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Mental Rotation at 7 Years: Relations with Prenatal Testosterone Levels and Spatial Play Experiences

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Biological and social-experiential factors appear to play a role in the male advantage in spatial abilities. In the present study, relations among prenatal testosterone levels, spatial play experiences, and mental rotation task performance were explored in 7-year-old boys and girls. A positive correlation was observed between prenatal testosterone levels and rate of rotation in girls. The findings were less clear for boys, but suggested the opposite pattern of results. Relations between spatial play preferences and mental rotation task performance were not observed in children of either sex. These findings are consistent with the hypothesis that testosterone acts on the fetal brain to influence the development of spatial ability.

It is widely acknowledged that males perform better than females on tasks requiring spatial ability (Linn & Petersen, 1985; Maccoby & Jacklin, 1974) with the most robust male superiority appearing on tasks that require mental rotation (Linn & Petersen, 1985; Voyer, Voyer & Bryden, 1995). Although Maccoby and Jacklin (1974) concluded that sex differences in spatial ability do not emerge until adolescence, more recent studies have observed such differences in children (e.g., Kerns & Berenbaum, 1991). Both biological and social-experiential hypotheses have been proposed to account for the

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male advantage. Theories about biological influences include early exposure to masculinizing hormones (Geschwind & Galaburda, 1987; Hines & Shipley, 1984; Money & Ehrhardt, 1972; Reinisch, 1974; Reinisch, Gandelman, & Spiegal, 1979; Resnick, Berenbaum, Gottesman, & Bouchard, 1986), and sex differences in cerebral lateralization and brain structure (Levy & Reid, 1978; McGlone, 1980). Social-experiential influences include sex role socialization and motivational factors, but most research interest has focused on understanding the role of experiences and activities requiring spatial abilities, such as involvement in 'masculine' play (Baenninger & Newcombe, 1989; Nash, 1979; Newcombe, Bandura, & Taylor, 1983; Sherman, 1967; Fagot & Littman, 1976; Serbin & Connor, 1979).

The purpose of the present study is to examine the relations among prenatal testosterone (T) exposure, spatial play experiences, and mental rotation performance at age 7. More specifically, T levels from the second trimester of fetal development and spatial play experiences are examined in relation to a chronometric measure of mental rotation in 7-year-old girls and boys.

THE TESTOSTERONE HYPOTHESIS

In animals, T acts on the developing brain during critical periods of pre- or neonatal development to masculinize postnatal behavior (Goy & McEwen, 1980). In early studies, the influence of prenatal T exposure and deprivation on reproductive behavior was examined. More recently, studies have explored influences on nonreproductive behaviors such as spatial ability where it has been observed that early exposure to gonadal steroids improves learning on a radial-arm maze task in female rats (Beatty, 1979, 1984; see review by Williams & Meck, 1991). Some researchers have suggested that prenatal T may have demasculinizing effects on behavior in males (see review by Reinisch, Ziemba-Davis, & Sanders, 1991), although this hypothesis is not fully supported and no prenatal effects on spatial ability in males have been observed. Several researchers, however, have reported inverse relations between circulating adult T levels and spatial ability in males (Gouchie & Kimura, 1991; Shute, Pellegrino, Hubert, & Reynolds, 1983).

Geschwind and Galaburda (1987) also have proposed relations between prenatal T and spatial ability. Specifically, they hypothesize that T acts on the developing brain to slow growth in the left hemisphere, leading to compensatory development of the right hemisphere and enhanced spatial abilities. Very high levels of T, however, may affect both left and right hemisphere development, leading to diminished spatial abilities. Accordingly, they propose a curvilinear relation (inverted U) between prenatal T and spatial ability, with optimal levels in the low male range. Thus, they predict positive relations between prenatal T and spatial ability in girls and negative relations in boys (see McManus & Bryden, 1991).

In humans, it has not been possible to study the relations between prenatal

T exposure and spatial ability directly because of the inability to manipulate prenatal hormone levels. Most investigations, therefore, have examined populations with atypical prenatal hormone exposure. One such group is individuals with congenital adrenal hyperplasia (CAH), a condition in which an inborn error of metabolism results in the prenatal production of very high levels of adrenal androgens. The most carefully controlled study to date (Resnick et al., 1986) found that adolescent girls and adults with CAH performed better than unaffected controls on paper-and-pencil tests of mental rotation ability (i.e., Card Rotations and Mental Rotations). No effects were seen in males with CAH.

Another population of interest are children of mothers who were treated with diethylstilbestrol (DES) during pregnancy. DES is a synthetic estrogen that has potent masculinizing effects in fetal animals (Goy & McEwen, 1980). One study in humans reported no differences between DES daughters and their unexposed sisters on a mental rotation task (i.e., Spatial Relations subtest of the Primary Mental Abilities Test; Hines & Shipley, 1984).

Findings from studies of atypical populations are limited with regard to generalizations that can be made about the relation between prenatal androgens and the development of spatial abilities in normal individuals. Individuals with CAH have an atypical exposure to other hormones as well, such as corticosteroids and progesterone (Greenspan & Forsham, 1986). Moreover, hormone levels may not be adequately controlled after birth, so the influences of pre- and postnatal hormones cannot be disentangled. Finally, the possibility cannot be ruled out that the gene causing CAH may influence spatial ability. Similar constraints limit interpretation of findings from studies of samples exposed to DES. For example, the mothers of children exposed to DES have been treated with exogenous steroids, confounding interpretations of the effects of normal prenatal exposure.

In an attempt to examine hormone–behavior relations in a normal population, Jacklin, Wilcox, & Maccoby (1988) explored the relation between androgen levels in umbilical cord blood sampled at birth and spatial ability at 6 years. Girls with higher perinatal T levels had lower levels of spatial ability as assessed with the spatial relations subtest of the Primary Mental Abilities Test, a test involving mental rotation. No relations were observed in boys. These findings are contradictory to those observed in adolescent girls with CAH. Although the method of using hormone levels from cord blood does permit investigation of hormone–behavior relations in normal samples, the effects of labor and delivery on circulating androgen levels are unknown. In addition, hormone levels obtained from cord blood may be unrelated to levels in midgestation when maximal sex differences in T levels are observed, and when androgens are believed to exert their effects on the developing brain (Nagmani, McDonough, Ellegood, & Mahesh, 1979; Abramovich & Rowe, 1973).

We have attempted to overcome the limitations in previous studies by using prenatal T levels from the second trimester as measured in amniotic fluid obtained by amniocentesis (Finegan, Bartleman, & Wong, 1989). Previously, we examined the relation between prenatal T and cognitive abilities at age 4 (Finegan, Niccols, & Sitarenios, 1992). Inverse relations between prenatal T and Block Building scores on the McCarthy Scales of Children's Abilities, a test of spatial visualization (Linn & Petersen, 1985) were observed in girls and no relations were observed in boys (Finegan et al., 1992). The inverse relation we observed between prenatal androgen exposure and spatial ability in normal girls is consistent with relations observed by Jacklin et al. (1988), but is contradictory to relations observed in atypical samples, and to those predicted by the testosterone hypothesis. In the present paper, we apply our method to the study of mental rotation at age 7.

THE SPATIAL EXPERIENCE HYPOTHESIS

Differential exposure to spatial play activities also has been proposed to account for the male advantage with spatial tasks (Newcombe, Bandura, & Taylor, 1983; Sherman, 1967). There are, for example, small but significant relations between retrospective accounts of spatial activity and mental rotation ability (Baenninger & Newcombe, 1989), and two studies with preschoolers have revealed positive relations between play with ''boys' toys'' and enhanced abilities in spatial visualization (Connor & Serbin, 1979; Fagot & Littman, 1976; Serbin & Connor, 1979). Recently, Voyer and Isaacs (1993) reported that participation in sports involving spatial ability predicted enhanced performance on a test of mental rotation (Vandenberg & Kuse, 1978) in university undergraduates.

Although it is possible that prenatal T exposure and spatial play experiences contribute independently to individual differences in spatial ability, it is also possible that influences of prenatal T could be mediated through an effect on play behavior. Goy (1968) found that sexually dimorphic play behavior in rhesus monkeys was influenced by prenatal T exposure, and in humans, girls with CAH were found to have a higher level of preference for boys' toys than their unaffected female relatives (Berenbaum & Hines, 1992).

MENTAL ROTATION TASKS

Care must be taken when examining relations between prenatal T or spatial experience and mental rotation ability because the measures used may not be sufficiently sensitive. On paper-and-pencil tests of mental rotation, for example, subjects may use a wide range of strategies, only some of which may be influenced by prenatal T exposure or spatial experience. Such tests typically yield a single total score, which cannot capture the subjects's strategy, or tap performance on components of the task. The locus of sex differences in mental rotation could lie in accuracy, rate of rotation, speed in perceptual matching, checking, simple reaction time, or in strategy. For these reasons, subjects in the present study completed a chronometric mental rotation task (see Cooper & Shepard, 1973; Shepard & Metzler, 1971) to permit the independent examination of strategy, accuracy, rate of rotation, and perceptual speed. Each of these variables then can be examined in relation to prenatal T levels and spatial play experiences.

METHOD

Subjects

Participants were 60 7-year-old children (29 girls and 31 boys) who have been followed since the second trimester in order to study the effects of amniocentesis on developmental outcome (Finegan et al., 1984, 1990). Mothers of children in the sample were healthy and were eligible for amniocentesis because they were over age 35 at the time of their child's birth.

Procedure

Within 2 months of their seventh birthday, the children completed a computer-presented mental rotation task as part of a test battery, while parents completed a questionnaire about their child's play preferences. The children were tested by an individual who was blind to individual children's T levels. Three parents did not complete the questionnaire, and 16 children did not complete the mental rotation task because they failed to pass criterion (see below).

Testosterone levels. Amniotic fluid samples obtained between 14 and 20 weeks gestation had been frozen and were available for assay (29 females and 31 males; see Finegan et al., 1989). Amniotic fluid T was measured by radioimmunoassay (Wong, Wood, & Johnson, 1975) and quality control tests confirmed the precision, stability, and reproducibility of the assays. The means and standard deviations were not significantly different from those determined for a larger sample by the same laboratory (Wong, Doran, Falk, Taylor, & Mee, 1980). Testosterone levels in our sample did not vary as a function of birth order (cf. Maccoby, Doering, Jacklin, & Kraemer, 1979).

Levels of T in amniotic fluid vary as a function of gestational age (Nagamani et al., 1979); therefore, the relation between T level and gestational age was examined for our sample. There was a positive linear relation in females, $r(27) = .59$, $p < .01$. Regressing T on gestational age for females resulted in a regression equation of $T = -26.20 + 2.59$ gestational age ± error. The coefficient associated with the slope of this equation was significantly different from zero, $t(27) = 3.82$, $p < .001$. Quadratic relations were not observed. Variations in T levels obtained from the females in our sample, therefore, were a function of both individual differences in T concentration and gestational age when the levels were obtained. For females, the coefficient for the regression equation indicated that T levels increased an average of 2.59 ng/dl per week during the period when gestational age was between 14 and 20 weeks. Because individual differences in T level were of primary interest, levels were corrected for gestational age by calculating the best estimate of T level for each subject at the median gestational age of 16 weeks.

In male fetuses, there were no significant linear or quadratic relations between T levels and gestational age when the amniotic fluid samples were obtained. For consistency and ease of interpretation, T levels for males also were corrected even though their levels were unrelated to gestational age, $r(29) = -.10$, n.s., based on the regression equation $T = 59.73-1.25$ gestational age ± error. Corrected T levels were used in all subsequent analyses.

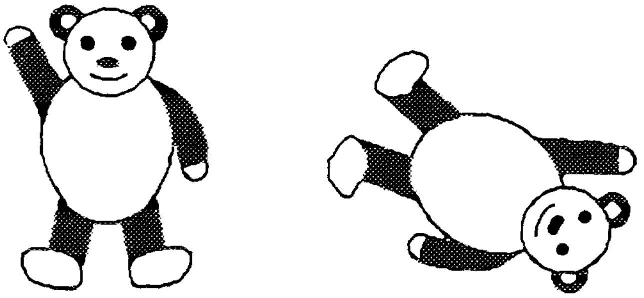

FIG. 1. A sample trial at 120° of rotation. Subjects decide whether the bears have same or different arms raised.

Spatial play experiences. Spatial play experiences were assessed by parent-report using the Child Games Inventory (Bates & Bentler, 1973) which lists 65 children's games and activities. Parents indicated whether or not their child regularly engages in each game or activity and showed to what extent the child enjoys the activity on a 5-point scale ranging from (1) *little enjoyment* to (5) *great enjoyment.* The item was scored as "0" if the child never participated in the activity. A spatial play experiences measure was calculated for each child, based on the mean score for 19 items that were identified by the authors as spatial in nature. Spatial items were activities that required the spatial manipulation of objects (Resnick et al., 1986), or were sports obviously requiring spatial ability (Voyer & Isaacs, 1993). These spatial items are listed in the Appendix.[1]

Mental rotation: The teddy bear game. A computer-presented version of a task devised by Marmor (1975, 1977), which involves mental rotation was developed to be presented on a Macintosh computer (Niccols & Finegan, 1987). In the experimental trials, two black and white bear forms were displayed simultaneously. For half the presentations, the bears had the same arm raised and, in the remaining presentations, they had different arms raised. Children indicated their response—*same* or *different*—by pushing one of two buttons. The bear on the right-hand side of the display screen was presented in an upright position or rotated 30°, 60°, 90°, 120°, 150°, or 180° clockwise within the picture plane, while the bear on the left-hand side of the screen remained upright. An example of a *same* pair is presented in Fig. 1.

The experimental procedure had four parts: (a) pre-training on *same/different* judgments (4 trials), (b) criterion test (10 to 24 trials), (c) pretraining on the rotation task (10 trials), and (d) experimental test (42 trials). The task required 15 to 30 min to complete.

The ability to discriminate between *same* and *different* was assessed with a criterion test in which equal numbers of *same* and *different* pairs were displayed in random order. On each trial, two teddy bears were presented simultaneously in the upright position (0° rotation). After each response, feedback was given by screen display ("Correct!" "Incorrect") and by the examiner. Criterion was met if the subject responded correctly on any 10 consecutive trials or on any 20 of the 24 total trials. Sixteen children did not meet this criterion and did not participate in the experimental trials. An additional three children were excluded because their mothers did not complete the questionnaire on child play preferences. Subsequent analyses, therefore, are based on 41 children (21 girls and 20 boys).

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[1] Factor analysis of the Child Games Inventory (Bates & Bentler, 1973) reveals three sex-typed factors: masculine athletic, masculine nonathletic, and feminine. Because our specific hypothesis was that spatial play experiences (and not masculine play per se) would be related to mental rotation ability, a score based on activities involving spatial abilities was used.

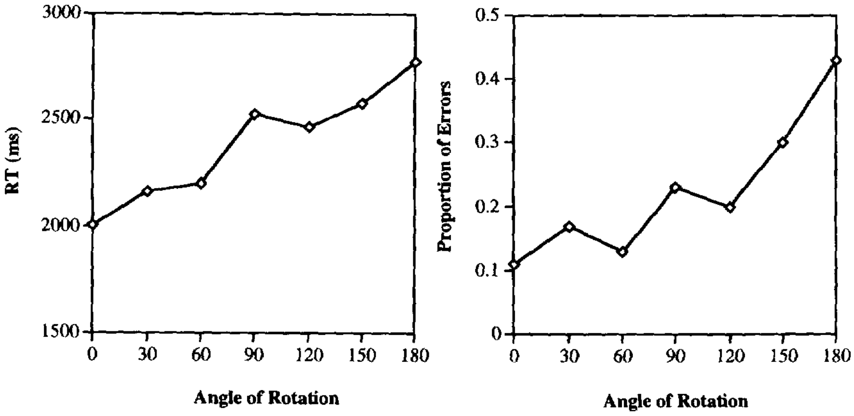

FIG. 2. Response times and error rates as a function of angle of rotation.

Each subject completed 10 practice trials followed by 42 experimental trials (six per orientation condition) randomly ordered with the following restrictions: (a) a given orientation condition never was presented twice consecutively, (b) *same* or *different* pairs never were presented more than four times consecutively, and (c) equal numbers of *same* and *different* trials were presented at each orientation. Feedback regarding accuracy was not provided during the experimental test.

Several measures were obtained from the mental rotation task. Accuracy was measured for same and different trials combined, at each angle of rotation. Response times for correct *same* trials were plotted as a function of angle of rotation. Regression lines ($y = mx + b$) were computed for each subject, indicating the intercept (b) and the slope (m) of the function. The inverse of the regression line slopes provided a measure of rate of mental rotation, computed in degrees per second. The intercept of the function reflected the time required for perceptual encoding, decision-making, and response. The shape of the function was used as an indication of the subject's strategy: More linear functions were considered to reflect a rotational strategy (Cooper & Shepard, 1973; Shepard & Metzler, 1971).

RESULTS

Preliminary Analyses

To examine the adequacy of the task in eliciting mental rotation, group performance was examined with repeated measures analyses of variance (ANOVAs) over the seven angles of rotation for both response time and accuracy. If the task captures mental rotation, then linear trends should be observed between angle of rotation and response time and accuracy. Analysis of response times yielded a significant effect of orientation, $F(6, 210) = 10.72$, $p < .001$. A trend analysis indicated that the linear component accounted for 89% of the variance in the orientation effect. A similar analysis of error rates yielded a significant effect of orientation, $F(6, 240) = 21.11$, $p < .001$. The linear trend accounted for 79% of the variance in the orientation effect. Response times were positively correlated with error rates, $r(5) = .92$, suggesting that a speed-accuracy trade-off did not occur. Response time and accuracy functions appear in Fig. 2.

TABLE 1

Prenatal Testosterone Levels, Spatial Play Experiences, and Mental Rotation Parameters

	Girls				Boys			
	Rotators (n = 12)		Non-rotators (n = 9)		Rotators (n = 13)		Non-rotators (n = 7)	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Prenatal T (ng/dL)	14.69	(2.46)	16.31	(2.92)	38.11	(9.38)	43.61	(12.40)
Spatial play	1.20	(0.47)	1.27	(0.53)	2.11	(0.53)	1.95	(0.57)
Mental rotation parameters								
Accuracy	.80	(0.16)	.70	(0.19)	.84	(0.10)	.71	(0.10)
Mean RT (ms)	2207.00	(282.54)	2685.00	(495.56)	2529.00	(420.82)	2063.00	(563.13)
Rotation rate (°/sec)	186.00	(59.79)	—	—	174.00	(78.10)	—	—
Intercept (ms)	1.86	(0.47)	2.48	(0.44)	1.93	(0.33)	1.91	(0.42)

We investigated the possibility of highly unusual data points (i.e., outliers) among individual children's mental rotation task parameters. Two children had negative rates of rotation and one had a rate more than three standard deviations above the mean. These rotation rates were excluded from all analyses. All other data from these subjects was used.

Children were classified as rotators or nonrotators on the basis of their mental rotation functions. Children with stronger relationships between response time and orientation are more likely to be using a rotational strategy, and those with weaker relationships are more likely to be using a nonrotational strategy (or no strategy at all). Examination of the r^2 values for individual children's response time functions revealed considerable variability (range = .00 to .91). Children were classified as rotators when their r^2 value was .40 or higher. This value was obtained by examining the univariate distribution of r^2 values. A simple median split resulted in a slightly higher cutoff value, but there was a discernable gap in the distribution around r^2 = .40 suggesting that this value may be an appropriate dichotomization point.

Sex and Strategy Effects

Means of all variables, for girls and boys by strategy group, are presented in Table 1. Rotation rates for the nonrotators were not considered. To examine sex and strategy differences in prenatal T, spatial play, and mental rotation parameters separate 2 (Sex) × 2 (Strategy) ANOVAs were conducted for each variable. For T levels, a main effect of sex was observed, $F(1, 37) = 110.71, p < .001$: Boys had higher mean T levels than girls. A main effect of sex was also observed for spatial play experiences, $F(1, 37) = 25.56$, $p < .001$: Boys engaged in more spatial play than girls. Importantly, children with high prenatal T levels were not more likely to be in the rotation group, nor were children who engaged in relatively high levels of spatial play more likely to be rotators.

With regard to mental rotation parameters, a main effect of strategy was

TABLE 2
Correlations among Prenatal Testosterone Levels, Spatial Play Experiences, and Mental Rotation Parameters in Girls (n = 12) and Boys (n = 13)

	Accuracy	Mean RT	Rotation rate	Intercept
		Rotating girls (n = 12)		
Prenatal T	.05	−.63*	.67*	.22
Spatial play	.22	−.17	.11	−.14
		Non-rotating girls (n = 9)		
Prenatal T	.01	.08	—	.22
Spatial play	.05	−.37	—	−.52
		Rotating boys (n = 13)		
Prenatal T	.34	.02	−.62*,[a]	−.18
Spatial play	.06	.01	−.03	.02
		Non-rotating boys (n = 7)		
Prenatal T	−.05	−.40	—	−.31
Spatial play	.15	.31	—	.37

[a] When influential data from two boys were included, this correlation became r = −.32, ns.

* $p < .05$.

observed for accuracy, $F(1, 37) = 5.92, p < .05$. Rotators were more accurate than non-rotators. A sex by strategy interaction was observed for mean response time, $F(1, 37) = 11.59, p < .01$. Analysis of simple effects revealed that, among rotators, girls were significantly faster than boys, and among nonrotators, boys were significantly faster than girls. A sex by strategy interaction also was observed for intercepts, $F(1, 37) = 5.61, p < .05$. Simple effects analysis revealed that, among non-rotators, girls had significantly higher intercepts than boys. Among rotators, no significant sex difference in intercepts was observed.

Relations between Prenatal T Levels, Spatial Play, and Mental Rotation

In order to examine relations between prenatal T levels, spatial play experiences, and mental rotation parameters, Pearson product–moment correlations were calculated among all variables, for each sex and strategy group separately. Although multiple regression procedures would allow the variables to be examined simultaneously, statistical power considerations argued against the use of these procedures. Correlations for each sex by strategy group are presented in Table 2. No significant correlations were observed when all subjects were combined. Among girls using a rotational strategy, however, prenatal T level was positively correlated with rotation rate, $r(9) = .67$, p. = .02, and negatively correlated with response time, $r(10) = -.63$, p. = .03, indicating that girls with higher prenatal T levels rotated faster, and had shorter mean response times. Spatial play was not correlated with

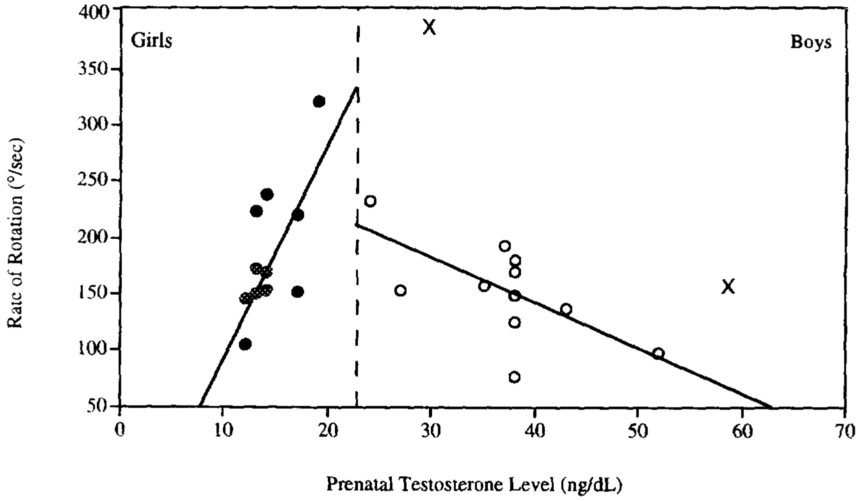

FIG. 3. Scatterplot of prenatal T levels and rotation rate for rotating girls and boys. A positive correlation was observed in girls, and a negative correlation was observed in boys. Data for two influential data points for boys are indicated (X).

any mental rotation parameter in girls, nor was it correlated with prenatal T levels.

Statistical diagnostic procedures revealed two influential data points in the relation between prenatal T and rotation rate in boys. As Fig. 3 shows, these data do not fit the pattern observed for the other subjects. When these points were included in the analyses, the correlation between prenatal T and rotation rate was $r(11) = -.32$, n.s. When these points were omitted, the correlation became $r(9) = -.62$, $p = .04$. The correlations between prenatal T and rotation rate were significantly different in girls and boys ($r(9) = .67$ vs. $r(9) = -.62$, $z = 3.24$, $p = .002$). Spatial play was not related to any mental rotation parameter in boys, nor was it related to prenatal T levels. Relations between prenatal T and rotation rate in girls and boys are depicted in Fig. 3.

DISCUSSION

Hypothesized relations between prenatal T levels and postnatal cognitive abilities have been a subject of intense interest and debate. Here, the first data are presented on relations between prenatal T levels, spatial play experiences, and mental rotation abilities in normally developing boys and girls. An overall sex difference in mental rotation performance was not observed. There was, however, an interaction between sex and strategy such that, among those using a rotational strategy, girls were faster than boys, and among those using a nonrotational strategy, boys were faster than girls. This pattern of sex differences is not consistent with the male advantage seen in adults, most of whom use a rotational strategy. Our findings are not easily interpretable and require further investigation.

With regard to predictors of mental rotation performance, the findings reveal that higher T levels were associated with faster rates of rotation in girls and slower rates of rotation in boys. Spatial play was not associated with mental rotation abilities in girls or in boys. Moreover, prenatal T levels were not associated with spatial play in children of either sex.

Relations with Prenatal Testosterone Levels

The present findings for girls indicate that higher levels of prenatal T are related to shorter response times and faster rates of rotation among girls who use a rotational strategy. Relations between prenatal T levels and mental rotation task performance (i.e., response times, accuracy, or intercept) were not observed in girls who use a nonrotational strategy. It is possible that the alternative strategies brought to bear on the task by this group are not related to prenatal T levels.

This finding of a positive relation between prenatal T and a spatial ability in girls is consistent with that observed in animals (Williams & Meck, 1991) and in women with CAH (Resnick et al., 1986). The relation is inconsistent, however, with our previous finding of an inverse relation between prenatal T and performance on a block building task in the same sample of girls when they were age 4 and with Jacklin et al.'s (1988) finding of a negative relation between prenatal T levels in cord blood at birth and girls' performance on the spatial subtest of the PMA at 6½ years. The inconsistency of findings in our sample at 4 and 7 years may be partly explained by task differences. Although block building and mental rotation both may broadly be described a "spatial" in nature, block building involves spatial visualization not mental rotation (Linn & Petersen, 1985). Furthermore, the block-building task used with 4-year-olds may be a less reliable measure of spatial ability than the chronometric task used in the present study because it involves motor skill to manipulate objects in three dimensions. The discrepancy between the present findings and those of Jacklin et al. (1988) is more difficult to explain, as their subjects were of similar age to those in our study, and the PMA-spatial has a rotational component. In their study, Jacklin et al. assessed T levels at birth, however, whereas we examined levels in the second trimester, when sexual differentiation of the brain is most likely to occur. Furthermore, levels in cord blood following birth may be less reflective of fetal exposure than T levels in amniotic fluid, because they may reflect transient changes in hormone levels associated with labor and delivery (Greenspan & Forsham, 1986).

Prenatal T levels were inversely associated with rate of rotation in boys among those using a rotational strategy. We are more circumspect about the findings in boys because the relation is observed only when two influential data points are removed from the analysis. In previous studies, relations between prenatal T and spatial ability have not been observed in males (Jacklin et al., 1988; Resnick et al., 1986), and prenatal T levels were not associated with block building scores in this same sample of boys at age 4 (Finegan et al., 1992). An inverse relation between prenatal T and rotation rate is consistent, however, with the hypothesis that high levels of prenatal T may demasculinize the male brain (Geschwind & Galaburda, 1987; Reinisch et al., 1991) and with findings of a curvilinear relation between circulating T levels and spatial ability (Gouchie & Kimura, 1991; Shute et al., 1983).

Relations with Spatial Play Experiences

Spatial play experiences were not related to mental rotation performance in either girls or boys. Other researchers have observed relations between spatial play and some aspects of spatial ability (Baenninger & Newcombe, 1989; Fagot & Littman, 1976; Serbin & Connor, 1979; Voyer & Issacs, 1993). It is possible that a more sensitive measure of spatial play than the one we used might have revealed stronger relations with mental rotation performance. We obtained parental report of children's play *preferences* and not a direct observational measure of children's actual play behavior.

Prenatal T levels were not associated with spatial play experiences. The hypothesis that prenatal T levels influence mental rotation ability through an effect on play behavior was therefore not supported. Berenbaum and Hines (1992) found that girls with CAH chose stereotypically "masculine" toys over "feminine" toys, and other researchers have observed relations between CAH and reports of masculine childhood play (Dittman et al., 1990; Slijper, 1984). Our failure to find a relation between prenatal T and spatial play could reflect limitations in our measure of spatial play, as discussed above. Alternatively, prenatal T levels within the normal range for each sex may not be associated with play preferences.

Comments

The present study is limited by small sample size because prenatal T levels were available only for 61 subjects. Of these, 26% did not pass the same/different criterion on the rotation task, and the data for an additional 26% suggested that they were not using a rotational strategy. The inability of a large proportion of our 7-year-old sample to complete the mental rotation task is surprising given that Marmor (1975, 1977) used a noncomputerized version of the same task successfully with 5-year-olds. Marmor reports group data only and does not report rotation functions or accuracies for individual subjects, so it is impossible to determine if all the subjects were using a rotational strategy.

It has been suggested that prenatal T levels should not be expected to show relations with abilities that do not show sex differences favoring males. In the present study, a positive correlation was observed between prenatal T levels and rate of rotation in girls although the sex difference favored girls. There are two possible explanations for this finding. First, it may reflect the distribution of T levels in the present sample. If the optimal T level for rotational ability is in the low male range (Geschwind & Galaburda, 1987; Shute et al., 1983), one might expect to find a sex difference favoring females if the sample contained many girls with T levels in the high female range, but few boys with levels in the low male range, even though the sex difference might favor males in the population. An examination of the distribution of T levels in Fig. 3 reveals this to be the case for the present sample. An alternative explanation is that T is related to within-sex variability in rotation, but not to between-sex variability.

Although a discussion of the mechanisms through which prenatal T might affect spatial ability is beyond the scope of this paper, it should be noted that, in animals, T is converted to estradiol before exerting many of its masculinizing effects on the central nervous system (Hines & Gorski, 1985; MacLusky & Naftolin, 1981; MacLusky, Naftolin, & Goldman-Rakic, 1986). Thus, the relation between T and mental rotation ability in the present study may actually reflect an association with estradiol, or another metabolite whose levels may be related to levels of T.

Finally, the reader should be reminded that causal interpretations are unjustified from the present correlational study. Thus, relations between prenatal T and mental rotation ability may be mediated by other variables, or may reflect the common influence of an unknown third variable. Of course, ethical considerations constrain experimental manipulations in humans so correlational studies are necessarily the best that may be achieved. It may, however, be concluded that the correlations in the present study are consistent with the hypothesis that T acts prenatally to enhance mental rotation ability in females and may diminish mental rotation ability in males.

APPENDIX

"Spatial" Items Selected from Bates and Bentler's (1973) Child Games Inventory

Basketball
Blocks
Builds forts and huts
Baseball
Darts
Dodgeball
Draw and paint
Climb trees
Football

Hockey
Hunting
Marbles
Soccer
Softball
Volleyball
Play with toy tools
Play with toy vehicles
Using tools
Sewing

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