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Sex hormones and mental rotation: An intensive longitudinal investigation

Delphine S. Courvoisier [a,*], Olivier Renaud [a], Christian Geiser [b], Kerstin Paschke [c], Kevin Gaudy [a], Kirsten Jordan [d]

[a] Department of Psychology, University of Geneva, 40 bd Pont-d'Arve, Switzerland
[b] Department of Psychology, Utah State University, 2810 Old Main Hill, Logan, UT 84322-2810, USA
[c] Department of Cognitive Neurology, Georg August University Göttingen, Robert-Koch-Str. 40, 37075 Göttingen, Germany
[d] Department of Forensic Psychiatry and Psychotherapy, Georg August University Göttingen, Rosdorfer Weg 70, 37081 Goettingen, Germany

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ABSTRACT

The present study used an intensive longitudinal design to examine whether mental rotation performance varies according to a monthly cycle in both males and females and whether these variations are related to variations in progesterone, estradiol, and testosterone levels. We collected reaction time and accuracy data for 10 males and seven females each workday over eight weeks using 136 pairs of mental rotation stimuli/day, and measured sexual hormones concentrations in the saliva twice a week. A mixed linear model statistical analysis revealed that all females and seven males showed significant cycle effects in mental rotation performance. The female cycle showed an amplitude that was twice as large compared with the amplitude found in males. For males and females, estradiol and testosterone were significantly linearly and quadratically related to interindividual variation in performance at the beginning of the study (progesterone was linearly related to performance for females). The association between testosterone and performance differed across sexes: for males, it had an inverse U-shape, for females it was U-shaped. Towards the end of the study, none of the hormones were significantly related to performance anymore. Thus, the relationship between hormones and mental rotation performance disappeared with repeated testing. Only estradiol levels were significantly elevated at the lowest point of the cycle in mental rotation performance in females. In conclusion, in this intensive longitudinal study spanning two months, a monthly cycle in mental rotation performance was found among both males and females, with a larger cycle's amplitude for females.

Introduction

Mental rotation (i.e., the ability to rotate mental representations of two- or three-dimensional objects; Johnson (1990), Shepard and Metzler (1971)) is a task that consistently presents large sex differences in performance, especially for more complex stimuli. Indeed, mean differences in performance in favor of males are often found to be larger than half a standard deviation for three-dimensional mental rotation tasks (Geiser et al., 2008a; Linn and Petersen, 1985; Masters and Sanders, 1993; Ocklenburg et al., 2011; Voyer et al., 1995), and these differences already exist at an early age (Moore and Johnson, 2008; Titze et al., 2009).

Sex steroids (hormones) influence, at least in part, sex differences in spatial abilities and, more specifically, in mental rotation (Hausmann, 2010; Hines, 2010; Jancke and Jordan, 2007; Kimura, 1996). This influence begins during early phases of development (e.g., McCarthy et al., 2009), and persists throughout life (e.g., Gouchie and Kimura, 1991; Liben et al., 2002; Vuoksimaa et al., 2012). Administration of sex hormones may increase performance (Stangl et al., 2011). Longitudinally, there is also a relationship between levels of menstrual cycle hormones and performance in cognitive tests (for an overview, see Hausmann et al., 2009). Females show lower mental rotation performance during the follicular or midluteal phase, which corresponds hormonally to high estrogen and progesterone levels, and higher scores during menses (the menstruation phase) corresponding to low estrogen and progesterone levels (Hampson, 1990; Maki et al., 2002; Moody, 1997; Philips and Silverman, 1997; Schöning et al., 2007; Silverman and Phillips, 1993).

Testosterone has also been associated with mental rotation performance (Hooven et al., 2004; Thilers et al., 2006), but the form and direction of the association have been inconsistent across studies. Some have reported a positive relationship (the higher the testosterone level, the higher the performance; e.g., Hausmann et al., 2009, 2000), whereas others have found the relationship to follow an inverted U-shape, with best performance occurring when testosterone is neither too low nor too high (O'Connor et al., 2001) or found a negative relationship (Vuoksimaa et al., 2012). Recent work by Celec, Ostatnikova, and colleagues suggests that cyclic variations in mental rotation performance may also exist for males due to a circatrigintan (i.e., 30 days) testosterone rhythm (Celec et al., 2003; Ostatnikova et al., 2010).

* Corresponding author at: William James Hall, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, USA.
E-mail address: courvoisier@fas.harvard.edu (D.S. Courvoisier).

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Other studies found no significant relationship between the performance on spatial tasks and hormonal fluctuations during the menstrual cycle (Epting and Overman, 1998; Gordon and Lee, 1993; Halari et al., 2005; Peters et al., 1995; Puts et al., 2010; Rosenberg and Park, 2002), or between performance in a mental rotation task and testosterone (Burkitt et al., 2007; Puts et al., 2010). One possible explanation is that mental rotation performance may depend on interindividual variations in sex hormones (i.e., a woman with higher testosterone may perform better than a woman with less testosterone), but not on intraindividual differences (i.e., the same woman's performance may not change even when her level of testosterone is higher).

The purpose of the present study was twofold. In order to study potential cyclic variations in mental rotation performance and their relation to hormone levels within individuals, we employed an intensive longitudinal design. In this design, we measured mental rotation performance every weekday (except weekend days) over eight weeks in several male and female participants. Sex hormones were measured twice a week over the same period. This procedure allowed us to examine, for each individual, whether mental rotation performance shows intraindividual cyclic variations and how these variations relate to actual hormone concentrations.

The second purpose of this study was to examine whether the influence of hormones on mental rotation performance changes over the course of repeated testing. Mental rotation skills are highly trainable (e.g., Heil et al., 1998; Kass et al., 1998) and performance can be substantially improved by repeated administration of similar stimuli (Geiser et al., 2008b; Jordan and Wuestenberg, 2010). Likewise, a study examining knot tying performance under laparoscopy showed that the impact of camera angle was less important for experienced surgeons than for novice surgeons (Conrad et al., 2006). It is therefore interesting to study whether the impact of hormones on performance is attenuated by repeated exposure to mental rotation tasks. To our knowledge, no studies so far have examined whether the influence of sex hormones on mental rotation performance changes when mental rotation abilities are subject to intensive testing. In the present study, we therefore examined the effect of sex hormones on intra- and interindividual differences both at the beginning and at the end of the 8-week period to test whether the influence of hormones on mental rotation performance is attenuated as participants become more and more experienced with the task.

In summary, the present study tested the following hypotheses: We expected that cyclic variations in performance would be found in both sexes, with the male cycle corresponding to a monthly rhythm influencing testosterone levels in males (Celec et al., 2003) and the female cycle corresponding to the menstrual cycle. Performance in males was hypothesized to be positively associated with testosterone levels. In females, we hypothesized that phases of low performance would be associated with higher levels of estrogen, progesterone and testosterone.

With regard to training effects due to intensive repeated testing, we hypothesized that the influence of hormones on performance would become less important over the course of the study such that there would be significant relationships between hormones and mental rotation performance at the beginning, but not at the end of the study.

Method

Participants

Nineteen individuals (10 men and 9 women) working at a Swiss University were recruited for this experiment. None of the participants used any neuroactive or hormone substances, or medications (including contraceptives). All women reported having a regular menstrual cycle (between 26 and 30 days). One participant withdrew from the study and another participant became pregnant and was excluded from the study. Thus, the final sample comprised 17 (7 females and 10 males) participants. The mean age of the final group was 26.8 years ($SD = 4.1$, range = 23–37 years). The mean number of days per subject on which the mental rotation task was performed was 34.8 ($SD = 7.2$, range = 19–43).

Procedure and materials

Participants were asked to do a mental rotation task (details are given below) each weekday (except weekends) for eight weeks in order to hit and follow at least one menstrual cycle. All participants took the test in the morning. They performed a 10–15 minute mental rotation task with perspective drawings of three-dimensional block objects. In addition, participants provided saliva samples two times per week at 3–4 day intervals in order to determine the concentration of testosterone, progesterone, and estradiol. The saliva samples were taken just before and immediately after the mental rotation task to improve the quality of the sample. Participants were informed about the purpose of the study. The ethics committee of the Department of Psychology, University of Geneva, approved the research, and informed consent was obtained from all participants.

Mental rotation task

At each trial two three-dimensional cube constructions similar to the mental rotation stimuli developed by Shepard and Metzler (1971) were presented on a computer screen. Each test stimulus represented a pair of two objects composed from cubes with different angles of rotation between them. Each object was a) made from 10 single cubes, b) contained two arms with three single cubes, c) and the arms pointed to different directions (for a detailed description of the stimuli, see Paschke et al., 2012). Any stimulus in which some parts of the object could occlude other parts was excluded. Moreover, the objects could be identical or mirror images of each other. Cubes were drawn with perspective and shade. Participants had to decide if the two objects were identical in shape or mirror images of each other. In each session, 136 pairs of stimuli (72 test and 64 control stimuli) were randomly drawn from an item pool, which comprised a total of 544 stimuli. This was done in order to minimize memory effects that may occur over the course of an intensive longitudinal study. Otherwise, participants may just retrieve repeatedly administered stimuli from memory rather than actually perform mental rotations after they have been exposed to the same stimuli for some time (Heil et al., 1998). Control stimuli were similar to test stimuli. They also could be either identical or mirror images, but had no angular disparity. Rotation was realized in steps of 20°, resulting in 10 different angular disparities from 0 to 180°, including the controls. Participants were instructed to respond as quickly and accurately as possible, but no time limit was given. A pair of stimuli appeared simultaneously after a warning prompt (a cross in the middle of the screen), then disappeared as soon as the participant pressed the button, followed by a one second break, until the next warning prompt appeared automatically. Participants did not receive any feedback during or after the test.

Response time was measured for each presentation of stimulus pairs and for each participant. Due to numerous outlying reaction times and large number of inaccurate answers, the first two days were considered as “warming-up” sessions, and data from these two days were discarded for all participants. Median response time on correct items was then obtained for each angular disparity (from 0 to 180° by 20° increment) and for each type of stimulus (same vs. mirror image), yielding 20 measures per participant per time point. Even though taking the median response time removed potential outliers, the data still showed a higher variability for higher RTs. Thus, the logarithm of the median response time was used which greatly reduced issues of heteroscedasticity. Furthermore, due to possible differences in participants' choices between precision and rapidity, we