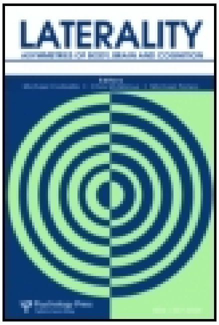


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# Dichotic listening asymmetry: Sex differences and menstrual cycle effects

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# Dichotic listening asymmetry: Sex differences and menstrual cycle effects

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The impact of menstrual cyclicity and sex differences on dichotic listening was studied in 25 women and 20 men (aged 20–25 years). Dichotic listening was administered using consonant-vowel (CV) stimuli and tested across three attention conditions. Women were tested at two points in the menstrual cycle (Day 2–5: low oestrogen and progesterone/Low-EP; Day 18–25: high oestrogen and progesterone/High-EP). Men were tested once. Performance averaged across attention conditions was analysed for menstrual cycle and sex effects. Significant menstrual cycle phase effects were observed in women. At the High-EP phase women showed a greater right ear advantage (REA) compared to the Low-EP phase. Sex differences were found when dichotic listening asymmetry in men was compared to women at the Low-EP, but not the High-EP phase. In contrast to laterality effects, baseline perceptual performance (total right plus left ear response) was similar in men and women at both phases of the menstrual cycle. Results support a role for ovarian hormones in shaping laterality of speech perception in women. This study also emphasises the importance of considering menstrual cycle effects when evaluating sex differences in dichotic listening.

Dichotic listening is a widely used behavioural indicator of laterality in speech processing (Hugdahl, Carlsson, Uvebrant, & Lundervold, 1997). A common finding in dichotic listening testing with syllables and words is the right-ear-advantage (REA) resulting from a greater number of correct responses from the right compared to the left ear. High REA indicates a greater degree of lateralisation in perceptual asymmetry, and results from a combination of several neuropsychological factors. These include predominance of cortical and subcortical pathways for right ear input (Hugdahl, 2003), left-hemisphere specialisation for the processing of syllables (Hugdahl, 2003; Hugdahl et al., 1999; Rimol, Specht, Weis, Savoy, & Hugdahl,

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2005), and the interhemispheric mechanisms involved in processing the two competing auditory inputs (Hugdahl, 2003; Kimura, 1967; Zaidel, 1983).

Sex differences have been reported in the dichotic listening literature. However, these findings are not consistent across studies (Hiscock, Inch, Jacek, Hiscock-Kalil, & Kalil, 1994). Some studies have shown larger asymmetry in men than women (Cowell & Hugdahl, 2000; Weekes, Zaidel, & Zaidel, 1995) while others have not (Demarest & Demarest, 1981; Foundas, Corey, Hurley, & Heilman, 2006; Hiscock & MacKay, 1985). Cowell and Hugdahl (2000) showed that REA decreased with age in women and increased with age in men across the adult lifespan. Thus, the male-greater-than-female asymmetry was more prominent in older compared to younger adults. These findings indicate that differences between men and women across adulthood contribute one source of sex-related variation in dichotic listening.

Another possible source of sex-related variation in dichotic listening derives from hormonal fluctuations across the menstrual cycle in young women. Studies examining perceptual asymmetry of words and consonant-vowel syllables have demonstrated a greater REA at high compared to low hormonal phases. Greater perceptual asymmetries were observed at the midluteal phase, when both oestrogen and progesterone levels were high (Hampson, 1990b; Sanders & Wenmoth, 1998; Weekes & Zaidel, 1996) and at the preovulatory phase when oestrogen levels were high (Hampson, 1990a).

In the current study, effects of menstrual cyclicity and sex on perceptual asymmetry were examined in a sample of healthy young adults. Data were analysed to confirm reports that laterality of syllable perception was enhanced during the midluteal phase of the menstrual cycle. Data were compared between men and women at both the midluteal and menstrual phases to systematically examine the impact of menstrual cyclicity on sex differences in dichotic listening performance.

# METHOD

## Participants

A total of 25 female and 20 male participants were recruited from the University of Sheffield student population (see Table 1). All were right-handed, native English speakers, with no known history of neurological, speech, language, or hearing difficulties. Women had regularly occurring menstrual cycles (mean length 29.24 days, $SD = 2.45$). They were not using oral contraceptives and had not been pregnant or lactating for at least 1 year prior to the study. Written informed consent was obtained from each participant. The research protocol was approved by the Department of

Human Communication Sciences Research Ethics Committee, University of Sheffield.

## Behavioural testing

The data presented in this article were drawn from a larger-scale research project that examined a range of behaviours including speech production (Wadnerkar, Cowell, & Whiteside, 2006). The test battery included an initial interview to collect demographic information, family, hormonal, medical, and educational history. Baseline testing for IQ and handedness was conducted for all participants. IQ was assessed using the Vocabulary and Matrix Reasoning subtests of the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999). Handedness scores were computed from observation of participants completing a series of 20 behaviours. The 20 behavioural items were based on the original set of 10 items used by Oldfield (1971) or derived from these (e.g., Oldfield item: open box lid; derived item: remove a small object from the box). These were supplemented with items shown by Healey, Liederman, and Geschwind (1986) to contribute to one of four neuropsychological dimensions of motor asymmetry, or were adaptations to these (e.g., Healey item: swing a bat; adapted item: swing a badminton racquet). Participants were asked to demonstrate their use of each item and to indicate if they would use either or both hands for any of the tasks. Handedness scores were calculated by assigning 2 points for each right-hand item and 2 points for each left-hand item. For bimanual items, 1 point was assigned to the right and 1 point to the left hand. Points were totalled for right hand and left hand across all items, and the final score computed by subtracting the number of left-hand points from the right-hand points (Right hand – Left hand). The span of possible scores ranges from $-40$ (consistent left-handedness) to $+40$ (consistent right-handedness). Individuals who scored above zero on the handedness test battery were confirmed as right-handed.

Testing for other measures, including dichotic listening, took place across two sessions for women, who were tested once during the menstrual phase (Day 2–5: low oestrogen and progesterone/Low-EP; mean = 4.04 days, $SD =$ 0.93) and once during the midluteal phase (Day 18–25: high oestrogen and progesterone/High-EP; mean = 20.84 days, $SD = 2.46$). The midluteal phase was confirmed by counting backwards from the onset of the next menstrual cycle. For all women, the midluteal test phase was within 14 days counting backwards from the onset of the next menstrual cycle (mean = 8.40 days, $SD = 3.14$). Administration of the first test session was counterbalanced, such that 13 women started testing during the menstrual phase, and 12 women started testing during the midluteal phase. Men were tested once, a design element supported by good test–retest reliability of dichotic listening asymmetry effects (Hugdahl & Hammar, 1997).

The dichotic stimuli combined six stop consonants with the vowel /a/ to form CV syllables (/pa/, /ba/, /ta/, /da/, /ka/, and /ga/) (Hugdahl, 2003). These syllables were combined into 36 stimulus pairs, which included six homonyms. Homonyms were used to evaluate auditory sensory ability and were not included in analyses of perceptual performance or laterality. Each syllable had a duration of approximately 400 ms with an interval of 4 seconds between presentations. Dichotic stimuli were delivered from an audio CD player (Sony ZS-D55) and headphones (Sennheiser EH2270). The task was administered using three attention conditions. In the non-forced attention condition, participants reported the syllable they heard most clearly for each trial. In the forced-right condition, participants reported syllables they heard most clearly from the right ear. In the forced-left condition, they reported syllables heard most clearly from the left ear. Non-forced was the starting condition. The order of forced-right and forced-left conditions was counterbalanced across participants (Hugdahl, 2003). The number of correct right ear (RE) and left ear (LE) responses was recorded and averaged across the three attention conditions for each participant to control for unwanted effects of attentional bias. A variant of this procedure was previously used to remove attention bias effects from dichotic listening data in a sample of healthy young men and women (Rimol, Eichele, & Hugdahl, 2006).

Average right and average left ear responses served as the dependent variables for examining the impact of hormone phase and sex differences on perceptual performance and asymmetry. The laterality index [(RE – LE)/(RE + LE)] was also used for key comparisons. A within-subjects repeated measures design was used to compare dichotic listening performance at the Low-EP versus High-EP phases in women. A between-subjects design was used for the two sex difference analyses in order to compare men to women at the High-EP phase and the Low-EP phase. Order effects were examined for the women's data. This was done to confirm that data could be pooled across the two counterbalanced conditions. It also allowed examination of whether the repeated testing, rather than menstrual phase *per se*, was related to changes in dichotic listening scores.

## RESULTS

Means and standard deviations for age, handedness, and IQ are presented in Table 1. No significant differences between men and women were observed for Age, $t(43) = 0.72$, $p > .05$; Handedness, $t(43) = 0.67$, $p > .05$; Vocabulary T score, $t(43) = 0.09$, $p > .05$; or FSIQ, $t(43) = 0.82$, $p > .05$. Men had

TABLE 1
Means (*SD*) for age (years), handedness and IQ for women ($N = 25$) and men ($N = 20$)

| | | | *IQ* | | |
|---|---|---|---|---|---|
| | *Age* | *Handedness* | *Vocabulary T score* | *Matrix Reasoning T score* | *FSIQ* |
| Women | 22.56 (2.04) | 32.12 (8.25) | 64.40 (6.11) | 57.48 (6.32) | 120.16 (7.86) |
| Men | 22.15 (1.69) | 33.45 (3.25) | 64.25 (5.53) | 60.45 (4.82) | 122.05 (7.44) |

marginally higher Matrix Reasoning T scores compared to women, $t(43) = 1.73$, $p = .09$.

## Menstrual cycle effects

Effects of menstrual cycle phase were analysed using ANOVA with Phase (Low-EP; High-EP) and Ear (Right; Left) as repeated measures. The main effect of Phase was not significant, $F(1, 24) = 1.59$, $MSE = 2.12$, *ns*, indicating that the total number of responses was not affected by the menstrual cycle. Ear was highly significant, $F(1, 24) = 44.29$, $MSE = 12.47$, $p < .001$, with a higher number of reports from the right ear in both menstrual cycle phases (Table 2). There was a significant interaction of Phase × Ear, $F(1, 24) = 7.31$, $MSE = 2.77$, $p < .02$, which reflected significantly more right ear responses (Right ear at High-EP vs Low-EP: Mean difference = 1.27, 95% CI 0.18 to 2.35) and a non-significant trend towards fewer left ear responses at the High-EP phase (Left ear at High-EP vs Low-EP: Mean difference = −0.53, 95% CI −1.23 to 0.16). Consistent with these results, the laterality index was greater at the High-EP compared to the Low-EP phase, $F(1, 24) = 7.03$, $MSE = 0.01$, $p < .02$ (Figure 1).

TABLE 2
Dichotic listening scores

| | *Right ear* | *Left ear* |
|---|---|---|
| Low-EP | 12.51 (2.15) | 8.71 (1.79) |
| High-EP | 13.77 (2.65) | 8.17 (2.02) |
| Men | 13.80 (1.90) | 7.70 (1.27) |

Means (*SD*) for right and left ear dichotic listening scores averaged across the three attention conditions for men ($n = 20$) and women ($n = 25$) at low (Low-EP) and high oestrogen and progesterone (High-EP) menstrual cycle phases.

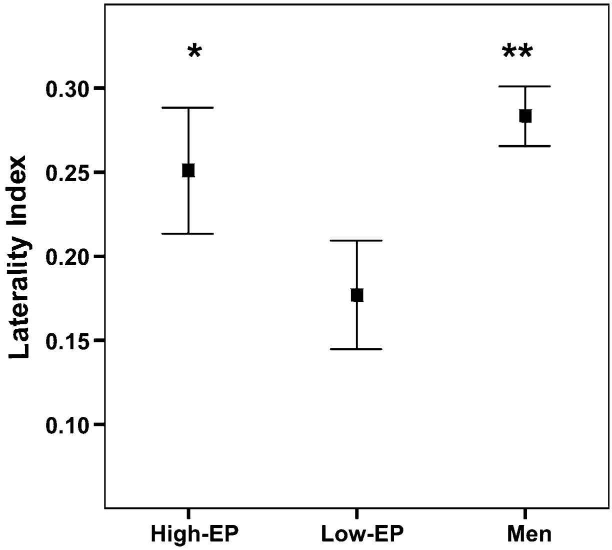


**Figure 1.** Mean laterality index (±standard error) for men ($n$ =20) and women ($n$ =25) at the Low-EP and High-EP phases of the menstrual cycle. Comparisons are to women at the Low-EP phase (*$p$ <.05, **$p$ <.01). Error bars for the repeated measures comparison across the menstrual cycle underestimate significance.

## Sex differences

Sex differences were analysed using ANOVAs with Ear (Right; Left) as the repeated measure and Sex as the grouping variable. Two ANOVAs were computed to examine sex differences between men and women at the Low-EP and High-EP phase, respectively.

When men were compared to women at the Low-EP phase, the main effect of Sex was not significant, $F(1, 43) = 0.19$, $MSE = 2.43$, *ns*, indicating that the total number of responses did not differ between the groups. Ear was highly significant, $F(1, 43) = 128.48$, $MSE = 4.24$, $p < .001$, with a higher number of reports from the right ear in both sexes (Table 2). Sex × Ear effects, $F(1, 43) = 6.94$, $MSE = 4.24$, $p < .02$, were also significant. This interaction reflected the higher degree of asymmetry in men (Right ear vs Left ear: Mean difference = 6.10, 95% CI 5.21 to 6.99) compared to women at the Low-EP phase (Right ear vs Left ear: Mean difference = 3.80, 95% CI 2.35 to 5.25). Consistent with these results, the laterality index was greater in men compared to women at the Low-EP phase, $F(1, 43) = 7.39$, $MSE = 0.02$, $p < .01$ (Figure 1).

When men were compared to women at the High-EP phase, the main effect of Sex was not significant, $F(1, 43) = 0.42$, $MSE = 2.64$, *ns*, indicating that the total number of responses did not differ between the groups. Ear was highly significant, $F(1, 43) = 129.76$, $MSE = 5.86$, $p < .001$, with a higher number of reports from the right ear in both sexes (Table 2). Sex × Ear effects, $F(1, 43) = 0.24$, $MSE = 5.86$, *ns*, were not significant. Consistent with these results, the laterality index did not differ between men and women at the High-EP phase, $F(1, 43) = 0.53$, $MSE = 0.02$, *ns* (Figure 1).

## Test order effects across the menstrual cycle

Possible effects of test order were investigated using ANOVA with Order (Tested first at Low-EP $n = 13$; Tested first at High-EP $n = 12$) as the grouping variable, and the repeated measures variables of Phase (Low-EP; High-EP) and Ear (Right; Left). Consistent with results reported above, the main effect of Phase was not significant, $F(1, 23) = 1.49$, $MSE = 2.19$, *ns*, and Ear, $F(1, 23) = 43.72$, $MSE = 12.46$, $p < .001$, and Phase × Ear effects remained significant, $F(1, 23) = 7.04$, $MSE = 2.89$, $p < .02$.

There was no significant effect of Order, $F(1, 23) = 0.61$, $MSE = 1.59$, *ns*, indicating that the total number of responses was not affected by the start phase of the repeated test sessions. Also, Order did not interact with Phase [Phase × Order: $F(1, 23) = 0.27$, $MSE = 2.19$, *ns*], Ear [Ear × Order: $F(1, 23) = 1.02$, $MSE = 12.46$, *ns*], or Phase × Ear [Phase × Ear × Order: $F(1, 23) = 0.03$, $MSE = 2.89$, *ns*]. Right ear and left ear scores for the two Low-EP sub-samples did not differ as a function of Order: Right: $t(23) = 0.94$, *ns*; Left: $t(23) = 1.01$, *ns*. The same was true for right and left ear scores for the two High-EP sub-samples: Right: $t(23) = 0.95$, *ns*; Left: $t(23) = 0.37$, *ns*.

Consistent with the above results, the laterality index was greater at the High-EP compared to the Low-EP phase, $F(1, 23) = 6.80$, $MSE = 0.01$, $p < .02$, but there was no interaction of Phase × Order, $F(1, 23) = 0.07$, $MSE = 0.01$, *ns*. The laterality index for the two Low-EP sub-samples, $t(23) = 1.07$, *ns*, and the laterality index for the two High-EP sub-samples, $t(23) = 0.71$, *ns*, did not differ as a function of Order (Figure 2). Overall, these results indicate that the menstrual cycle phase effects were independent of test order effects.

# DISCUSSION

Women showed a larger REA at the High-EP phase compared to the Low-EP phase. These findings are consistent with previous studies (Hampson, 1990b; Sanders & Wenmoth, 1998; Weekes & Zaidel, 1996). Lack of a significant overall menstrual cycle phase effect indicated that the same number of correct responses was reported by women at both phases, and that only the left–right distribution of responses across ears was affected.

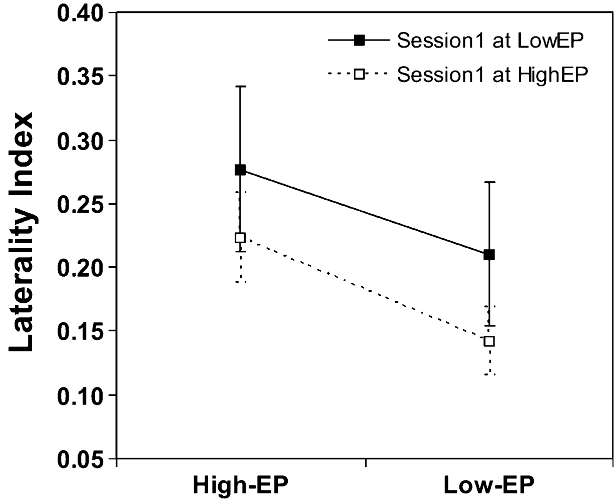


**Figure 2.** Mean laterality index (±standard error) for women at the Low-EP and High-EP phases of the menstrual cycle. Means are plotted as a function of test order with women ($n$ = 13) tested first at the Low-EP phase (filled squares, solid lines) compared to women ($n$ = 12) tested first at the High-EP phase (open squares, dashed lines).

Thus, women tested at the High-EP phase made more right ear responses and fewer left ear responses compared to when they were tested at the Low-EP phase. Previous studies have also shown a midluteal phase increase in the number of right ear responses and decrease in the number of left ear responses (Hampson, 1990b; Sanders & Wenmoth, 1998; Weekes & Zaidel, 1996). Analysis of order effects confirmed that the repeated measure itself was not the source of laterality shifts. Women who completed the first test session at Low-EP showed an increase in asymmetry at the second test session (at High-EP). Similarly, women who completed the first test session at High-EP showed a decrease in asymmetry at the second test session (at Low-EP). Thus, the second test session was not associated with a consistent pattern of increase or decrease in laterality that would indicate learning repetition effects. The interpretation that laterality changes across the menstrual cycle are hormonally based and may be linked to oestrogen is further supported by increased dichotic listening asymmetry in women at the late follicular phase of the menstrual cycle (Hampson, 1990a).

Sex differences in dichotic listening, with males having a greater REA than women, have been reported in some (Cowell & Hugdahl, 2000; Weekes et al., 1995) but not all studies (Foundas et al., 2006; Hiscock et al., 1994). In the current study a significant sex difference in laterality was found only when men were compared to women at the Low-EP phase. At the High-EP phase, the asymmetry patterns of men and women were virtually identical, in particular for the number of right ear responses. The current study indicates that discrepancies among published reports in the literature are based partly on variation linked to menstrual cycle phase. Comparisons of dichotic listening between young adult men and women may include a proportion of women at high and at low hormone phases of the menstrual cycle. Studies that test a larger proportion of women at the high hormone phases of the cycle would be less likely to show sex differences in laterality index.

In addition to hormone fluctuations in young adults, variation in dichotic listening is also affected by sex differences in ageing. Cowell and Hugdahl (2000) showed age-related decrease in the right ear advantage in women compared to age-related increase in men from age 20 to 70 years. In that study, sex differences were more prominent as age increased. Just as lower dichotic listening asymmetry in young women may be related to lower hormone levels at the menstrual phase of the cycle, so decreases in asymmetry in older women may have been due in part to reductions in ovarian hormone levels with advancing age. Failure to restrict the age range, or control for age-related factors that interact with sex, may have contributed to the lack of consistent male–female differences reported in the literature. Age may also have an impact on studies of menstrual cycle effects. A study of women aged 17–46 years (Alexander, Altemus, Peterson, & Wexler, 2002) did not show increased laterality for tests of verbal dichotic listening across all days of the month that corresponded to the midluteal phase as defined in the current study. Studies that showed effects consistent with the current results included women under 40 years of age.

Results showed that Phase and Sex were not significant in analyses that featured significant Phase × Ear and Sex × Ear interactions. This dissociation between perceptual acuity and laterality provided a firm basis from which to examine the role of hormones in shaping lateralised dichotic listening performance. Asymmetry in dichotic auditory perception is due to a complex combination of neurofunctional processes that include predominant auditory pathways for right ear input, left hemisphere asymmetry in the processing of consonant-vowel syllables, and interhemispheric mechanisms that mediate the processing of the competing right and left ear inputs. Organisational and activational hormonal factors may affect dichotic listening performance via any or all levels of this system. Anatomical (Kulynych, Vladar, Jones, & Weinberger, 1994) and functional (Phillips, Lowe, Lurito, Dzemidzic, & Mathews, 2001; Shaywitz et al., 1995) brain research has shown that men have a greater asymmetry in language regions compared to women. In women, cortical laterality for processing both higher- and lower-order language-based tasks varies across the menstrual cycle and is mediated by both oestrogen and progesterone (Fernandez et al., 2003; Hampson, 1990a; Hausmann, Becker, Gather, & Güntürkün, 2002; Holländer, Hausmann, Hamm, & Corballis, 2005). Taken together, this literature supports the notion that sex differences in lateralised language systems are organised partly by the effects of hormones in early development, and that in women the activational effects of ovarian hormones continue to mediate speech and language lateralisation throughout adulthood.

Changes in speech functions in relation to the menstrual cycle are not limited to lateralised perception of syllables. A range of speech production parameters are also affected, including syllable production speed (Hampson, 1990a,b; Hampson & Kimura, 1988) and acoustic phonetic features such as voice onset time (Wadnerkar et al., 2006; Whiteside, Hanson, & Cowell, 2004). Thus, women at the High-EP phase of the menstrual cycle outperform men on speech production tasks but perform similarly to men on lateralised speech perception tasks. Syllable perception and production are functions associated with left hemisphere laterality (Bohland & Guenther, 2006; Hugdahl et al., 1999; Riecker et al., 2005; Rimol et al., 2005), and in women asymmetry of these systems may be optimised at a particular hormonal state. Such a mechanism accounts for a neurofunctional profile that combines right ear lateralisation for syllable perception with rapid and accurate articulation of syllables in women at the midluteal phase of the menstrual cycle. These results lend partial support for the direct access processing model (Mead & Hampson, 1996) where hormone levels affect lateralisation through modulation of hemispheric function.

The corpus callosum is also believed to play a key role in dichotic listening performance in the majority of individuals who show left hemispheric lateralisation for language. In this context, the callosum facilitates transfer of left ear (right hemisphere) input to the left hemisphere for processing. Thus, a smaller corpus callosum has been associated with greater functional separation of the hemispheres (Hines, Chiu, McAdams, Bentler, & Lipcamon, 1992; Pollmann, Maertens, von Cramon, Lepsien, & Hugdahl, 2002; Reinvang, Bakke, Hugdahl, Karlsen, & Sundet, 1994). Sex differences in dichotic listening across the life span (Cowell & Hugdahl, 2000) paralleled effects independently observed in corpus callosum anatomy (Cowell, Allen, Zalatimo, & Denenberg, 1992). Jointly, these studies (Cowell & Hugdahl, 2000; Cowell et al., 1992) suggest that as hormone levels decrease in women between the third and fifth decades of life, increases in anterior corpus callosum size may lead to less separation (i.e., greater connection) of left and right hemispheres, and, in turn, to the observed decrease in REA. In men, the anterior callosum decreased with age after the third decade of life, possibly contributing to greater separation of left and right hemispheres, and, in turn, to the increase in REA. These studies of ageing effects across the adult lifespan provide a framework for understanding the more transient effects of hormones across the menstrual cycle. Accordingly, increased dichotic asymmetry at the High-EP phase may be attributed in part to decreased efficiency in callosal relay. This model has been proposed on the basis of greater differences between right and left ear scores at the High-EP phase for CV syllables (Weekes & Zaidel, 1996) and emotional tones (Mead & Hampson, 1996). Indeed, recent research in the motor system has directly linked ovarian hormone fluctuations across the menstrual cycle with changes in transcallosal function (Hausmann et al., 2006).

The current study demonstrated effects of the menstrual cycle on dichotic listening asymmetry and the impact of these changes on the measurement of sex differences. It also showed independence between the basic ability to perceive syllables and the lateralisation of syllable perception when studied in relation to menstrual cycle mediated effects and sex differences. The study was methodologically limited in two respects. First, without hormone assays, the precise contributions of sex hormones to dichotic listening asymmetries could not be assessed. In addition, the influence of the menstrual cycle on other neurocognitive systems, such as those that regulate emotional state and higher-order language functions (Alexander et al., 2002; Altemus, Wexler, & Boulis, 1989), and their impact on dichotic listening asymmetry for CV syllable perception could not be ascertained. Nevertheless, our findings in the context of the wider literature on menstrual cyclicity and sex difference effects support a role for ovarian hormones in the regulation of lateralised speech functions in humans. The work also suggests that asymmetry of speech in women is regulated through a combination of changes to hemisphere function and callosal transfer mechanisms.

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