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Androgens and eye movements in women and men during a test of mental rotation ability

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Abstract

Eye movements were monitored in 16 women and 20 men during completion of a standard diagram-based test of mental rotation ability to provide measures of cognitive function not requiring conscious, decisional processes. Overall, women and men allocated visual attention during task performance in very similar, systematic ways. However, consistent with previous suggestions that sex differences in attentional processes during completion of the mental rotation task may exist, eye movements in men compared to women indicated greater discrimination and longer processing of correct alternatives during task performance. Other findings suggested that androgens may enhance cognitive processes that are recruited differentially by women and men as a function of the task. Specifically, smaller (i.e., more masculine) digit ratios were associated with men's shorter fixations on distracters, suggesting that perinatal androgen action may influence brain systems that facilitate the identification of relevant task stimuli. In women, higher circulating testosterone levels appeared to contribute to more general processes engaged during task performance, for example higher levels of visual persistence. It is possible that variability in the relative contribution of such hormone sensitive cognitive processes to accuracy scores as a function of different sample characteristics or assessment methods may partially account for the inconsistent findings of previous research on hormonal factors in mental rotation ability.

Keywords: Sex differences; Eye tracking; Spatial ability

In other species, hormonal factors that direct the sexual differentiation of brain substrates in perinatal life and modulate their expression in postnatal life are well-established determinants of sex differences in behavior (Breedlove et al., 1999; Goy and McEwen, 1980). Increasingly, comparative research on human behavior supports the hypothesis that hormonal factors also contribute to sex-linked behavior in children and adults (Cohen-Bendahan et al., 2005; Collaer and Hines, 1995). Yet, evidence for a role of prenatal and postnatal hormones in the development of the large and reliable sex difference in the ability to mentally rotate objects (Linn and Petersen, 1974; Voyer et al., 1995) remains equivocal.

The hypothesis that higher levels of prenatal androgens in men organize brain systems that better support mental rotation ability, for instance, is consistent with recent reports of significant associations between accuracy scores and the ratio of the second to fourth digits in men (Kempel et al., 2005; Manning and Taylor, 2002; McFadden and Shubel, 2003), a putative marker of perinatal androgen action (Brown et al., 2002; Manning et al., 2003, 1998; McIntyre, 2006) and with earlier studies showing enhanced abilities in girls exposed to higher levels of prenatal androgens because of an endocrine disorder (Hampson et al., 1998; Resnick et al., 1986). However, other investigations of sex-linked cognitive behavior find no relationship (Austin et al., 2002; Coolican and Peters, 2003; Poulin et al., 2003) or the opposite association (Putz et al., 2004) between androgen sensitivity (as indicated by digit ratios) and measures of mental rotation ability in women and men. Further, other researchers measuring spatial abilities following atypical prenatal androgen exposure have reported enhanced performance in girls on a targeting task that shows a large male advantage but not on a three-dimensional mental rotation test (Hines et al., 2003). This last finding has suggested that the relative contribution of hormonal and experiential factors to spatial abilities varies across tasks, such that sex-linked factors

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in postnatal life may be more significant determinants of the sex difference in mental rotation ability.

One possibility is that sex differences in levels of hormones following reproductive maturity contribute to behavioral variability between and within the sexes, presumably by the differential activation of neural systems organized by hormones earlier in prenatal life (Collaer and Hines, 1995). The activational hypothesis is supported by studies showing sex-linked cognitive abilities (including spatial abilities) fluctuate with levels of estradiol and testosterone across the human menstrual cycle (Hampson, 1990a,b) and reports of within-sex correlations between hormones and task performance in women and men (Moffat and Hampson, 1996). However, although some menstrual cycle research indicates that mental rotation ability is enhanced during times of low ovarian steroid production (Hausmann et al., 2000), others have found mental rotation ability is unrelated to menstrual cycle phase (Epting and Overman, 1998). Similarly, whereas significant correlations between endogenous testosterone levels and mental rotation ability have been reported in adults (Moffat and Hampson, 1996), more recent research has found that sex-linked spatial abilities, including mental rotation, were unrelated to individual differences in levels of circulating sex steroids and gonadotropins in healthy women and men (Halari et al., 2005). Likewise, in research on the behavioral effects of exogenous androgen administration to individuals with androgen deficiencies, marked elevations in circulating levels of hormone were not associated with significant improvements in performance on measures of two-dimensional (Liben et al., 2002) or three-dimensional (Alexander et al., 1998) mental rotation ability.

It is generally assumed that accuracy scores (the primary dependent variable across studies) are measures of the ability to mentally rotate objects. However, accuracy scores are also influenced by decisional processes (Hooven et al., 2004) that may contribute to their apparent sensitivity to factors such as propensity to guess (Voyer and Saunders, 2004), time constraints (Voyer, 1997), socioeconomic status (Levine et al., 2005) and the presence of emotional stimuli (Alexander, 2005). Therefore, a useful strategy in research aiming to better understand the role of hormones in sex differences in mental rotation ability may be to include measures of cognition that are not dependent on conscious, decisional processes during task performance. The potential value of this approach is implied in the previous speculations that attentional processes during mental rotation ability may differ between women and men (Jordan et al., 2002; Peters, 2005) and supported by recent research on mental rotation ability in men suggesting higher levels of circulating testosterone in men may improve performance on mental rotation tasks by enhancing discrimination between different objects (Hooven et al., 2004).

An examination of such processes in the context of hormone–behavior research was accomplished in the present investigation by monitoring eye movements in women and men during completion of a widely used diagram-based test of mental rotation, the redrawn Vandenberg and Kuse Mental Rotations Test (Peters et al., 1995; Vandenberg and Kuse, 1978). The rationale for examining eye movements in research on sex-linked cognitive processes included evidence that eye movement patterns can differentiate between individuals who successfully and unsuccessfully solve a diagram-based problem (Grant and Spivey, 2003), evidence that eye movements are an implicit, unobtrusive measure of performance (Richardson and Spivey, 2000) and evidence that, compared to percentage correct or reaction time measures, eye movements permit stronger inferences about cognitive function, specifically the allocation of visual attention (Hayhoe, 2004). Indicators of visual attention such as fixation number and fixation duration, for example, are generally thought to reflect visual interest and processing efforts, respectively (Rayner, 1998). We reasoned that because eye movements are implicit and sensitive to online visual and cognitive processes, eye movements may reveal sex-linked information processes that, compared to response accuracy, show a stronger association to hormonal factors. We tested this hypothesis by examining whether eye movements during task performance were associated with salivary levels of sex steroids and digit ratios.

Method

Participants

Participants were 16 women and 20 men between 18 and 35 years of age who were enrolled in an introductory psychology course at Texas A&M University. Women and men reported being in good health (i.e., no systemic disease) and none were using hormonal preparations, including hormonal contraceptives. All participants were tested individually in a session lasting approximately 40 min. All participants provided signed, informed consent and received partial course credit for their participation in the protocol.

Measures

Cognitive tasks

Participants first completed a vocabulary test (Ekstrom et al., 1976), a measure of general cognitive ability that typically does not show a sex difference. Mental rotation ability was assessed using the redrawn Vandenberg and Kuse Mental Rotations Test (Peters et al., 1995; Vandenberg and Kuse, 1978) that consists of 24 items, each depicting five line drawings of a three-dimensional block figure. One figure is the target, two figures are the target figure depicted in a different rotation (i.e., correct alternatives) and two figures are distracters. The task instructions (to identify the two rotated versions of the target figure) and time constraints (3 min per 12 test items separated by a 2-min rest interval) were identical to the paper and pencil version of the task. However, to permit eye tracking during completion of the test, the 24 items (i.e., each set of five figures) were presented one at a time on a 17-in. computer monitor. The size of each resulting array was approximately 2.5 in. by 7.5 in., with individual figures sized at approximately 2.5 in. by 1.5 in. Participants verbally identified the serial position of the two correct alternatives from left to right (e.g., “one and four”) before pressing the space bar to advance to the next item. An experimenter recorded verbal responses and later scored the total number of responses identifying both correct items (maximum score: 24), a method that maximizes the sex difference in performance (Voyer et al., 1995).

Eye movement data collection

Eye movements were monitored using an infra-red eye tracker with remote optics (Model 504, Applied Science Laboratory) that can measure gaze position with an accuracy of approximately 0.5° of visual angle, a margin of error consistent with the natural function of the human eye. The remote optics system uses corneal and retinal reflections of infra-red light to determine eye gaze with a