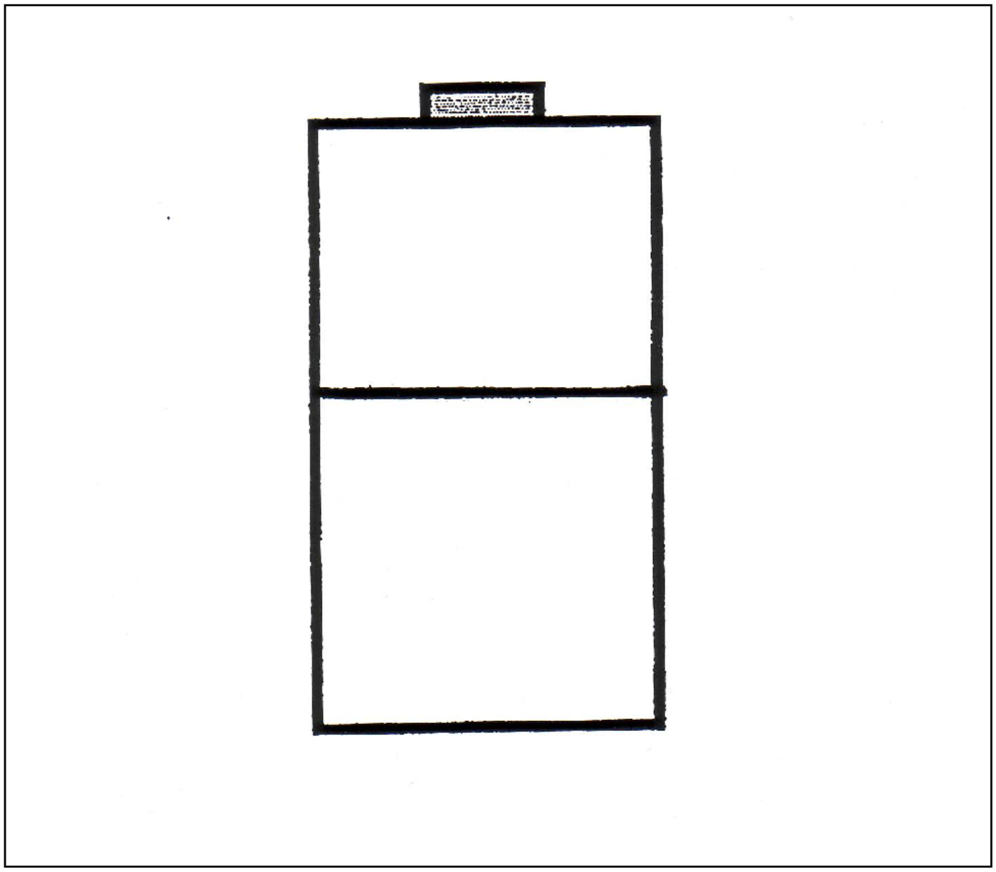

Figure 1. Example of glass jar given in water level task.

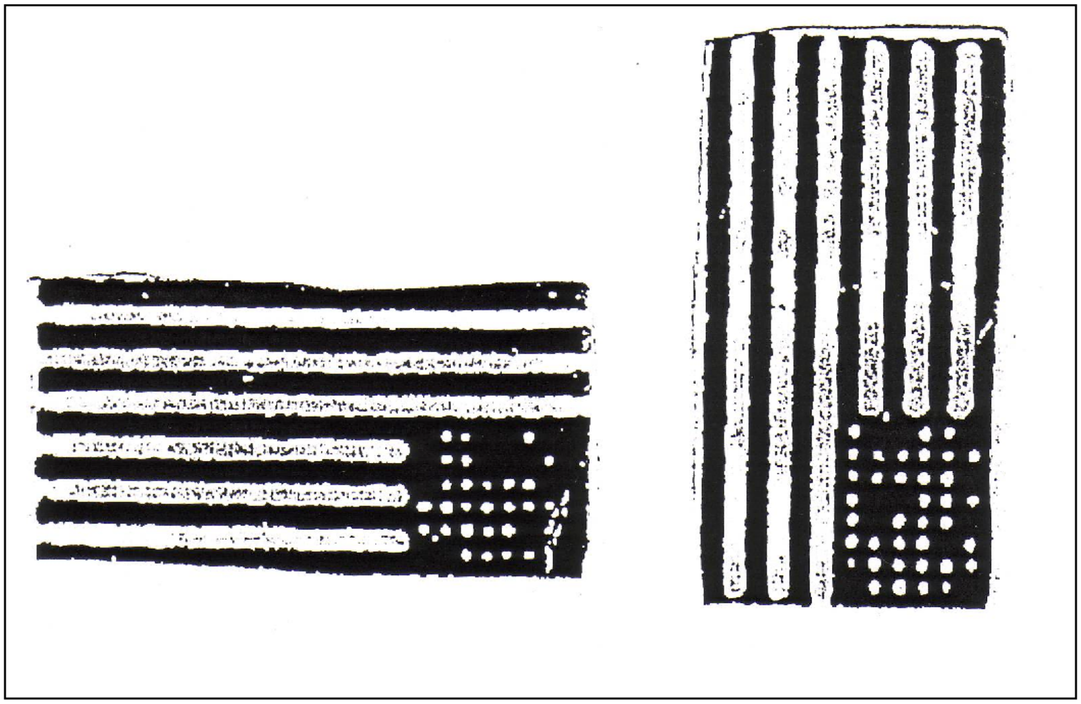

Figure 2. Example of mirror images of flags given in flag task.

holding a basketball in either his left or right hand (See Figure 3). Each figure was shown at 0, 45, 90, 135, 180, 225, 270, 315, and 360 degree rotations on a computer screen. Subjects had 10 seconds per rotation (for 24 trials) to decide which hand the man is holding the basketball in. Subjects were asked to indicate their choice by pressing one of two keys on a keyboard with either their left or right hand.

Male figures presented from the front view assess three-dimensional rotation and male figures presented from the back view assess two-dimensional rotation. The dependent measures are number of correct responses, latency of response (reaction time), and processing time as a function of rotation angle (slope). Slope is a measure of efficiency; a steeper slope represents a more efficient rotation. Tasks of this kind have been shown to have a male advantage (Resnick et al., 1986).

Task 4: Purdue Pegboard. Subjects were asked to insert pegs into holes on a pegboard as quickly and accurately as possible. Participants were asked to perform the series of tasks with their dominant hand, non-dominant hand, both hands, and an assembly of pegs, washers, and collars. They had 30 seconds for the first three conditions and one minute for the assembly. The dependent measure is the number of correct insertions in the time allowed. This task was developed by Tiffin (1968) as a fine-motor manual dexterity skill screening device for employees in industrial jobs and it has been shown to have a female advantage (Hampson & Kimura, 1992).

Task 5: Object Memory (Additional Figures). Subjects were asked to study a page consisting of 27 line drawings of uncommon objects for 60 seconds (See Figure 4). The study page was removed and a second sheet was presented with 23 added objects. Subjects were given 60 seconds to cross out any objects that were not on the original

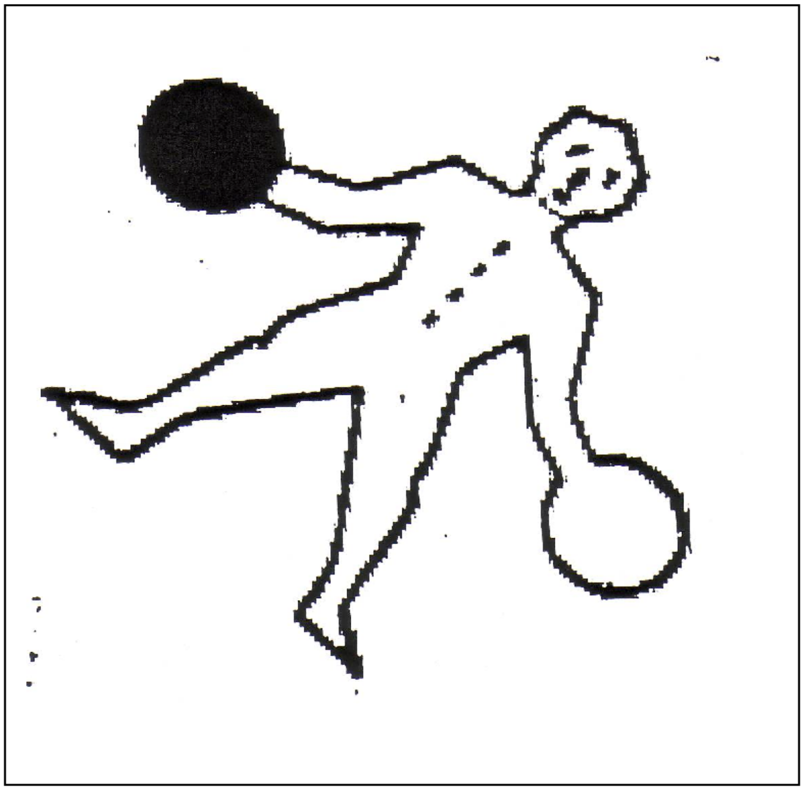

Figure 3. Example of Basketball Man seen from front view.

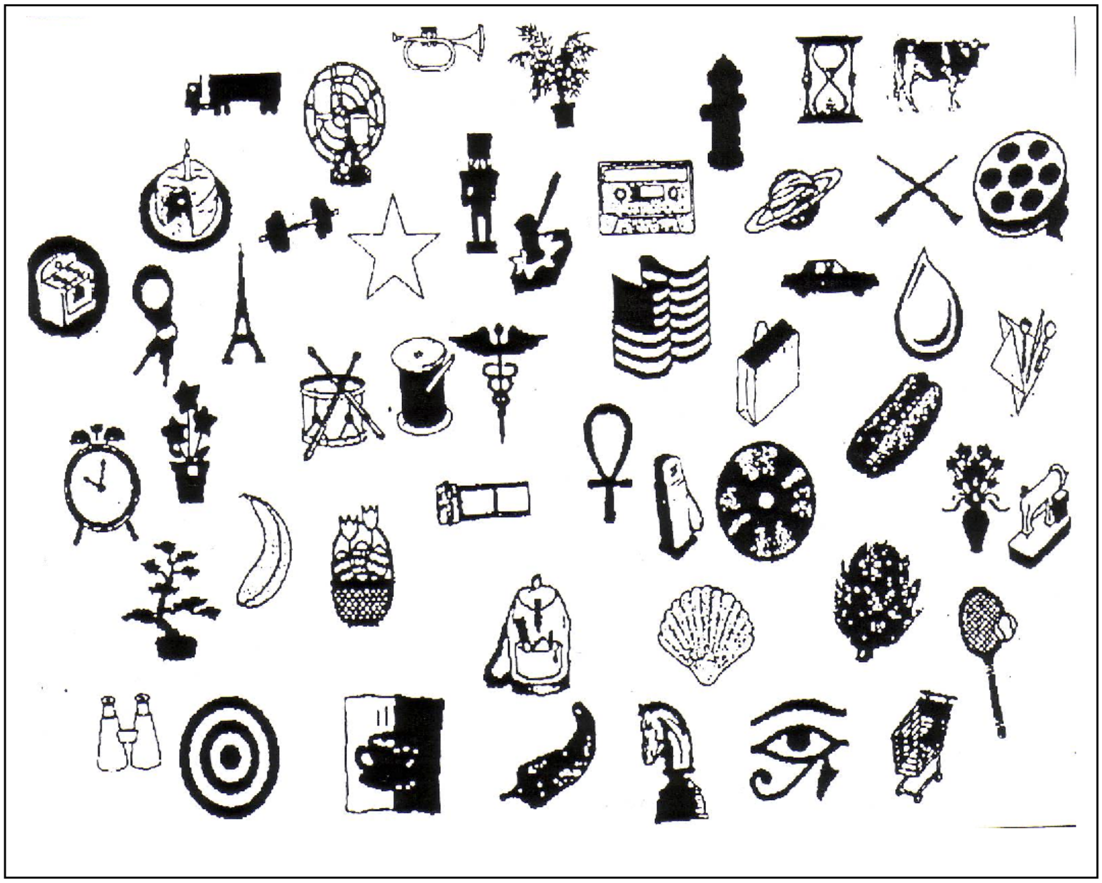

Figure 4. Example of Object Memory for Additional Figures test sheet.

study page. The dependent measure is number of correct responses, errors of omission, and errors of commission. This task was developed by Eals and Silverman (1994) to measure visual recognition memory and location memory and it has been shown to have a female advantage.

Task 6: Object Memory (Relocated Figures). This task is a continuation of the previous object memory task. The additional figures sheet was removed and the subject was given a third sheet with the same objects as the original study page, however, some of the items have been moved to a new location on the sheet (See Figure 5). Subjects were given 60 seconds to circle any object that has remained in the same location and cross out any object that has been moved to a new location. The dependent measure is number of correct and number of incorrect. This task again, has been shown to have a female advantage.

Hormonal Assays

Following completion of the test battery, a trained technician or registered nurse administered a finger prick using a sterile, disposable spring-loaded lancet. 50uL of blood were collected on a blood spot card. The blood spot cards was placed on a drying rack for 24 hours then refrigerated until they could be mailed. Blood spot cards were sent to the Behavioral Endocrinology Laboratory at Pennsylvania State University for assays to be performed. Testosterone and estradiol were assayed for males and testosterone, estradiol, and progesterone were assayed for females. Progesterone levels are only measured in females for the purpose of detecting menstrual cycle phases in which both estrogen and

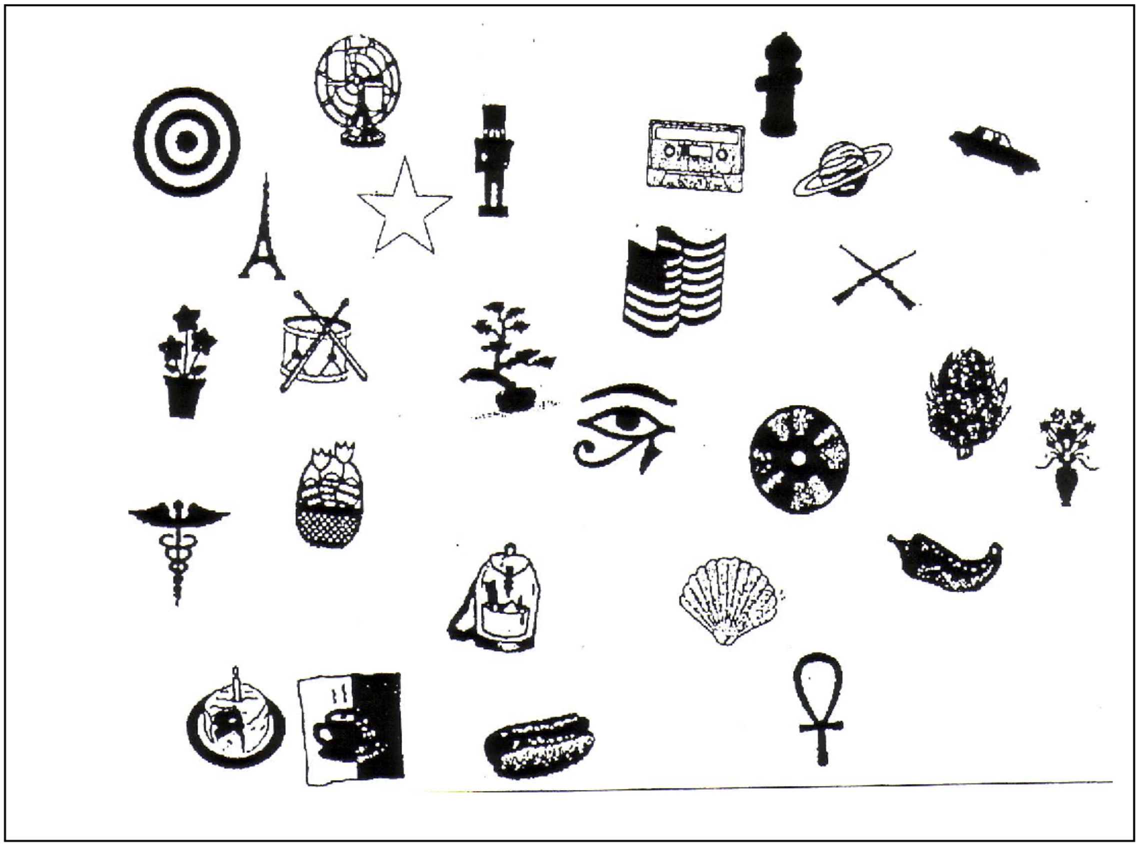

Figure 5. Example of Object Memory for relocated figures test sheet.

progesterone are low (menses) and high (midluteal). Each sample was assayed twice and the average value was used in data analysis.

RESULTS

Analyses were performed to investigate six hypotheses. Hypothesis I stated that male and female adolescents' performance will significantly differ on each of the cognitive tasks in year 4. More specifically, hypothesis I stated that, in year 4, males will perform superior to females on the "male-advantage" tasks and females will perform superior to males on the "female-advantage" tasks.

Hypothesis II stated that year 4 performance scores will differ from years 1, 2, and 3 scores. Year 4 scores will not differ from the adult population scores.

Hypothesis III stated that males and females will differ in hormone levels in each year. Specifically, males will have a higher testosterone level and females will have higher estradiol and progesterone levels.

Hypothesis IV stated that year 4 hormone levels will differ from years 1, 2, and 3 hormone levels. Specifically, hormone levels will increase each year for males and females and will equal adult hormone level by year 4.

Hypothesis V stated that hormone level will be predictive of performance on the cognitive tasks. Specifically, there will be a positive correlation between levels of estradiol and scores on the Purdue Pegboard task and object memory tasks and a negative correlation between levels of estradiol and scores on the water level task, the flags task and the basketball man task. There will be a positive correlation between testosterone and scores on the water level task, the flags task and the basketball man task and a negative correlation between levels of testosterone and scores on the Purdue Pegboard task and object memory tasks.

Hypothesis VI stated that the rate of hormonal change will effect task performance. Specifically, those subjects with a greater hormonal change across years will perform worse than those subjects with a gradual hormonal change.

Hypothesis I and II

In order to investigate hypotheses I and II, that male's and female's performance will differ and year four performance scores will differ from years 1, 2, and 3 scores, the following analyses were performed. Only significant findings are reported here.[1,2]

Female-Advantaged Tasks

Purdue Pegboard Task. Mean pegboard scores (± *SD)* by sex on each of the four test conditions in each year are given in Tables 1-5. These values are also displayed (±*SE)* in Figures 6-9. A 2 (sex) x 4 (test time) repeated measures GLM was conducted to test Hypothesis I. There was a marginally significant main effect of sex in year 1 for the non-dominant hand condition, F (1,137) = 3.74, p = .0553, MSE = 2.24. Year 1 females (M=13.22) inserted more pegs than year 1 males (M=12.73). There was no significant effect of sex in year 2, 3, and 4.

In the adult sample, main effects of sex were found in all conditions except the assembly condition. In the dominant hand condition, F (1,107) =14.05, p= .0003, MSE=2.84. In the non-dominant hand condition, F (1,107) = 4.16, p= .04, MSE = 2.78. In the both hands condition, F (1,107) =4.29, p= .04, MSE = 13.12. Females performed superior to males in each of these conditions.

Table 1

Mean pegs inserted for each condition of the Purdue Pegboard task for males and females at year 1.

	N	M	SD
Males			
Dominant Hand	66	13.56	1.88
Non-dominant Hand	66	12.73	1.54
Both Hands	66	21.36	3.27
Assembly	66	32.18	6.16
Females			
Dominant Hand	73	13.89	1.73
Non-dominant Hand	73	13.22	1.45
Both Hands	73	21.57	2.94
Assembly	73	33.82	5.35

Table 2

Mean pegs inserted for each condition of the Purdue Pegboard task for males and females at year 2.

	N	M	SD
Males			
Dominant Hand	53	14.32	1.89
Non-dominant Hand	53	13.75	1.84
Both Hands	53	22.72	2.96
Assembly	53	34.87	5.83
Females			
Dominant Hand	54	14.5	1.53
Non-dominant Hand	54	13.5	1.34
Both Hands	54	22.44	3.12
Assembly	54	35.26	5.13

Table 3

Mean pegs inserted for each condition of the Purdue Pegboard task for males and females at year 3.

	N	M	SD
Males			
Dominant Hand	45	14.53	1.65
Non-dominant Hand	45	13.80	1.72
Both Hands	45	23.08	3.26
Assembly	45	37.47	5.30
Females			
Dominant Hand	50	14.80	1.47
Non-dominant Hand	50	14.24	1.65
Both Hands	50	23.36	2.61
Assembly	50	36.88	6.63

Table 4

Mean pegs inserted for each condition of the Purdue Pegboard task for males and females at year 4.

	N	M	SD
Males			
Dominant Hand	40	15.15	1.64
Non-dominant Hand	40	14.25	1.71
Both Hands	40	24.42	2.82
Assembly	40	38.10	5.00
Females			
Dominant Hand	44	15.61	1.49
Non-dominant Hand	44	14.42	1.71
Both Hands	44	24.38	2.80
Assembly	44	39.45	5.25

Table 5

Mean pegs inserted for each condition of the Purdue Pegboard task for males and females in the adult sample.

	N	M	SD
Males			
Dominant Hand	34	13.85	1.74
Non-dominant Hand	34	13.32	1.55
Both Hands	34	22.53	3.21
Assembly	34	37.35	5.10
Females			
Dominant Hand	75	15.16	1.66
Non-dominant Hand	75	14.03	1.72
Both Hands	75	24.08	3.79
Assembly	75	38.34	5.10

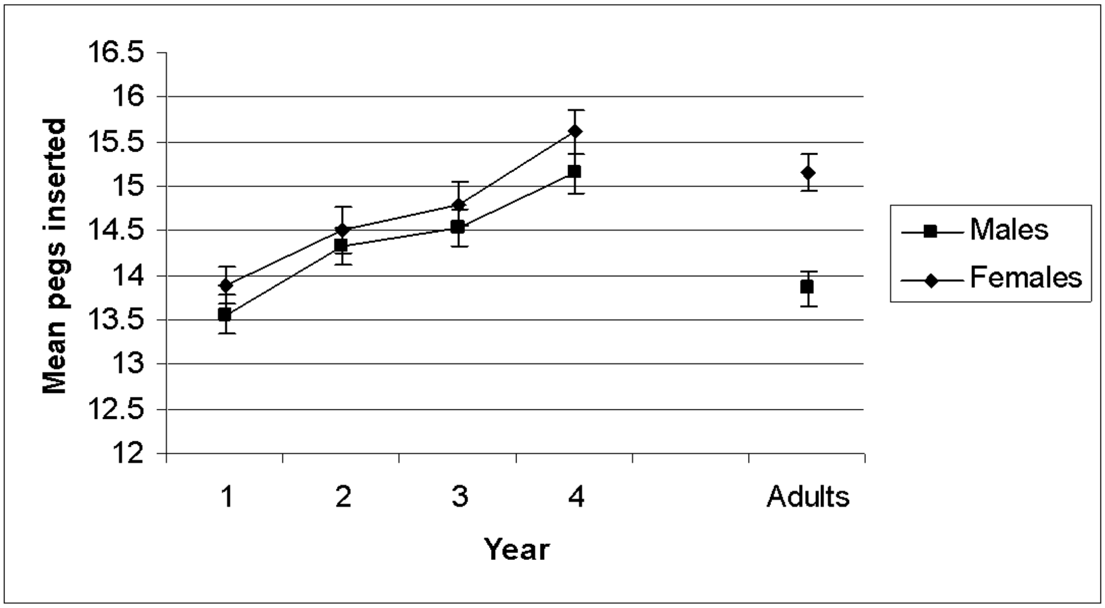

Figure 6. Mean scores (±*SE*) for the dominant hand condition of the Purdue Pegboard task for males and females in years 1, 2, 3, and 4 and the adult sample.

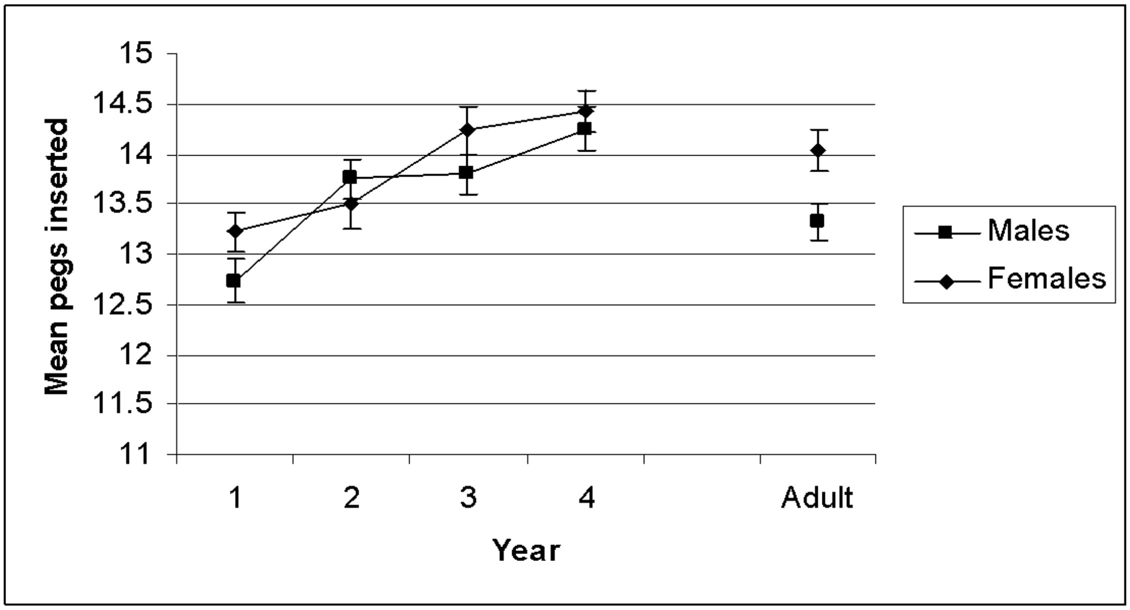

Figure 7. Mean scores (±*SE*) for the non-dominant hand of the Purdue Pegboard task for males and females in years 1, 2, 3, 4 and the adult sample.

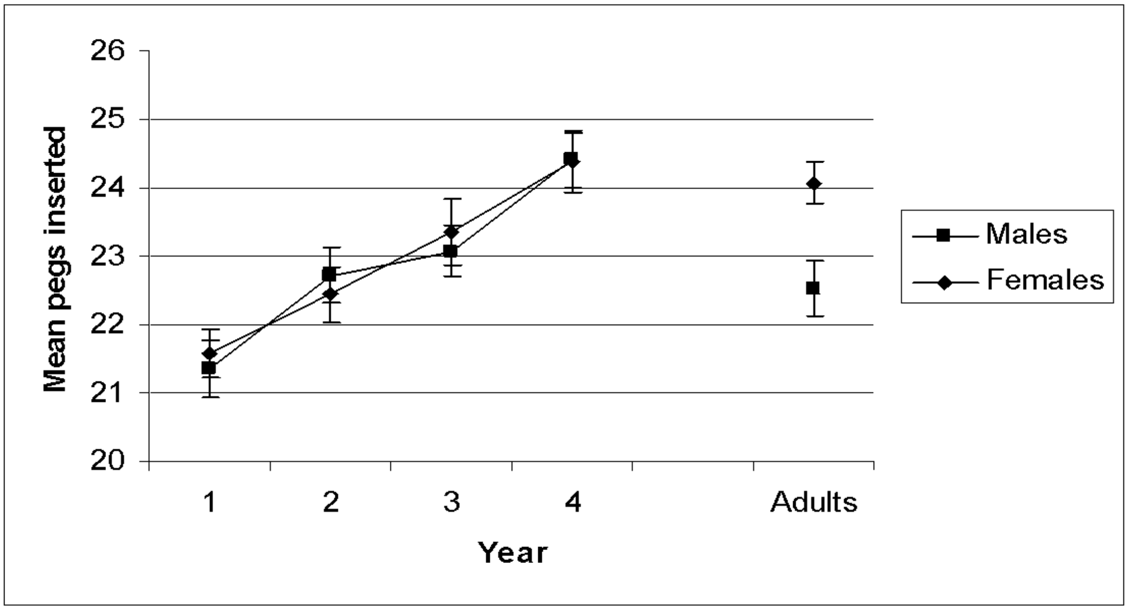

Figure 8. Mean scores (±*SE*) for the both hands condition of the Purdue Pegboard task for males and females in years 1, 2, 3, 4 and the adult sample.

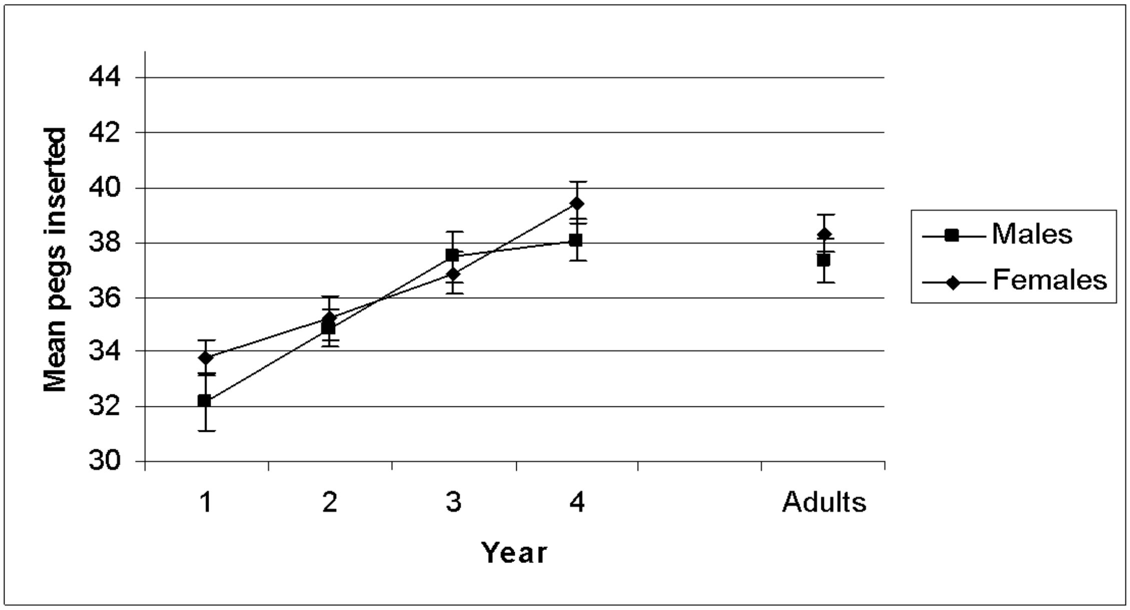

Figure 9. Mean scores (±*SE*) for the assembly condition of the Purdue Pegboard task for males and females in years 1, 2, 3, 4 and the adult sample.

There was a significant main effect of test time (year) in each condition. In the dominant hand condition there was a significant effect of year for females, F (4,291) = 10.03, p< .0001, MSE =2.56, such that adult females as well as females in years 2 (M =14.56), 3 (M= 14.80), and 4 (M=15.61) outperformed females in year 1 (M=13.89). Females in year 4 significantly outperformed females in year 2. There was a significant effect of year for males in the dominant hand condition, F (4, 233) =5.70, p= .0002, MSE = 3.19, such that males in years 3 (M=14.53) and 4 (M=15.15) outperformed males in year 1 (M=13.56). Additionally, males in year 4 outperformed adult males (M=13.85).

In the non-dominant hand condition, there was a significant effect of year for females, F (4,291) =5.92, p< .0001, MSE= 2.40. Adult females (M=14.03) as well as females in years 3 (M= 14.24) and 4 (M= 14.36) outperformed females in year 1 (M= 13.22). Females in year 4 significantly outperformed females in year 2 (M=13.50). There was a significant effect of year in the non-dominant hand condition for males, F (4,233) = 7.29, p< .0001, MSE= 2.81. Males in years 2 (M=13.75), 3 (M= 13.80), and 4 (M=14.42) outperformed males in year 1 (M= 12.73). Again, males in year 4 outperformed adult males.

In the both hands condition, there was a significant effect of year for females, F (4,291) =8.64, p < .0001, MSE = 9.86. Adult females (M= 24.08) as well as females in years 3 (M= 23.36) and 4 (M= 24.39) outperformed females in year 1 (M= 21.57). Females in year 4 outperformed females in year 2 (M= 22.72). There was a significant effect of year for males in the both hands condition, F (4,237) = 6.27, p < .0001, MSE = 9.74. Males in years 3 (M= 23.09) and 4 (M= 24.42) outperformed males in year 1 (M= 21.36).

Finally, in the assembly condition, there was a significant effect of year for females, F (4,291) = 9.89, p < .0001, MSE=31.64. Adult females (M= 38.35) as well as females in years 3

(M= 36.88) and 4 (M= 39.45) outperformed females in year 1 (M= 33.82). Adult females as well as females in year 4 also outperformed females in year 2 (M= 35.26). There was a significant effect of year for males in the assembly condition, F (4,233) = 10.44, $p < .0001$, MSE = 31.36. Adult males (M= 37.35) as well as males in years 3 (M= 37.47) and 4 (M=38.10) were superior to males in year 1 (M= 32.18). Year 4 males were superior to males in year 2 (M= 34.87).

Object Memory: Additional Figures Task. Mean errors of commission and mean errors of omission are displayed for each year by sex in Tables 6-10. These values (±*SE)* are also displayed in Figures 10 and 11. A 2 (sex) x 4 (test time) repeated measures GLM was conducted for each error type in this task. There were no significant effects of sex in years 1, 2, 3 or 4.

In the adult sample, a marginally significant effect of sex was found for the errors of omission, F (1,108)= 3.64, p= .059, MSE = 6.08. Females made less errors (M=1.00) than males (M=1.97).

There was a significant main effect of test time (year) for errors of commission for females, F (4,280)) = 2.71, p = .03, MSE = 1.54. Specifically, females in year 4 (M= .50) made significantly fewer errors than females in year 1(M=1.18). There was a significant main effect of test time (year) for errors of omission for females, F (4.284) = 2.66, p= .03, MSE = 4.39. Specifically, females in years 3 (M= .74) and 4 (M=.85) made significantly fewer errors than females in year 1 (M=1.82).

Table 6

Mean errors for the Object Memory tasks for Year 1.

	N	M	SD
Males			
Errors of Omission	64	2.72	3.32
Errors of Commission	64	1.04	1.57
Relocation Errors	64	7.67	4.35
Females			
Errors of Omission	72	1.82	2.73
Errors of Commission	72	1.18	1.72
Relocation Errors	72	7.54	4.61

Table 7

Mean errors for the Object Memory tasks for Year 2.

	N	M	SD
Males			
Errors of Omission	52	.94	1.51
Errors of Commission	52	.65	1.04
Relocation Errors	52	6.0	4.20
Females			
Errors of Omission	50	.98	1.73
Errors of Commission	50	.70	.99
Relocation Errors	50	5.94	4.20

Table 8

Mean errors for the Object Memory tasks for Year 3.

	N	M	SD
Males			
Errors of Omission	43	1.16	1.93
Errors of Commission	43	.53	1.09
Relocation Errors	43	6.69	4.91
Females			
Errors of Omission	47	.74	1.52
Errors of Commission	47	.81	1.29
Relocation Errors	47	5.83	3.87

Table 9

Mean errors for the Object Memory tasks for Year 4.

	N	M	SD
Males			
Errors of Omission	39	.87	1.83
Errors of Commission	39	.51	.64
Relocation Errors	39	5.85	3.61
Females			
Errors of Omission	40	.85	1.59
Errors of Commission	40	.50	.85
Relocation Errors	40	4.93	2.38

Table 10

Mean errors for the Object Memory tasks in the adult sample.

	N	M	SD
Males			
Errors of Omission	34	1.97	3.08
Errors of Commission	34	.82	1.08
Relocation Errors	34	6.29	4.47
Females			
Errors of Omission	76	1.0	2.14
Errors of Commission	76	.63	.93
Relocation Errors	76	5.30	3.91

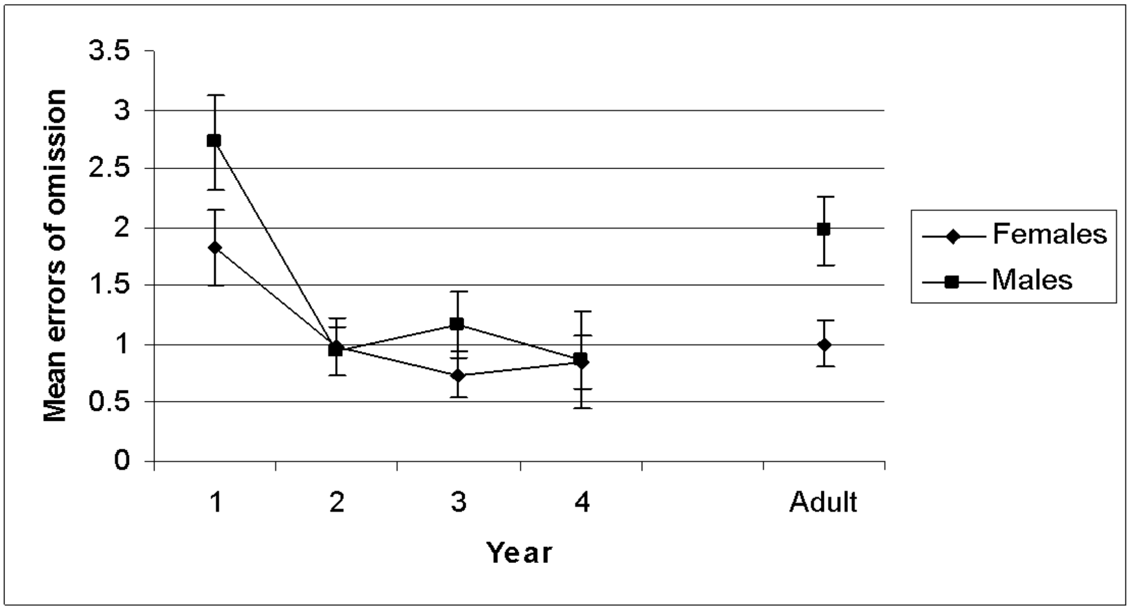

Figure 10. Mean scores (±*SE*) for the Object Memory task, errors of omission, for males and females in years 1, 2, 3, and 4 and the adult sample.

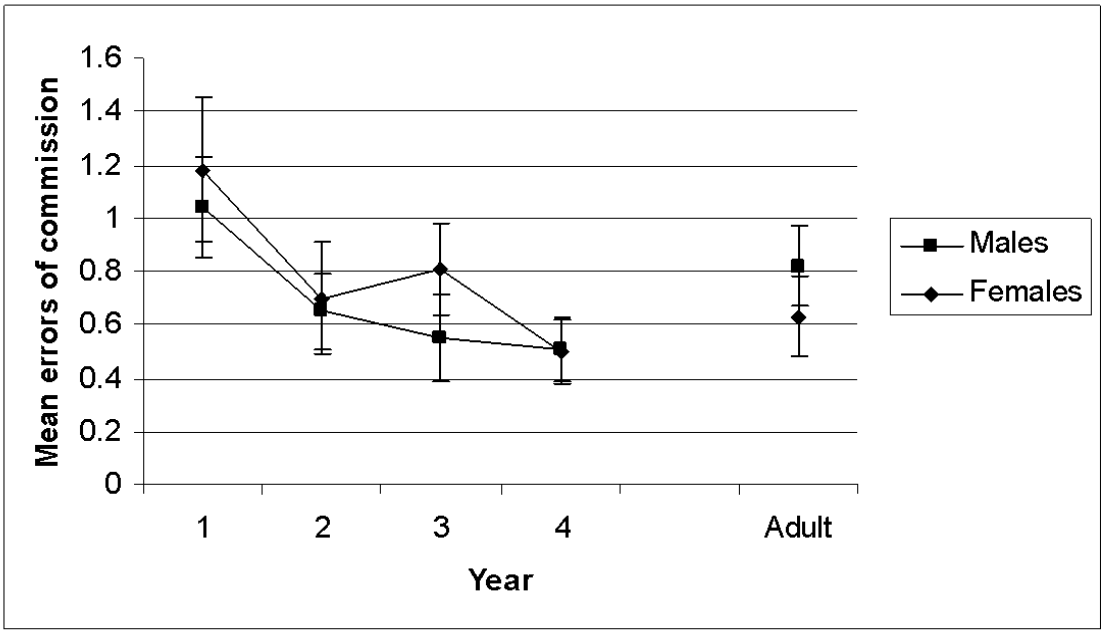

Figure 11. Mean scores (±*SE*) for the Object Memory task, errors of commission, for males and females in years 1, 2, 3, and 4 and the adult sample.

There was a significant effect of year for males, F (4,227) = 5.48, p = .0003, MSE = 6.21. Males made significantly more errors of omission in year 1 (M=2.72) than in years 2 (M= .94), 3 (M=1.16) and 4 (M=.87). There were no other significant differences between years.

Object Memory: Relocated Figures Task. Mean errors for each year by sex are displayed in Tables 6-10 and in Figure 12. There were no significant effects of sex in years 1, 2, 3, or 4. There was no significant effect of sex for the adult sample.

There was a significant main effect of test time (year) for females, F (4,280) =4.04, p= .0034, MSE= 15.84. Specifically, females in years 3 (M=5.82) and 4 (M=4.92) made significantly fewer errors than females in year 1 (M=7.54).

Male-Advantaged Tasks

Flags Task. Mean flags correct (±*SD*) for males and females in each year are displayed in Table 11. These values (±*SE)* are also displayed in Figure 13. A 2 (sex) x 4 (test time) repeated measures GLM was performed. There was no significant effect of sex in years 1, 2, 3, or 4.

In the adult sample, there was a significant main effect of sex, F (1,108) = 17.79, p < .0001, MSE = 46.99. Males performed significantly better (M=43.91) than females (M=37.95).

There was a significant main effect of test time (year) for females, F (3,219) =9.53, p < .0001, MSE = .64.67. Specifically, females in years 2 (M=40.21), 3 (M=40.75), and 4 (M= 42.64) performed significantly better than females in year 1 (M=35.27). Females performed significantly better in year 4 than in year 2. Additionally, females in year 4 outperformed adult females (M=37.95).

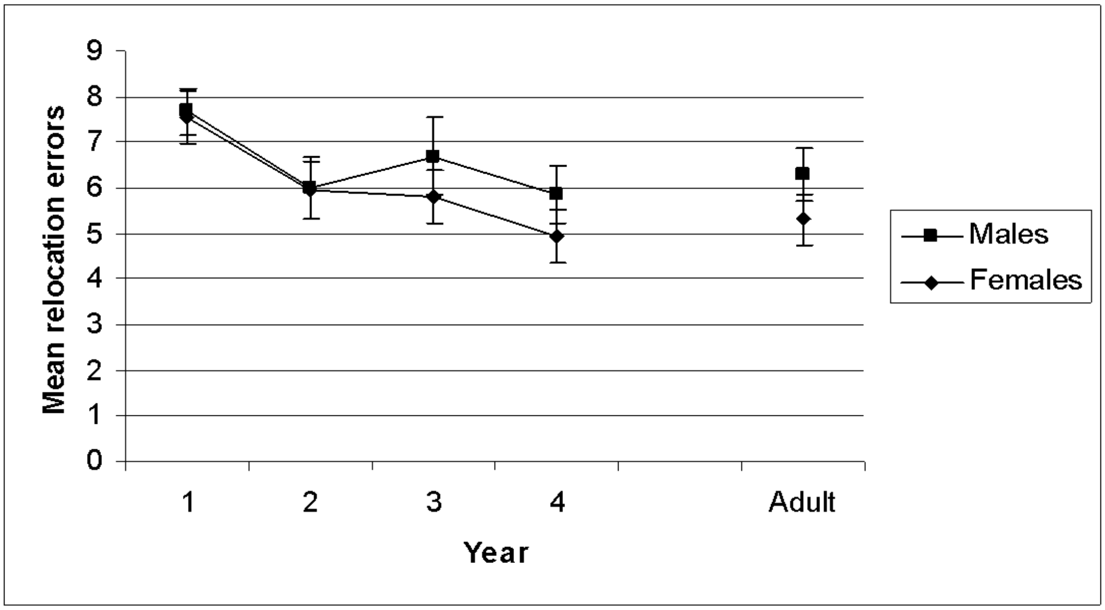

Figure 12. Mean scores (±*SE*) for the Object Memory for Relocated Objects task, number incorrect, for males and females in years 1, 2, 3, and 4 and the adult sample.

Table 11

Mean flags correct for males and females in years 1, 2, 3, 4 and the adult sample.

	N	M	SD
Males			
Year 1	69	37.58	9.32
Year 2	54	42.26	6.18
Year 3	46	42.91	6.27
Year 4	41	44.51	4.30
Adults	34	43.91	4.76
Females			
Year 1	74	35.27	9.80
Year 2	56	40.21	7.51
Year 3	48	40.75	6.98
Year 4	45	42.64	6.31
Adults	76	37.95	7.60

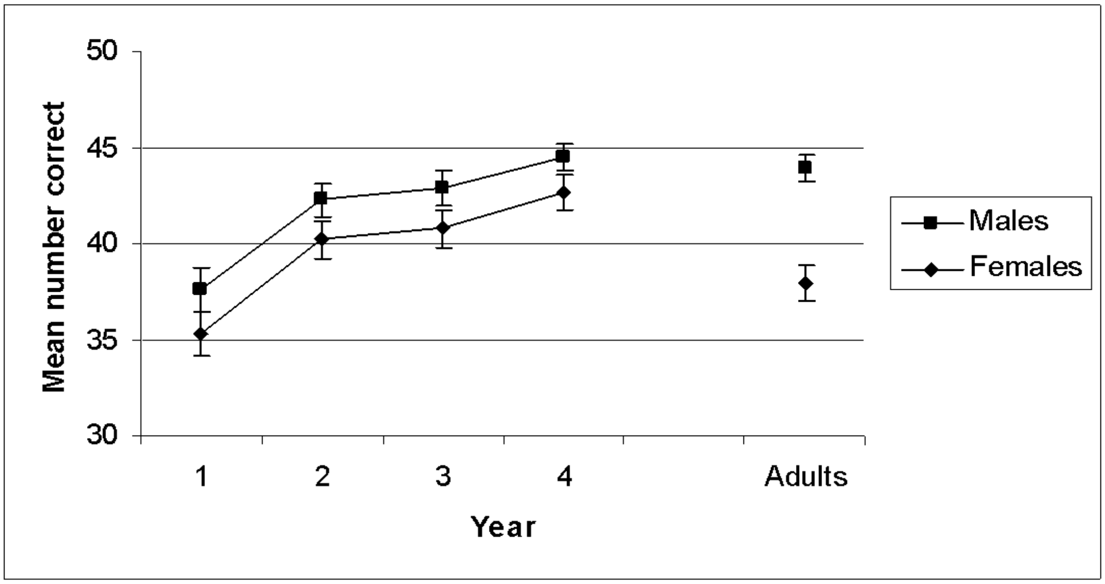

Figure13. Mean scores (±*SE*) on the Flags Task for males and females in years 1, 2, 3, 4 and the adult sample.

There was a significant effect of year for males also, $\underline{F}$ (3,206) = 10.18, $\underline{p} < .0001$, $\underline{MSE}$ = 50.67. Adult males as well as males in years 2 ($\underline{M}$=42.26), 3 ($\underline{M}$=42.91) and 4 ($\underline{M}$=44.51) performed significantly better than in year 1 ($\underline{M}$=37.58).

Water Level Task. Mean degrees (±*SD)* from horizontal for each angle of the water level task are presented for each year by sex in Table 12. These values (+*SE)* are also displayed in Figures 14 and 15.

Exploratory analysis for this task revealed perhaps the most interesting findings of the study. Participants made very few errors on the 90 degree angle and 180 degree angle conditions of the task, therefore, these angles were eliminated from these analyses. The frequency distributions for the 45 degree angle condition and the 135 degree angle condition were almost identical, therefore, these conditions were combined for the analyses. The 45/135 degree angle condition showed a bimodal distribution. It is from this point that the following conclusions were made.

Until now, "horizontal" was considered the only correct answer for the Water Level task. It seems that participants in this study made two types of errors. One type of error was made with the decision to rely on the internal context of the task rather that the external context. The internal context refers to the sides of the glass jar and the external context refers to the flat table on which the jar sits (this is traditionally considered the correct context.) When participants relied on internal contexts, they drew a 45 degree line instead of the correct horizontal line. These types of errors will be referred to as "error of decision".

Table 12

Mean degrees from horizontal for each angle of the water level task, by sex and year.

		Year				
Rotation		1	2	3	4	Adult
45/135	Male	29.40	15.11	14.37	13.62	6.45
		(ns)	(p=.01)	(p= .02)	(ns)	(p=.0002)
	Females	32.96	24.7	23.61	18.66	21.52
90/180	Male	15.36	10.96	6.97	7.15	4.93
		(ns)	(ns)	(p= .02)	(ns)	(ns)
	Female	20.33	13.48	15.90	12.31	11.53

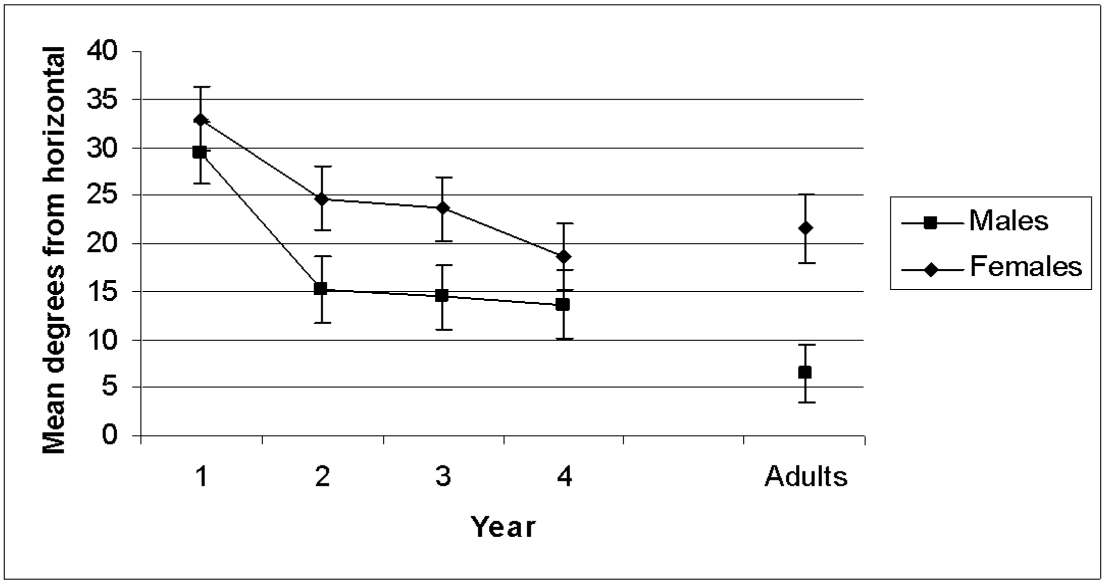

Figure 14. Mean scores (±*SE*) for the 45/135 degree angle combination of the Water Level task for males and females in years 1, 2, 3, and 4 and the adult sample.

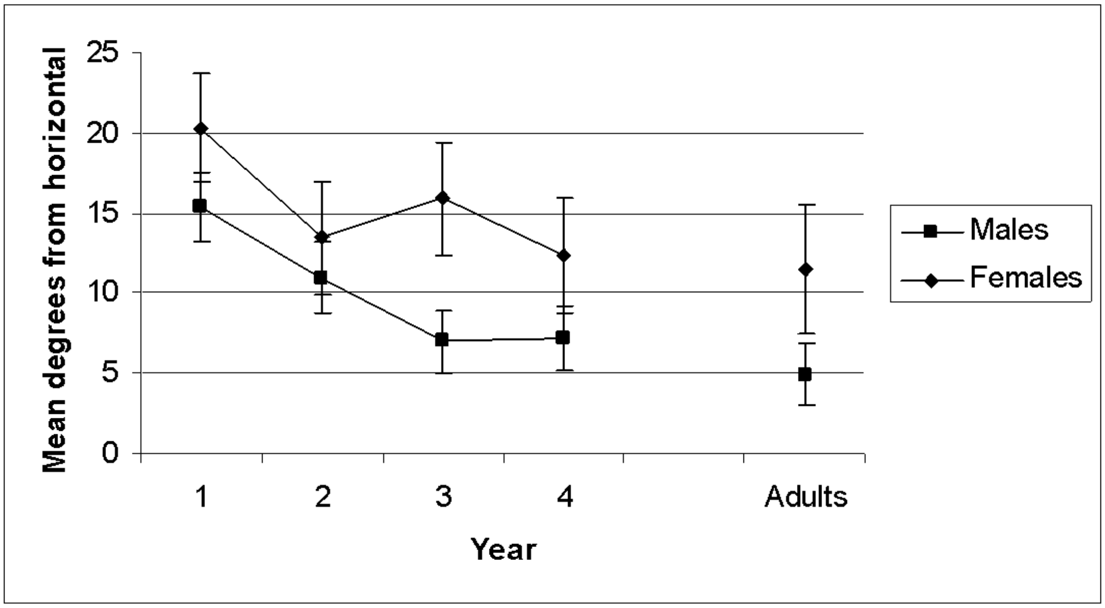

Figure 15. Mean scores (±*SE*) for the 90/180 degree angle combination of the Water Level task for males and females in years 1, 2, 3, and 4 and the adult sample.

A second type of error will be referred to as "errors of precision". These are the errors surrounding the line drawn, whichever line that may have been. For instance, participants may have drawn a 47 or 48 degree line instead of the 45 degree line. (See Figure 16) The following results should be interpreted keeping this bimodal distribution in mind. Further statistical analyses regarding the separate distributions will be reserved for another paper.

A 2 (sex) x 4 (test time) repeated measures GLM was performed for these combinations of angles. (It should be noted that the dependent measure for the water level task is "degrees from horizontal", therefore, the lower score equals better performance).

In year 2, there was a significant effect of sex for the 45/135 degree angle combination, F (1,104) = 6.67, p = .011, MSE = 365.02, such that males (M=15.11) significantly outperformed (were more precise) females (M= 24.7).

In year 3, there was a significant effect of sex for the 45/135 degree angle combination, F (1, 94) = 5.84, p = .018, MSE = 349.74, such that males (M= 14.37) significantly outperformed (were more precise) females (M = 23.61).

Among the adult sample, there was a significant main effect of sex for the 45/135 degree angle combination, F (1,107) = 15.21, p = .0002, MSE = 343.25. Males (M= 6.45) significantly outperformed (were more precise) females (M= 21.52).

For females, there were significant effects of test time (year). There was a significant effect of test time for the 45/135 degree angle combination, F (4, 294) = 4.56, p = .0014, MSE = 413.15. Adult females (M= 21.52) as well as females in year 4 (M= 18.66) significantly outperformed (were more precise) females in year 1 (M= 32.96).

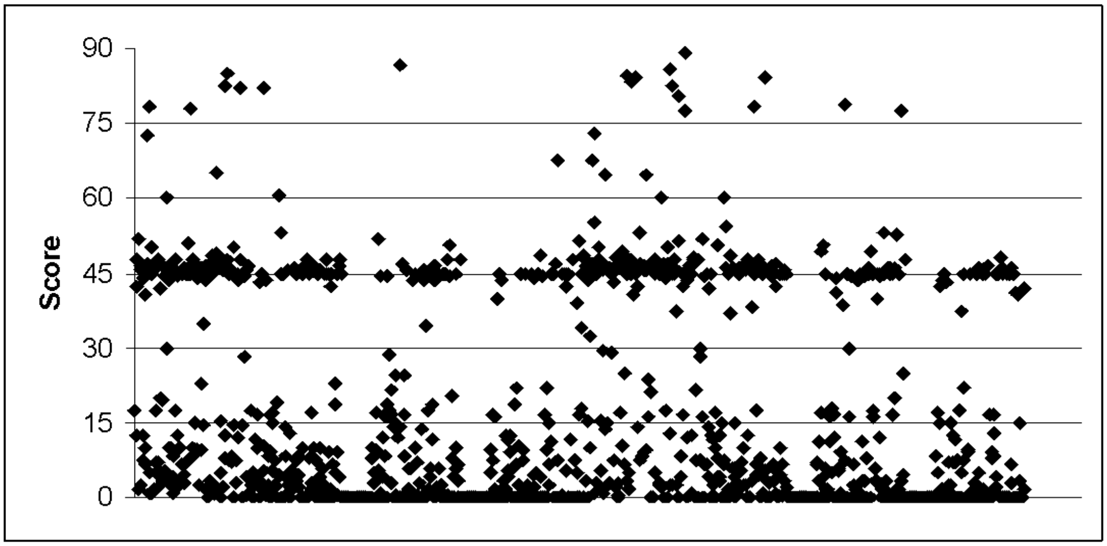

Figure 16. Score distribution for the 45/135 degree angles of the Water Level task with all four years combined.

For males, there were significant effects of test time (year). There was a significant effect of test time for the 45/135 degree angle combination, F (4, 236) = 11.31, p < .0001, MSE = 335.07. Adult males (M= 6.45) as well as males in years 4 (M= 13.62), 3 (M= 14.37) and 2 (M= 15.11) significantly outperformed males in year 1 (M= 29.42).

Basketball Man Task. Participants with error rates greater than .2 were omitted from these analyses.

Mean scores for this task in each year are presented in Tables 13-17. Separate regression analyses were performed for each participant in each year on the front (three dimensional) and the back (two dimensional) rotation conditions. Slopes obtained from these regression analyses were used to obtain estimates of the increase in reaction time as a function of rotation angle. The resultant slopes, intercepts, R2s, and error rates were entered into a 2 (sex) x 4 (test time) repeated measures GLM. There were no significant effects of sex in years 1 and 2.

In year 3, there was a significant effect of sex for the back slope dependent variable, F (1, 58) = 8.52, p= .0050, MSE= .00000712. Females (M= .0059) had a significantly steeper slope than males (M = .0039). There was a marginally significant effect of sex for the combined (front and back) slope, F (1, 58) = 3.21, p= .078, MSE = .0000049. Females (M= .0053) had a steeper combined slope than males (M= .004).

There was a significant effect of sex for the R2 (combined front and back rotations) dependent variable, F (1, 58) = 4.88, p = .031, MSE = .026. Females (M= .362) had a significantly higher R2 than males (M= .270).

Table 13

Mean slope, intercept, r2, and error rates (%) in both the 2-D and 3-D rotation conditions for year 1.

Year 1	Females				Males			
Front View (3-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.007	1.65	.295	.04	.005	1.63	.22	.04
SD	.007	.661	.221	.06	.005	.66	.17	.06
Back View (2-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.005	1.34	.33	.03	.005	1.26	.30	.02
SD	.004	.60	.22	.05	.005	.42	.19	.16

Table 14

Mean slope, intercept, r2, and error rates (%) in both the 2-D and 3-D rotation conditions for year 2.

Year 2	Females				Males			
Front View (3-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.005	1.55	.29	.06	.006	1.38	.24	.05
SD	.006	.602	.22	.06	.006	.51	.20	.06
Back View (2-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.004	1.18	.29	.03	.004	1.12	.34	.015
SD	.003	.49	.18	.04	.004	.41	.21	.04

Table 15

Mean slope, intercept, r2, and error rates (%) in both the 2-D and 3-D rotation conditions for year 3.

Year 3	Females				Males			
Front View (3-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.005	1.49	.29	.03	.004	1.44	.24	.04
SD	.006	.57	.27	.05	.004	.48	.19	.06
Back View (2-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.006	.96	.43	.015	.004	1.12	.31	.017
SD	.002	.36	.19	.03	.003	.35	.22	.04

Table 16

Mean slope, intercept, r2, and error rates (%) in both the 2-D and 3-D rotation conditions for year 4.

Year 4	Females				Males			
Front View (3-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.004	1.21	.31	.02	.005	1.19	.19	.046
SD	.002	.38	.20	.04	.005	.34	.21	.057
Back View (2-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.003	.916	.32	.035	.004	.989	.29	.025
SD	.002	.322	.19	.042	.003	.375	.19	.05

Table 17

Mean slope, intercept, r2, and error rates (%) in both the 2-D and 3-D rotation conditions for the adult sample.

Adults	Females				Males			
Front View (3-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.008	1.17	.31	.24	.004	1.10	.24	.031
SD	.003	.57	.20	.04	.005	.34	.21	.047
Back View (2-D)								
	Slope	Intercept	r2	Errors	Slope	Intercept	r2	Errors
Mean	.006	.832	.32	1.00	.004	.906	.277	.035
SD	.004	.242	.20	.36	.003	.261	.197	.06

In year 4, there was a significant effect of sex for the front R2 variable, F (1, 51) = 4.43, p= .04, MSE = .037. Females (M= .308) had a significantly higher R2 than males (M= .196). There was a marginally significant effect of sex for the R2 (combined) variable, F (1, 51) = 3.35, p = .073, MSE = .019. Females (M= .316) had a higher R2 than males (M= .245).

In the adult sample, there was a significant effect of sex for the front slope dependent variable, F (1, 50) = 5.42, p= .024, MSE = .0000036. Females (M= .008) had a significantly steeper slope than males (M= .004). There was also a significant effect of sex for the back slope dependent variable, F (1, 50) = 4.62, p= .036, MSE = .0000015. Females (M= .006) had a significantly steeper slope than males (M= .0035). There was a significant effect of sex for the combined slope (front and back rotation conditions), F (1, 51) = 7.38, p= .009, MSE = .000016. Females (M= .0067) had a significantly steeper slope than males (M= .0036).

There were significant effects of test time (year) for females. For females, there was a significant effect of year for the front slope dependent variable, F (4,151) = 2.46, p = .047, MSE = .000031. Females in year 1 (M= .007) had a significantly steeper slope than adult females (M= .003). For females, there was a significant effect of year for the front intercept dependent variable, F (4, 151) = 3.93, p = .0046, MSE = .340. Year 1 (M= 1.65) females had a significantly higher intercept than adult females (M= 1.17) and females in year 4 (M= 1.21). Females in year 2 (M= 1.55) also had a significantly higher intercept than adult females and females in year 4. There was a significant effect of year for the back slope dependent variable, F (4,151) = 4.68, p = .0014, MSE = .000009. Females in year 1 (M = .005) had a significantly steeper slope than adult females (M= .003) and females in year 4 (M= .003). Females in year 3 (M= .005) also had a significantly steeper slope than adult females and females in year 4. There was a significant main effect of year for the back intercept variable, F (4,151) = 7.02, p< .0001, MSE = .211.

Females in year 1 (M= 1.34) had significantly higher intercepts than adult females (M= .83) and females in years 3 (M= .96) and 4 (M= .92). Females in year 2 (M= 1.18) also had a higher intercept than adult females. There was a significant effect of year for the combined slope (front and back) variable, F (4,151) = 4.83, p = .0011, MSE = .0000099. Females in year 1 (M= .006) had a significantly steeper slope than adult females (M= .003) and females in years 2 (M= .004) and 4 (M= .003). There was a significant effect of year for the combined intercept (front and back) variable, F (4,151) = 7.11, p< .0001, MSE = .189. Females in year 1(M= 1.5) had a significantly higher intercept than adult females (M= 1.00) and females in years 3 (M= 1.22), and 4 (M= 1.065). Females in year 2 (M= 1.36) also had a higher slope than adult females and females in year 4.

There were significant effects of year for males. There was a significant effect of year for the front intercept variable, F (4,164) = 5.73, p = .0002, MSE = .261. Males in year 1 (M= 1.63) had a significantly higher intercept than adult males (M= 1.10) and males in years 2 (M= 1.37) and 4 (M= 1.19). Males in year 3 (M=1.44) also had a higher intercept than adult males. There was a significant effect of year for the back slope variable, F (4,164) = 2.81, p = .027, MSE = .000013. Males in year 1 (M= .005) had a significantly steeper slope than adult males (M= .002). There was a significant effect of year for the back intercept variable, F (4,164) = 4.29, p = .0025, MSE = .143. Males in year 1 (M=1.26) had a significantly higher intercept than males in year 4 (M= .989) and adult males (M= .906). Males in years 2 (M=1.12) and 3 (M= 1.12) also had a higher intercept than adult males. There was a significant effect of year for the combined intercept (front and back) variable, F (4,164) = 7.23, p< .0001, MSE = .138. Males in year 1 (M=1.45) had a higher intercept than males in year 2 (M=1.25), 4 (M= 1.09) and adult males (M= 1.00). Males in years 2 and 3 (M= 1.28) also had higher intercepts than adult males.

Hypotheses III and IV

In order to investigate the hypotheses that males and females will differ in hormone levels and, furthermore, hormone levels for males and females will increase each year and begin to approach adult level in year 4, the following analyses were conducted. Only significant finding are reported here.[3,4] Mean hormone levels for each year and sex are displayed in Figures 17-19.

Each hormone was entered into a 2 (sex) x 4 (test time) repeated measures GLM. As predicted, there were significant effects of sex and year for testosterone and estradiol. Progesterone levels were only measured for female participants.

Testosterone. There was a significant effect of sex for testosterone level in year 1, $\underline{F}$ (1,113) = 27.03, $\underline{p} < .0001$, $\underline{MSE} = .147$. Males ($\underline{M}$= .439) had a significantly higher testosterone level than females ($\underline{M}$= .067). There was a significant effect of testosterone level in year 2, $\underline{F}$ (1, 87) = 42.34, $\underline{p}< .0001$, $\underline{MSE}$= .273. Males ($\underline{M}$= .836) had a significantly higher testosterone level than females ($\underline{M}$= .836). There was a significant

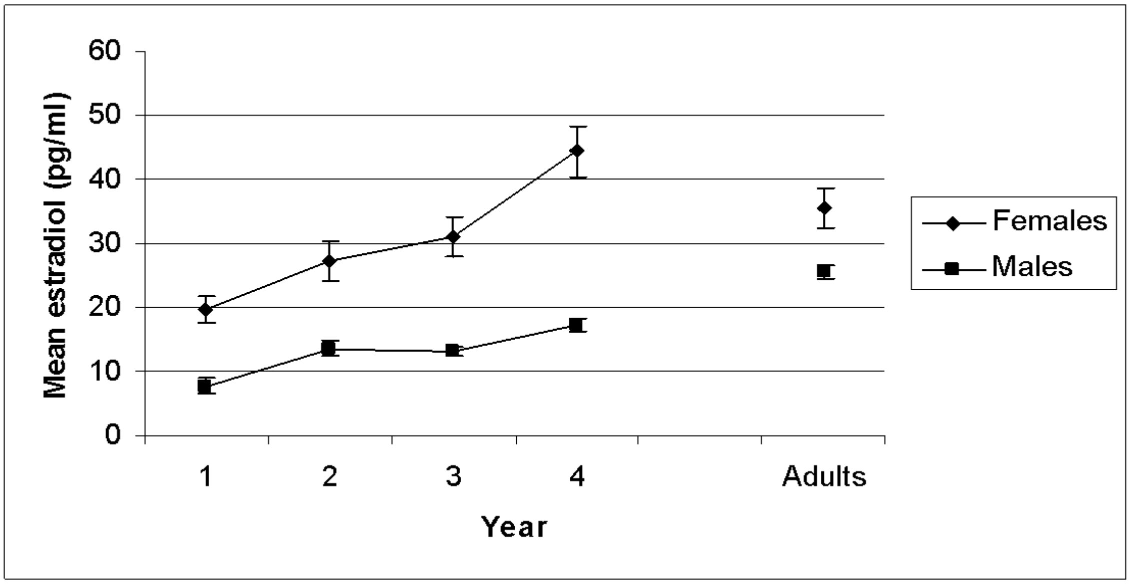

Figure 17. Mean estradiol levels (±*SE*) for males and females at years 1, 2, 3, and 4 and the adult sample.

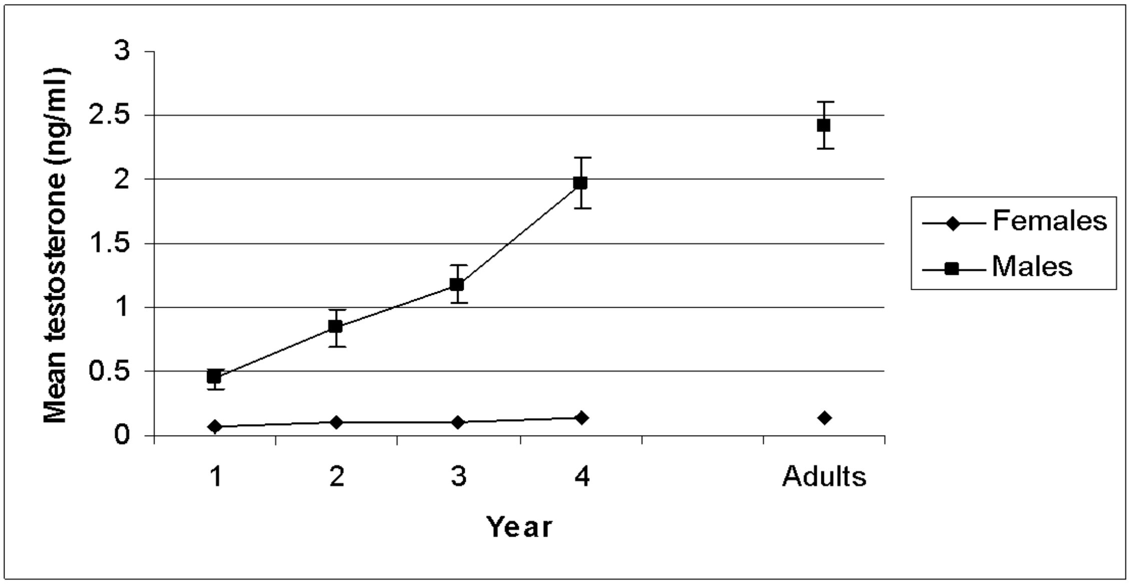

Figure 18. Mean testosterone levels (±*SE*) for males and females at years 1, 2, 3, and 4 and the adult sample.

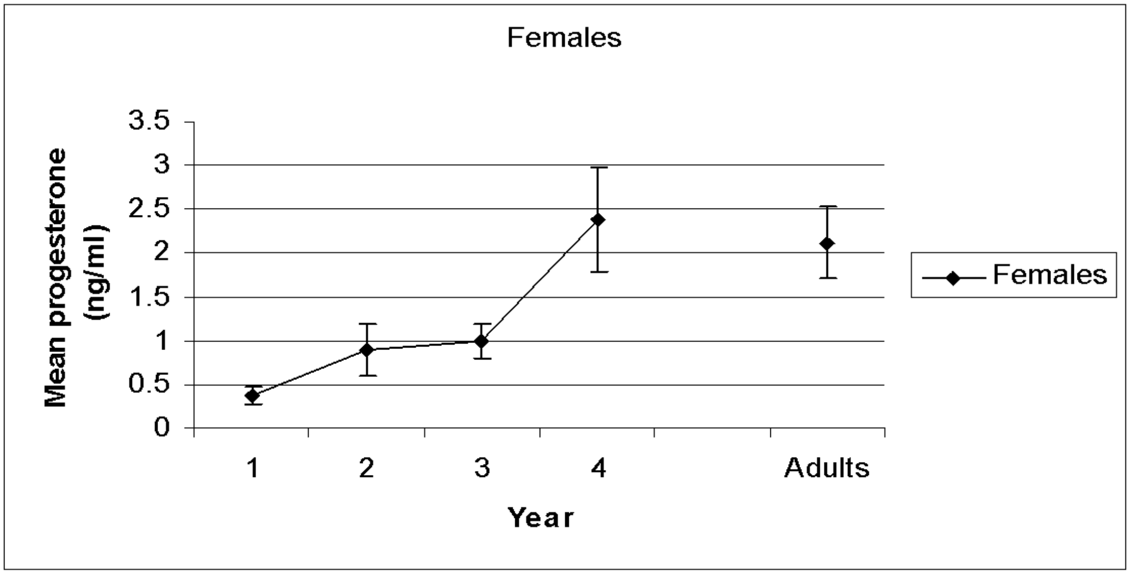

Figure 19. Mean progesterone levels (±*SE*) for females in years 1, 2, 3, and 4 and the adult sample.

effect of testosterone level in year 3, F (1, 70) = 20.94, p< .0001. Males (M=1.18) had a higher testosterone level than females (M= .102). There was a significant effect of sex in year 4, F (1, 85) = 208.72, p< .0001, MSE = .345. Males (M=1.966) had a significantly higher testosterone level than females (M= .145). There was a significant effect of sex in the adult population, F (1,101) = 648.45, p< .0001, MSE = .182. Males (M= 2.425) had a significantly higher testosterone level than females (M= .129).

There was a significant effect of year for males, F (4,208) = 55.45, p < .0001, MSE = .51. Testosterone levels in the adult sample (M= 2.42) were greater than in years 1 (M= .44), 2 (M= .84), 3 (M=1.18), and 4 (M=1.97). Testosterone levels in year 4 were greater than in years 3, 2, and 1.

There was a significant effect of year for females, F (4,248) = 8.29, p< .0001, MSE = .006. Females in years 2 (M = .11) and 4 (M= .14) as well as adult females (M= .13) had significantly higher testosterone levels than in year 1 (M=.067).

Estradiol. There was a significant effect of sex in year 1, F (1,118) = 28.62, p < .0001, MSE = 148.40. Females (M= 19.64) had a significantly higher estradiol level than males (M= 7.74). There was a significant effect of sex in year 2, F (1, 89) = 20.08, p < .0001, MSE = 209.41. Females (M= 27.23) had a significantly higher estradiol level than males (M=13.62). There was a significant effect of sex in year 3, F (1, 70) = 31.72, p < .0001, MSE = 184.49. Females (M= 31.09) had a higher estradiol level than males (M = 13.05). There was a significant effect of sex in year 4, F (1, 73) = 29.46, p< .0001, MSE = 465.50. Females (M= 44.44) had a higher estradiol level than males (M= 17.34). There was a significant effect of sex in the adult sample, F (1,104) = 4.42, p= .038. Females (M=35.50) had a higher level of estradiol than males (M= 25.42).

There was a significant effect of year for males, F (4,206) = 45.57, p < .0001, MSE= 39.11. Adult males (M=25.42) had higher estradiol levels than males in years 1 (M= 7.74) 2 (M= 13.62), 3 (M= 13.05), and 4 (M= 17.34). Males in year 4 had higher estradiol levels than in years 3 and 1. Males in year 3 had higher estradiol levels than in years 2 and 1. Males in year 2 had higher estradiol than in year 1.

There was a significant effect of year for females, F (4,248) = 7.89, p< .0001, MSE = 525.24. Adult females (M= 35.50) had a higher estradiol level than females in year 1 (M= 19.64). Females in year 4 (M= 44.40) had a higher estradiol level than in years 2 (M= 27.23) and 1.

Progesterone. There was a significant effect of year for females, F (4,256) = 8.37, p< .0001, MSE = 5.05. Adult females (M= 2.12) and females in year 4 (M= 2.39) had significantly higher progesterone levels than females in years 1 (M= .37) and 2 (M= .89).

Hypothesis V

In order to investigate the hypothesis that there would be positive correlations between estradiol level and negative correlations between testosterone and scores on the "female-advantaged" tasks, and positive correlations between testosterone and negative correlations between estradiol on the "male-advantaged" tasks, the following analyses were performed. Separate hormone x cognitive task regressions were performed for each year by sex. Only significant results are reported here.[5]

Female-Advantaged Tasks

Purdue Pegboard Task. In year 1, for females, estradiol was marginally predictive of performance on the non-dominant hand condition of this task, t (51) = -1.88, p= .06.

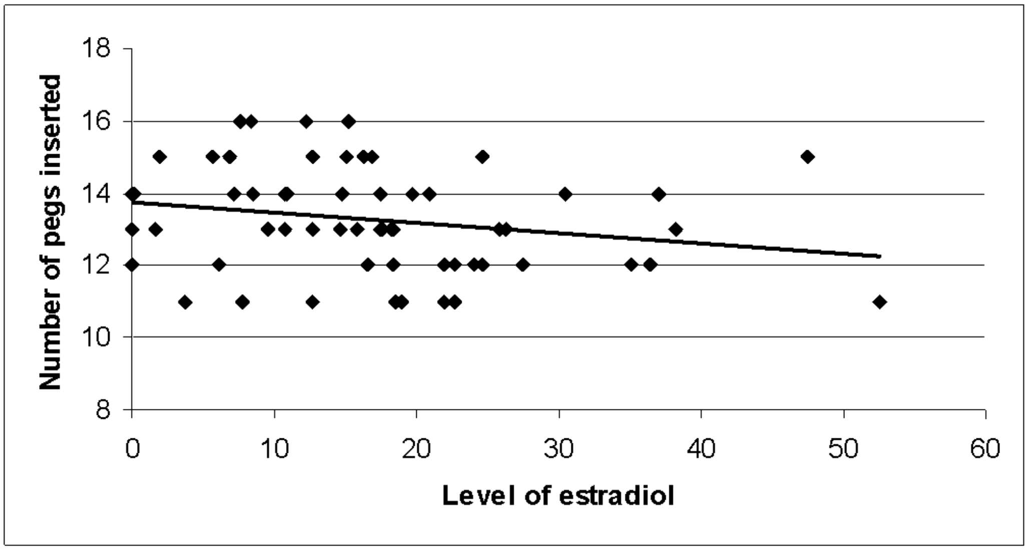

Figure 20. Year 1 females non-dominant hand performance on the Purdue Pegboard task as a function of estradiol.

Higher levels of estradiol were associated with decreased performance (fewer pegs inserted). No other results were significant for females in this task among all four years.

For males, in year 1, testosterone was predictive of performance on the assembly condition of this task, $t(51) = -2.02$, $p = .048$. Higher testosterone was associated with decreased performance. Estradiol was also predictive of performance on the assembly condition of this task in year 1, $t(51) = -3.34$, $p = .0016$. Higher estradiol was associated with decreased performance. There was also a significant testosterone, estradiol interaction such that, $t(51) = 2.06$, $p = .04$. Fifteen percent of the variance in this task can be accounted for by variation in circulating hormones.

For males, in year 2, testosterone was predictive of performance on the dominant hand condition of this task, $t(37) = -2.15$, $p = .038$. (See Figure 21) Higher levels of testosterone were associated with decreased performance. Thirteen percent of the variance in this task can be accounted for by variation in circulating hormones. Testosterone was predictive of performance on the assembly condition of this task for year 2, $t(37) = -2.34$, $p = .024$. (See Figure 22) Higher levels of testosterone are associated with decreased performance. Estradiol was predictive of performance on the assembly condition, $t(37) = -2.19$, $p = .035$. (See Figure 23) Higher levels of estradiol are associated with decreased performance. There was also a testosterone, estradiol interaction such that, $t(37) = 2.12$, $p = .04$. Sixteen percent of the variance in this task can be accounted for by variation in circulating hormones. No other results were significant for males among all four years.

Object Memory: Additional Figures Task. There were no significant results for females in this task among all four years.

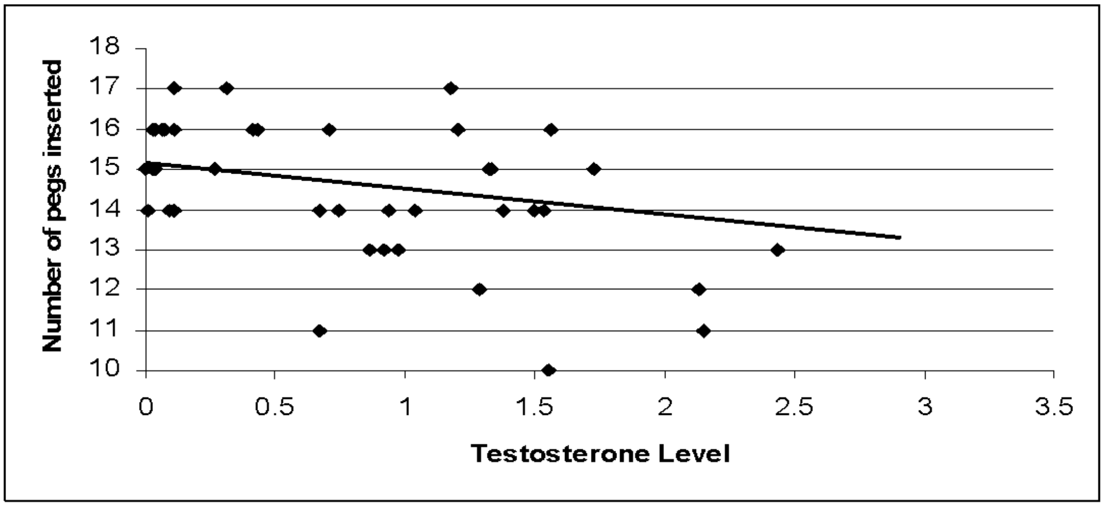

Figure 21._ Year 2 males' dominant hand performance on the Purdue Pegboard task as a function of testosterone.

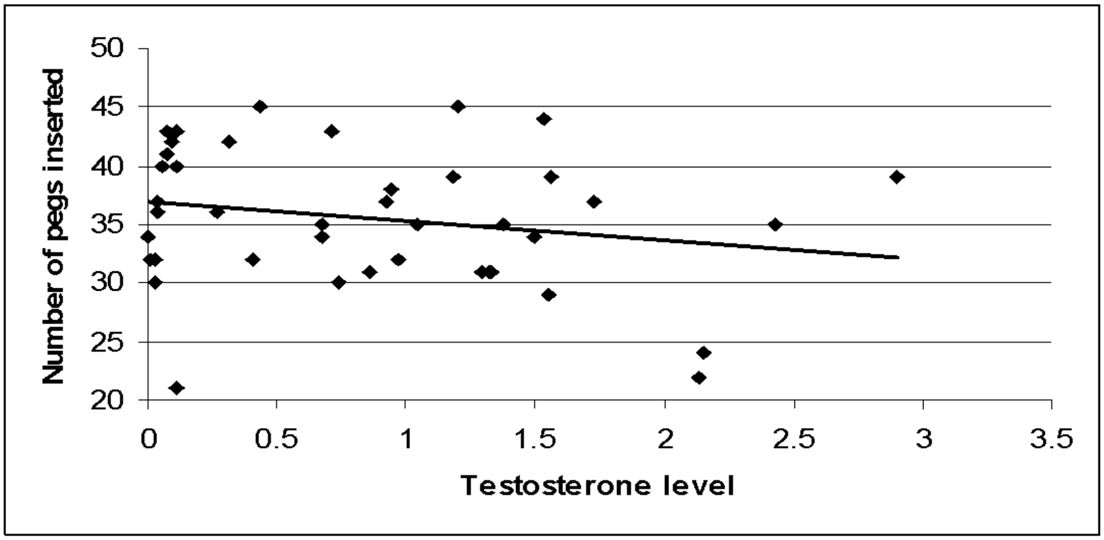

Figure 22. Year 2 males' assembly condition performance on the Purdue Pegboard task as a function of testosterone.

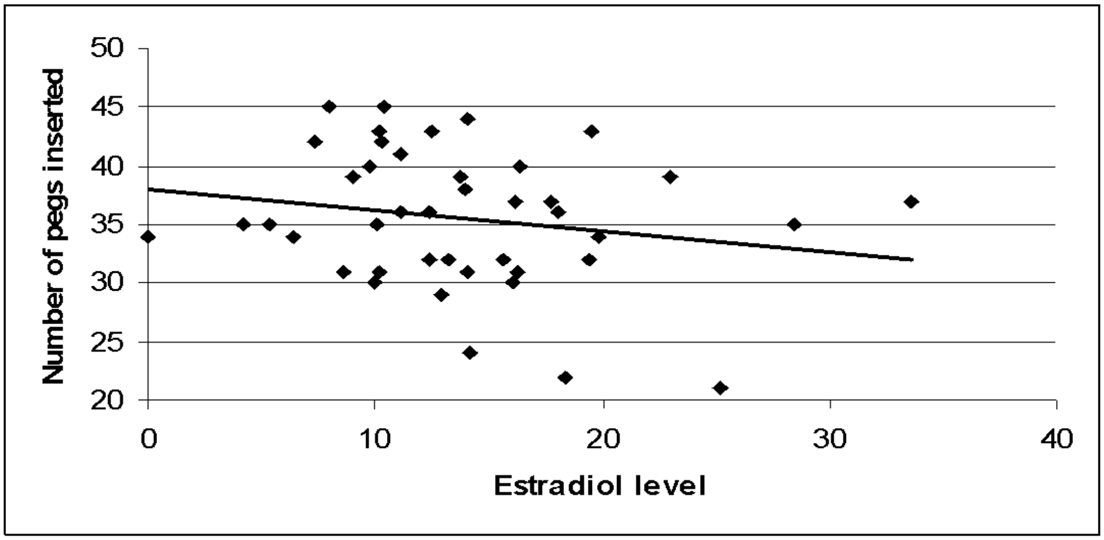

Figure 23. Year 2 males' assembly condition performance of the Purdue Pegboard task as a function of estradiol.

For males, in year 1, testosterone was predictive of performance, t (51) = 2.55, p = .014. Higher levels of testosterone were predictive of decreased performance (increased errors of commission) on this task. There was also a significant testosterone, estradiol interaction such that, t (51) = -2.33, p = .024. Twelve percent of the variance in this task can be accounted for by variation in circulating hormones.

For males, in year 2, estradiol was predictive of performance on this task, t (51) = 2.73, p = .009. (See Figure 24) Higher estradiol was associated with decreased performance (increased errors of omission) on this task. Nineteen percent of the variance in this task can be accounted for by variation in circulating hormones. No other results were significant in this task for males among all four years.

Object Memory: Relocated Figures Task. There were no significant results for this task for either sex among all four years.

Male-Advantaged Tasks

Flags Task. For females, in year 3, testosterone was predictive of performance, t (28) = 2.14, p = .04. (See Figure 25) Higher testosterone was associated with increased performance (more flags correct). There was also a significant testosterone, estradiol interaction such that, t (28) = -2.75, p = .01. Thirty percent of the variance in this task can be accounted for by variation in circulating hormones.

There were no significant results for males in this task among all four years.

Basketball Man Task. Again, all participants with an error rate above .2 on this task were excluded from these analyses. For females, in year 1, testosterone was predictive of the front (3-dimensional rotation) R2 on this task, t (34) = -2.31, p = .027.

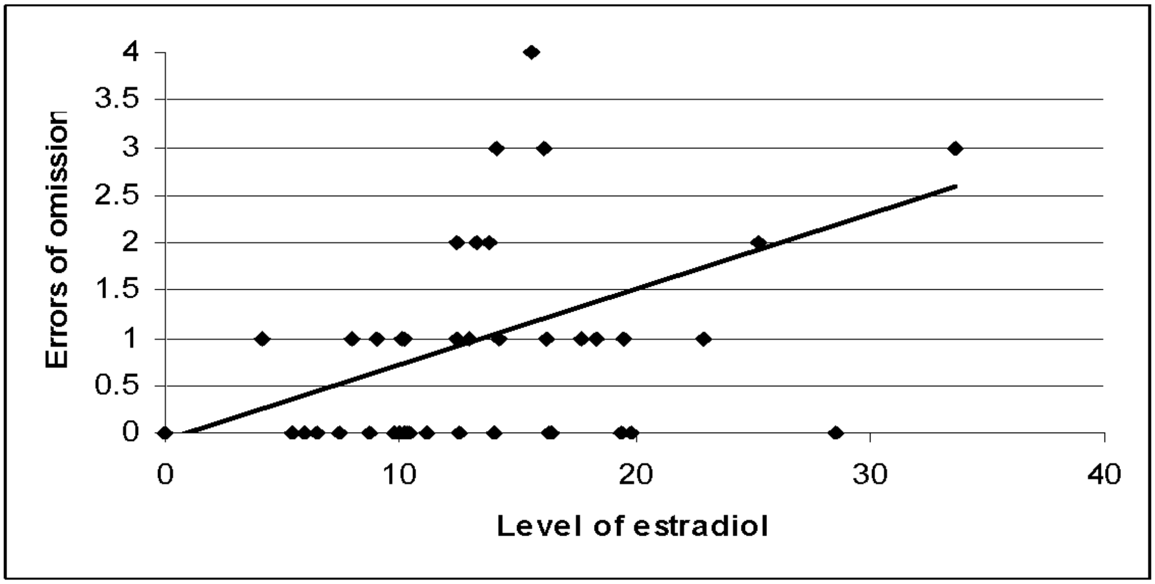

Figure 24. Year 2 males' performance on the Object Memory: Additional Figures task as a function of estradiol.

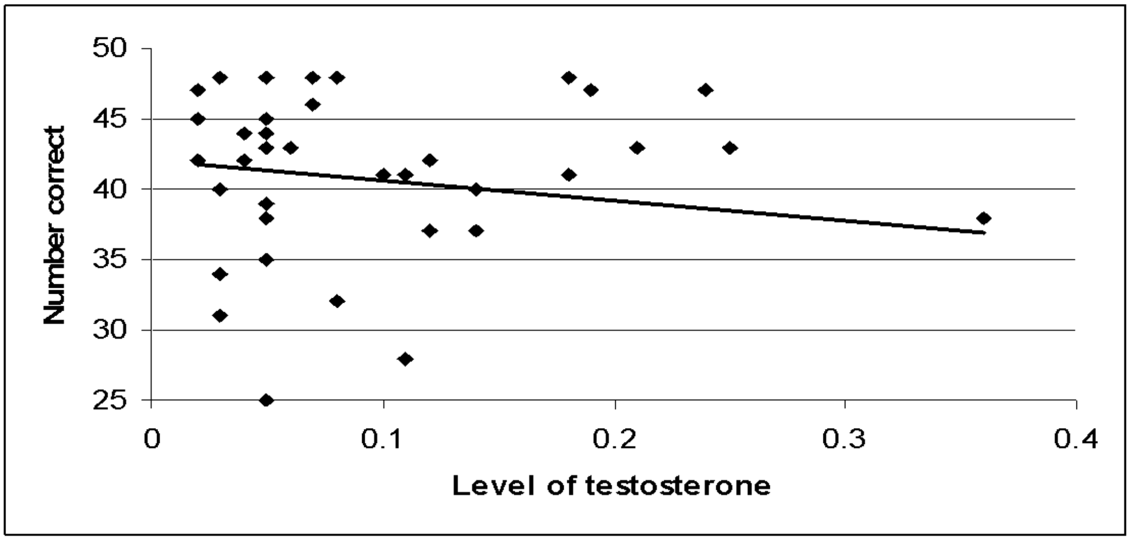

Figure 25. Year 3 females' performance on the Flags task as a function of testosterone.

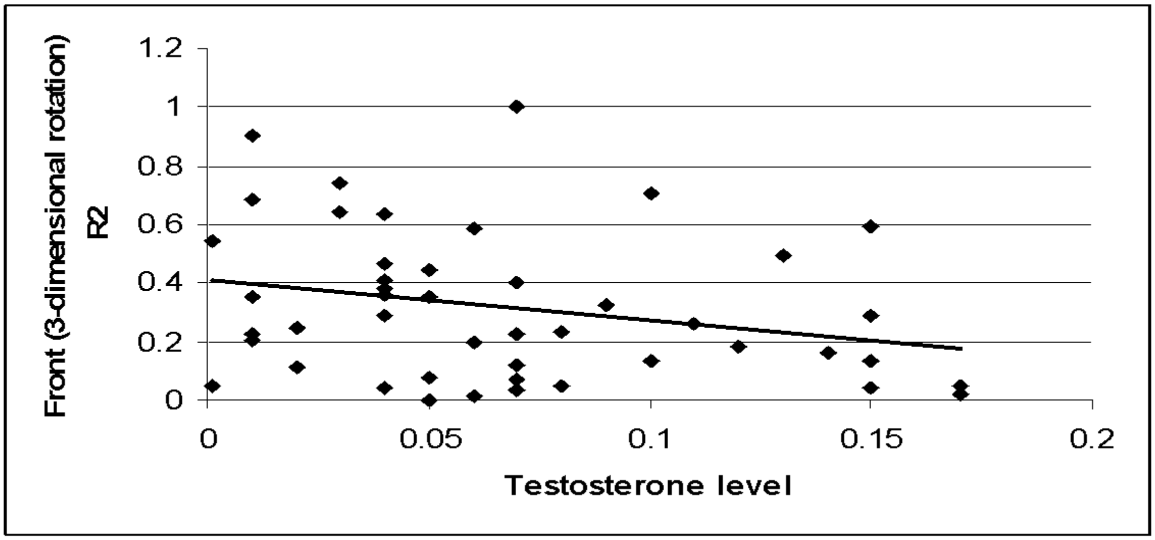

Figure 26. Year 1 females' performance on the front (3-dimensional rotation) condition of the Basketball Man task as a function of testosterone.

Fifteen percent of the variance in R2 can be accounted for by variation in circulating hormones.

For females, in year 2, there was a testosterone, estradiol interaction for the front (3-dimensional rotation) error rate on this task such that, t (28) = 2.10, p = .045. Seventeen percent of the variance in front error rate can be accounted for by variation in circulating hormones.

For females, in year 3, testosterone was predictive of the front intercept on this task, t (13) = -2.10, p = .05. (See Figure 27) Higher testosterone was associated with higher intercepts (slower reaction time). There was a significant testosterone, estradiol interaction such that, t (13) = 3.12, p = .008. Fifty eight percent of the variance in front intercept can be accounted for by variation in hormones. Testosterone was marginally predictive of back slope (2-dimensional rotation) on this task, t (13) = -2.01, p = .065. (See Figure 28) Higher testosterone was associated with flatter slopes. There was a significant testosterone, estradiol interaction for the back slope on this task such that, t (13) = 2.70, p = .018. Forty-four percent of the variance in back slope can be accounted for by variation in hormones.

For females, in year 4, estradiol was predictive of front R2, t (21) = -1.80, p =.019. Higher estradiol was associated with decreased R2. There was also a testosterone, estradiol interaction such that, t (21) = 2.84, p = .009. Twenty-eight percent of the variance in R2 can be accounted for by variation in circulating hormones.

For males, in year 1, estradiol was predictive of the back intercept of this task, t (37) = 2.48, p = .018. (See Figure 29) Higher estradiol was associated with higher intercept (decreased reaction time). Seventeen percent of the variance in back intercept

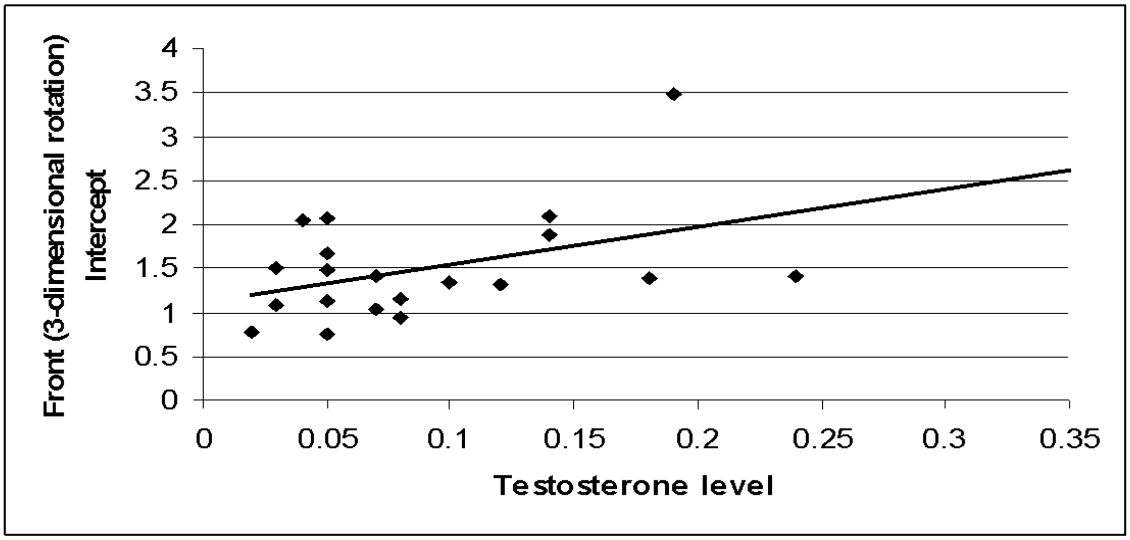

Figure 27. Year 3 females' performance on the front (3-dimensional rotation) condition of the Basketball Man task as a function of testosterone.

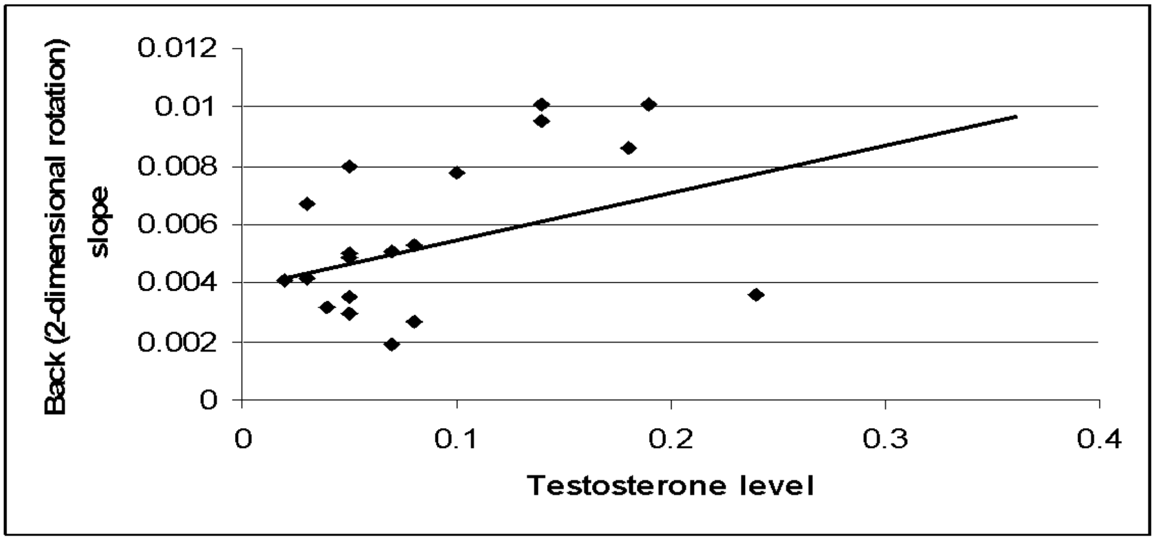

Figure 28. Year 3 females' performance on the back (2-dimensional rotation) condition of the Basketball Man task as a function of testosterone.

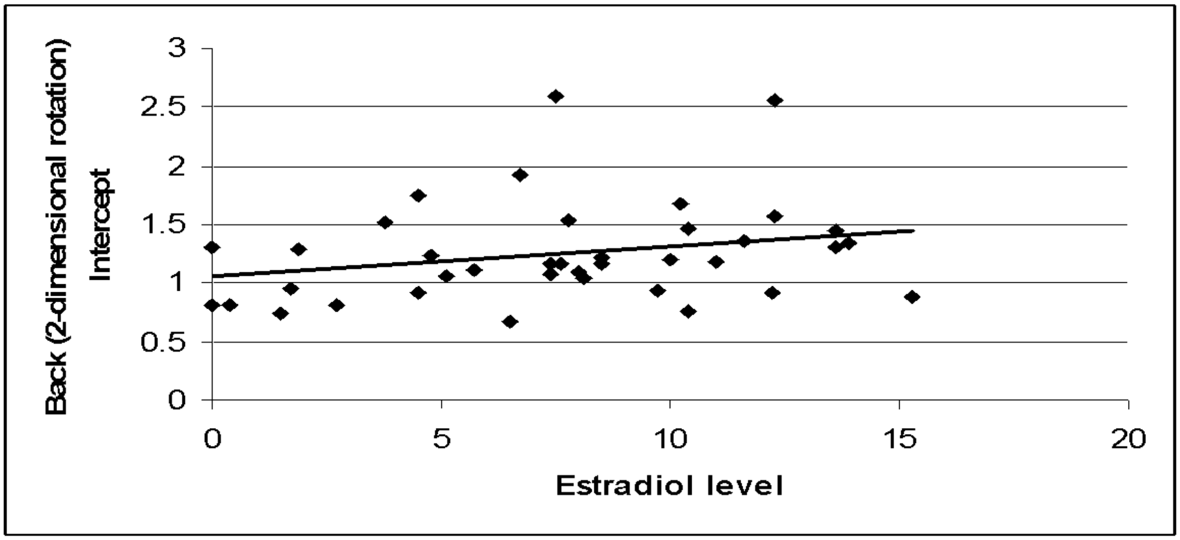

Figure 29. Year 1 males' performance on the back (2-dimensional) rotation condition as a function of estradiol.

can be accounted for by variation in hormones. For males, in year 2, testosterone was predictive of back intercept, t (29) = -2.16, p = .039. Higher testosterone was associated with lower back intercepts (decreased reaction times). Thirty-seven percent of the variance in back slope can be accounted for by variation in circulating hormones.

For males, in year 4, estradiol was predictive of the front intercept in this task, t (25) = 3.12, p = .004. (See Figure 30) Higher estradiol is associated with higher front intercept (increased reaction time). There was also a testosterone, estradiol interaction such that, t (25) = -2.27, p = .032. Forty-one percent of the variance in front intercept can be accounted for by variation in circulating hormones.

Water Level Task. For females in year 2, estradiol was predictive of performance on the 45/135 degree angle combination, t (54) = 1.96, p = .055. (See Figure 31) Higher estradiol was associated with decreased performance (increased degrees from horizontal). Eight percent of the variance in this task can be accounted for by variation in circulating hormones.

For females in year 4, testosterone was predictive of performance on the 45/135 degree angle combination, t (31) = 1.99, p = .055. Higher testosterone was associated with decreased performance (increased degrees from horizontal). Fourteen percent of the variance in this task can be accounted for my variation in circulating hormones.

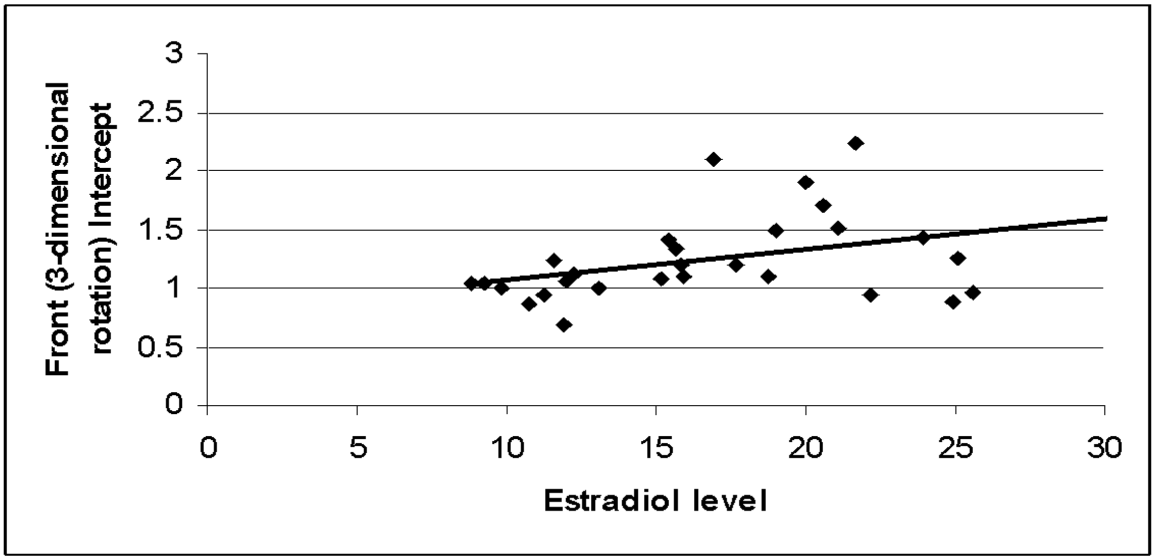

Figure 30. Year 4 males' performance on the front (3-dimensional rotation) condition of the Basketball Man task as a function of estradiol.

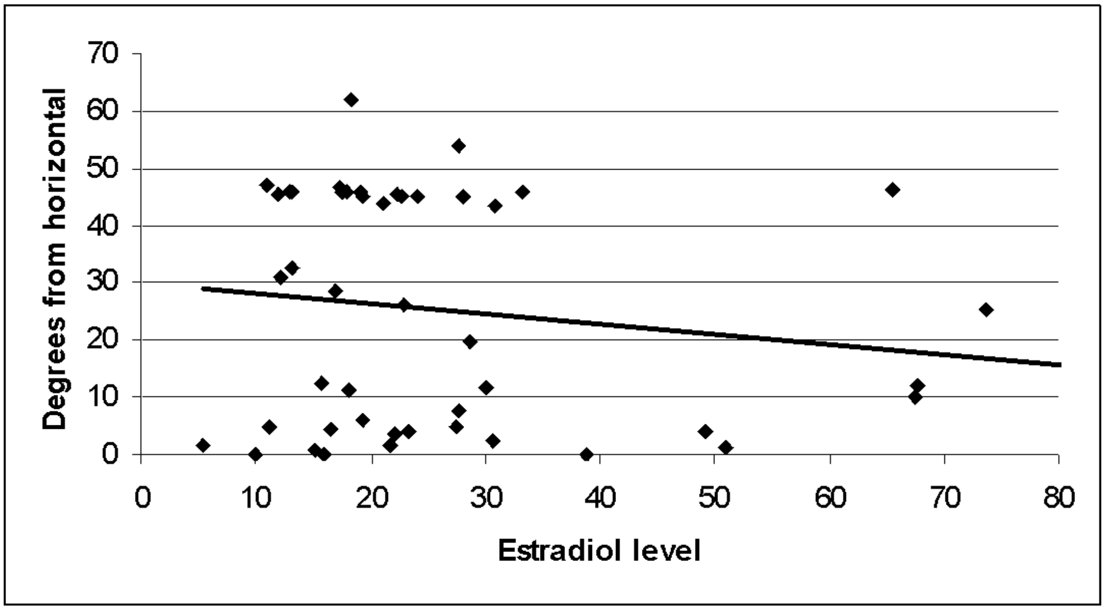

Figure 31. Year 2 females' performance on the 45/135 degree angle combination of the Water Level task as a function of estradiol.

Hypothesis VI

In order to investigate the hypothesis that hormone change will be correlated with change in task performance, the following analyses were conducted. Difference scores (change scores) were calculated for each hormone and each cognitive task for all four years. The difference between year 2 scores and year 1 scores will be referred to as difference score 1. The difference between year 3 scores and year 2 scores will be referred to as difference score 2. The difference between year 4 scores and year 3 scores will be referred to as difference score 3. Separate hormone x cognitive task regressions were performed for each difference score by sex. Only significant results will be reported here. [6]

Female-Advantaged Tasks

Purdue Pegboard Task. For females, difference score 2, change in estradiol was predictive of non-dominant hand performance, t (25) = -2.49, p = .019. (See Figure 32) A higher increase in estradiol was associated with decrease in performance (less pegs inserted). There was also a testosterone, estradiol interaction such that, t (25) = -2.47, p= .021. Forty-one percent of the variance in this task can be accounted for by variation in circulating hormone changes.

For females, difference score 3, change in estradiol was predictive of assembly performance on this task, t (16) = -2.17, p = .045. (See Figure 33) A higher increase in estradiol was associated with decreased in performance. Thirty-five percent of the variance on this task can be accounted for by variation in hormone changes.

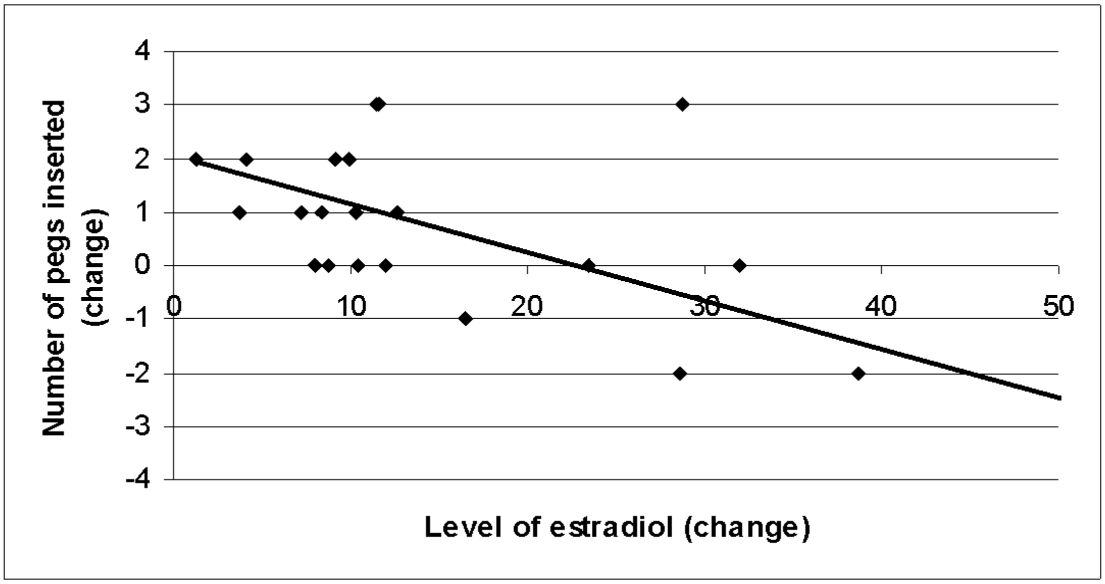

Figure 32. Females, difference score 2, on the non-dominant hand condition of the Purdue Pegboard task as a function of change in estradiol.

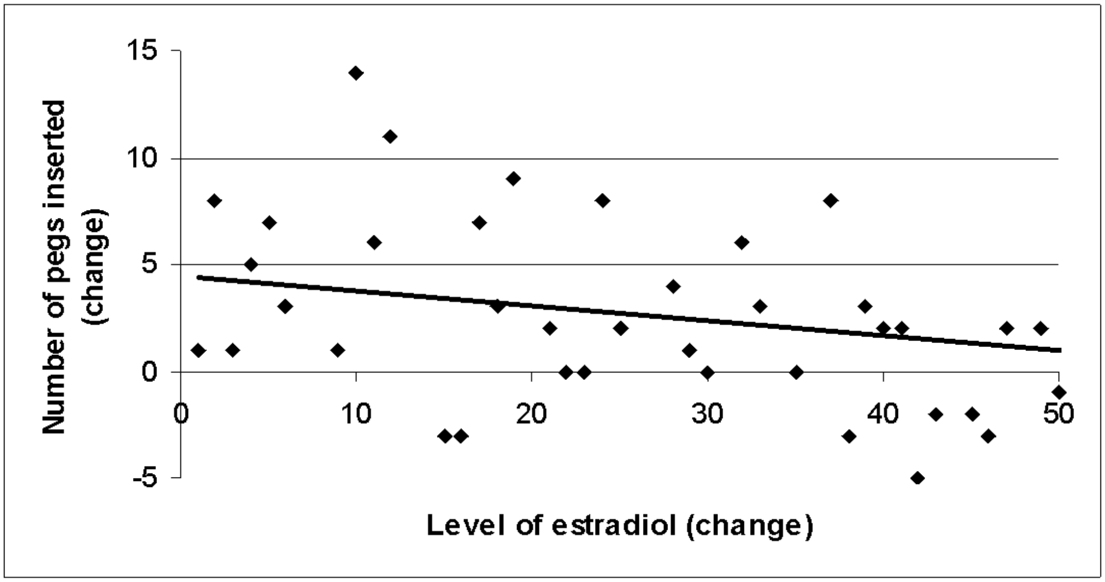

Figure 33. Females, difference score 3, performance on the assembly condition of the Purdue Pegboard task as a function of change in estradiol.

Object Memory: Additional Figures Task. There were no significant results for this task for either sex among all four years.

Object Memory: Relocated Figures Task. For males, difference score 2, change in testosterone was predictive of errors, $\underline{t}(30) = 2.10$, $\underline{p} = .04$. An increase in testosterone was associated with a decrease in performance (more errors). Change in estradiol was also predictive of errors, $\underline{t}(30) = -2.15$, $\underline{p} = .039$. A decrease in estradiol was associated with decreased performance. No other results were significant for this task among all four years. Seventeen percent of the variance in errors can be accounted for by variation in hormone change.

Male-Advantaged Tasks

Flags Task. There were no significant results for this task for either sex among all four years.

Basketball Man Task. Again for this task, participants with errors rates above .2 were excluded from these analyses. For males, difference score 1, change in estradiol was predictive of back (2-dimensional rotation), $\underline{t}(28) = 2.00$, $\underline{p} = .05$. An increase in estradiol was associated with higher r2. There was also a testosterone, estradiol interaction, $\underline{t}(28) = -2.05$, $\underline{p} = .05$. Eighteen percent of the variance in r2 can be accounted for by variation in hormone change.

For males, difference score 3, change in estradiol was predictive of front intercept, $\underline{t}(17) = 2.94$, $\underline{p} = .009$. An increase in estradiol was associated with higher intercept (increase reaction time). There was a significant testosterone, estradiol interaction on the front intercept variable of this task such that, $\underline{t}(17) = 2.45$, $\underline{p} = .025$. Thirty-seven percent of the variance in front intercept can be accounted for by variation in hormone change.

Water Level Task. For females, difference score 1, change in testosterone was predictive of performance on the 45/135 degree angle combination of this task, t (35) = 2.50, p = .017. An increase in testosterone was associated with decreased performance (increased degrees from horizontal). Seventeen percent of the variance in this task can be accounted for by variation in circulating hormones.

DISCUSSION

The results of the study will be discussed according to the six hypotheses in the order in which they were reported.

Hypothesis I

It was hypothesized that male and female adolescents' performance will significantly differ on each of the cognitive tasks in year 4. More specifically, year 4 males will perform superior to year 4 females on the "male-advantaged" tasks and year 4 females will perform superior to year 4 males on the "female-advantaged" tasks.

Female-Advantaged Tasks

Purdue Pegboard Task. Among adolescents there were no significant sex differences on any condition of this task beyond year 1 of the study. In the adult sample, significant sex differences (female superior) were found in the dominant hand condition, the non-dominant hand condition and the both hands condition. There was no significant sex difference among adults on the assembly condition.

It is interesting that, among adults, there were sex differences (female superior) in all conditions except the assembly condition. It is possible that finger size plays a role in fine manual dexterity. If this were the case, females would seem to have a distinct advantage over males due to their smaller hand/finger size. At first glance this may seem to account for the female superiority on three conditions, however, the assembly condition, more than the other three conditions, requires handling the smallest objects of the pegboard and this condition revealed no significant sex differences.

There are other explanations for lack of significance on this condition. One explanation for the lack of sex differences is that the assembly condition involves a fundamentally different skill than the other three conditions. The dominant hand and non-dominant conditions involve using a single hemisphere of the brain. On the both hands condition, both hemispheres are used simultaneously. The assembly condition is different because it requires a strategy and action of rapidly "switching" from one hemisphere to the other several times. Perhaps speed of hemispheric alteration is equivalent in males and females. In other words, perhaps the added "cognitive strategy" component of this condition masks the "raw speed/dexterity" component and renders the sexes equal.

The lack of sex differences in years 2, 3, and 4 suggest a possible practice effect. However, it seems unlikely that participants could demonstrate a practice effect on this type of task given there is a year between trials. Another possibility is that the sample of adults obtained was extraordinary in some way. This possibility can be rejected by the fact that Epting and Overman (1998) found almost exactly the same results in their sample of adults.

It is of course suggested that hormones play a role in these findings. Adolescent males have not yet reached adult testosterone level as of this fourth year of the study, yet they performed superior to adult males, this could be evidence for the optimal range theory or "not enough testosterone to hurt" theory. However, this theory still does not explain the female superiority in year one. Unfortunately, no one hypothesis completely explains these results.

Object Memory: Additional Figures and Relocated Figures Tasks. There were no significant sex differences in either task in years 1, 2, 3 or 4. In the adult sample there was only a marginally significant ($p = .059$) sex difference found for errors of omission on the Additional Figures task, females outperformed males. These results fail to replicate Eals and Silverman's (1992) findings of a significant female-advantage on these tasks among adolescents and adults. This is the second study from our lab that failed to replicate Eals and Silverman's (1992) findings (Epting & Overman, 1998). In fact, the authors themselves failed to replicate these findings two years later (Eals & Silverman, 1994). In summary, the evidence for sex differences in this task is inconsistent.

Male-Advantaged Tasks

Flags Task. There were no significant sex effects found for this task in years 1, 2, 3, or 4. As predicted, adult males outperformed adult females on this task. The results of this task will be discussed in further detail in "Hypothesis II".

Water Level Task. As mentioned in the results section, the 45 degree angle and the 135 degree angle conditions of this task were combined. Participants made very few errors on the 90 degree and 180 degree angles of this task, therefore, these two conditions were also combined.

Adult males significantly outperformed adult females in this task. There were also significant sex differences found in the adolescent sample in years 2 and 3, in the predicted direction (male superior). The lack of significant sex differences in years 1 and 4 are consistent with Nyborg's "Optimal Range" Theory (Nyborg, 1983). Nyborg used this theory to explain low spatial ability before puberty (year 1) and high spatial ability after puberty (year 4) in late maturing girls. The relationship between hormones and the Water Level task will be discussed later.

Basketball Man Task. Significant sex differences were found, in the predicted direction, of this task for the adult sample. Adult females had significantly steeper slopes (back and front) than adult males. Therefore, it can be said that males are more "efficient" rotators than females. While there were no significant sex differences in years 1 and 2 of the study, sex differences were found in years 3 and 4. All significant findings were in the predicted direction, with males having shallower slopes than females. These findings are consistent with Voyer, Voyer, and Bryden's (1995) findings that the magnitude of sex differences, on mental rotation tasks, are correlated with increases in age. The authors found no significant sex differences in participants below the age of 13 and always found sex differences with participants above age 18.

Hypothesis II

It was hypothesized that males' and females' year 4 performance scores would differ from years 1, 2, and 3 scores. Furthermore, year 4 scores would not differ from the adult population scores.

Female-Advantaged Tasks

Purdue Pegboard Task. Females in year 4, in the dominant hand condition of this task, outperformed females in years 1 and 2 as predicted, however, there was no difference between years 4 and 3. As predicted, by year 4, adolescent females' performance equaled that of adults' (See Table 18). Year 4 males outperformed males in year 1. Interestingly, males in year 4 also outperformed adult males (See Table 19). This further supports the theory of a nonlinear relationship between hormone levels and certain abilities (Hampson & Kimura, 1992), in that males may not have reached a testosterone level high enough to effect performance on this task.

Females in year 4, in the non-dominant hand condition of this task, again outperformed females in years 1 and 2 as predicted, however, there was no difference between year 4 and year 3. There was no difference between adult performance and year 4 performance as predicted. Year 4 males outperformed males in year 1 as well as adult males. The results of this condition mirror the results of the dominant hand condition.

Year 4 females, in the both hands condition of this task, outperformed females in year 2. Year 4 males outperformed year 1 males.

Year 4 females, in the assembly condition, outperformed females in years 1 and 2. Year 4 males performed superior to males in years 1 and 2 also.

Table 18

Adolescent and adult female performance comparison on the Purdue Pegboard task.

CONDITION	**YEARS 1, 2, 3 AND 4 COMPARISON**	**YEARS 1, 2, 3 AND 4 COMPARISON TO ADULTS**
Dominant Hand	Years 2, 3, 4 > 1 Year 4 > 2	Adults > 1
Non-dominant Hand	Years 3, 4 > 1 Year 4 > 2	Adults > 1
Both Hands	Years 3, 4 > 1 Year 4 > 2	Adults > 1
Assembly	Years 3, 4 >1 Year 4 >2	Adults > 1, 2

Table 19

Adolescent and adult male performance comparison on the Purdue Pegboard task.

CONDITION	**YEARS 1, 2, 3 AND 4 COMPARISON**	**YEARS 1, 2, 3 AND 4 COMPARISON TO ADULTS**
Dominant Hand	Years 3, 4 > 1	Year 4 > Adults
Non-dominant Hand	Years 2, 3, 4 >1	Year 4 > Adults
Both Hands	Years 3, 4 >1	No sig. differences
Assembly	Years 3, 4 > 1 Year 4 > 2	Adults > 1

In conclusion, females' year 4 performance scores are no different than adult performance scores on this task as expected. Year 4 males outperformed adults on the dominant hand and the non-dominant hand conditions of this task. The fact that male testosterone level has not yet reached adult level is not a sufficient enough explanation for these findings. Again, no one theory can be used to explain these mixed results.

There seems to be a trend among adolescents, where year 4 scores are different than all years except year 3 scores among conditions. This trend follows the hormone trend in which females in year 4 had a higher estradiol level than in years 2 and 1, but not different than year 3. Year 4 females also had higher progesterone levels than females in years 1 and 2, but no different than year 3. Hampson (1990) found that females performed better on tests of manual coordination during the time in their menstrual cycle when estrogen and progesterone are high. Kimura and Hampson (1994) found that women performed better at manual sequencing tasks when on estrogen replacement therapy than when off estrogen replacement therapy. The authors noted that these dexterity tasks appeared to be more sensitive to fluctuations in estrogen than spatial tasks, which may be more influenced by fluctuations in testosterone. Janowsky, Oviatt, and Orwoll (1994) also found that increases in testosterone were not associated with increased performance on tests of fine motor dexterity (The Grooved Pegboard Test). The relationship between hormones and the Purdue Pegboard task will be discussed in greater detail later.

Object Memory: Additional Figures Task. Females in year 4 made significantly fewer errors of commission and errors of omission than year 1 females. Year 4 males also made significantly fewer errors of omission than year 1 males. Year 4 performance scores were not different from the adult sample performance scores as expected.

Object Memory: Relocated Figures Task. Again, females in year 4 made significantly fewer errors than year 1 females. Year 4 females' performance was not significantly different than adult females' performance as predicted.

The results of this task, at first glance, suggest a practice effect from year to year, however, this is unlikely for two reasons. One, the length of time given to study the items on the page is short (30 seconds) compared to the length of time between test sessions (one year). Also, year 4 performance is equal to that of adults, who had no practice. Another possibility is that adolescent memory is getting better across years. However, perhaps the most likely explanation lies in the understanding of instructions for this task. Although there is no empirical data to support this explanation, experimenters report having to explain the instructions of the task several times to younger participants.

Male-Advantaged Tasks

Flags Task. (See Table 20) Year 4 females outperformed females in years 1 and 2. Again, year 4 females' performance did not differ from females' year 3 performance. Interestingly, year 4 females outperformed adult females. Year 4 males outperformed year 1 males. There was no difference between year 4 males' performance and adult performance on this task as predicted. It should be noted that performance on this task may be heavily influenced by "understanding" of the task directions. Experimenters found it was necessary to make "cut-outs" of the flags and manually exhibit to the adolescent participants, how the flags could be rotated in different ways. Adolescent participants were also allowed to practice the task and were asked to demonstrate correct performance before being allowed to begin. Adult participants were simply read the task instructions. It may be the case that adult females, who were given task directions only once, may not have understood the task as well as year 4 females, who were given the task directions several times and in different ways over the years. Adult males, it seems, understood the task after having the directions read only once.

Water Level Task. Year 4 females outperformed females in year 1. There was no significant difference between adult females and year 4 females as predicted. Year 4 males outperformed males in year 1. There was no significant difference between adult males and year 4 males as predicted. Adolescent's performance began to approach adult performance level in year 2 of the study. These findings are somewhat inconsistent with Voyer, Voyer, and Bryden's (1995) findings that spatial perception performance increases with increases in age.

Basketball Man Task. Year 4 females had a significantly lower intercept (front and back) than females in years 1 and 2. Year 4 females also had a shallower back slope than females in years 1 and 3. Year 4 females' performance did not differ from adult females' performance. Year 4 males' also had lower intercepts than males in year 1.

There appears to be no difference between year 4 males' performance and adult performance on this task. These findings were all found to be in the predicted direction.

It should be noted that the only true measure of reaction time for this task is the back (two dimensional) rotation condition. The front (three dimensional) condition is more a measure of mental rotation. Figure 34 is an example, in theory, of how the data of these two conditions should look.

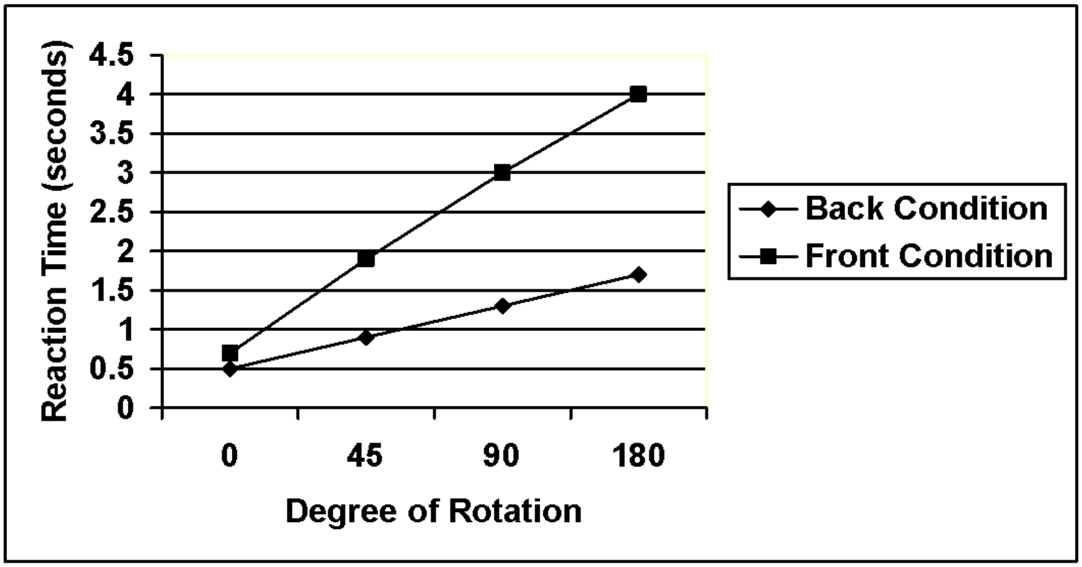

Figure 34. Theoretical example of data from the Basketball Man task.

Table 20

Year 4 males and females performance as compared to years 1, 2, 3 and adults on the Flags task.

GENDER	**YEARS 1, 2, 3 AND 4 COMPARISON**	**YEARS 1, 2, 3 AND 4 COMPARISON TO ADULTS**
MALES	Years 2, 3, 4 >1	Adults > Year 1
FEMALES	Years 2, 3, 4 > 1 Year 4 > 2	Year 4 > Adults

Table 21

Male and females performance comparison in years 1, 2, 3, 4 and adults on the front slope variable of the Basketball Man task.

GENDER	**YEAR 1, 2, 3, and 4 COMPARISON**	**YEAR 1, 2, 3, and 4 COMPARISON TO ADULTS**
MALES	No significant differences	No significant difference
FEMALES	No significant differences	Year 1 > Adults

* (> = steeper slope)

Table 22

Male and females performance comparison in years 1, 2, 3, 4 and adults on the back slope variable of the Basketball Man task.

GENDER	**YEAR 1, 2, 3, and 4 COMPARISON**	**YEAR 1, 2, 3, and 4 COMPARISON TO ADULTS**
MALES	No significant differences	Year 1 > Adults
FEMALES	Years 1, 3 > 4	Years 1, 3 > Adults

* (> = steeper slope)

Table 23

Male and females performance comparison in years 1, 2, 3, 4 and adults on the combined slope variable of the Basketball Man task.

GENDER	**YEAR 1, 2, 3, and 4 COMPARISON**	**YEAR 1, 2, 3, and 4 COMPARISON TO ADULTS**
MALES	No significant differences	No significant difference
FEMALES	Year 1 > 2, 4	Year 1 > Adults

* (> = steeper slope)

Table 24

Male and females performance comparison in years 1, 2, 3, 4 and adults on the front intercept variable of the Basketball Man task.

GENDER	**YEAR 1, 2, 3, and 4 COMPARISON**	**YEAR 1, 2, 3, and 4 COMPARISON TO ADULTS**
MALES	Year 1 > 2	Years 1, 3 > Adults
FEMALES	Year 2 > 4	Years 1, 2 > Adults

* (> = higher intercept)

Table 25

Male and females performance comparison in years 1, 2, 3, 4 and adults on the back intercept variable of the Basketball Man task.

GENDER	**YEAR 1, 2, 3, and 4 COMPARISON**	**YEAR 1, 2, 3, and 4 COMPARISON TO ADULTS**
MALES	Year 1 > 4	Years 1, 2, 3 > Adults
FEMALES	Year 1 > 3, 4	Years 1, 2 > Adults

* (> = higher intercept)

Table 26

Male and females performance comparison in years 1, 2, 3, 4 and adults on the combined intercept variable of the Basketball Man task.

GENDER	**YEAR 1, 2, 3, and 4 COMPARISON**	**YEAR 1, 2, 3, and 4 COMPARISON TO ADULTS**
MALES	Year 1 > 2	Years 1, 2, 3 > Adults
FEMALES	Year 1 > 3, 4 Year 2 > 4	Year 1, 2 > Adults

* (> = higher intercept)

In summary, it can be said that although there is a hint of an increase in efficiency for female adolescents, in general, adolescents do not become more efficient (shallower slope) with increases in age, however, they do become faster (lower intercept) in this task.

Hypothesis III

It was hypothesized that males and females will differ in hormone levels in year 4. Specifically, males will have higher testosterone levels than females and females will have higher estradiol levels than males.

Testosterone

As predicted, males had greater levels of testosterone than females in each year of the study, as well as in the adult sample.

Estradiol

As predicted, females had greater levels of estradiol than males in each year of the study, as well as in the adult sample.

Hypothesis IV

It was hypothesized that hormone levels for males an females would increase each year and begin to approach adult hormone level in year 4 of the study.

Testosterone

Year 4 males' testosterone levels were higher than testosterone levels in years 1, 2, and 3 as predicted. However, year 4 males have not yet reached adult testosterone level. Year 4 females have reached adult hormone level with respect to testosterone as predicted.

Estradiol

Year 4 males had higher estradiol levels than males in years 1 and 3. However, year 4 males have not yet reached adult estradiol level. Year 4 females had higher estradiol levels than females in year 1. Year 4 females have reached adult estradiol level, and in fact have been at adult level since year 2 of the study.

In conclusion, while adolescent females in year 4 of the study have reached adult hormone level, adolescent males are still hormonally immature as compared to adults.

Hypothesis V

It was hypothesized that there would be positive correlations between estradiol level and negative correlations between testosterone level and scores on the "female-advantaged" tasks. It was also hypothesized that there would be positive correlations between testosterone and negative correlations between estradiol on the "male-advantaged" tasks.

Female-Advantaged Tasks

Purdue Pegboard Task. Contrary to predictions, estradiol was negatively associated with performance on this task (non-dominant hand condition) for females in year 1 of the study. For males, estradiol was also negatively associated with performance on this task (assembly condition) in years 1 and 2. However, for males in year 1 and 2, testosterone was negatively associated with this "female-task" performance (assembly condition) as predicted.

Object Memory: Additonal Figures Task. For males, in years 1 and 2, testosterone was negatively associated with performance on this task as predicted. However, estradiol was also negatively associated with performance for males in year 2.

Male-Advantaged Tasks

Flags Task. For females, in year 3, testosterone was positively associated with performance on this task as predicted.

Water Level Task. For females, in year 2, estradiol was negatively associated with performance on this task as predicted. However, for females, in year 4, testosterone was also negatively associated with performance, contrary to expectations.

Basketball Man Task. For females, in year 3, testosterone was positively associated with performance as expected. Higher testosterone was associated with faster reaction times and flatter slopes. For males, in years 1 and 4, estradiol was negatively associated with performance as expected. Higher estradiol was associated with slower reaction time. For males, in year 2, testosterone was positively associated with performance as predicted. Higher testosterone was associated with faster reaction time.

Hypothesis VI

It was hypothesized that magnitude of hormone change would be correlated with change in task performance. Specifically, participants with greater hormonal change will perform worse than participants with gradual hormonal changes.

Female-Advantaged Tasks

Purdue Pegboard Task. For females, greater increases in estradiol were associated with less improvement on this task as predicted. This was true for females from year 2 to year 3 on the non-dominant hand condition as well as females from year 3 to year 4 on the assembly hand condition.

Object Memory: Relocated Figures Task. For males, greater increases in testosterone were associated with smaller improvements in performance as predicted. This was found for males from year 2 to year 3. However, greater increases in estradiol were associated with greater improvements in performance during this same time.

Male-Advantaged Tasks

Water Level Task. For females, greater increases in testosterone were associated with smaller improvements in performance on this task as predicted. This was found for females from year 1 to year 2.

Basketball Man Task. For males, greater increase in estradiol was associated with greater increase in intercepts (increase reaction time). This result was in the predicted direction.

CONCLUSION

The complex results of this study are somewhat hard to summarize. Some findings are consistent with previous research while others contradict previous research. Some findings are in the predicted direction while others are in the opposite direction. The fact remains that there are sex differences in adults that appear to be correlated with circulating testosterone and estradiol. In adolescents, many significant sex differences found were in the predicted direction. The findings of the relationship between these sex differences and circulating hormones are mixed.

It is suggested (Kimura & Hampson, 1992) that, because the size of hormonal effects on cognition, memory, and motor speed is small, it is difficult to isolate and distinguish these effects experimentally. Nonetheless, it is important to continue to investigate these small effects in order to develop new hypotheses regarding hormonal effects on the human brain and cognition.

Perhaps the most surprising finding of the present study may be the fact that 16 year-old males are still hormonally immature as compared to young adults. This evidence should encourage future researchers to continue to follow participants from late adolescence into adulthood. Finally, it should be noted that implementing a more advanced level of statistical analysis could reveal more detailed conclusions regarding these hypotheses.

FOOTNOTES

The following notes include the results for each hypothesis when the Bonferonni correction procedure was applied.

[1]The Bonferroni correction procedure for Hypothesis I resulted in an α of .0002. With this correction applied, there are still significant effects of sex for Hypothesis I.

[2]The Bonferroni correction procedure for Hypothesis II resulted in an α of .0005. With this correction applied, the majority of effects of year would still be significant for Hypothesis II.

[3]The Bonferroni correction procedure for Hypothesis III resulted in an α of .003. With this correction applied, all of the sex effects for testosterone and estrogen would still be significant.

[4]The Bonferroni correction procedure for Hypothesis IV resulted in an α of .003. With this correction applied, all of the effects of year would still be significant.

[5]The Bonferroni correction procedure for Hypothesis V resulted in an α of .0001. With this correction applied, no effects for Hypothesis V would be significant.

[6]The Bonferroni correction procedure for Hypothesis VI resulted in an α of .0002. With this correction applied, no effects for Hypothesis VI would be significant.

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APPENDIX A

Appendix A. Letter sent to parents of adolescents.

UNCW

THE UNIVERSITY OF NORTH CAROLINA AT WILMINGTON

ANNOUNCING: YEAR FOUR OF THE MIDDLE SCHOOL LEARNING PROJECT!

To the parents of ,

We are pleased to announce the beginning of the fourth year of the Middle School Learning Project. Thanks to you and your child, years one, two and three were a great success with about 200 parents and children participating. Year four promises to tell us even more about the role of hormones on learning in adolescents.

This year we are able to offer some new incentives for your participation.
Parents' Prize: A $15 gift certificate from Harris Teeter, this certificate will be honored at any Harris Teeter grocery store.

Child's Prizes: A gift certificate for Millenium Music and a gift bag with various coupons and other prizes.

Please remember that it is **critical** for your child to be tested all four years of the project for us to get an accurate picture of learning changes that occur during puberty. *** **NOTE: Within the next month we will be calling you to schedule an appointment for you and your child.**

If you have any questions, you may call research assistants Krisha Frassrand or Shi Ansel at 962-7147 or Dr. William Overman at 962-3379 and leave a message if no one is in either office.

Thank you very much for your participation in this very important project.

Sincerely,

William Overman, Ph.D. Principal Investigator	Shi Ansel Graduate Research Assistant	Krisha Frassrand Research Assistant

Date your child was tested year one:

APPENDIX B

Appendix B. Informed Consent Form.

INFORMED CONSENT

The following study is being conducted to examine how hormones affect learning. You will complete six (6) short paper and pencil tasks.

In addition, an experienced nurse will be giving you a finger prick in order to obtain a few drops of blood on a collection card. We will send the drops of blood to a lab in order to measure hormone levels. Finally, you will be asked to fill out a short questionnaire.

All of the information you provide us is strictly confidential. Code numbers, not names, will be used in the data analysis.

Again, all of the information is confidential. No names will be used in the data analysis or in written reports.

Your participation is completely voluntary, and you may choose to leave at any time without penalty. Thank you for your participation in this important study.

This study may not have direct benefits and applications to the immediate participants, but we hope that, in the future, what we learn by your participation will help us understand how hormones affect learning and thinking.

I have read and understand the above information. By signing this consent form, I am indicating that I am voluntarily participating in this study. I understand that I may withdraw at any time without penalty.

________________	________	____________________	________
Your signature	Date	Witness's signature	Date

APPENDIX C

Appendix C. Subject Information Sheet.

Survey

1. Middle School attended: ______________________________

2. High School attending: ______________________________

3. Birthday: Month __________ Date __________ Year __________

4. What is your race? Please circle.

   Caucasian African-American Hispanic Asian Native American

   Other ____________________

5. Do you take any medications on a regular basis? If so, please indicate.

6. Did you take any medications today, that you do not usually use, such as cough syrup or a decongestant?

7. Are you diabetic or do you have any other medical conditions?

8. Height______________ Weight______________

Females Only

9. Have you started your period? Please circle. Yes No

   If yes, when did you experience your first period? If you are not sure, please try to make an accurate guess.

   __________ Year _________

   When was the first day of your last period? Month __________ Day __________

   Do you have your period every month? Yes No

   If yes, how many days per month are you on your period? 1 2 3 4 5 6 7

10. Do you take/use any of the following birth control methods? Please circle.

    Birth Control Pills Depo-Provera Norplant

    Other (Please indicate) ______________________________

APPENDIX D

Appendix D. Parent Information Sheet.

Confidential Information about parents

1. Mother's date of birth .... ____ mo ____ yr
2. Highest level of education completed by mother? _____years
3. Occupation of mother (please be as specific as possible): ________

   ____

4. Father's date of birth .... ____ mo ____ yr
5. Highest level of education completed by father? _____ years
6. Occupation of father (please be as specific as possible): _________

   ____

7. With whom does the child live? ____ Mother ____Father ____Both
8. Please list child's brothers and sisters (and ages) who are living at home:

Child's Name	Age	Child's Name	Age

9. Total family income last year:

   ____ Below $12,000   ____ $12,001 - $16,000

   ____ $16,001 - $20,000   ____ $20,001 - $30,000

   ____ $30,001 - $40,000   ____ $40,001 - $50,000

   ____ over $50,000

THANK YOU FOR RESPONDING TO THIS QUESTIONNAIRE.

PLEASE RETURN IT IN THE SELF ADDRESSED ENVELOPE TO DR. WILLIAM OVERMAN, UNC-W PSYCHOLOGY DEPARTMENT