# Effects of Hormonal changes on Temporal Perception and Speech Perception in Noise in Females

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## Abstract

*The menstrual cycle is a cyclic fluctuation of ovarian hormonal level in females. Studies have shown that changes in gonadal steroids (estrogen and progesterone) can affect auditory abilities. In the present study, effect of hormonal changes on temporal processing and speech perception in noise in females (across three phases of the menstrual cycle) was studied. A total of 20 female participants with an average 28 days of regular menstrual cycle in the age range of 19-24 years were included in this study. Temporal abilities were assessed using gap detection test and modulation detection test and speech perception in noise was assessed through Quick-SIN in Kannada. All the participants were tested three times during a single menstrual cycle i.e., menstrual phase (cycle days of 1-5 days), ovulation phase (cycle days of 12-15 days) and luteal phase (cycle of 18-25 days). The results showed poorest gap detection and modulation detection threshold during the menstrual phase followed by luteal phase and significant better thresholds were obtained during the ovulation phase. Speech perception in noise test also showed a significant better threshold during ovulation and luteal phase compared to menstrual phase. To conclude, hormonal fluctuation affects temporal perception and speech perception in noise across the menstrual cycle and better thresholds were noted during the ovulation phase. Further, the present study highlights the importance of considering the different phases of menstrual phase while studying the female participants.*

***Key Words:*** *Menstrual cycle, Modulation detection, Gap detection.*

## Introduction

Hormones are chemical messengers that are produced in one part of the body, travel through the blood stream, and affect other parts of the body in both males and females. Estrogens and progesterone are female ovarian hormones and testosterone is a male hormone. In females, hormonal fluctuations, these ovarian hormones occur during the menstrual cycle (Farage, et al., 2008).

The menstrual cycle is a periodic virginal bleeding cycle of physiological changes that occurs in females. There are three phases in 28 days of menstrual cycle, i.e. follicular phase or menstrual phase (cycle of 1-5 days, with lowest estrogen and progesterone), ovulation or mid cycle phase (cycle of 12-15 days, with high estrogen and low progesterone) and luteal phase (cycle of 18-25 days, with moderately high estrogen and high progesterone) (Elliott-Sale & Martin, 2013). During the first half of 28 days cycle, the follicles grow and mature under the dominant influence of follicle stimulation hormone and some luteinizing hormones thus is termed as the follicular phase. Early in this phase, follicular estrogen secretion is low, but towards the middle of the cycle, there is a burst of estrogens from the dominant follicle which is called ovulation phase. After ovulation, corpus- luteum is formed, causing progesterone hormone to dominate over estrogen. This final level of the menstrual cycle is called the luteal phase. Afterwards falling levels of progesterone triggers the next menstrual cycle (Ferin, Jewelewicz, & Warren, 1993; Franz, 1988). So, there are changes in estrogen and progesterone concentration in each stage of the menstrual cycle within females.

These hormones play important role in numerous physiological functions like estrogen regulates or directly alters auditory processing of acoustic signals in the brain (Remage-Healey, 2012; Tabuchi et al., 2011; Tremere, Jeong & Pinaud, 2009; Yoder & Vicario, 2012), interprets auditory information, enhances the representation of sounds in auditory cortex (Remage-Healey, 2012) which is transmitted to sensory-motor parts of the brain (McCarthy, 2008; McEwen, 2002). It also affects neurotransmission, cellular processes, neural plasticity and biochemistry in the brain (Gawali, Rokade, Janvale & Mehrotra, 2009). Neuroimaging F-MRI studies also support for structural changes that alters brain volume during the menstrual cycle. During the ovulation phase, there are significant changes in blood-oxygen-level-dependent (BOLD) responses in gray matter and CSF volume in females (Hagemann, 2011). Transcranial magnetic stimulation also supports above findings and suggests that there is more central inhibition with high progesterone level (luteal phase) than low progesterone level (follicular phase) (Smith et al., 1999).

Estrogens and progesterone can also alter neuronal functioning through receptors distributed throughout the different parts of the central nervous system and by influencing different neurotransmitter systems. Studies

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have shown that there are significant changes in latencies of various auditory evoked potentials during menstrual cycle, indicating changes at the level of the central auditory pathway (Mann, Singh, Sidhu & Babbar, 2012; Natarajan, Dharshni, Ukkirapandian & Lakshmi, 2014; Walpurgera, Pietrowskyb, Kirschbaumc & Wolf, 2004; Yadav, Tandon, & Vancy, 2002). The Excitatory nature of estrogen makes the auditory system sensitive and it becomes more sensitive when estrogen circulation is in highest peak in ovulation phase (Al-Mana, Ceranic, Djahanbakhch & Luxon, 2008).

Psychoacoustics studies have also shown fluctuations in various parameters during menstrual cycle. A study done to assess perception of binaural beats showed that the perception was best during the mid phase of menstrual cycle compared to other phases. In the same study auditory perception was also assessed using octave matching task, click lateralization task and frequency just noticeable difference (JND) task. Results showed that for the octave matching task and click lateralization task, there was significant changes across the menstrual cycle and better performance was noted post-period. The reason for the same was speculated to the biochemical changes that occur during normal cyclic hormonal fluctuations which results in auditory acuity changes during menstrual cycle. The changes in synchronous neural firing affect temporal coding, pitch extraction and conduction velocity of processing auditory information. This could be due to the alteration in sodium and potassium metabolism, which is important for axonal conduction and synaptic transmission results (Haggard & Gaston, 1978).

Temporal processing is an important auditory skill that is necessary for the complex auditory task necessary for higher level auditory processing. Effect of ovarian hormones on temporal processing, by itself has not been studied; however, estrogen levels in brain regions have shown to have influence on auditory processing. The neuromodulatoy action of estrogen modulates neural coding of acoustic signals and cortical plasticity, so the auditory processing area of brain cell becomes sensitive to encode acoustic feature of sound. In a study, auditory perception abilities declined in zebrafish when the action of estrogen was blocked through injecting the auditory cortex. (Remage- Healey, 2012). It was also reported that increased amount of estrogen causes the brain cells to identify more subtle sound components and strengthens the auditory encoding, so auditory perception became better (Remage-Healey, Coleman, Oyama & Schlinger, 2010). Similar results were also seen in the duration discrimination task, where thresholds improve after estrogen injection (Pleil, Cordes, Meck & Williams, 2011).

Ovarian hormone has shown to have an influence on speech perception in noise also. It is reported that progesterone interferes more in the perception of speech in background noise**.** In a study, hearing in noise test (HINT) was done among post- menopause women, those taking estrogen plus progestin, those taking estrogen alone, and those not taking any hormones. Results showed that women taking both estrogen and progestin had a poorer speech perception in background noise than women in the other two groups. This finding suggests that increased estrogen shows benefit on speech recognition in noise and increase progesterone, show opposite effects (Guimaraes et al., 2006).

Speech perception is lateralized to the left hemisphere (Hugdahl & Westerhausen, 2010) and high level of ovarian hormone during menstrual cycle increases the coherence of speech perception and production within the dominant left hemisphere (Wadnerkar, Cowell & Whiteside, 2006; Wadnerkar, Whiteside & Cowell, 2008). High-estrogen phases of the menstrual cycle is associated with enhanced left-hemisphere processing (greater right ear advantages) and low-estrogen phases are associated with better right-hemisphere processing, thus showing cerebral asymmetry during menstrual cycle in young healthy women. This supports a role of ovarian hormones in shaping hemispheric laterality of speech perception (Cowell, Ledger, Wadnerkar, Skilling & Whiteside, 2011; Wadnerkar, Whiteside & Cowell, 2008) and changes in perceptual asymmetry for dichotic consonant-vowel (CV) listening in women within the menstrual cycle (Altemus, Wexler, & Boulis, 1989). The efferent auditory pathway is a feedback mechanism of auditory system which also plays an important role in speech perception in noise. Studies have shown that blockage of estrogen increases contralateral suppression of DPOAE affecting the auditory integrity (Thompson, Xiaoxia & Frisina, 2006). Thus, hormonal fluctuations during the menstrual cycle in healthy females affect Neuro-anatomy as well as neurophysiology of peripheral and central auditory nervous system which results in changes in auditory behavior. In the present study, the effects of hormonal changes on temporal perception and speech perception in noise in females across three phases of the menstrual cycle (average 28 days of normal menstrual cycle).

## Method

### Research design

The time series design was used to fulfil the aim of the present study.

### Participants

To fulfil the objectives of the study, 20 female participants with an average 28 days (27-31 days of length) of regular menstrual cycle (Cox, 1980) in the age range of 19-24 years (Mean age: 20.61 years, SD: 1.88) was taken. None of them have otological and medical history, history of use of steroids and hormonal pills, neurological abnormality, diagnosed premenstrual syndrome, lactation and pregnancy during the last year.

All participants had pure tone threshold within 15dBHL at octave frequencies between 250Hz to 8KHz, speech recognition threshold of up to 25 dBHL, and speech identification of monosyllables of at least 88%, with "A" type tympanogram and acoustic reflexes present. All females were native Kannada speakers and voluntarily participated in the study. They were not paid for participation.

**Procedure**

Written consent was taken from all the subjects for willingly participating in the study. First, the routine audiological evaluation was done to ensure normal hearing sensitivity. Following that temporal abilities were assessed through gap detection test (GDT) and temporal modulation detection test (MDT). Speech perception in noise was assessed through Quick – SIN in Kannada. All participants were tested three times during a single menstrual cycle i.e., follicular phase or menstrual phase (cycle days to 1-5 days, with lower estrogen and progesterone), ovulation or midcycle phase (cycle days of 12-15 days, with high estrogen and low progesterone) and the luteal phase or premenstrual phase (cycle days of 18-25 days, with moderately high estrogen and high progesterone).

*Temporal Tests*

Temporal perception tests (gap detection test and modulation detection test) were carried out by using Maximum Likelihood Procedure (MLP) toolbox, which implements an MLP in Matlab (Grassi & Soranzo, 2009). MLP stimuli were generated at 44,100 Hz sampling rate and three-interval, alternate forced-choice method was used to track threshold. A 79.4% correct response criterion of psychoacoustic function was used to track the threshold. 5-6 practice items were given for both the tests before the beginning of the actual test.

*Gap Detection Threshold*. The gap detection threshold was measured binaurally by asking the client to detect a variable temporal gap in the center of a 500 ms duration broadband noise. Broadband noise was used as stimulus as its spectrum does not change with the insertion of the gap (Moore, 2003). This noise had cosine rise and fall time of 0.5msec. Gap duration was varied according to listener's performance using maximum likehood procedure (MLP) and the participant's task was to identify which noise contained a gap.

*Modulation Detection Threshold.* The modulation detection threshold was estimated by presenting modulated and unmodulated stimuli binaurally. The participant's task was to identify which block had the modulated noise. A 500 ms duration and 10 msec cosine rise and fall time Gaussian noise which was sinusoidal amplitude modulated at modulation frequencies of 8 Hz, 20 Hz, 60 Hz and 200 Hz were used as stimuli (Bacon & Viemeister, 1985). The modulation detection thresholds were expressed in dB by using the following formula:-

Modulation detection thresholds in dB = 20 log10 m.

Where;

m = modulation detection threshold in percentage.

*Speech Perception in Noise*

Speech perception in noise testing was done to measure understanding of 50 % of the words in sentences (SNR-50). Three equivalent sentence lists of Kannada Quick Speech in Noise test (Avinash, Methi, & Kumar, 2010) were used as stimuli. Each list contains 7 sentences and each sentence has five key words mixed with 8-talker speech babble noise at different signal to noise ratio (SNR). The SNR varied from +8 dB to -10 dB in 3 dB steps in each successive subtest in a list. Each sentence was presented binaurally through a laptop connected with calibrated headset (PC310). Before starting of the test, subjects were instructed to listen, and then repeat the presented sentence and 1 point was awarded for each correctly repeated keyword. The presentation of the list was randomized across three phases of menstrual cycle. The total possible score of each list was 35 points. The SNR-50 was calculated using the Spearman- Karber equation (Finney, 1952) as:-

SNR-50 = i+1/2 (d) - (d) (# correct) / w

Where;

i = the initial presentation level

d = the attenuation step size

w = number of keywords per decrement

# Correct = total number of correct keywords

## Results

The main aim of the present study was to assess the effect of hormonal changes on temporal perception and speech perception in noise in females across three phases of menstrual cycle (average 28 days of regular menstrual cycle). The SPSS software version 17.0 was used for statistical analysis. The results of the current study are discussed in following headings:

- Effect of hormonal changes on temporal perception.
- Effect of hormonal changes on speech perception in noise test (SPIN).

**Effect of hormonal changes on temporal perception**

Temporal perception was assessed across three phases of the menstrual cycle in females through gap detection in noise test and modulation detection test.

*Gap Detection Test*

Figure 1 shows the mean GDT score across three phases of the menstrual cycle along with a single standard deviation (SD) error bar. In the figure, x-axis represents different phases of single menstrual cycle and the y-axis represents the gap detection threshold (ms). It is evident from the figure that menstrual phase shows poorest gap detection threshold followed by luteal phase and best threshold was obtained during the ovulation phase.

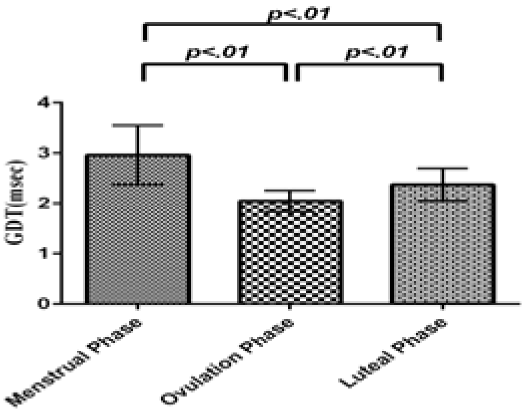


**Figure 1: Mean scores and one standard deviation (SD) error bar for GDT across three phases of single menstrual cycle.**

Repeated measures ANOVA was done to assess the significance in GDT across three phases of the menstrual cycle. The results indicated a significant main effect of menstrual cycle on GDT (F = 24.396; p<.01). Later, Bonferroni test was done to see a pairwise comparison among three phases of the menstrual cycle. The result showed that GDT was significantly different between all pairs of the menstrual cycle. Table 1 shows pairwise comparison results for all the phases.

**Table 1**: *Bonferroni test for pairwise comparison of GDT among three phases of menstrual cycle*

| | Menstrual Phase | Ovulation Phase | Luteal phase |
|---|---|---|---|
| Menstrual Phase | _ | .914* | . 588* |
| Ovulation Phase | -.914* | _ | -.327* |
| Luteal Phase | -.588* | .327* | _ |

* indicate the mean difference is significant at the P<.01 levels.

*Modulation Detection Test*

The modulation detection threshold was carried out for four different modulation frequencies (8Hz, 20Hz, 60Hz & 200Hz) across three different phases of the menstrual cycle. Figure-2 shows the mean and standard deviation of modulation detection threshold at all modulation frequencies across three phases of the menstrual cycle in females. In this figure, x-axis indicates modulation frequencies in Hz and y-axis indicates modulation detection threshold (dB) for each phase of the menstrual cycle. From the figure it can be inferred that menstrual phase shows poorest modulation detection threshold followed by luteal phase and best threshold were obtained during the ovulation phase.

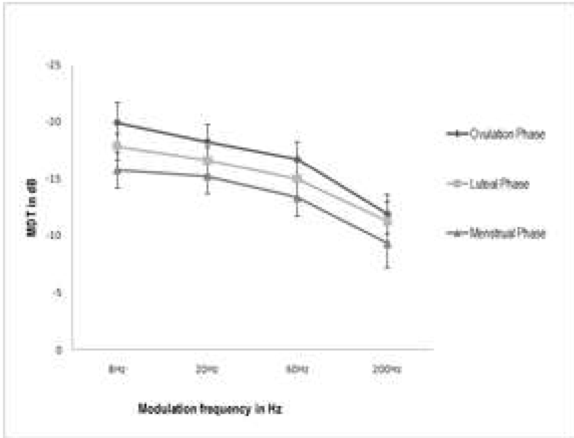


**Figure 2: Mean MDT at 8Hz, 20Hz, 60Hz and 200Hz across three phases of menstrual cycle, Error bars depict one standard deviation (SD) of errors.**

Repeated measures ANOVA results indicated a significant main effect of menstrual cycle on MDT for all the modulation frequencies (T able 2).

**Table 2:** *F-value and significant level for MDT frequencies across three phases of menstrual cycle*

| MDT frequency | 8Hz | 20Hz | 60Hz | 200Hz |
|---|---|---|---|---|
| F-value 12.386* | | 80.784* | 35.535* | 39.569* |

* indicate p<.01 level of significant.

Pairwise comparison using Boneferroni's test showed statistically significant (p<.01) mean differences between all pair phases of the menstrual cycle for all modulation frequencies. However, there was no significant difference noted between ovulation and luteal phase for 200Hz modulation frequency (p >.05).

**Effect of hormonal changes on Speech Perception in Noise**

Figure 3 shows the mean and standard deviation of the SNR-50 value across three phases of the single menstrual cycle. In this figure, x-axis represents three phases of single menstrual cycle and the y-axis represents SNR-50 (dB) value. From the figure it can be concluded that menstrual phase shows poorest SNR-50 (dB) followed by luteal phase and best SNR-50 was obtained during the ovulation phase.

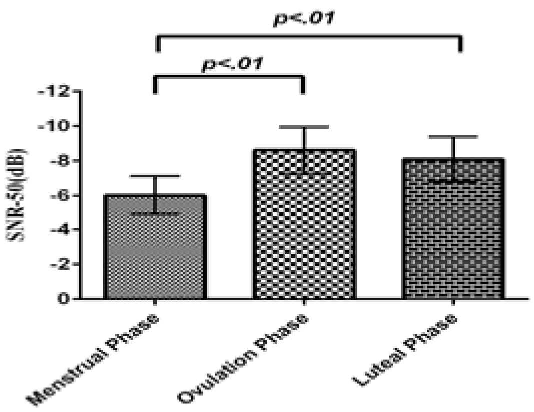


**Figure 3: Mean scores and one standard deviation error bar of SNR-50 across three phases of single menstrual cycle.**

Repeated measures ANOVA indicated that there was a significant main effect of menstrual cycle on SNR-50 (F = 24.284, P<. 01). Later, the Bonferroni test showed that there were significant mean differences between menstruation and ovulation phase (p<.01) and menstrual phase and luteal phase (p<.01), but such significant differences did not exist between ovulation and luteal phase (p>.05) (Table 3).

**Table 3**: *Bonferroni test for pairwise comparison of SNR-50 among three phases of menstrual cycle*

| Phases | Menstrual Phase | Ovulation Phase | Luteal Phase |
|---|---|---|---|
| Menstrual Phase | _ | 2.600* | 2.086* |
| Ovulation Phase | -2.600* | _ | -.514 |
| Luteal Phase | -2.086* | .514 | _ |

* indicate the mean difference is significant at the p<.01 levels.

## Discussion

The current study was conducted with the aim to assess the effects of hormonal changes on temporal perception and speech perception in noise in females across three phases of the menstrual cycle (average 28 days of normal menstrual cycle).

### Effect of hormonal changes on Temporal Perception

The GDT findings of the current study showed that the larger silent interval was required to detect gaps in noise during the menstrual phase compared to ovulation and luteal phase. Similar findings were noted for MDT also wherein larger modulation depth was required for modulation detection in noise at four different modulation frequencies during the menstrual phase when compared to ovulation and luteal phase. Thus, the findings of both GDT and MDT suggest the poorest temporal resolution ability during menstrual phase, followed by luteal phase and best temporal resolution ability during the ovulation phase. These findings may be attributed to the fluctuation in estrogen and progesterone level across different phases of the menstrual cycle, which affects peripheral as well as central auditory processing.

Similarly, Pleil et al. (2011) found better duration discrimination scores post estrogen injected in female rats. It was hypothesized that rapid and acute estrogen level, increases temporal processing of auditory information. Al-Mana et al. (2008) reported that during ovulation phase best cochlear acuity is noted and auditory system is most sensitive. Higher levels of estrogen during the ovulation phase excites auditory nerve resulting in faster axonal conduction of auditory processing at the cortical level. It is also believed that acute estrogen level increases glutamate excitatory neurotransmitter which would result in better auditory processing for temporal perception during the ovulation phase compared to menstrual and luteal phase.

Moreover, possible explanation for poor scores during the luteal phase could be due to the extra release of neuro-inhibitory neurotransmitter i.e. GABA due to higher progesterone levels which inhibits temporal processing of auditory information in auditory cortex (Smith et.al., 1999).

In the present study it was also noted that MDT at 200 Hz modulation frequency did not show a significant difference during ovulation and luteal phase. This could be because of the higher modulation rate itself, which is difficult to be detected in the auditory system. Also, slight differences in estrogen level between ovulation and luteal phase would have resulted in the similar excitation and central conduction.

### Effect of hormonal changes on Speech Perception in Noise

The results of the present study showed speech perception in noise thresholds during ovulation and luteal phase better when compared to menstrual phase. Similar results were reported by Guimaraes, et al. (2006), in which study hearing in noise test (HINT) was done for each ear in three postmenopausal females groups taking hormonal replacement therapy i.e. estrogen treated group, estrogen plus progesterone treated group and no hormonal therapy treated group. The findings showed poor HINT score obtained in estrogen plus progesterone taking group compared to estrogen alone and control group. It was concluded that presence of progesterone interferes speech perception in noise and higher estrogen results in better speech perception in noise. In the present study also better speech perception in noise was noted during ovulation and luteal phase which could be due to the relatively higher estrogen level compared to menstrual phase. It is also hypothesized that neural synchronization at the level of the brainstem and cortical level are important for speech perception in noise (Anderson, Skoe, Chandrasekaran & Kraus, 2010). This synchronization might increase when there is an increase in the level of estrogen because it is excitatory in nature which could excite auditory nerve and cortical circuits leading to rapid neural firing (spike) and resulting in the rapid temporal processing of auditory information (Remage Healey, Jeon & Joshi, 2013; Smith et.al. 1999).

Another outcome of the present study was that SNR-50 did not differ significantly between ovulation and luteal phase. This could be explained based on the functioning of medial olivocochlear bundle. The MOC system plays an important role in speech perception in noise (Mishra & Lutman, 2014). Animal studies on "MOC antimasking" hypothesis suggested that activation of the MOC system result increases the response of transient signals embedded in continuous noise contralaterally at a moderate level (Kawase et al. 1993). Al-Mana, Ceranic, Djahanbakhch, and Luxon (2010) studied contralateral suppression of OAE during four different phases of regular menstrual cycle i.e. early and late stages of follicular luteal phase. They found reduced MOC suppression during the late follicular phase (ovulation) but opposite effect was seen during the luteal phase. So, excitatory effects of estrogen during ovulation reduced MOC suppression which would result in increased cochlear response to noise as reported in the same study. Thus, this reduction in MOC suppression would have lead to reduced speech perception in noise during the ovulation phase. Thus, no significant difference was noted in SPIN between ovulation and luteal phase.

To conclude, current temporal perception tests, i.e. GDT and MDT finding shows significant better temporal perception during the ovulation phase compared to menstrual and luteal phase. It may be hypothesized that higher estrogen level increases glutamate excitatory neurotransmitter resulting in faster axonal conduction of auditory processing at the cortical level. In this study, significant poorer temporal processing was seen during the luteal phase compared to ovulation phase. It may be believed that higher progesterone level during this phase, releases more amount of GABA inhibitory neurotransmitter which inhibits temporal processing of auditory information. Moreover, poorest temporal processing during the menstrual phase could be due to lower estrogen level compared to the other two phases. The SNR-50 finding in the current study also showed significant better speech perception in noise during ovulation and luteal phase compared to menstrual phase. It could also be contributing to the increase in the level of estrogen, which provides better synchronization of auditory nerve and cortical circuits. Thus, hormonal fluctuation during menstrual cycle affects temporal perception and speech perception in noise in females as seen in the current study. Thus, the null hypothesis is rejected in the present study.

**Conclusion**

To conclude, menstrual phase showed poorest threshold followed by luteal phase and best threshold was obtained during the ovulation phase for both gap detection test and modulation detection test. Also poorest speech perception was seen during the menstrual phase compared to ovulation and luteal phase. However, the SNR-50 value did not differ significantly between ovulation and luteal phase.

Thus, it can be concluded that hormonal fluctuation during menstrual cycle affects temporal processing and speech perception in the presence of noise. This could be due to varying levels of estrogen and progesterone. The study would help in understanding which hormone has more effects on temporal perception and speech perception ability in noise. Moreover, this study provides further insight about the effects of hormonal agents like steroids and contraceptive on hormonal synthesis and its effects in central processing of auditory information. Further, the present study highlights the importance of considering the menstrual phase while studying the female participants.

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