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Verbal and music dichotic listening tasks reveal variations in functional cerebral asymmetry across the menstrual cycle that are phase and task dependent

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Abstract—Two dichotic listening tests, one a verbal consonant-vowel identification task, the other a musical chord recognition task, were administered to 32 women at two points during the menstrual cycle, menses (when oestrogen is low) and the midluteal phase (when oestrogen is high), in a counterbalanced repeated measures design. The degree of asymmetry changed across the cycle for both syllables and music. The right ear advantage recorded for the verbal task was greater during the midluteal phase than during menses. The left ear advantage recorded for the music task was greater during menses than during the midluteal phase. These reciprocal changes in asymmetry were the result of consistent changes in ear performance. From menses to the midluteal phase, left ear (right hemisphere) performance fell significantly for both tasks whereas right ear (left hemisphere) performance showed a small, but non-significant, increase. The findings are discussed in the light of evidence for phasic activational effects of gonadal steroids on both asymmetry and cognition which provide an explanation for the sometimes elusive nature and small effect size of sex differences in these characteristics. The relationships between sex differences in asymmetry and cognition are re-examined.

Key Words: gonadal steroid hormones; cognition; sex differences.

Introduction

Functional cerebral asymmetry, as measured by lateralised performance on auditory and visual–perceptual tasks and cognitive abilities, especially the performance of spatial and verbal tasks, are two related areas of psychology in which possible sex differences continue to be a matter of interest [4, 13, 18, 25, 27, 34, 35]. Not only have the nature and origins of these sex differences generated much debate but their very existence has been questioned [6, 9, 10, 12, 20]. One reason for this controversy is the widely held view that sex-related patterns of functional asymmetry and cognitive abilities are hard-wired and fixed. This view has been challenged by reports that cognitive performance [14–16] and the degree of asymmetry [1, 5, 7, 15, 17, 30] change across the menstrual cycle, although the latter studies appear to disagree on the point in the cycle at which asymmetry is greatest. In this study we present evidence of orderly changes in perceptual asymmetry across the menstrual cycle which provide an explanation for the apparent conflict in the published reports and a framework which incorporates a logical association between sex-related patterns of asymmetry and cognitive ability.

The debate concerning the origins of sex differences revolves around the relative influence of biological and psychosocial factors [13]. The most direct evidence for a biological input comes from work on brain development and sexual behaviour in rodents where studies have demonstrated that gonadal steroids exert two very different influences (for reviews see [3, 29]). Prenatal exposure triggers permanent, presumably hard-wired, organizational effects whereas periodic fluctuations in adult gonadal steroid levels produce phasic activational effects on brain and behaviour. An increasing number of studies have revealed similar organizational [8] and activational [22] effects on cognitive functions in humans.

At a time when hard-wired organisational effects dominated thinking, Levy [23, 24] proposed that sex differ-

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ences in cognitive abilities may be explained by sex differences in brain organisation. According to this hypothesis, male superiority in spatial ability is the product of the marked lateralization of verbal abilities to the left and spatial abilities to the right hemisphere. In women, the presence of some verbal ability in the right hemisphere is said to account for both their superior verbal ability and their inferior spatial abilities. Voyer's meta-analytic review of sex differences in functional brain asymmetry [34] found men to be more lateralized than women and concluded that this finding specifically supported Levy's hypothesis. The studies reviewed by Voyer represent the traditional approach to sex differences as long-lasting products of early brain organisation. Here we turn to the activational effects that circulating hormones may exert on the adult brain.

Gonadal steroids have been linked to activational effects on human cognition by reports of reciprocal changes in the performance of sexually dimorphic tasks across the menstrual cycle [14–16]. Male-favouring spatial tasks are performed better at menses when oestrogen is low and female-favouring verbal tasks better during the preovulatory and midluteal phases when oestrogen is high. If sex differences in cognitive abilities and functional asymmetry are related as Levy suggested, then changes in task performance across the menstrual cycle should be accompanied by complementary changes in perceptual asymmetry. From Levy's hypothesis we might expect the male pattern of more marked asymmetry at menses when performance favours spatial tasks and the female pattern of reduced asymmetry later in the cycle when performance favours verbal tasks.

To investigate this possibility we reviewed [31] six studies of changes in asymmetry across the menstrual cycle [1, 5, 7, 14, 17, 30] which, together, used a total of ten tasks to measure perceptual asymmetry. Two of the tasks revealed greater asymmetry at menses when oestrogen is low [17, 30], five tasks showed no significant changes [5, 7, 17] and two [5, 14] found greater asymmetry later in the cycle when oestrogen is high. One study [1] reported a decrease in asymmetry from the follicular to the late luteal phase, however, because oestrogen levels are changing during these phases, it is impossible to interpret this finding in the present context. Overall, although the number of studies is small, these results do not confirm our prediction from Levy's hypothesis because there appears to be as much support for greater asymmetry later in the cycle as there is at menses.

It is widely accepted that the direction of functional asymmetry generated by a task is dependent on the cognitive processing it elicits. Verbal processing yields a left hemisphere advantage while non-verbal (visuo–spatial) processing yields a right hemisphere advantage. Thus it is possible that the point in the menstrual cycle of greatest asymmetry depends on the task employed to measure that asymmetry and specifically on the direction of the asymmetry that it generates. In the present study we tested this hypothesis using two dichotic listening tasks: a music task reported to generate a right hemisphere advantage and a verbal task that typically generates a left hemisphere advantage. Both tasks were completed at menses and during the midluteal phase by naturally cycling women in a counterbalanced repeated measures design.

Method

Participants

Thirty-two women with a mean age of 24 years ($r = 18$–37) participated in this study. The women were selected on the basis of the following inclusion criteria: they were right handed; they had no left handed parents or sibs; they were not taking oral contraceptives nor other steroid medication; they had no known hormonal dysfunction; and all reported regular menstrual cycles of between 23 and 31 days ($M = 28.8$) days. The handedness of potential subjects was assessed by asking them to state which hand they would normally use to perform 10 unimanual tasks. Only women who wrote with their right hand and used this hand for at least seven of the nine other tasks were selected.

Procedure

At recruitment potential subjects completed a questionnaire to establish handedness, familial sinistrality, menstrual cycle length and regularity, use of oral contraceptives and brief medical history. On the basis of the predicted start date of their next period women who met the inclusion criteria were either given a predicted midluteal appointment for their first test session (midluteal-menses group) or asked to telephone when their next period started in order to arrange their first test session in the menstrual phase of the next cycle (menses-midluteal group). The same procedure was used to arrange the second test session such that each woman was tested at menses and the midluteal phase. At each session the women completed both the dichotic verbal and music tasks. The order of testing for tasks and phases of the cycle was counterbalanced between subjects in a repeated measures design.

Menstrual cycle phase. The sharp midcycle preovulatory oestrogen peak cannot be predicted accurately in advance because any variation in cycle length occurs in the follicular phase [2]. Such events must be determined by countback from the onset of the next menstruation. Because facilities for hormone assays were not available we chose to test at points in the cycle when the windows for high and low oestrogen levels are large. For high oestrogen we chose the midluteal phase and tested 6–8 days before the predicted start of the next menstruation. In practice the midluteal testing was conducted between 2 and 11 days ($M = 7.7$) prior to the start of menstruation with all but five of the subjects tested between 5 and 10 days. For low oestrogen we tested 3–5 days ($M = 4.3$) following the start of menstruation in order to avoid any discomfort that may have been associated with Days 1 and 2. Given that our interest lies in possible differences in performance between the low oestrogen menstrual and high oestrogen midluteal phases of the cycle the fact that a few subjects were tested early or late in the luteal phase when oestrogen may have been lower would reduce the probability of significant effects.

Measures of cerebral asymmetry. Two dichotic listening tasks, were used to measure functional cerebral asymmetry at each of the two test sessions. The left hemisphere verbal task was a consonant-vowel identification task which typically generates a right ear advantage in our laboratory. Subjects completed a single block of 10 practice trials with the sounds *baa*, *daa*, *gaa*, *taa*, *paa*, *kaa* and four blocks of 30 experimental trials with the sounds *bee*, *dee*, *gee*, *tee*, *pee*, *kee* during which each sound was presented 20 times to each ear. For each trial conflicting sounds were presented concurrently one to each ear with an interval of 5 s between presentations during which subjects recorded their responses. To avoid channel biases the headphones were reversed between Blocks 2 and 3 of the experimental trials. The order of these channel to ear pairings was counterbalanced between subjects.

For the right hemisphere task we chose a musical chord recognition task for which a marked left ear advantage has been reported [11]. The stimuli were four tone chords recorded from an electronic keyboard. The task used four chords, A major, A flat major, B major and B flat major, each lasting 2.5 s. A trial began with the concurrent presentation of a conflicting pair of chords, one chord to each ear, for 2.5 s. Then, at intervals of 1.5 s, the dichotic presentation was followed by each of the four chords presented for 2.5 s binaurally and a final 5 s interval during which subjects indicated on the response sheet which of these chords (1, 2, 3 and 4) they had heard. The task began with four practice trials followed by two blocks of 12 experimental trials in which each chord was presented six times to each ear paired with every other chord in the opposite ear. To avoid channel biases the headphones were reversed between Blocks 1 and 2. The order of these channel to ear pairings was counterbalanced between subjects.

In both the verbal and music tasks subjects were asked to record first the sound that they were most certain they had heard and then the other sound that they thought they had heard. Some subjects on some trials recorded only one sound so the total number of sounds correctly recorded was used as the dependent variable.

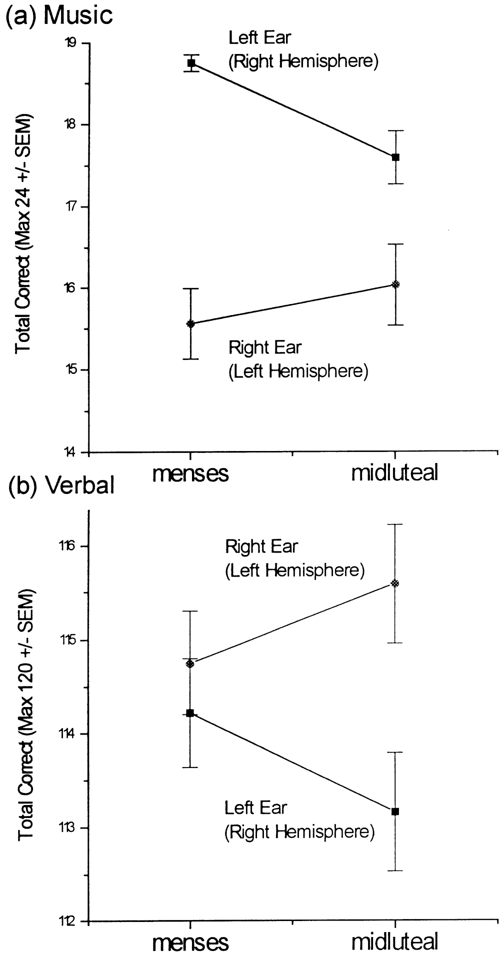

Fig. 1. Mean correct identifications (and standard error) recorded for items presented to the left and right ears in two dichotic listening tasks administered sequentially to naturally cycling women at menses and the midluteal phase of the cycle in a counterbalanced repeated measure design: (a) data from the musical chord recognition task which shows a left ear (right hemisphere) advantage and greater functional asymmetry at menses than during the midluteal phase; (b) data from the verbal identification task which shows a right ear (left hemisphere) advantage and greater functional asymmetry during the midluteal phase than at menses.

Results

Figure 1 shows the total correct responses for the left and right ears at the menses and midluteal test sessions. The data from the two tasks were submitted to separate 2×2 analyses of variance with ear and phase as within subjects variables. These analyses revealed the expected left ear (right hemisphere) advantage (LEA) for the music task ($F(1,31) = 40.69$, $P = 0.001$) and a right ear (left hemisphere) advantage (REA) for the verbal task ($F(1,31) = 10.44$, $P = 0.003$). The main effect of menstrual cycle phase was not significant for either task (music $F(1,31) = 3.15$, $P = 0.086$; verbal $F(1,31) = 0.12$, $P = 0.73$) but there was a significant interaction between ears and phase of the cycle for both the music ($F(1,31) = 11.12$, $P < 0.002$) and verbal ($F(1,31) = 13.81$, $P = 0.001$) tasks.

Following Howell [19] we used repeated measures *t*-tests to examine changes in performance across the cycle. The LEA for the music task was significant at both phases of the cycle (menses $t(31) = 6.79$, $P = 0.0001$; midluteal $t(31) = 3.73$, $P = 0.0008$) whereas the REA for the verbal task was significant for the midluteal phase ($t(31) = 4.68$, $P = 0.0001$) but not for menses ($t(31) = 1.02$, $P = 0.31$). Although the LEA for the music task was significant at each phase, nevertheless there was a significant decrease in asymmetry, as measured by the ear difference scores, from menses to the midluteal phase ($t(31) = 3.34$, $P = 0.002$). In contrast, the verbal task showed an increase in ear difference scores from menses to the midluteal phase ($t(31) = 3.72$, $P = 0.0008$). These reciprocal changes in asymmetry were confirmed by an analysis of the number of individuals showing greater asymmetry at each phase (Table 1). For the music task, more women recorded a greater ear difference at the menses than midluteal test ($X^2 = 11.3$, df. = 1, $P < 0.005$) whereas, for the verbal task, more women recorded a greater ear difference at the midluteal than menses test ($X^2 = 8.0$, df. = 1, $P < 0.005$).

As seen in Fig. 1, these reciprocal changes in asymmetry across the menstrual cycle were the result of consistent changes in ear performance: for both tasks, from menses to the midluteal phase, left ear (right hemisphere)

Table 1. The numbers of participants recording greater ear difference scores on the dichotic music and verbal tasks at menses and midluteal phases

	Greater ear difference score		
	Menses	No difference	Midluteal
Music task	28	2	2
Verbal task	4	0	28

performance fell significantly (music task $t(31) = 3.57$, $P = 0.0012$; verbal task $t(31) = 2.04$, $P = 0.049$) whereas right ear (left hemisphere) performance showed a small increase which was not significant for the music task $t(31) = 1.57$, $P = 0.13$) but approached significance for the verbal task $t(31) = 1.86$, $P = 0.073$).

Discussion

In the present study, with verbal and music tasks presented sequentially to the same subjects in a counterbalanced repeated measures design, dichotic listening has revealed reciprocal changes in functional asymmetry across the menstrual cycle (Fig. 1). The verbal task generated a right ear (left hemisphere) advantage and greater asymmetry during the midluteal phase whereas the music task generated a left ear (right hemisphere) advantage and greater asymmetry during menses. Previous studies have reported greater asymmetry at only one point in the cycle but when the outcomes are analysed by task their findings are concordant with our data. The two studies that employed non-verbal right hemisphere tasks [17, 30] recorded greater asymmetry at menses while the two that employed left hemisphere tasks [5, 14] found greater asymmetry later in the cycle during the midluteal and preovulatory phases respectively. Two points emerge clearly from these findings: first, that the degree of cerebral asymmetry recorded is dependent on the phase of the cycle at which testing occurs; second, that the phase of the menstrual cycle at which greater asymmetry is recorded is dependent on the type of task employed. Given that studies do not normally control for phase of cycle it is not surprising that sex differences in functional cerebral asymmetry have proved elusive.

The traditional view, backed by much convergent evidence from other modalities and from clinical studies [4], is that ear advantages reflect the superior performance of the contralateral hemisphere and that sex differences in degree of perceptual asymmetry reflect differences in brain organisation. McFadden [26] has suggested that lateral and sex differences in the peripheral auditory system may underpin the observed cortical differences in speech perception. Specifically, he argues that, because they are subject to less efferent inhibition from spontaneous otoacoustic emissions, females and right ears are more sensitive than males and left ears. However, a recent report [21] failed to confirm this hypothesis, finding a greater efferent influence on the right ear than on the left and no peripheral sex difference. In the absence of sex differences, it seems unlikely that peripheral effects underpin the changes in asymmetry recorded in our dichotic study. This view is strengthened by the observation that of the four previous studies reporting a change in asymmetry across the menstrual cycle [5, 14, 17, 30], all but one [14] used visual rather than auditory stimuli, as did Mead and Hampson [28] whose work is discussed below.

Figure 1 shows that the changes in asymmetry for both tasks are the product of similar shifts in ear (hemisphere) performance across the menstrual cycle. Left ear (right hemisphere) performance was significantly better during menses when oestrogen is low than during the midluteal phase of the menstrual cycle when oestrogen is high, suggesting that increased oestrogen levels are associated with a decrement in right hemisphere performance. Mead and Hampson [28] have recently reported remarkably similar findings from a study using the divided visual field paradigm. They found that the left visual field performance was better at menses than during the midluteal phase for both a verbal left hemisphere rhyming task and a non-verbal right hemisphere face recognition task.

In addition to the marked decrease in left ear (right hemisphere) performance the present study also recorded a tendency for the right ear (left hemisphere) performance to show a reciprocal increase. In support of left hemisphere changes we should note that Bibawi *et al.* [5] recorded a significant improvement in left hemisphere performance from menses to the midluteal phase while Hampson [14] reported both a left ear decrease and a right ear increase in performance from menses to the higher oestrogen preovulatory phase. Together, these studies suggest that changes from low to high oestrogen have opposing effects on the two hemispheres, suppressing the activity of the right while simultaneously enhancing that of the left. Such reciprocal changes in hemisphere activity provide an explanation for the parallel changes in the performance of sexually dimorphic tasks which see a deterioration in right hemisphere spatial ability and an improvement in left hemisphere verbal ability from low to high oestrogen phases of the cycle [14–16].

Insofar as better verbal performance is associated with greater asymmetry for verbal tasks, these findings are incompatible with Levy's Cognitive Crowding Hypothesis [23, 24] which associates reduced asymmetry with the female pattern of better verbal ability. We cannot comment directly on the relative degree of asymmetry in women compared with men because our study, like most studies of the menstrual cycle, did not employ a male control group, however, the study by Bibawi *et al.* [5] is an exception. Although the relevant statistical comparisons between the men and women are not quoted, from their fig. 1 it appears that at Test Session 2 (the midluteal test for women) left visual field (right hemisphere) performance did not differ between men and women but the right visual field (left hemisphere) performance of women was better than that of men. It would appear that asymmetry may sometimes be greater in women than men but more studies with a male control group and a range of tasks is required before we can draw firm conclusions.

Among studies of changes in asymmetry across the menstrual cycle neither the present nor any other that compares the midluteal phase with menses can differentiate between oestrogen and progesterone because both hormones are low at menses and high during the midluteal phase, however, there are two reasons for believing oestrogen to be the critical hormone. First, Hampson [14] tested during the preovulatory phase when oestrogen peaks but progesterone is low and found perceptual asymmetry for a verbal task to be greater during the preovulatory peak. Second, convincing evidence for a causal effect of gonadal steroids on brain function comes from studies of transsexuals. Following treatment with antiandrogens and oestrogen, male-to-female transsexuals show a rapid shift from male-typical to female-typical patterns of cognitive performance [33]. Incidentally, female-to-male transsexuals treated with testosterone show a shift from female to male typical performance [32]. Thus it appears that whatever hardwiring occurs in the foetus the human brain retains a degree of plasticity and remains susceptible to the activational effects of oestrogen and testosterone in adult life. For further discussion of hormonal influences on asymmetry and cognition see [31].

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