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The relationship of male testosterone to components of mental rotation

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Abstract

Studies suggest that higher levels of testosterone (T) in males contribute to their advantage over females in tests of spatial ability. However, the mechanisms that underlie the effects of T on spatial ability are not understood. We investigated the relationship of salivary T in men to performance on a computerized version of the mental rotation task (MRT) developed by [Science 171 (3972) (1971) 701]. We studied whether T is associated specifically with the ability to mentally rotate objects or with other aspects of the task. We collected hormonal and cognitive data from 27 college-age men on 2 days of testing. Subjects evaluated whether two block objects presented at different orientations were the same or different. We recorded each subject's mean response time (RT) and error rate (ER) and computed the slopes and intercepts of the functions relating performance to angular disparity. T level was negatively correlated with ER and RT; these effects arose from correlations with the intercepts but not the slopes of the rotation functions. These results suggest that T may facilitate male performance on MRTs by affecting cognitive processes unrelated to changing the orientation of imagined objects; including encoding stimuli, initiating the transformation processes, making a comparison and decision, or producing a response.

Keywords: Spatial ability; Testosterone; Mental rotation; Slope; Intercept; Response time

1. Introduction

On average, human males outperform females in tests of spatial ability (Voyer, Voyer, & Bryden, 1995). A wealth of data from human and animal studies suggests that the relatively high concentration of testosterone (T) in males plays a critical role in their superior performance (Liben et al., 2002). However, the mechanisms through which T may affect spatial ability are not understood, and studies suggest that high T is not always associated with better performance among men (Moffat & Hampson, 1996). Because performing a spatial task, like any mental task, involves a series of distinct cognitive and motor processes (Sternberg, 1969), if T does modulate performance, it may do so through its relationship to any one or more of these processes. Relating T levels to relatively coarse measures of performance may not accurately reflect the relationship of T to the abilities of interest. To our knowledge, no published studies have investigated the relationship of T levels to the processes that actually transform objects in mental images per se, as distinct from other aspects of the task—such as the processes that encode the stimuli, initiate the transformation processes, make a comparison, or produce a response. To understand how T is related to variations in cognitive ability, we must analyze aspects of task performance that reflect distinct processes.

Organizational and activational effects of T influence spatial ability. In mammals, organizational effects of T occur primarily during a critical period in pre- and early post-natal development during which sexual differentiation occurs. In developing fetuses, higher levels of T and its metabolites (primarily DHT and estradiol) not only promote the development of male sexual organs, they also lead to the "masculinization" of the brain, resulting in the development of sexually-dimorphic brain structures. Studies with non-human mammals have shown that these brain structures later play a key role in the expression of male-typical behaviors, including enhanced spatial ability (Isgor & Sengelaub, 1998; Sherry, Jacobs, & Gaulin, 1992). Activational effects normally occur during and after adolescence in response to the action of circulating T. In adult males, higher T levels (typically three to ten times higher in human males than in females (Yen, Jaffe, & Barbieri, 1999)) modulate gene expression in specific brain regions (some of which have sexually differentiated patterns of androgen receptor

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concentration (Kruijver, Fernandez-Guasti, Fodor, Kraan, & Swaab, 2001)) to facilitate the expression of male-typed behaviors and cognitive patterns (Williams & Meck, 1991). Research on humans of both sexes who have experienced atypical levels of androgens during the organizational stage suggests that male-typical T levels lead to superior spatial ability in adulthood (Hampson, Rovet, & Altmann, 1998; Hier & Crowley, 1982).

Research on the activational effects of T on spatial ability in humans has focused on relationships between current T levels and performance on spatial tasks, or how performance varies with changes in T levels. Many researchers have reported that T level is correlated with performance on spatial tasks (Liben et al., 2002); but more than that, studies also suggest that changes in T level in adulthood cause differences in spatial abilities. Results indicate that male-typical T levels in adulthood lead to superior performance on spatial tests, but do not improve performance on non-spatial tasks, such as those measuring verbal ability (e.g., Janowsky, Oviatt, & Orwoll, 1994; Slabbekoorn, van Goozen, Megens, Gooren, & Cohen-Kettenis, 1999; Van Goozen, Cohen-Kettenis, Gooren, & Frijda, 1994).

Although studies have consistently found that T levels within the normal adult-male range are accompanied by a sex-based advantage on spatial tasks, the literature on the relationship between current T level and performance on spatial tasks within males is less consistent. Some studies report negative relationships (e.g., Gouchie & Kimura, 1991; Moffat & Hampson, 1996), some report positive relationships (e.g., Christiansen & Knussmann, 1987; Silverman, Kastuk, Choi, & Phillips, 1999), and others have found no relationship (e.g., Alexander et al., 1998; McKeever, Rich, Deyo, & Conner, 1987). The inconsistent results might be explained by differences in any of the following factors: methods of measuring T levels (i.e., time of day when the sample is taken, assay methods, sampling serum vs. saliva), subject samples, and measures of spatial ability (Silverman et al., 1999). In this article, we focus on the relationship of salivary T to response time (RT), and error rate (ER), associated with two classes of processes on a standard test of spatial abilities, namely, mental rotation.

Tests of spatial ability have been categorized into three types, each measuring a distinct aspect of this ability. Specifically, spatial perception tests assess the ability to determine spatial relations, such as in the Rod and Frame test (Witkin & Asch, 1948); spatial visualization tests assess the processing of complex spatial information, such as in the Embedded Figures Test (Witkin, 1950) in which subjects must remember geometric forms and then pick them out from more complex forms; and mental rotation tasks (MRTs) assess the ability to rotate mental images of objects. MRTs consistently yield the largest effect sizes, of any cognitive or spatial test specifically, for sex differences in performance. Of the MRTs, the effect sizes (expressed as the number of standard deviations by which male performance is greater than female performance) are highest for the Vandenberg and Kuse MRT (herein referred to as "VK") (Vandenberg & Kuse, 1978), and range from 0.7 (Voyer et al., 1995) to 0.9 (Linn & Petersen, 1985). The magnitude of this sex difference has remained constant over time (Masters & Sanders, 1993), and is evident cross-culturally (Halpern & Tan, 2001; Oosthuizen, 1991).

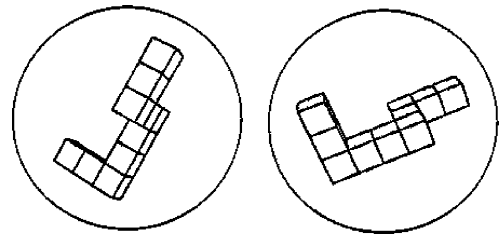

Fig. 1. Sample trial from Shepard and Metzler MRT 40° rotation—Different objects.

The VK is an adaptation of a task developed by Shepard and Metzler in 1971 (Shepard & Metzler, 1971), which was used to demonstrate that internal mental representations share spatial properties with the external objects they depict. On each trial of the Shepard and Metzler MRT (SM), subjects view a pair of two-dimensional projections of three-dimensional block objects, and the members of each pair usually are at different orientations. An example trial is presented in Fig. 1. Half the time the two objects have identical shapes, and half the time they are mirror images. Subjects must decide, as quickly and accurately as possible, whether the members of each pair are the same or different objects. Shepard and Metzler observed that in trials in which the two objects were the same, RT was a strong linear function of the degree of angular disparity between the objects. They inferred that to compare the objects in each pair and make a decision about similarity, the subjects "mentally rotated" one object into congruence with the other, so that the imagined object followed a trajectory analogous to that of a physical object rotated manually. The finding of a linear relationship between angle and RT is robust (e.g., Shepard & Judd, 1976; Wexler, Kosslyn, & Berthoz, 1998).

In 1978, Vandenberg and Kuse (1978) created a timed, paper-and-pencil MRT, which incorporated the block figures from the SM. Their version of the task includes 20 trials, set up as shown in Fig. 2. Subjects choose which two of the four target objects they believe are identical to the standard, and have six min to complete as many of the trials as possible. Points are awarded for each correct choice.

The VK represented an improvement over the SM in that it can be easily administered to large groups. Most studies on the relationship between T level and mental rotation ability use the VK, and furthermore, the bulk of the data on sex differences in mental rotation ability is derived from this test. But even on this specific test, the literature on the relationship between performance and salivary T yields contradictory results. Silverman et al. (1999) found that more T was associated with better performance on the VK