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Salivary testosterone does not predict mental rotation performance in men or women

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ABSTRACT

Multiple studies report relationships between circulating androgens and performance on sexually differentiated spatial cognitive tasks in human adults, yet other studies find no such relationships. Relatively small sample sizes are a likely source of some of these discrepancies. The present study thus tests for activational effects of testosterone (T) using a within-participants design by examining relationships between diurnal fluctuations in salivary T and performance on a male-biased spatial cognitive task (Mental Rotation Task) in the largest sample yet collected: 160 women and 177 men. T concentrations were unrelated to within-sex variation in mental rotation performance in both sexes. Further, between-session learning-related changes in performance were unrelated to T levels, and circadian changes in T were unrelated to changes in spatial performance in either sex. These results suggest that circulating T does not contribute substantially to sex differences in spatial ability in young men and women. By elimination, the contribution of androgens to sex differences in human performance on these tasks may be limited to earlier, organizational periods.

Introduction

In animal models, adult behavioral sex differences have generally been found to result from either the sex difference in circulating androgens such as testosterone (T) in adulthood, or the sex difference in exposure to androgens earlier in life, for example during the perinatal period (Morris et al., 2004). These two modes of producing behavioral sex differences have been described as "activational" and "organizational," respectively (Phoenix et al., 1959). Although there are interesting exceptions to these two modes of differentiation, and they often act through similar neural mechanisms (Arnold and Breedlove, 1985), the dichotomy nevertheless holds true in many cases.

Men and women perform similarly on tests of overall intelligence but differ on tests that measure specific cognitive abilities (Hines, 2004). The largest cognitive sex differences are found in the domain of spatial ability, with men tending to outperform women (Maccoby and Jacklin, 1974). These differences may be due partly to lasting organizational effects of prenatal or early postnatal androgens (Collaer et al., 2009; Puts et al., 2008), and/or pubertal androgens (Hier and Crowley, 1982). Some human and rodent evidence suggests a curvilinear relationship between androgen signaling and spatial ability, such that organizational effects of androgens improve performance on some spatial tasks in females and impair performance on these tasks in gonadally intact males (Puts et al., 2007).

Androgens may also have transient activational effects on spatial ability in adults, but evidence for this is equivocal. Several studies have found significant relationships between T levels and spatial ability in between-participants comparisons of adults (e.g., Christiansen, 1993; Christiansen and Knussmann, 1987; Driscoll et al., 2005; Gordon and Lee, 1986; Hausmann et al., 2009, 2000; Hooven et al., 2004; Moffat and Hampson, 1996a; Silverman et al., 1999), although others have not (e.g., Falter et al., 2006; Halari et al., 2005; Hassler et al., 1992; Janowski et al., 1998; Kampen and Sherwin, 1996; Matousek and Sherwin, 2010; McKeever and Deyo, 1990) (see Table 1 and Discussion). Moreover, correlations between adult androgen levels and spatial performance in between-participants studies leave questions about when during development androgen affects spatial ability. Testosterone production rate is highly heritable (Meikle et al., 1988), and it is therefore possible that intrasexual differences in circulating T persist throughout life. If so, associations between adult androgen levels and spatial ability may reflect prior organizational effects of hormones.

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Table 1
Results of previous studies that have investigated between-subjects relationships between spatial ability and T. '0' indicates no relationship, '+' and '−' indicate positive and negative relationships, respectively. 'NL' indicates a nonlinear relationship (quadratic or third-order polynomial).

Study	Sample size	Mean age (SD, range)	Sample method	Samples, sessions	Task	Results
Alexander et al. (1998)	33M, 10M	41.1 (20–59); 33.4 (21–44)	Blood	"Multiple," 1	MRT	0
					Surface development	0
					Paper folding	0
					Hidden patterns	0
Burkitt et al. (2007)	39F, 36M	19.9 (2.8)	Saliva	2, 1	MRT	+
					Virtual Morris water task	F:+, M:0
Christiansen and Knussmann (1987)	110M	24.1 (20–30)	Blood	1, 2	Block design	0
					Leistungsprufsystem subtest 8	+
					Leistungsprufsystem subtest 9	0
			Saliva	1, 2	Block design	0
					Leistungsprufsystem subtest 8	0
					Leistungsprufsystem subtest 9	0
Christiansen (1993)	114M	26.4 (4.7, 18–38)	Blood	1, 1	Dichaptic stimulation test	+
			Saliva	1, 1	Dichaptic stimulation test	+
Driscoll et al. (2005)	16F, 16M	20–over 60	Saliva	1, 1	Virtual Morris water task	F:0, M:+
Falter et al. (2006)	22F, 24M	(19–41)	Saliva	1, 1	MRT	0
					Targeting	0
					Perceptual discrimination	0
	34F, 35M	F:24.1(4.6); M:24.1 (3.0)			Disembedding	F:+ for 1 of 2 tasks, M:0
Gordon and Lee (1986)	32M	(18–35)	Blood	11, 2	Cognitive laterality battery	
					– Localization	0
					– Orientation	Session 1:+, Session 2:0
					– Touching blocks	0
					– Form completion	0
Gouchie and Kimura (1991)	46F, 42M	F:21.5 (18–31); M:21.0 (18–27)	Saliva	2, 1	Paper folding	0
					MRT	0
Halari et al. (2005)	42F, 41M	F:27.69, (3.96); M:28.31 (4.81)	Blood	1, 1	MRT	0
					Computerized judgment of line orientation	0
					Modified judgment of line orientation	0
Hassler et al. (1992)	25F, 26M	F:18.77 (1.42); M:19.16 (1.65)	Blood	1, 1	Spatial relations test	0
					Hidden patterns	0
					Dichaptic stimulation test	0
Hausmann et al. (2000)	12F	29.1 (4.4, 23–38)	Blood	2, 1	MRT	+
					Mirrors pictures test	0
					Hidden figures test	0
Hausmann et al. (2009)	51F, 45M	23.4 (4.7), 25.8 (7.2)	Saliva	1, 1	MRT	F:0, M:+
Hooven et al. (2004)	28M	23 (4)	Saliva	1, 2	MRT	+
Janowski et al. (1998)	17F, 29M	F:29.8 (3.2, 24–34); M:28.5 (3.1, 23–34)	Blood	2, 2	Block design task	0
					Card rotation	0
Kampen and Sherwin (1996)	32M	21.1 (18–29)	Blood	1, 1	MRT	0
Klaiber et al. (1967)	50M	21.65 (0.92)	Urine	1, 2	Block design task	−
Matousek and Sherwin (2010)	54M	68.6 (4.4)	Blood	1, 1	MRT	0
					Paper folding	0
					Water level test	0
					Block design test	0
McKeever et al. (1987)	42F, 41M	Unstated	Blood	1, 1	Stafford identical blocks test	0
McKeever and Deyo (1990)	58M	Undergraduates	Blood	4, 1	Stafford identical blocks test	0
					Minnesota Paper Forms Board	0
Moffat and Hampson (1996a)	40F, 40M	F:23.0 (4.09); M:21.8 (2.35)	Saliva	2, 1	MRT	F:0, M:NL
					Paper folding	0
Neave et al. (1999)	25F, 33M	F:28.75 (19–43); M:28.6 (18–51)	Saliva	1, 1	MRT	NL
Shute et al. (1983) 1	48F, 43M	24.5 (16–41)	Blood	1, 1	French Reference Kit for Cognitive Factors — spatial tests	F:0, M:NL
Shute et al. (1983) 2	12F, 12M	24.5 (16–41)	Blood	1, 1	Minnesota Paper Forms Board	0
					Primary mental abilities test/comprehensive ability battery space test	0
Silverman et al. (1999)	59M	22.42 (3.02)	Saliva	2, 2	MRT	+
Young et al. (2010)	26 young M, 62 old M	(25–35), (60–80)	Blood	1, 2	MRT	Young M:0, old M: +
					Figure discrimination task	0

Causal relationships are best tested by hormonal manipulation. Demonstrating that androgen treatment elicits a particular behavioral change, and that removal of treatment abolishes this effect, constitutes strong evidence for activational effects of the hormone. Several studies have reported activational effects of androgens on spatial task performance, but those that are placebo-controlled often fail to demonstrate significant effects (reviewed in Puts et al., 2007). Furthermore, these studies are frequently carried out using small and possibly unrepresentative clinical samples, such as hypogonadal males, Alzheimer patients, Turner Syndrome patients, and female-