Behavioral Neuroscience
2000, Vol. 114, No. 6, 1245-1250

BRIEF COMMUNICATIONS

Sex Hormones Affect Spatial Abilities During the Menstrual Cycle

Markus Hausmann
Ruhr-Universität Bochum

Ditte Slabbekoorn, Stephanie H. M. Van Goozen, and Peggy T. Cohen-Kettenis
University Hospital Utrecht

Onur Güntürkün
Ruhr-Universität Bochum

The aim of this study was (a) to show that different measures of spatial cognition are modulated by the menstrual cycle and (b) to analyze which steroid is responsible for these cognitive alterations. The authors collected blood samples in 3-day intervals over six weeks from 12 young women with a regular menstrual cycle to analyze concentrations of estradiol, progesterone, testosterone, luteinizing hormone, and follicle-stimulating hormone. The performance on 3 spatial tests was measured during the menstrual and the midluteal phase. A significant cycle difference in spatial ability as tested by the Mental Rotation Test was found, with high scores during the menstrual phase and low scores during the midluteal phase. Testosterone had a strong and positive influence on mental rotation performance, whereas estradiol had a negative one. These results clearly indicate that testosterone and estradiol are able to modulate spatial cognition during the menstrual cycle.

Gender differences in some cognitive abilities are well documented (Kimura, 1992; Maccoby & Jacklin,1974). Although performances of both genders overlap to a large degree (McKeever, 1995) women tend to outperform men in specific aspects of verbal ability (Halpern, 1986; McGlone, 1980), whereas men achieve higher scores in spatial tasks (Halpern, 1996; Hyde, 1981; McGee, 1979; Voyer, Voyer, & Bryden, 1995; Witkin, Dyk, Faterson, Goodenough, & Karps, 1962).

Although the magnitude of gender differences in spatial abilities seems to have decreased slightly in recent years (Masters & Sanders, 1993; Voyer, et al., 1995) and gender differences in some visuo-spatial tasks can be eliminated through practice (Baenninger & Newcombe, 1995; Kass, Ahlers, & Dugger, 1998), different meta-analyses indicate that gender differences in spatial abilities do exist and are robust (Linn & Peterson, 1985; Silverman, Phillips, & Silverman, 1996; Tapley & Bryden, 1977; Voyer, et al., 1995). Most particularly, the Mental Rotation Test (MRT; Peters, Laeng, et al., 1995; Vandenberg & Kuse, 1978), which uses depictions of 3-D cube figures designed by Shepard and Metzler (1971), appears to produce the most reliable gender difference of all spatial tests (Voyer, et al., 1995). To perform the 3-D MRT the participant must imagine the cube stimuli revolvering in 3-D space (Collins & Kimura, 1997). The male advantage in mental rotation decreases with picture plane rotations in 2-D space. The meta-analysis of Voyer et al. (1995) could show that, on average, males outperform females in mental rotation by about 0.6 SD units but by only 0.2 SD units for the spatial visualization category including, for excample, the Hidden Figures Test (Ekstrom, French, & Harman, 1976), in which participants must find a simple figure embedded within a complex pattern (Voyer, et al., 1995). Probably, however, 3-D processes are not a prerequisite for large gender differences, because Collins and Kimura (1997) found a similar male advantage when task difficulty was increased for their 2-D mental rotation test.

Gender differences in spatial abilities and in some other cognitive and motor tests probably arise at least in part because of sex-steroid influences. This hypothesis arises from the observation that high levels of female hormones, especially of estradiol (Hampson, 1990a), enhanced performance on tests at which females excel but were detrimental to performance on tasks at which males excel (Hampson & Kimura, 1988). Apart from the organizational effects of gonadal hormones on spatial abilities during early phases of development (Christiansen, 1993; Williams & Meck, 1991), activational influences of sex steroids on these abilities persist during the whole lifetime (Gouchie & Kimura, 1991; Kimura, 1996; Slabbekoorn, Van Goozen,

Markus Hausmann and Onur Güntürkün, Biopsychologie, Fakultät für Psychologie, Ruhr-Universität Bochum, Germany; Ditte Slabbekoorn, Stepahnie H. M. Van Goozen, and Peggy T. Cohen Kettenis, Department of Child and Adolescent Psychiatry, University Hospital Utrecht, Utrecht, The Netherlands.

This research was supported by the Alfried Krupp-Stiftung. Special thanks to Michael Peters for the Mental Rotation Test material, to Dr. Belkien & Partners for the hormone analyses, and to M. May and O. Besser for collecting 180 blood samples.

Correspondence concerning this article should be addressed to Markus Hausmann, Biopsychologie, Fakultät für Psychologie, Ruhr-Universität Bochum, D-44780 Bochum, Germany. Electronic mail may be sent to markus.hausmann@ruhr-uni-bochum.de.

Megens, Gooren, & Cohen-Kettenis, 1999; Van Goozen, Cohen-Kettenis, Gooren, Frijda, & Van de Poll, 1994). Both organizational and activational studies generally show decreases in spatial abilities with increased estrogen levels, consistent with observed sex differences. Corresponding increases in spatial performance with increased testosterone levels tend to occur for females but not for males (Silverman & Phillips, 1993). Males frequently show an inverse effect (Gouchie & Kimura, 1991). However, Ho, Gilger, and Brink (1986) suggested that spatial information-processing should be more sensitive to hormonal changes than traditional psychometric measures.

The levels of the female sex hormones, especially of estradiol and progesterone, vary dramatically with the menstrual cycle. If these steroids affect spatial ability, the performance in spatial tests should change with hormonally distinct cycle phases in spontaneously cycling women. This would support the notion of the activating effects of sex hormones. Indeed, several studies found menstrual cycle effects in spatial tests with low performance scores during the follicular or midluteal phase (elevated estrogen or elevated estrogen and progesterone levels) and higher performances during menses (low gonadal hormone levels) (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Phillips & Silverman, 1997). However, these relations could not always be confirmed. Epting and Overman (1998) found no evidence that performances on four spatial tasks differed with menstrual cycle, although results in three out of four spatial tasks revealed a significant gender difference (see also Gordon & Lee, 1993). Currently, it is not entirely known why some studies reveal cycle-phase-related differences in the spatial abilities and others do not.

Hormone measurements are vitally important when doing menstrual cycle studies. For example, Gordon, Corbin, and Lee (1986) had to eliminate nearly half of their female participants (11 of 24) from further analyses because post hoc hormone assays revealed that they were not tested in the expected cycle phase. Although direct hormone assays should be a prerequisite to define the menstrual cycle phase and to analyze the relationship between cognitive performance and several critical sex hormones that are known to fluctuate during the menstrual cycle, only 11 of 62 studies of cognition and the menstrual cycle performed hormone measurement as part of their analysis (Epting & Overman, 1998). Only two of these studies (Gordon & Lee, 1993; Hampson, 1990a) investigated the relationship between sex hormones and the performance of different visuo-spatial tasks in spontaneously cycling women during the menstrual cycle. Hampson (1990a) found an inverted U-shaped relationship between estradiol and the performance of the Space Relations Test. 3-D or 2-D mental rotation tests and hormone measures of the gonadotropins (luteinizing [LH] and follicle-stimulating hormone [FSH]) and testosterone were not included in that study. In contrast, Gordon and Lee (1993) found no relationship between estradiol and sex-biased visuo-spatial abilities, including tasks of mental rotation of 3-D figures. This lack of support for a hormone-behavior correlation in female participants replicates previous findings by Gordon et al. (1986). However, Gordon and Lee (1993) found relationships between the gonadotropins and cognitive function. FSH had been negatively and LH positively correlated to a visuo-spatial composite score, including mental rotation of 3-D figures.

In the course of an analysis of steroid-modulated cognitive and cerebral processes over the whole menstrual cycle, we collected blood samples to analyze several sex hormones that are known to fluctuate during the menstrual cycle and that are discussed for their cognitive effects. Hormones were measured over 6 weeks in 3-day intervals. We measured the performance on three spatial tests during two sessions (2nd and 22nd cycle day) to hit the menstrual and midluteal phases, respectively. The frequent hormone measurements over 6 weeks allowed a nearly perfect validation of individual cycle phases and an analysis of the potential neuroactive hormone(s).

Beyond the nearly perfect validation of individual cycle phases, this study regarded the influence of the most potentially relevant sex hormones (estradiol, progesterone, LH, FSH, and testosterone) on different sex-biased visuo-spatial tasks, especially of the MRT (Peters, 1995), during the menstrual cycle for the first time.

Method

Participants

12 woman (students of different departments) participated in this experiment. The mean age of the group was 29.1 years (SD = 4.4, range = 23-38 years). Participants were recruited by announcements and were paid for their participation. None of the women used oral contraceptives or any other neuroactive substances. They also reported having a regular menstrual cycle between 27 and 29 days. Post hoc analysis of three successive cycles revealed a median cycle length of 29 days.

Procedure and Materials

All participants started with blood samples at the same day. We collected further blood samples in 3-day intervals over 6 weeks. Thus, altogether, we collected 15 blood samples for each woman (180 blood samples for the whole group) to pattern the whole menstrual cycle. Participants were tested counterbalanced during the 2nd and 22nd cycle day so that we could hit the menstrual and the midluteal phases, respectively. Half of the group started with the first cognitive test at the 22nd cycle day, whereas the other half started during menses. Each person participated at the same time of the day over the course of the complete study. Blood samples were taken immediately after each test session. Plasma samples were stored at –22 °C until all participants had completed the tests. Estradiol, progesterone, testosterone, LH, and FSH concentrations of each plasma sample were analyzed, by an independent professional hormone analysis laboratory, with commercially available radioimmunoassay kits (DPC Biermann GmbH, Bad Nauheim, Germany).

The following three spatial tasks were selected.

Mental Rotation Test

We used the Revised Vandenberg & Kuse Mental Rotation Test with two versions (MRT-A and MRT-B) of similar difficulty (Peters, 1995). Each version contains two parts with 12 items. For each part the participant has 3 min. Each item consists of a target figure and four stimulus figures on the right. Two of these stimulus figures are rotated versions of the target figure, and two of the stimulus figures cannot be matched to the target figure. One point is given if both of the stimulus figures that match the target figure are identified correctly. More information specific to the revised Vandenberg and Kuse test can be found in Peters, Chrisholm, and Laeng (1995), and Peters, Laeng, et al. (1995).

Mirror Pictures Test

This subtest of the *WILDE-Intelligenz-Test* (Jäger & Althoff, 1994) is a 2-D mental rotation test and includes two parallel versions. Each test contains 24 items with five line drawings each.

One of five shows a figure that is different and cannot be rotated to be identical with the other four line drawings. The participants have 3 min to choose as many as possible of the odd ones.

Hidden Figures Test

This test of visual interference (Lezak, 1995) measures flexibility in dealing with conflicting gestalts (Corkin, 1979) and is considered to be a measure of spatial ability (Watson & Kimura, 1991). The version of Hidden Figures that we used is a subtest of the Differentieller Fähigkeitstest (Differential Ability Test; Horn, 1984). Each item consists of four complex geometrical figures. One of them contains a special sample shape that is obscured by other lines. The participant has 3 min to complete 10 items. Gender differences in the Hidden Figures test were found in favor of men in several studies (Davis & Eliot, 1994; Witkin et al., 1962).

To control for potential systematic variations in mood that may influence performance for cognitive tasks, we applied a German mood scale (Zerssen, 1976).

We used two parallel versions for all paper-and-pencil tests because each woman was tested twice, once during menses and once during the midluteal phase. Although no differences between these parallel versions were found on the pre-tests, they were balanced over the two test sessions. Additionally, the different tasks on their part were balanced.

Results

To compare the task performances during menses and the midluteal phase, 4 women (33%) were excluded because post hoc hormone assays revealed that these participants were not in the expected cycle phase. Examples for an included and an excluded case are given in Figure 1. We used the more conservative non-parametric Wilcoxon signed ranks test for two related samples, because of the small sample size. The analysis of mood differences between menstrual and luteal phases yielded no significant result (Wilcoxon, $T = 12.5$, $n = 8$, $p > .05$).

The paired comparison of the 3-D MRT yielded a significant performance difference between menstrual and midluteal cycle phases (Wilcoxon, $T = 1.5$, $n = 8$, $p = .021$). On this task, the mean performance of all women decreased during the midluteal phase as compared with that during the menstrual phase. Only one woman showed a reversed pattern. It should be noted that this result appeared only when all female participants were in the expected cycle phase. In contrast, neither the 2-D mental rotation task (Mirror Pictures; Wilcoxon, $T = 7.5$, $n = 8$, $p > .05$) nor the

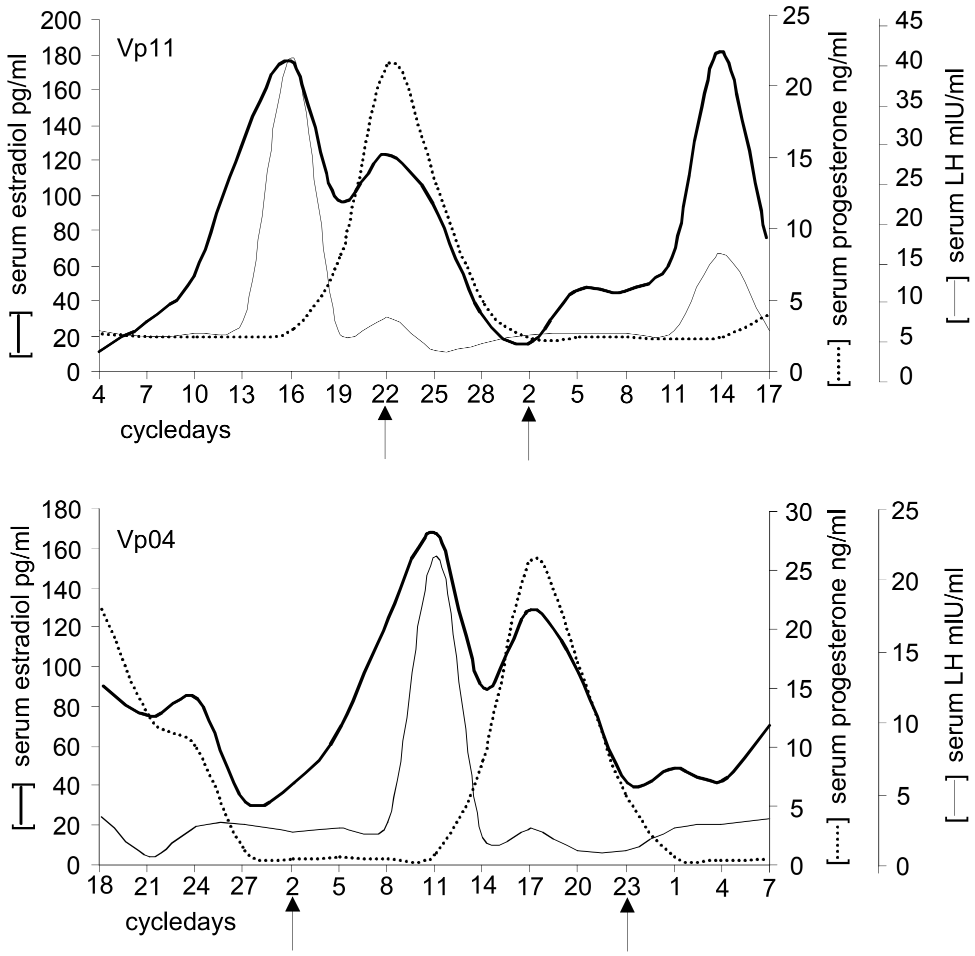

Figure 1. Examples of 1 female participant included (Vp11; top) from analysis and 1 excluded (Vp04; bottom). Arrows indicate test sessions at the 2nd and 22nd cycle days. Estradiol, progesterone and luteinizing hormone (LH) concentration curves are shown. For Participant Vp11, testing was successfully done at midluteal phase (high estradiol and progesterone levels) and menses (lowest gonadal hormone levels), but midluteal phase was missed in Participant Vp04. LH-peaks indicate time of ovulation for each woman.

Hidden Figures showed cycle-dependent performance shifts (Wilcoxon, $T = 13$, $n = 8$, $p > .05$). Means and standard deviations for both cycle phases are shown in Table 1.

Table 1
Means, Standard Deviations and Maximum Scores for the Women During Menses and the Midluteal Cycle Phase on Each Dependent Measure

	Menses		Midluteal		
Task	M	SD	M	SD	Max
MRT	10.50*	4.63	7.38	3.16	24
Mirror Pictures	9.88	2.36	11.13	2.10	24
Hidden Figures	6.75	2.87	6.38	2.62	10
Mood Scale	14.25	9.79	15.88	8.73	0 - 56

Note. Mood scale values range between *euphoric* (0) and *extremely depressive* (56). MRT = Mental Rotation Test.
*$p < 0.05$.

We computed correlations and stepwise multiple regression analyses with the data of all 12 participants to detect possible influences of a hormone or a hormone composition on performance in all three spatial ability tasks. Correlations were computed for both test sessions separately (each session included data of Cycle Day 2 and Cycle Day 22) to analyze independent hormone-performance relationships only and to detect stability of potentially significant results.

In view of the significant differences between menses and the midluteal phase of the MRT, we expected a hormonal modulation of task performance. Stepwise multiple regressions for Session 1 data yielded a significant model, $F(1,11) = 7.59$, $p = .02$, if concentrations of only testosterone, $\beta = .66$, $T(12) = 2.75$, $p = .02$, were included and concentrations of estradiol, progesterone, and both gonadotropins were excluded. The correlation coefficient R was .66, explaining 43% of the variance. Stepwise multiple regression of Session 2 data revealed a slightly different result. The best fitting and significant model was obtained, $F(1, 11) = 13.49$, $p = .002$, if both estradiol, $\beta = -.92$, $T(12) = -5.08$, $p = .001$ and testosterone levels, $\beta = .54$, $T(12) = 2.99$, $p = .015$, were entered into the regression. The correlation coefficient for the second session was $R = .87$, explaining 75% of variance.

In accordance with Gordon and Lee (1986), we computed partial correlations of MRT performance and each hormone. Because the levels of hormones are theoretically related to each other, it was important to see the unique contribution to the variance of each hormone when the linear relationship with the other hormones had been statistically removed from the dependent cognitive scores and the independent hormone measurements. For MRT performance a negative relationship with estradiol and a positive correlation with testosterone concentration were expected. One-tailed statistics were computed because of our directed hypotheses for both steroids. Indeed the relationship between estradiol and MRT performance was large and negative in both sessions, though only one is reliable with this small sample size. Estradiol was significantly correlated with MRT performance in Session 2 ($R = -.70$, $p = .026$), whereas the negative correlation in Session 1 was not significant ($R = -.48$, $p > .05$). The expected positive relationship with testosterone was significant for both sessions (Session 1: $R = +.67$, $p = .035$; Session 2: $R = +.71$, $p = .024$). No other significant hormone-MRT performance relationships were observed. Although the MRT results were significantly correlated with performance in the 2-D mental rotation test (Mirror Pictures) in Session 1 ($R = .72$, $p < .01$), stepwise multiple regression yielded no significant model for the latter task. Additionally, no other correlation statistics showed significance.

In contrast, a stepwise multiple regression procedure for performance with Hidden Figures gave a significant model, if LH, $\beta = -.68$, $T(12) = -2.98$, $p = .014$, entered the regression equation, $F(1, 11) = 8.87$, $p = .014$ ($R = .69$, $R^2 = .47$), but this result appeared in Session 2 alone. Partial correlation between Hidden Figures performance and LH was significant in Session 2 ($R = -.79$, $p = .021$), but not in Session 1 ($R = -.18$, ns).

Moreover the results of the Hidden Figures were not correlated with the performance of MRT and Mirror Pictures in both sessions (all $Rs < \pm.26$, ns), indicating that Hidden Figures measures spatial aspects different from both mental rotation tests.

Discussion

The most important result of the present study is the significant difference in spatial ability as tested by the MRT between menstrual and midluteal phases in a design with a nearly perfect validation of the menstrual cycle. Although the sample size was small, this effect was very clear. The performance of all but one woman during the midluteal phase was decreased compared with that during the menstrual phase. This result is in agreement with most studies investigating the relationship between the menstrual cycle and spatial abilities (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Phillips & Silverman, 1997). In accordance with Phillips and Silverman (1997) and Silverman and Phillips (1993), the result appeared in the 3-D spatial test (MRT) only, an effect which could also in principle be related to a higher task difficulty (Collins & Kimura, 1997). In accordance with other studies (Hampson, 1990a; Phillips & Silverman, 1997; Silverman & Phillips, 1993), estradiol had a strong influence on this result, at least in Session 2. However, estradiol does not seem to be the only steroid that has an impact on spatial cognition. Testosterone alone and testosterone combined with the negative influence of estradiol had strong and positive influences on MRT performance.

Hassler, Gupta, and Wollmann (1992) found a negative correlation between the testosterone-estradiol ratio and spatial performance in men and women, with both steroids separately not being significantly related to any of the cognitive tests used. In our study, both steroids influenced performance independently and in an inverted manner, with high estradiol concentrations leading to a decrease and high testosterone to an increase in spatial MRT scores. This accords with the known activating effect of androgens on spatial ability as shown in a group of female-to-male transsexuals (Slabbekoorn et al., 1999, Van Goozen et al., 1994; Van Goozen, Cohen-Kettenis, Gooren, Frijda, & Van de Poll, 1995) and underlines the importance of determining the unique contribution of each hormone. Moreover, Janowsky, Oviatt, and Orwoll (1994) found that exogenous testosterone administration enhanced spatial cognition in elderly men. They supposed the change of performance to be mediated by testosterone´s inhibitory effect on estrogen, because lower estradiol levels were related to better performances in the testosterone-treated group. Unfortunately, the authors could not determine a possible interaction of testosterone and estradiol on performance. According to our results in women, both steroids seem to have a cumulative effect on spatial performance in the MRT.

Progesterone and gonadotropins were not associated with spatial performance. The only exception was a single negative correlation between LH and the Hidden Figures in Session 2. This resembles the data pattern of Ho, Gilger, and Brink (1986), who found a faster response rate and less stringent decision criteria in spatial tasks during ovulation, a phase defined by the LH peak. Although Hidden Figures is considered to be a measure of spatial ability (Watson & Kimura, 1991), it most likely measures aspects different from those captured by MRT and Mirror Pictures. This is supported by the absence of significant correlations between scores obtained with Hidden Figures and the other two mental rotation tasks, whereas MRT and Mirror Pictures are significantly related.

A prerequisite of the present study was the determination of hormone concentrations to validate cycle phases and to reveal relationships between hormones and spatial cognition. Indeed, one third of the participants had to be excluded because of post hoc hormone assays, a value which is in the range of other studies (46%: Gordon et al., 1986; 27%: Hausmann & Güntürkün, 2000; 25%: Metcalf & MacKenzie, 1980; 23%: Mead & Hampson, 1996).

We conclude that spatial performance is sensitive to hormonal fluctuations over the menstrual cycle and that different aspects of spatial abilities are related to different hormones or hormone combinations, resulting in task-specific results. Task difficulty and/or 3-D processes seem to be aspects that are able to modify these results to some extent.

References

Baenninger, M., & Newcombe, N. (1995). Environmental input to the development of sex-related differences in spatial and mathematical ability. *Learning and Individual Differences*, *7*, 363-379.

Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1947). *Differential Aptitude Tests, Form A*. New York: Psychology Corporation.

Christiansen, K. (1993). Sex hormone-related variations of cognitive performance in !Kung San hunter-gatherers of Namibia. *Neuropsychobiology*, *27*, 97-107.

Collins, D. W., & Kimura, D. (1997). A large sex difference on a two-dimensional mental rotation task. *Behavioral Neuroscience*, *111*, 845-849.

Corkin, S. (1979). Hidden-Figures-Test performance: Lasting effects of unilateral penetrating head injury and transient effects of bilateral cingulotomy. *Neuropsychologia*, *17*, 585-605.

Davis, D., & Eliot, J. (1994). Comparison of related perceptual tests. *Perceptual and Motor Skills*, *79*, 399-402.

Ekstrom, R. B., French, J. W., & Harman, H. H. (1976). *Manual for kit of factor-referenced cognitive tests*. Princeton, NJ: Educational Testing Service,

Epting, L. K., & Overman, W. H. (1998). Sex-sensitive tasks in men and women: A search of performance fluctuations across the menstrual cycle. *Behavioral Neuroscience*, *112*, 1304-1317.

Gordon, H. W., Corbin, E. D., & Lee, P. A. (1986). Changes in specialized cognitive function following changes in hormone levels. *Cortex*, *22*, 399-415.

Gordon, H. W., & Lee, P. L. (1986). A relationship between gonadotropins and visuospatial function. *Neuropsychologia*, *24*, 563-576.

Gordon, H. W., & Lee, P. L. (1993). No differences in cognitive performance between phases of the menstrual cycle. *Psychoneuroendocrinology*, *18*, 521-531.

Gouchie, C., & Kimura, D. (1991). The relationship between testosterone levels and cognitive ability patterns. *Psychoneuroendocrinology*, *16*, 323-334.

Halpern, D. F. (1986). *Sex differences in cognitive abilities*. Hilsdale: Lawrence Erlbaum Associates.

Halpern, D. F. (1996). Sex, brains, hands, and spatial cognition. *Developmental Review*, *16*, 261-270.

Hampson, E. (1990a). Estrogen-related variations in human spatial and articulatory-motor skills. *Psychoneuroendocrinology*, *15*, 97-111.

Hampson, E. (1990b). Variations in sex related cognitive abilities across the menstrual cycle. *Brain and Cognition*, *14*, 26-43.

Hampson, E., & Kimura, D. (1988). Reciprocal effects of hormonal fluctuations on human motor and perceptual-spatial skills. *Behavioral Neuroscience*, *102*, 456-459.

Hassler, M., Gupta, D., & Wollmann, H. (1992). Testosterone, estradiol, ACTH and musical, spatial and verbal performance. *International Journal of Neuroscience*, *65*, 45-60.

Hausmann, M., & Güntürkün, O. (2000). Steroid fluctuations modify functional cerebral asymmetries: The hypothesis of progesterone mediated interhemispheric decoupling. *Neuropsychologia*, 38, 1362-1374.

Ho, H.-Z., Gilger, J. W., & Brink, T. M. (1986). Effects of menstrual cycle on spatial information-processes. *Perceptual and Motor Skills*, *63*, 743-751.

Horn, R. (1984). *Differentieller Fähigkeitstest* [Differential Ability Test]. Weinheim, Germany: Beltz Test.

Hyde, J. S. (1981). How large are cognitive gender differences? *American Psychologist*, *36*, 892-901.

Jäger, A. O., & Althoff, K. (1994). *Der WILDE-Intelligenz-Test (WIT)* [The WILDE Intelligence Test]. Göttingen, Germany: Hogrefe & Huber.

Janowski, J. S., Oviatt, S. K., & Orwoll, E. S. (1994). Testosterone influences spatial cognition in older men. *Behavioral Neuroscience*, *108*, 325-332.

Kass, S. J., Ahlers, R. H., & Dugger, M. (1998). Eliminating gender differences through practice in an applied visual spatial task. *Human Performance*, *11*, 337-349.

Kimura, D. (1992). Sex differences in the brain. *Scientific American*, *267*, 118-125.

Kimura, D. (1996). Sex, sexual orientation and sex hormones influence human cognitive function. *Current Opinion in Neurobiology*, *6*, 259-263.

Lezak, M. D. (1995). *Neuropsychological assessment* (2nd ed.). New York: Oxford University Press.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, *56*, 1479-1498.

Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences*. Stanford: Stanford University Press.

Masters, M. S., & Sanders, B. (1993). Is the gender difference in mental rotation disappearing? *Behavior Genetics*, *23*, 337-341.

McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin*, *86*, 889-918.

McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *Behavioral Brain Sciences*, 3, 215-263.

McKeever, W. F. (1995). Hormone and hemisphericity hypotheses regarding cognitive sex differences: Possible future explanatory power, but current empirical chaos. *Learning and Individual Differences*, *7*, 323-340.

Mead, L. A., & Hampson, E. (1996). Asymmetric effects of ovarian hormones on hemispheric activity: Evidence from dichotic and tachistoscopic tests. *Neuropsychology*, *10*, 578-587.

Metcalf, M. G., & MacKenzie, J. A. (1980). Incidence of ovulation in young women. *Journal of Biosocial Science*, *12*, 345-352.

Peters, M. (1995). *Revised Vandenberg & Kuse Mental Rotations Tests: forms MRT-A to MRT-D* [Tech. Rep.]. Guelph (ON), Canada: University of Guelph, Department of Psychology, .

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A Redrawn Vandenberg & Kuse Mental Rotation Test: Different versions and factors that affect performance. *Brain and Cognition*, *28*, 39-58.

Peters, M., Chrisholm, P., & Laeng, B. (1995). Spatial ability, student gender and academic performance. *Journal of Engineering Education*, *84*, 69-73.

Phillips, K., & Silverman, I. (1997). Differences in the relationship of menstrual cycle phase to spatial performance on two- and three-dimensional tasks. *Hormones and Behavior*, *32*, 167-175.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701-703.

Silverman, I., & Phillips, K. (1993). Effects of estrogen changes during the menstrual cycle on spatial performance. *Ethology and Sociobiology*, *14*, 257-270.

Silverman, I., Phillips, K., & Silverman, L. K. (1996). Homogeneity of effect sizes for sex across spatial tests and cultures: Implications for hormonal theories. *Brain and Cognition*, *31*, 90-94.

Slabbekoorn, D., Van Goozen, S. H. M., Megens, J., Gooren, L. J. G., & Cohen-Kettenis, P. T. (1999). Activating effects of cross-sex hormones on cognitive functioning: a study of short-term and long-term hormone effects in transsexuals. *Psychoneuroendocrinology*, *24*, 423-447.

Tapley, S. M., & Bryden, M. P. (1977). An investigation of sex differences in spatial ability: Mental rotation of three-dimensional objects. *Canadian Journal of Psychology*, *31*, 122-130.

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations: A group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, *47*, 599-604.

Van Goozen, S. H. M., Cohen-Kettenis, P. T., Gooren, L. J. G., Frijda, N. H., & Van de Poll, N. E. (1994). Activating effects of androgens on cognitive performance: Causal evidence in a group of female-to-male transsexuals. *Neuropsychologia*, *32*, 1153-1157.

Van Goozen, S. H. M., Cohen-Kettenis, P. T., Gooren, L. J. G., Frijda, N. H., & Van de Poll, N. E. (1995). Gender differences in behaviour: activating effects of cross-gender hormones. *Psychoneuroendocrinology*, *20*, 343-363.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, *117*, 250-270.

Watson, N. V. & Kimura, D. (1991). Nontrivial sex differences in throwing and intercepting: Relation to psychometrically-defined spatial functions. *Personality and Individual Differences*, *12*, 375-385.

Williams, C. L., & Meck, W. H. (1991). The organizational effects of gonadal steroids on sexually dimorphic spatial ability. *Psychoneuroendocrinology*, *16*, 155-176.

Witkin, H. A., Dyk, R. B., Faterson, H. F., Goodenough, D. R., & Karps, S. A. (1962). *Psychological differentiation*. New York: Wiley.

Zerssen, D. (1976). *Die Befindlichkeits-Skala* [The Mood Scale]. Weinheim, Germany: Beltz-Verlag.

Received September 3, 1999
Revision received April 28, 2000
Accepted June 12, 2000