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Correlation Between Menstrual Cycle and Cognitive Performance in a Chimpanzee (*Pan troglodytes*)

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Extensive research on human subjects has tried to investigate whether there is a correlation between cognitive performance and the menstrual cycle. Less is known about the relationship between the menstrual cycle and task performance in other cognitive animals. We test whether the secretion of a sex hormone [luteinizing hormone(LH)] influences the performance of cognitive tasks by a female chimpanzee (*Pan troglodytes*) who is part of a long-term cognition research program. We focus on two cognitive tasks: an "easy task," which consists of simple numerical ordering, and a "difficult task," which combines numerical ordering with memorizing the numerals' spatial location. Data on the performance of these cognitive tasks, urine samples, and sexual swelling over six menstrual cycles showed that the chimpanzee's performance accuracy decreased and that the intertrial interval was longer during the LH-surge of the menstrual cycle, but only for the performance of the difficult task. These performance attributes seem to reflect a decrease in attention or motivation during ovulation. In summary, the cognitive performance of a chimpanzee was disturbed by hormonal changes despite her long-term experience in the tasks.

Keywords: chimpanzee (*Pan troglodytes*), cognitive performance, LH surge, menstrual cycle

Is there any correlation between cognitive performance and the menstrual cycle? A large volume of research in women has shown that hormonal variations during the menstrual cycle can have an effect on cognitive performance; especially in verbal related skills (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Maki, Rich, & Rosenbaum, 2002; Rosenberg & Park, 2002), manual/motor related skills (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Maki et al., 2002), and spatial skills (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Gunturkun, 2000; Maki et al., 2002; Silverman, & Phillips, 1993). For example, young women performed a Mental Rotation test better during their menstrual phase and worse during their midluteal phase, with performance influenced positively by testosterone and negatively by estradiol (Hausmann et al., 2000). However, reports also exist showing that there is no correlation between the menstrual cycle and cognitive performance. These include performance on verbal, manual, or spatial tasks (Epting & Overman, 1998; Gordon & Lee, 1993), typing tasks (Black & Koulis-Chitwood, 1990), and a flight simulator task (Mumenthaler, O'Hara, Taylor, Friedman, & Yesavage, 2001). Why do different studies yield such contradictory results? One possibility is that the differences can be attributed to different task demands. For example, some tasks rely on visual search, others on auditory matching, or manual work. Furthermore, task familiarity—such having to perform as a simple calculation versus controlling an unfamiliar flight simulator—might also influence subjects' performance. To elucidate the involvement of these and other factors, animal studies are effective ways of better understanding the correlation between menstrual cycle and cognition.

For example, many studies that examine the correlation between sexual hormones and cognitive performance have been performed with rodents (see Daniel, Fader, Spencer, & Dohanich, 1997; Korol & Kolo, 2002; Sava & Markus, 2005; Tropp, Figueiredo, & Markus, 2005; Daniel, 2006). Adult female meadow voles with low levels of estradiol show enhanced spatial learning abilities in a Morris water maze when compared with females with high levels of estradiol (Galea, Kavaliers, Ossenkopp, & Hampson, 1995). Learning strategies of female rats in water maze tasks have also been shown to change across their menstrual cycle (Korol, Malin, Borden, Busby, & Couper-Leo, 2004). Nonetheless, it is difficult to compare results from laboratory-animal studies with those from human subjects because there are large differences in the characteristics of their menstrual cycle, as well as large gaps in the complexity of their cognitive abilities.

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Studies on animals more closely related to humans, such as nonhuman primates, are few (Lacreuse, Verreault, & Herndon, 2001; Lacreuse, 2006; Lacreuse, Martin-Malivel, Lange, & Herndon, 2007). Chimpanzees are humans' closest evolutionary neighbors, but there are no studies that test the effects of the menstrual cycle on chimpanzee cognitive behavior. Chimpanzees and humans have a similar physiological system and menstrual cycle (Shimizu, Douke, et al., 2003; Shimizu, Udono, et al., 2003). On average, the menstrual cycle of chimpanzees is 33.5 (±3.9) days, and this is similar to the cycle of humans, which is 28.4 (±1.8) days (Shimizu, Douke, et al., 2003). One difference between chimpanzees and humans is that the chimpanzee evolved to advertise its reproductive status, while human females do not. The skin around a female chimpanzee's genital area swells at the time of the ovulation phase and deflates after ovulation. Genital swelling in chimpanzees correlates with hormonal changes (Deschner, Heistermann, Hodges, & Boesch, 2003, 2004; Emery & Whitten, 2003; Mcarthur et al., 1981). Measurements of the swelling can be used to detect the phase of the menstrual cycle, since it is difficult to collect daily blood samples from chimpanzee subjects when compared with other experimental animals. However, because the duration of maximum swelling can be long, that is, 6 to 18 days, performing hormonal analyses to detect the exact moment of ovulation may still be necessary (Deschner et al., 2003). The collection of urine samples has been demonstrated to be an adequate noninvasive method to extract and analyze chimpanzee sexual hormones (Deschner et al., 2003; Mcarthur et al., 1981). Thus, measuring sexual swelling in conjunction with sexual hormones through urine analysis may facilitate studies on chimpanzees' performance of cognitive tasks over the course of the menstrual cycle.

Here, for the first time we provide evidence that a chimpanzee's cognitive performance can fluctuate with its menstrual cycle. Our study focuses on an adult female with a normal menstrual cycle, whose performance on cognitive tasks can be tested regularly (Matsuzawa, Tomonaga, & Tanaka, 2006). We chose one of the most familiar tasks for this subject as the target cognitive task, that is, numerical ordering task. The subject was the first chimpanzee that learned to use Arabic numerals to label sets of real-life objects with the corresponding number (Matsuzawa, 1985) and later mastered various additional kinds of numerical skills (numerical estimation, Murofushi, 1997; numerical ordering, Biro & Matsuzawa, 1999; introduction of zero, Biro & Matsuzawa, 2001; enumeration of items, Tomonaga & Matsuzawa, 2002; working memory, Kawai & Matsuzawa, 2000; working memory with brief presentation, Inoue & Matsuzawa, 2007; and symbolic representation, Matsuzawa, 2009).

In the present study we use a relatively simple method to test the prediction that there is a relation between the menstrual cycle and cognitive performance. The subject has been asked to participate in the same cognitive tasks every day as part of its daily routine for many years (Matsuzawa, 2003). This made it possible to collect reliable cognitive performance data. In parallel, we collected urine samples to evaluate sexual hormone levels, and recorded the size of the subject's sexual swelling. We then examined the correlation between cognitive performance and different stages of the menstrual cycle using these data.

Method

Subject

The subject was a 29-year-old chimpanzee (*Pan troglodytes*) named Ai who is experienced at various cognitive tasks (Matsuzawa, 2003; Matsuzawa et al., 2006), and in particular has received extensive training on a numerical ordering task (Biro & Matsuzawa, 1999; Inoue & Matsuzawa, 2007; Kawai & Matsuzawa, 2000; Matsuzawa, 2009). After giving birth to her first son in April 2000, she restarted a regular menstrual cycle in February 2003. The subject is a member of a community of 14 individuals that span three generations and whose age ranges from 5 to 38 years. This community lives in a seminatural enriched environment at the Primate Research Institute of Kyoto University (Matsuzawa et al., 2006). Care and use of these chimpanzees adheres to the 2002 version of the "*Guide for care and use of laboratory primates*" of the Primate Research Institute, Kyoto University. The Animal Welfare and Animal Care Committee of the Institute approved the research design for this study.

Apparatus

Experiments were conducted in one of two adjacent testing booths (each 2.0 m in width, 3.2 m in depth, and 2.0 m in height) that have transparent glass walls and a vertical sliding door connecting them. The testing booth was equipped with a touch-screen monitor (Pro-Tect, PD-105TP15) controlled by a personal computer. Correct trials were followed by food rewards: a small 8 mm cube of apple or half a raisin was delivered automatically by a universal feeder (Biomedica, BUF-310-P50).

Stimuli

Stimuli used were Arabic numerals 0 through 9 displayed as white Gothic typeface, 3 cm in height, against a black background on the monitor. The numerals appeared in random positions within an 8 × 5 invisible matrix on the touch-screen monitor during each trial.

Procedure

We invited the subject to the booth from the outdoor compound by calling her name. The chimpanzee then voluntarily walked through a corridor to the booth. A trial began when the subject touched the white circle (start key) presented on the monitor. This was followed by the appearance of the numerical stimuli, which the subject was required to touch one by one in ascending order. Numerals correctly selected disappeared immediately from the monitor with a concurrent click sound as feedback. When the subject had touched all the numerals in the correct ascending order, a chime sounded and a food reward was delivered. If a numeral was selected incorrectly, the screen was cleared, a feedback buzzer sounded, and no food was delivered. The task was conducted for approximately 30 minutes a day, 5 to 6 days a week.

Easy task: Nonmasking task. The task was to touch adjacent numerals in ascending order (Figure 1-a). There were two conditions: one condition consisted of nine patterns which always started with 0, for example, 01, 012, .., 012345678, 0123456789. The second condition consisted of nine patterns which always

Figure 1. (a) A photograph illustrating the subject, Ai, engaged with the easy task, that is, a simple numerical ordering task. When a set of numerals appeared on the touch sensitive monitor, she was required to touch the numerals in an ascending order. (b) Ai engaged with the difficult task, that is, numerical memory task. Immediately after she touched the lowest numeral in a sequence of five, the other numerals were replaced with white squares. The subject was then required to touch the squares in the order corresponding to the numerals as originally shown.

ended with 9, for example, 89, 789, . . ., 123456789, 0123456789. Tests in each condition consisted of 50 trials chosen randomly from the nine possible patterns. The two conditions were tested on alternate days. To eliminate careless mistakes we adopted a correction method by repeating the same trial until the correct response was scored. The subject was asked to perform this "easy task" once during each of her daily sessions.

Difficult task: Masking task. This task was designed to test working memory, that is, the subject needed to memorize the location of the numerals in the correct ascending order (Figure 1-b). Five numerals were randomly chosen from the range 1 to 9; all 126 ($_9C_5$) possible combinations were tested. After the subject had touched the lowest numeral, all other numerals were replaced by white squares. The subject was then required to touch the white squares in the order corresponding to the numerals as originally shown. One session consisted of 50 trials. The correction method was not applied in this task. The subject was asked to perform this "difficult task" once per day, immediately after the "easy task."

Menstrual cycle. A menstrual cycle was defined to start from the first day of menstruation until the first day of the next menstruation. We collected daily urine samples from the subject. Ai was asked to urinate at a fixed place immediately after finishing the cognitive tasks, and the samples were kept in a freezer (−30 °C) until they were tested for sexual hormone levels. We analyzed hormone levels using a hemagglutination inhibition test (Hi-Gonavis, Mochida Pharmaceutical Co., Ltd) for urinary luteinizing hormone (LH; see Fujita, Matsuzawa, & Matsubayashi, 1999). In addition, we rated the sexual swelling of Ai's skin by visual inspection and also photographs: we asked her to present her ano-genital area against the glass wall and photographed sexual skin with a ruler in the background for scale (see Figure 2). Sexual swelling was classified into one of five levels from 0 (no swelling) to 4 (maximum swelling; see Deschner et al., 2003).

Analysis of cognitive performance. We compared Ai's performance on the two tasks among three phases of her menstrual cycle: a) menstruation phase, b) ovulation phase, and c) intermediate phase. Data were excluded if all three measures (task performance, hormone level from urine sample, and sexual swelling) were not recorded within the same session. Cognitive performances of the "easy task" and "difficult task" were collected during two successive sessions in each menstrual cycle phase, that is, a total of 68 sessions for each task from six consecutive menstrual cycles over the course of 225 days (October 2005 to May, 2006).

We compared the percent correct response, the inter-trial-interval (ITI) and the response time within a trial. Response time was calculated from correct trials only, to exclude the effects of

Figure 2. A photograph illustrating differences in the size of Ai's sexual swelling. The upper panel shows the minimum swelling (level 0) for the subject, while the lower panel shows maximum swelling (level 4).

cancelling behaviors caused by touching a numeral whatever near the start key, or, of simple missed-touch errors.

Results

We recorded 6 menstrual cycles for the single subject Ai (see Figure 3). Ai generally menstruated for 2 days. The average length of her cycle was 37 (±3) days. During a cycle Ai's sexual swelling gradually increased from the minimum level 0 until the maximum level 4 through a period of approximately 6 (±2) days, and then decreased to level 0 (Figure 4-a). A luteinizing hormone surge (LH surge) was indicative of her ovulation phase (Figure 4-b). The ovulation period was considered to last 2 days. The LH surge was always observed at the end of the maximal swelling period.

There was no statistically significant difference in the average percent correct in the subject's performance of the "easy task" during the different menstrual cycle phases [one-way ANOVA; $F(2, 33) = 2.18$, $p = .13$]. However, the chimpanzee performed poorly on the "difficult task" during the ovulation phase [one-way ANOVA; $F(2, 33) = 3.87$, $p < .05$]. A post hoc Fisher's LSD test revealed a significant difference in performance between ovulation and the intermediate phase ($p < .01$), and a tendency toward a difference in performance between ovulation and the menstruation phase ($p = .083$). However, there was no significant difference in performance between menstruation and the intermediate phase ($p = .47$; see Figure 5).

A similar pattern was observed in our analysis of ITIs. Ai showed a longer ITI for the "difficult task" during her ovulation phase [one-way ANOVA; $F(2, 33) = 4.76$, $p < .05$]. A post hoc Fisher's LSD test revealed significant differences in performance between ovulation and the menstruation phase ($p < .05$), and a tendency toward a difference in performance between ovulation and the intermediate phase ($p = .098$). There was no significant difference in performance between menstruation and the intermediate phase ($p = .27$). On the other hand, there were no statistically significant differences among the menstrual cycle phases in ITI during the "easy task" [one-way ANOVA; $F(2, 33) = 0.10$, $p = .90$; see Figure 6).

Ai showed similar patterns in response times within a trial in both the "easy task" and "difficult task." The first touch consistently took the longest, while all other subsequent touches had shorter response times. The subject showed this performance pattern throughout her menstrual cycle without any significant difference between phases for either the easy task [two-way ANOVA, phase main effect: $F(2, 165) = 2.48$, $p = .087$] or the difficult task [two-way ANOVA, phase main effect: $F(2, 165) = 0.96$, $p = .38$; Figure 7].

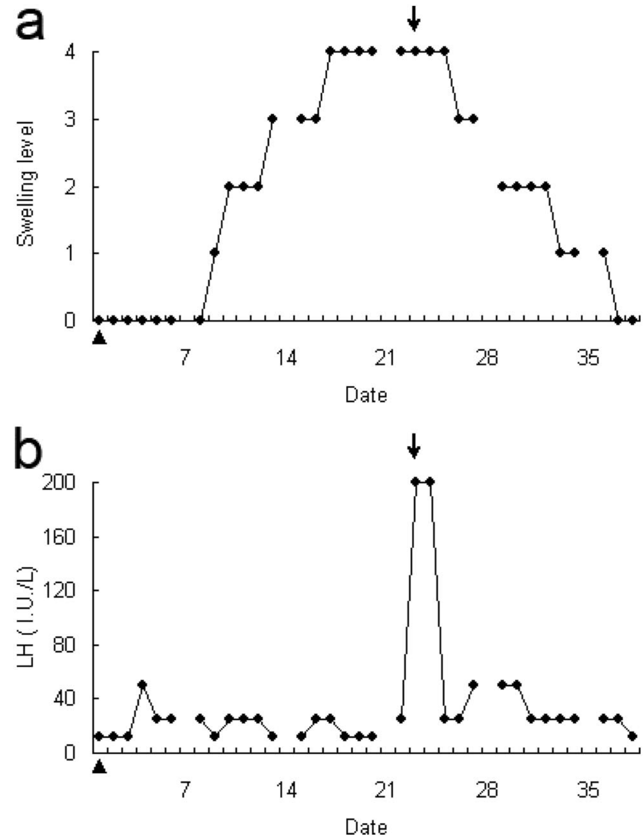

Figure 4. An example of swelling and hormone patterns in a typical menstrual cycle. The upper column (a) shows the changes in sexual swelling during a cycle. The lower column (b) shows changes in the level of LH hormone. The triangle represents the first day of menstruation. The arrow shows the first day of the LH surge.

Discussion

Our results suggest that the menstrual cycle can affect the cognitive performance of a chimpanzee: our subject's performance of a cognitively difficult task changed around the time of ovulation. This change is similar to that seen in women and female

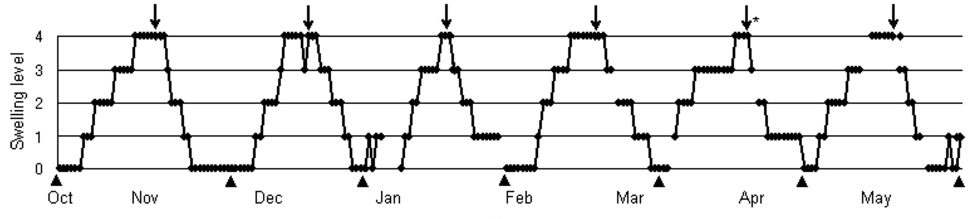

Figure 3. Changes in the level of sexual swelling through six contiguous menstrual cycles. A cycle starts from menstruation (triangle), and the swelling increases up to level 4. The LH surge (arrow) occurred at the last moment of maximum swelling. The asterisk (*) indicates a point where hormone levels were very low compared with other LH surges, and therefore, these data were excluded.

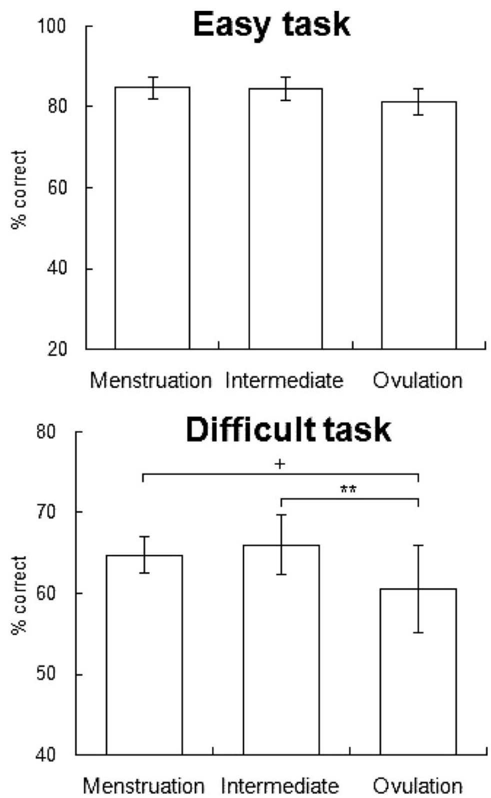

Figure 5. Performance (% correct) in the two tasks performed by the chimpanzee subject, Ai, during the three phases of the menstrual cycle (menstruation, intermediate, and ovulation). The upper panel shows performance of the easy task, while the lower panel shows the difficult task. $^{+}p < .1$. $^{**}p < .01$.

rhesus monkeys whose performance in spatial and memory tasks, respectively, is poorer during periods of high estrogen levels (Hampson, 1990a, 1990b; Hampson & Kimura, 1988; Hausmann et al., 2000; Lacreuse, 2006; Lacreuse et al., 2001; Phillips & Silverman, 1997).We found interesting that in contrast with the difficult task, the menstrual cycle does not affect performance of a cognitively easy task, even though both tasks entailed the sequential ordering of the same stimuli, that is, numerals.

Several possible explanations for the difference in the performance of the easy and difficult tasks can be given. Although this study was performed over multiple contiguous menstrual cycles, the subject's performance of the difficult task was affected only during the ovulation phase. One possible explanation is that, when compared to the difficult task, the easy task does not require additional skills. The easy task placed fewer cognitive demands on the subject, as suggested by the relatively high percent correct responses across the cycle. In contrast, the difficult task required close visual attention to the monitor, since numerals disappeared after the subject's initial touch and were replaced by white squares. Even a brief distraction may have easily led to confusion about the location and/or identity of the numerals presented, meaning that each trial of the difficult task required higher levels of concentration in order to enable a correct response.

The pattern of response times within a trial was consistent across the cycle regardless of task difficulty, that is, once the subject started she could complete a trial with stable latency. This suggests that the subject's ability to solve the task did not change. Yet, during the difficult task only, the ITI was longer during the ovulation phase. It seems that Ai showed a slight hesitation in starting each trial during this phase. In sum, our results clearly indicate that a cognitive task that requires visual concentration can be affected by the menstrual cycle, and detailed examination of our data suggests that this is not a matter of a decline in cognitive ability but a decline in motivation.

Several studies report many changes in behavioral patterns that seem typical and indicative of differences in motivation during the ovulation period. Penton-Voak et al. (1999) reported that women seemed to prefer more masculine male faces rather than more feminized male faces during the ovulation phase (see also Gangestad & Thornhill, 2008; Lacreuse et al., 2007). Moreover, Haselton, Mortezaie, Pillsworth, Bleske-Rechek, and Frederick (2007) reported that women had a tendency to dress much more attractively while they were ovulating. During our experiments we observed that our subject had a tendency to seek attention from certain individuals, including humans, around the period of her maximal sexual swelling. For example, she often presented her sexual swelling to male researchers, and ignored instructions from females or nonmasculine males, even those she usually had a good relationship with (Inoue, personal observation). Therefore, it seems that fluctuations in cognitive performance might also cor-

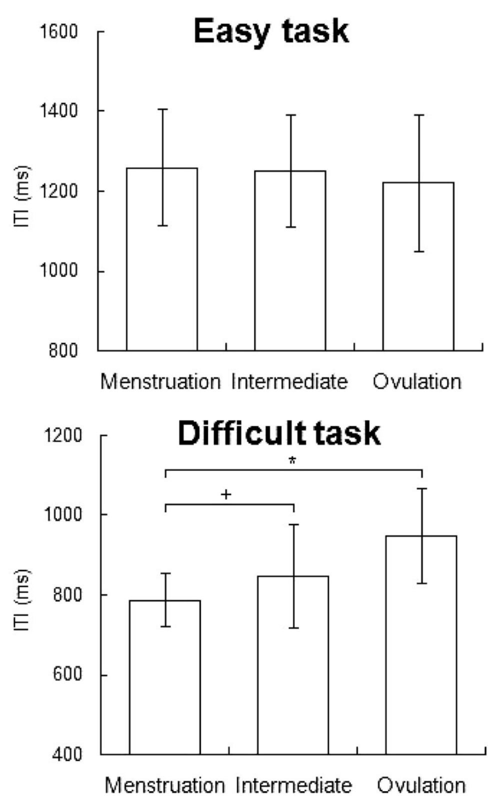

Figure 6. The Inter-trial-interval (ITI) in the two tasks performed by the chimpanzee subject, Ai, during the three phases of the menstrual cycle (menstruation, intermediate, and ovulation). The upper panel shows ITI for the easy task and the lower panel shows the difficult task. $^{+}p < .1$. $^{*}p < .05$.

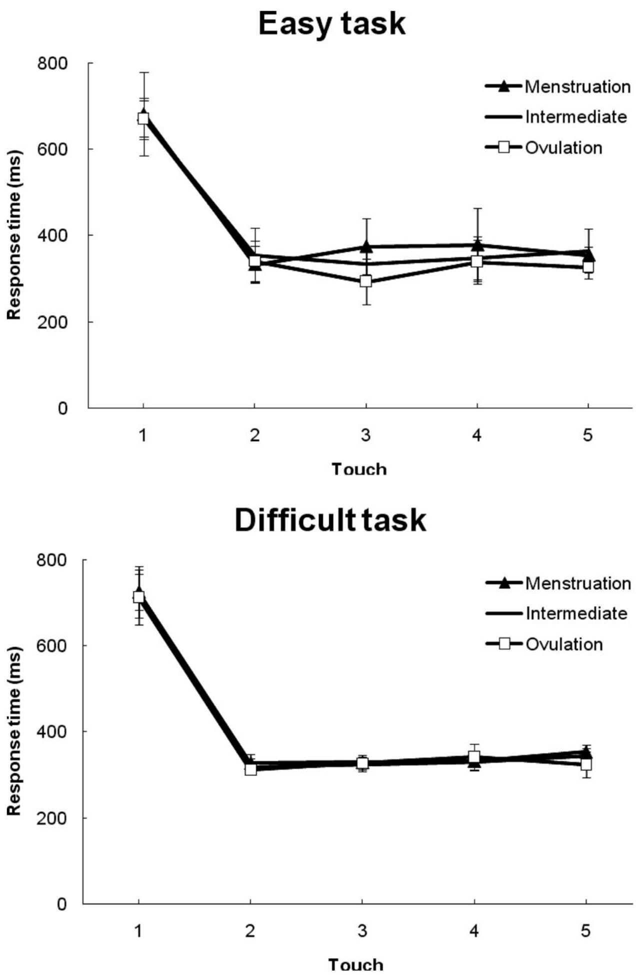

Figure 7. The pattern of response times within trials for the two tasks performed by the chimpanzee subject, Ai, during the three phases of the menstrual cycle (menstruation, intermediate, and ovulation). The upper panel shows results of five numeral sequences from the easy task, and the lower panel shows the difficult task.

relate with various conspicuous behaviors that appear during the period of ovulation.

In the wild, Pieta (2008) reported that female chimpanzees in Kibale National Park in Uganda show strategic mate choice that varies over the course of the menstrual cycle. Females tend to accept and mate with “eschewed males” in the nonperiovulatory period, and with “preferred males” in the periovulatory period (see also research at Mahale in Tanzania, Matsumoto-Oda, 1999; Taï Forest in Côte d’Ivoire, Stumpf & Boesch, 2006). An increase in locomotive activity and a decrease in foraging behavior around the period of ovulation in rodents, monkeys, chimpanzees, and even in humans, has also been reported (Fessler, 2003). Those results suggest that during the ovulation period, females devote more time and attention to mating activities, which might explain the decline in attention or motivation that we have reported for the ovulation phase of the menstrual cycle. Even with our subject’s long-term training and experience on the tasks, the influence of hormonal changes was substantial enough to disturb concentration.

Recently, we found that adult chimpanzees showed difficulties in a memory task (the difficult task of the current study) compared to young chimpanzees, even though subjects of both age groups were able to perform well in a nonmemory version of the same task (the easy task of the current study). Hence, experience of both tasks using the same stimuli did not influence working memory capability. Nonetheless, difference in age correlates with working memory capability (Inoue & Matsuzawa, 2009). This might suggest developmental changes in cognitive performance caused by shifting motivation or attention toward mating. That is, cognitive factors affecting the differences observed in previous studies on humans may not correspond to type of task, skill or experience. Instead, the factors responsible may be simpler—such as attention or motivation—and they may correlate with mating behavior influenced by sexual hormones. Our results are the first to show that cognitive performance may vary over the course of the menstrual cycle in a chimpanzee, but further studies examining potential correlations with mating behavior or developmental stages are needed to assess intraspecies differences in more detail.

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