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# THE EFFECTS OF NATURAL AND SURGICAL MENOPAUSE ON AUDITORY AND COGNITIVE PROCESSING

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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## Abstract

**Introduction:** Estrogen plays a vital role in various physiological processes. While its impact on peripheral hearing sensitivity has been explored, limited attention has been given to its effect on central auditory processes, particularly during menopause. The present study examines the effects of both natural and surgical menopause on temporal processing of sound, speech perception in noise (SPIN), and working memory.

**Material and methods:** Three groups of women aged 49–60 years were recruited: 20 women with natural menopause, 20 with surgical menopause, and 20 premenopausal women. Temporal processing was assessed using the modulation detection threshold (MDT) and gap detection threshold (GDT) tests, SPIN abilities were evaluated using the Speech Perception in Noise Test in Kannada (SPIN-K), and working memory was assessed through digit span and sequencing tasks.

**Results:** The group of women with surgical menopause had significantly poorer temporal processing abilities, as reflected in higher MDT and GDT thresholds than the other two groups. No significant differences in SPIN or working memory were observed among the groups.

**Conclusions:** The findings highlight the adverse effects of surgical menopause on auditory temporal processing, likely due to an abrupt decline in estrogen levels. These results underscore the importance of estrogen in auditory health and call for targeted interventions and further research to confirm and expand these findings.

**Keywords:** menopause • cognition • audition

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## WPŁYW MENOPAUZY NATURALNEJ I CHIRURGICZNEJ NA PRZETWARZANIE SŁUCHOWE I POZNAWCZE

### Streszczenie

**Wprowadzenie:** Estrogen odgrywa istotną rolę w różnych procesach fizjologicznych. Chociaż zbadano jego wpływ na czułość słuchu obwodowego, niewiele uwagi poświęcono jego oddziaływaniu na centralne procesy słuchowe, szczególnie w okresie menopauzy. Niniejsze badanie analizuje wpływ zarówno menopauzy naturalnej, jak i chirurgicznej na przetwarzanie czasowe dźwięku, percepcję mowy w hałasie (SPIN) oraz pamięć roboczą.

**Materiały i metody:** Do badania włączono trzy grupy kobiet w wieku 49–60 lat: 20 kobiet z menopauzą naturalną, 20 z menopauzą chirurgiczną i 20 kobiet przed menopauzą. Przetwarzanie czasowe oceniano za pomocą testów wykrywania progu modulacji (MDT) i wykrywania przerw w szumie (GDT), zdolności SPIN oceniano za pomocą testu percepcji mowy w hałasie w języku kannada (SPIN-K), a pamięć roboczą – za pomocą zadań sprawdzających zapamiętywanie zakresu cyfr i sekwencjonowanie.

**Wyniki:** Grupa kobiet z chirurgiczną menopauzą wykazywała znacznie mniejszą zdolność przetwarzania czasowego, co znalazło odzwierciedlenie w wyższych progach MDT i GDT w porównaniu do pozostałych dwóch grup. Nie zaobserwowano istotnych różnic w zakresie SPIN ani pamięci roboczej między grupami.

**Wnioski:** Wyniki badań wskazują na niekorzystny wpływ menopauzy chirurgicznej na słuchowe przetwarzanie czasowe, prawdopodobnie spowodowane gwałtownym spadkiem poziomu estrogenu. Wyniki te podkreślają znaczenie wpływu poziomu estrogenu na stan słuchu i wskazują na potrzebę podjęcia ukierunkowanych działań oraz dalszych badań w celu potwierdzenia i rozszerzenia tych wyników.

**Słowa kluczowe:** menopauza • funkcje poznawcze • słuch

| Key to abbreviations | |
|---|---|
| GDT | gap detection thresholds |
| MDT | modulation detection threshold |
| MLP | maximum likelihood procedure |
| NM | natural menopause |
| OAE | otoacoustic emission |
| PM | premenopausal women |
| SD | standard deviation |
| SM | surgical menopause |
| SNR | signal-to-noise ratio |
| SPIN | speech perception in noise |
| SPIN-K | Speech Perception in Noise Test in Kannada |

## Introduction

Menopause is characterized by the permanent discontinuation of menstruation resulting from a decline in ovarian follicular activity. The average age of menopause is around 51 years and is officially diagnosed when a woman has experienced 12 consecutive months of amenorrhea (absence of menstrual cycles) due to the permanent cessation of ovarian function. Perimenopause, characterized by fluctuating ovarian function, typically precedes a woman's last menstrual cycle by several years, marking the transition into full menopause [1]. Common symptoms include hot flashes, night sweats, mood swings, sleep disturbances, and vaginal dryness, affecting both physical and emotional well-being.

Many women experience symptoms during the first few months after menopause, and for most, these symptoms last 1–2 years. However, in some cases, they may continue for 3–5 years and are referred to as early menopausal complications. Underlying mechanisms of early menopausal complications include estrogen deficiency and its impact on neurotransmitters such as serotonin and endorphins [2].

In addition to natural aging, menopause can be induced by surgical procedures such as hysterectomy with bilateral oophorectomy (removal of the uterus and both ovaries). It can also be triggered by medical treatments for conditions like endometriosis and breast cancer, where antioestrogen medications or chemotherapy may be used [3]. The treatment and management of menopause focuses on alleviating bothersome symptoms and preventing long-term complications. Treatment for menopause involves a range of hormonal and non-hormonal options tailored to address specific symptoms and health considerations. Hormone therapy can be effective in relieving menopause symptoms, but it requires careful consideration of its potential risks. Non-prescription remedies should be used with caution due to limited scientific evidence supporting their safety and effectiveness [4].

Studies have shown that estrogen is important in numerous physiological functions. Estrogen regulates the auditory processing of acoustic signals in the brain [5,6]. It is therefore involved in interpreting auditory information and how it is represented in the auditory cortex before it is transmitted to sensory-motor parts of the brain [7,8]. Estrogen also affects neurotransmission and biochemistry in the brain [9]. Studies have shown that temporal resolution and speech perception in noise are better during the ovulation phase of the menstrual cycle [10] and that estrogen plays a role in maintaining verbal and visual memory [11]. Estrogen may also influence peripheral hearing sensitivity, suggesting that menopause should be recognized as a significant risk factor for the onset of hearing loss in women, possibly due to endocrinological effects on auditory function [12].

Since estrogen plays an important role in auditory processing, there are effects on temporal processing and speech perception in noise [13]. Temporal processing involves resolving fine details in a speech signal's spectrum or temporal envelope [14–16]. Several studies have established a link between temporal processing and speech perception in adverse listening conditions [17–20]. While hormonal effects on central auditory processing have been investigated in women during the menstrual cycle and under hormone therapy, research exploring the specific effects of natural and surgical menopause on auditory processing remains limited.

Cognitive complaints are also common near menopause [21]. There is a reduction in memory in women during the transition to menopause. There are symptoms such as difficulties learning, recalling new information, and having impaired episodic memory, which are early signs of Alzheimer's disease [22]. Thus, in women experiencing natural menopause, the levels of estrogen, progesterone, and androgens gradually decline for 5–10 years as the ovarian stroma continues to produce these hormones [23].

The impact of menopause on cognition is complex, and more research is needed to understand these relationships. Evidence from a clinical trial emphasizes the limited effectiveness of hormone initiation in improving cognitive function in older post-menopausal women (mean age > 60 years) [24]. This study is designed to study the effect of ovarian hormones as a result of natural menopause and surgical menopause on temporal processing, speech perception in noise, and working memory.

## Material and methods

### Research design

A between-group cross-sectional study design was used to compare auditory temporal processing, speech perception in noise, and auditory working memory across three distinct groups of women based on menopausal status. The participants were three groups ($n = 20$ per group) of right-handed women, aged 49–60 years, who were recruited for the study based on their menopausal status. Participants were recruited from gynaecology clinics as well as through community health programs and local women's groups.

*Group 1:* Natural menopause group. These were women who had experienced cessation of menstruation within the last 3 years, without any other major medical conditions (mean age: 54.7 ± 1.3 years).

*Group 2:* Surgical menopause group. These were women who had undergone bilateral oophorectomy (surgical removal of ovaries) within the past 3 years before the study and had not reached natural menopause (mean age 54.1 ± 1.1 years).

*Group 3:* Premenopausal group. This group consisted of age-matched women (mean age 53.9 ± 1.2 years) who reported having regular menstrual cycles (typically 25–35 days) for at least 3 consecutive months before enrollment. To verify the regularity of their cycles, participants kept a menstrual diary for 2–3 months before they participated in the study. The first day of menstruation was considered day 1 of the cycle. To minimize hormonal variability all tests were scheduled during the mid-follicular phase (days 7–10 of their menstrual cycle), a time when estrogen levels are rising but have not yet peaked.

All participants had normal hearing thresholds, with pure-tone averages within 15 dB HL at octave frequencies ranging from 0.25 to 8 kHz. They were native speakers of Kannada and had completed at least a primary school level of education. None of the participants were using hormonal therapy, including oral contraceptives or hormone replacement therapy. Individuals with a history of otological conditions, neurological or psychiatric disorders, cardiovascular or endocrine diseases, or other metabolic disorders were excluded from the study based on their self-reports during the initial screening interview. Additionally, participants who were employed in industrially noisy environments or who had a history of steroid use were not included. Prior to participation, written informed consent was obtained from all individuals. The study protocol was reviewed and approved by the institutional ethics committee.

All tests were conducted in a quiet room using a calibrated laptop and Sennheiser HD 559 headphones. The output was calibrated using a sound level meter to ensure stimuli were presented at 60 dB SPL. Tasks were counterbalanced across participants to control for order effects and fatigue. Temporal processing and speech perception in noise were assessed monaurally (both ears separately), and working memory tasks were assessed binaurally.

## Temporal processing evaluation

Temporal processing was assessed using gap detection thresholds (GDT) and modulation detection thresholds (MDT). These tests were done using the maximum likelihood toolbox (MLP), implemented in Matlab (2014 version). MLP offers a user-friendly graphical interface and includes pre-built psychoacoustic experiments. MLP utilizes numerous candidate psychometric functions, assessing the probability of the listener's response to all presented stimuli after each trial. The function with the highest probability guides stimulus selection for the subsequent trial, typically converging toward the most probable psychometric function and thereby facilitating more accurate threshold estimation. A three-interval alternative forced-choice method was used to estimate the thresholds of both ears.

*Gap detection threshold:* Temporal resolution ability was assessed using GDT where the goal was to determine the shortest detectable gap. Subjects performed a gap detection task with 750 ms Gaussian noise, where the gap duration varied adaptively based on performance. Both standard (continuous noise) and variable (noise with a gap) stimuli lasted 750 ms, with 0.5 ms cosine ramps. A three-interval, alternative forced-choice paradigm was used: on each trial of three blocks, two blocks consisted of a 750 ms broadband noise with no gap, and the other block had a variable stimulus with a gap inside it. The participant's task was to identify the variable block. The minimum and maximum duration of the gap used was 0.1 and 64 ms. The gap detection corresponding to the 79.4% point of the psychometric function was calculated using MLP.

*Modulation detection threshold:* A 1000 ms Gaussian noise was sinusoidally amplitude modulated at 8, 20, 60, and 200 Hz. In each trial, three stimulus intervals were presented: two contained standard (unmodulated) stimuli, while the third, selected at random, contained a modulated stimulus. Participants were asked to identify which interval contained the modulation. The modulated and unmodulated stimuli had equal root-mean-square (rms) power. The depth of modulation was adjusted based on the participant's responses until the 79.4% criterion level was reached.

## Speech perception in noise assessment

The Speech Perception in Noise Test in Kannada (SPIN-K), a test developed by Yathiraj and Vijayalakshmi [25], was used to assess participants' ability to perceive speech in the presence of noise. The test stimuli comprised phonemically balanced words presented with ipsilateral speech noise at 0 dB signal-to-noise ratio (SNR). The task of the participants was to repeat the words presented to them. During the assessment, two lists of 25 words each were presented to each ear. The percent correct scores were calculated for both ears.

## Auditory working memory assessment

Auditory working memory was assessed using digit span (forward and backward digit span) and digit sequencing (ascending and descending digit sequencing) using Smriti Shravan software [26]. The digits were presented with increasing test difficulty, using a 250 ms inter-stimulus interval and a 5000 ms response window for each stimulus during which participants were required to provide their response. The testing was done using Kannada digits from 1 to 9, and participants were asked to repeat the digit according to the digit span and digit sequence task. The scoring was based on the number of correct digits the participants reported concerning the task. The midpoint of the digit span and digit sequencing task was noted. The tests were done at 60 dB SPL binaurally [27].

## Data analysis

All analyses were performed using IBM SPSS version 20.0, and descriptive statistics were computed. Shapiro–Wilk tests were used to assess data normality. For non-parametric data, a Kruskal–Wallis test was used to compare group

**Table 1.** Results of tests on auditory and cognitive processing in women with natural menopause (NM), surgical menopause (SM), and premenopause (PM). There were multiple tests involving temporal perception (MDT and GDT), speech perception in noise (SPIN), and working memory (FR, BK, AS, and DS). A key to the tests is given below the table

| Auditory test | | Mean | Median | *SD* | Range | |
|---|---|---|---|---|---|---|
| | | | | | minimum | maximum |
| MDT 8 Hz R [dB] | NM | –30.91 | –32.60 | 3.41 | –34.25 | –24.25 |
| | SM | –27.39 | –28.22 | 4.17 | –34.25 | –20.45 |
| | PM | –33.13 | –33.47 | 1.34 | –34.86 | –30.25 |
| MDT 8 Hz L [dB] | NM | –31.41 | –32.45 | 3.86 | –37.85 | –24.25 |
| | SM | –27.54 | –28.22 | 4.18 | –36.45 | –21.65 |
| | PM | –33.22 | –33.00 | 1.79 | –37.85 | –30.55 |
| MDT 20 Hz R [dB] | NM | –33.03 | –35.22 | 6.26 | –39.25 | –21.40 |
| | SM | –26.42 | –26.60 | 3.69 | –34.20 | –19.65 |
| | PM | –31.96 | –32.25 | 2.92 | –37.70 | –22.80 |
| MDT 20 Hz L [dB] | NM | –34.95 | –36.67 | 5.15 | –39.25 | –24.35 |
| | SM | –25.03 | –24.37 | 4.05 | –32.30 | –17.55 |
| | PM | –31.27 | –31.00 | 2.37 | –36.48 | –24.55 |
| MDT 60 Hz R [dB] | NM | –34.31 | –34.82 | 2.19 | –36.80 | –29.45 |
| | SM | –22.49 | –22.63 | 4.99 | –34.25 | –14.35 |
| | PM | –29.46 | –30.27 | 2.97 | –32.75 | –20.15 |
| MDT 60 Hz L [dB] | NM | –33.28 | –33.00 | 2.22 | –36.80 | –29.45 |
| | SM | –22.14 | –22.45 | 4.73 | –32.25 | –13.35 |
| | PM | –28.63 | –29.62 | 3.67 | –34.42 | –22.45 |
| MDT 200 Hz R [dB] | NM | –25.72 | –27.15 | 4.94 | –34.25 | –13.65 |
| | SM | –12.59 | –13.20 | 3.54 | –19.25 | –6.15 |
| | PM | –23.54 | –24.00 | 3.18 | –30.25 | –18.45 |
| MDT 200 Hz L [dB] | NM | –23.37 | –25.65 | 3.17 | –34.25 | –20.40 |
| | SM | –12.62 | –13.65 | 3.57 | –19.35 | –5.85 |
| | PM | –24.68 | –24.82 | 4.04 | –33.30 | –15.85 |
| GDT R [ms] | NM | 3.77 | 3.52 | 1.84 | 1.26 | 7.43 |
| | SM | 6.01 | 5.96 | 1.87 | 2.27 | 10.79 |
| | PM | 4.95 | 4.57 | 1.61 | 2.80 | 8.96 |
| GDT L [ms] | NM | 3.99 | 3.52 | 1.99 | 1.95 | 7.93 |
| | SM | 5.61 | 5.70 | 2.20 | 2.16 | 10.14 |
| | PM | 4.49 | 4.72 | 1.20 | 2.16 | 7.23 |
| SPIN R [%] | NM | 57.90 | 56.00 | 9.39 | 44.00 | 72.00 |
| | SM | 56.00 | 56.00 | 8.99 | 36.00 | 68.00 |
| | PM | 61.60 | 62.00 | 8.64 | 44.00 | 80.00 |

**Table 1 continued.** Results of tests on auditory and cognitive processing in women with natural menopause (NM), surgical menopause (SM), and premenopause (PM). There were multiple tests involving temporal perception (MDT and GDT), speech perception in noise (SPIN), and working memory (FR, BK, AS, and DS). A key to the tests is given below the table

| Auditory test | | Mean | Median | *SD* | Range | |
|---|---|---|---|---|---|---|
| | | | | | minimum | maximum |
| SPIN L [%] | NM | 54.80 | 56.00 | 8.31 | 44.00 | 68.00 |
| | SM | 57.00 | 58.00 | 10.69 | 36.00 | 72.00 |
| | PM | 60.80 | 62.00 | 8.39 | 44.00 | 76.00 |
| FR (No. of digits repeated) | NM | 3.11 | 3.00 | 0.62 | 2.10 | 4.25 |
| | SM | 2.98 | 3.00 | 0.59 | 2.10 | 4.25 |
| | PM | 3.62 | 3.10 | 1.03 | 2.00 | 5.73 |
| BK (No. of digits repeated) | NM | 2.70 | 2.72 | 0.55 | 1.80 | 3.60 |
| | SM | 3.60 | 2.75 | 4.13 | 2.00 | 5.00 |
| | PM | 2.97 | 2.90 | 0.92 | 2.00 | 4.75 |
| AS (No. of digits repeated) | NM | 3.03 | 3.00 | 0.91 | 1.50 | 4.37 |
| | SM | 3.30 | 3.05 | 1.14 | 1.50 | 5.75 |
| | PM | 3.67 | 3.45 | 1.22 | 1.50 | 5.73 |
| DS (No. of digits repeated) | NM | 2.71 | 2.10 | 0.98 | 1.60 | 5.50 |
| | SM | 3.10 | 3.05 | 1.01 | 1.60 | 5.50 |
| | PM | 3.31 | 2.10 | 0.82 | 2.00 | 4.75 |

NM – Natural menopause women, SM – Surgical menopause women, PM – Premenopause women, MDT 8Hz R – Modulation detection threshold of 8 Hz in the right ear, MDT 8Hz L – Modulation detection threshold of 8 Hz in the left ear, MDT 20Hz R – Modulation detection threshold of 20 Hz in the right ear, MDT 20Hz L – Modulation detection threshold of 20 Hz in the left ear, MDT 60Hz R – Modulation detection threshold of 60 Hz in the right ear, MDT 60Hz L – Modulation detection threshold of 60 Hz in the left ear, MDT 200Hz R – Modulation detection threshold of 200 Hz in the right ear, MDT 200Hz L – Modulation detection threshold of 200 Hz in the left ear, GDT R – Gap detection threshold of the right ear, GDT L – Gap detection threshold of the left ear, SPIN R – Speech perception in noise in the right ear, SPIN L – Speech perception in noise in the left ear, FR – Forward digit span score, BK – Backward digit span score, AS – Ascending digit span score, DS – Descending digit span score

differences across outcome measures. For pairwise comparisons, Mann–Whitney *U*-test were applied.

## Results

Prior to conducting inferential statistics, a Shapiro–Wilk test was applied to assess the normality of data distribution for all outcome variables. The results indicated that the data for all central auditory processing and working memory measures violated the assumptions of normality ($p < 0.05$). Consequently, nonparametric statistical tests were used for subsequent analyses. Descriptive statistics, including the mean, median, standard deviation (*SD*), and range for all measures across the three groups, are provided in **Table 1**. Overall, women in the surgical menopause group exhibited lower performance on temporal processing tasks and SPIN compared to the other two groups.

### Temporal processing using MDT and GDT

**Figure 1** presents the MDT scores across all modulation frequencies (8, 20, 60, and 200 Hz) and all groups. The surgical menopause group (SM) showed consistently elevated thresholds across both ears, suggesting reduced temporal resolution. A Kruskal–Wallis test confirmed that there were statistically significant group differences for all MDT frequencies In the right ear, significant effects were observed at 8 Hz ($\chi^2(2) = 18.59$, $p < 0.001$), 20 Hz ($\chi^2(2) = 18.87$, $p < 0.001$), 60 Hz ($\chi^2(2) = 41.84$, $p < 0.001$), and 200 Hz ($\chi^2(2) = 38.74$, $p < 0.001$). In the left ear, corresponding frequencies also showed significant differences: 8 Hz ($\chi^2(2) = 19.88$, $p < 0.001$), 20 Hz ($\chi^2(2) = 29.85$, $p < 0.001$), 60 Hz ($\chi^2(2) = 38.38$, $p < 0.001$), and 200 Hz ($\chi^2(2) = 39.82$, $p < 0.001$). Follow-up analyses using a Mann–Whitney *U*-test revealed that women with surgical menopause performed significantly poorer than both women with natural menopause and premenopausal women at all tested frequencies in both ears ($p < 0.001$ for most comparisons). Additional comparisons showed that premenopausal women performed significantly worse than women with natural menopause at 60 Hz and 200 Hz in both ears, suggesting a more nuanced pattern of group differences (asterisks in **Figure 1**).

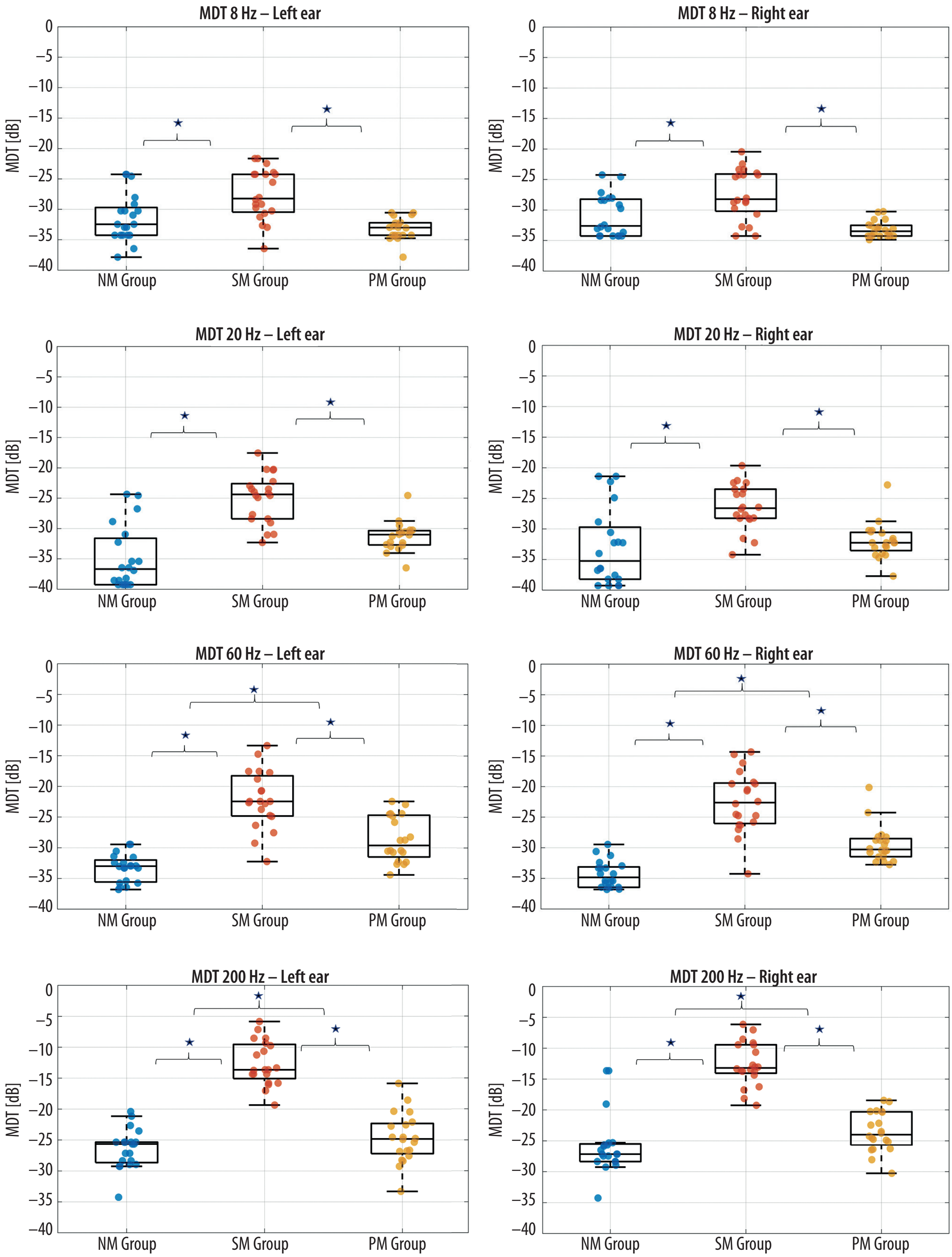


**Figure 1.** Comparison of MDT [dB] between groups of women with natural menopause (NM), surgical menopause (SM), and premenopausal women (PM). Boxes represent the interquartile range (25th to 75th percentiles), and the horizontal line indicates the median. The whiskers extend to the most extreme data points not considered outliers, and individual data points are shown as dots. Asterisks show significant differences ($p < 0.05$)

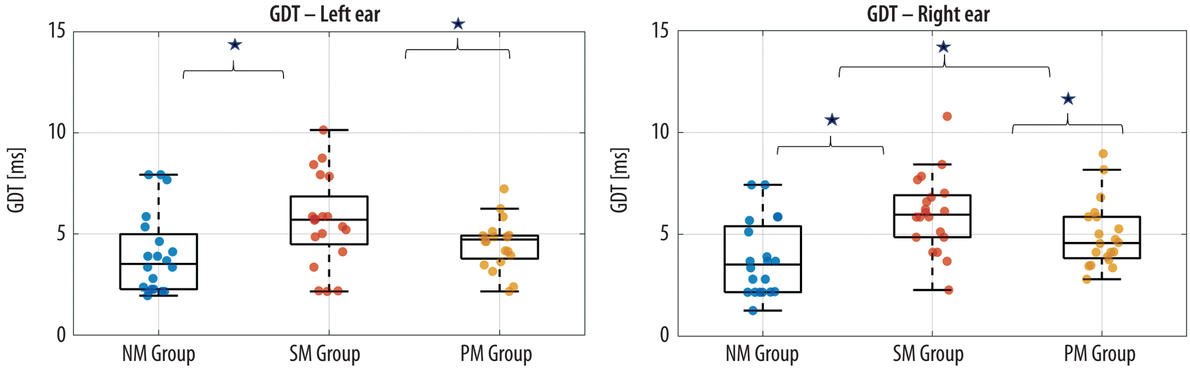


**Figure 2.** Boxplots of gap detection thresholds (GDT) among groups of women with natural menopause (NM), surgical menopause (SM), and premenopausal (PM). Key as per Figure 1

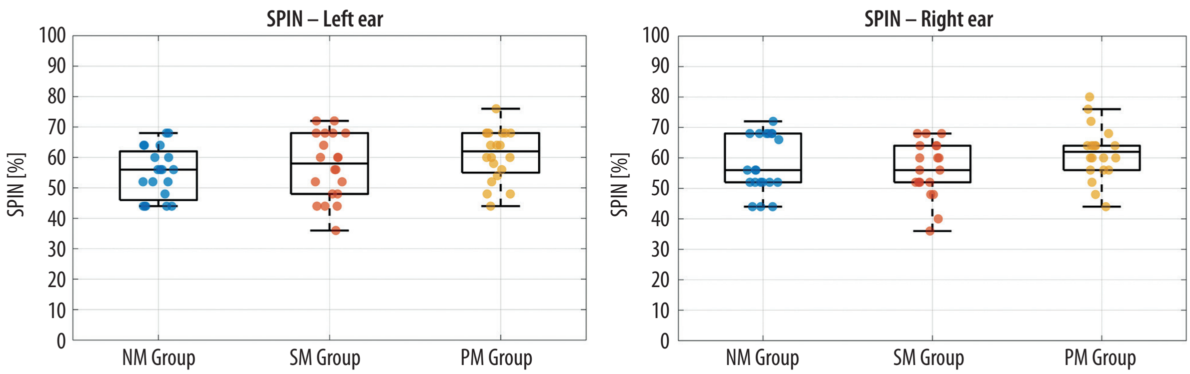


**Figure 3.** Boxplots of speech perception in noise (SPIN) among groups of women with natural menopause (NM), surgical menopause (SM), and premenopausal (PM). Key as per Figure 1

**Figure 2** displays GDT scores for each group. Women in the surgical menopause group again demonstrated elevated thresholds, indicating reduced sensitivity to temporal gaps in noise. Kruskal–Wallis test results showed significant differences between groups for both the right ear ($\chi^2(2) = 14.17$, $p = 0.001$) and the left ear ($\chi^2(2) = 8.39$, $p = 0.015$). Post hoc comparisons revealed that the surgical menopause group performed significantly poorer than both the natural menopause and premenopausal groups in both ears ($p < 0.05$). Furthermore, premenopausal women also performed significantly poorer than those in the natural menopause group for the right ear ($U = 113.00$, $p = 0.018$), but not the left.

## Comparison of SPIN across the three groups

Speech perception in noise performance was assessed using the SPIN test, and the results are illustrated in **Figure 3**. While the premenopausal group showed a trend toward better performance, Kruskal–Wallis test results indicated that the differences among groups were not statistically significant for either the right ear ($\chi^2(2) = 4.30$, $p = 0.117$) or the left ear ($\chi^2(2) = 2.96$, $p = 0.227$). Given the absence of significant group effects, pairwise comparisons were not conducted.

## Comparison of working memory abilities

Working memory was assessed using digit span (forward and backward) and digit sequencing (ascending and descending) tasks. **Figure 4** illustrates the performance across the three groups. Results of a Kruskal–Wallis test indicated no statistically significant differences for any of the working memory tasks. Specifically, the forward digit span yielded a $\chi^2(2)$ value of 5.34 ($p = 0.069$), the backward digit span yielded $\chi^2(2) = 0.238$ ($p = 0.888$), ascending digit sequencing yielded $\chi^2(2) = 3.549$ ($p = 0.170$), and descending digit sequencing yielded $\chi^2(2) = 5.604$ ($p = 0.061$). Although a few comparisons approached statistical significance, none met the threshold for further post hoc testing.

In summary, women who underwent surgical menopause demonstrated significantly poorer temporal processing abilities compared to both premenopausal women and women who had undergone natural menopause. While SPIN and working memory scores did not differ significantly across groups, the clear group differences in temporal processing suggest that abrupt cessation of ovarian function may have a negative impact on certain auditory processing mechanisms.

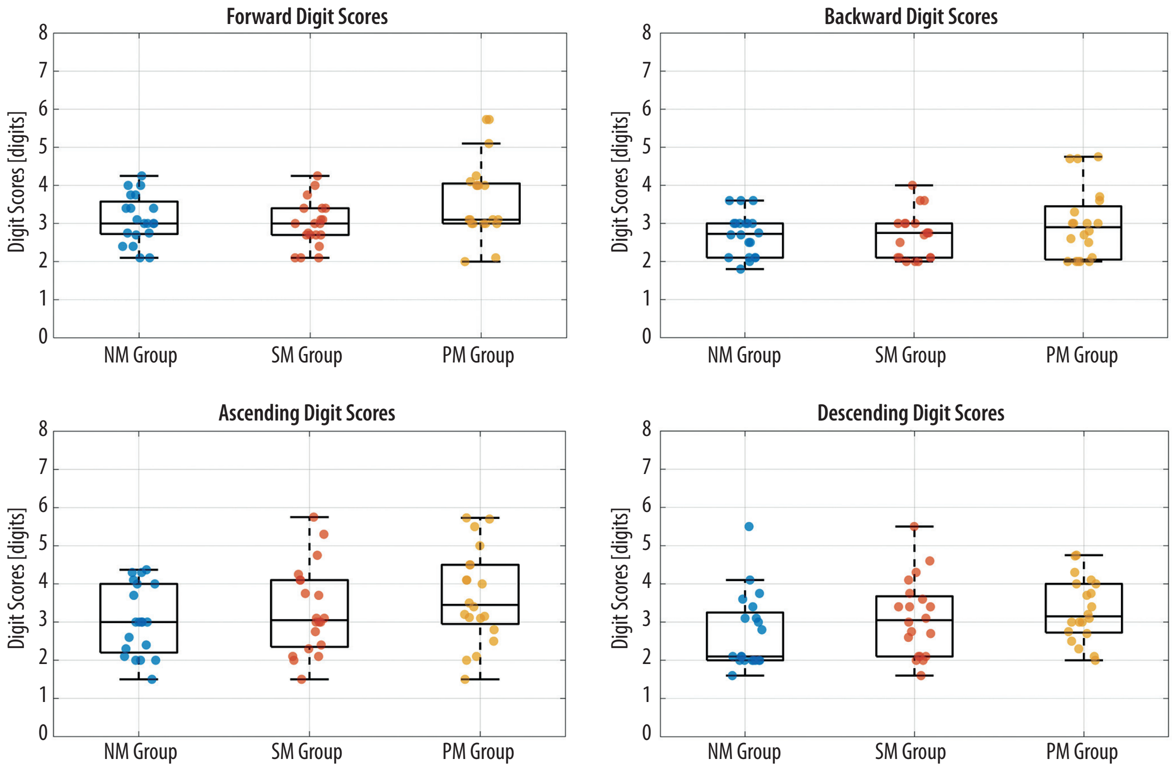


**Figure 4.** Boxplots of working memory abilities using digit span (forward and backward digit span) and digit sequencing (ascending and descending digit sequencing) among women with natural menopause (NM), surgical menopause SM), and premenopausal (PM). Key as per Figure 1

## Discussion

The study aimed to evaluate the effect of natural and surgical menopause on temporal processing, speech perception in noise, and working memory.

### Temporal processing abilities

Temporal processing refers to the auditory system's ability to process and interpret temporal aspects of sound. This includes detecting changes in sound over time, such as the duration, rhythm, and timing of auditory stimuli. Temporal perception is essential for understanding and processing speech, especially in noisy environments, as it helps distinguish between different phonemes and understand spoken language's timing and rhythm [28]. In this study, two tests were used to evaluate temporal processing abilities: MDT to detect amplitude modulation in a sound signal at different frequencies and GDT to detect silent gaps between sounds, providing insights into the temporal resolution of the auditory system.

This study found that women with surgical menopause exhibited poorer temporal processing abilities compared to those with natural menopause and premenopausal women. To the author's knowledge, this is the first study to report the impact of surgical menopause on temporal perception. Estrogen has been shown to enhance auditory sensitivity and temporal perception [29] and may influence hearing by altering blood flow within the cochlea [30]. The findings indicate that women who underwent surgical menopause may have experienced declines in various cognitive functions related to auditory processing. This decline was closely associated with a significant reduction in estradiol levels post-surgery, highlighting the critical role of estrogen in supporting cognitive and auditory health [31]. In this study, women with surgical menopause demonstrated the lowest scores, followed by women with natural menopause. These findings align with the study by Özgedik et al. [32], which reported that hearing thresholds and OAE amplitudes were significantly lower in women with surgical menopause compared to those with natural menopause. Menopause often coincides with auditory decline due to decreased estrogen levels, which play a protective role in maintaining auditory system health [33]. These results underscore the impact of surgical menopause on auditory temporal perception, emphasizing the importance of tailored auditory rehabilitation programs for this population.

Premenopausal women demonstrated poorer MDT compared to women with natural menopause. These findings are in agreement with earlier studies, which suggested that hormonal changes during menopause could impair auditory processing [34].

### SPIN results

SPIN assesses auditory closure abilities, which involve filling in missing or distorted parts of speech using context and linguistic knowledge. This skill is crucial for effective communication in everyday environments where background sounds are prevalent, such as in social gatherings, public places, or work settings [35]. SPIN tests help identify specific difficulties in auditory perception, guiding the development of targeted interventions and rehabilitation programs [36].

This study administered SPIN tests to assess the auditory closure abilities of three groups. The results indicate a better speech perception in noise among premenopausal women, although the differences were not statistically significant. The results are contrary to the literature, which states that hormonal changes affect auditory processing pathways, significantly impacting auditory perception [37]. These discrepancies may be attributable to differences in sample size, participant characteristics, stimulus parameters, or testing methods used in the present study. The reduction in speech perception is linked to the loss of estrogen, which helps protect auditory and cognitive functions [38]. The abrupt loss of estrogen has been associated with increased risks of cognitive decline and reduced neural efficiency, which are critical for tasks such as speech perception in noise [39]. The small sample size may have contributed to the lack of a significant difference observed in the present study.

### Working memory abilities

Working memory is a cognitive construct that temporarily stores and manipulates information essential for complex tasks such as language comprehension, learning, and reasoning [40]. It enables individuals to store and process information simultaneously, vital for activities like mental arithmetic, following multi-step instructions, and reading comprehension. Deficits in working memory can negatively impact academic performance, daily functioning, and overall cognitive health [40]. Estrogen plays a crucial role in cognitive functions, including working memory [41], and its decline following surgical or natural menopause may disrupt the neural circuits involved in working memory, leading to reduced performance in tasks such as digit span and sequencing [42].

The analysis of working memory using forward and backward digit span, as well as ascending and descending sequencing tasks, revealed no statistically significant differences across the groups. While some mean differences were observed, particularly higher variability in surgical menopause and a slight trend toward better performance in premenopausal women, these did not reach significance. These results suggest that while abrupt hormonal changes may influence basic auditory processing, their impact on verbal working memory may be limited or require a longer duration post-menopause to manifest significantly. Alternatively, the digit span tasks used in this study may not be sensitive enough to detect subtle differences in executive function or working memory capacity related to hormonal status.

## Conclusions

The study highlights the effects of menopause on temporal processing abilities, emphasizing the specific challenges encountered by women with surgical menopause, likely due to the abrupt reduction in estrogen levels critical for auditory processing. These findings reinforce the role of estrogen in temporal processing and underscore the necessity for further research with larger sample sizes. Additionally, tailored rehabilitation programs and interventions are crucial to addressing the unique challenges faced by this population.

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