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CROSS-SECTIONAL STUDY OF EXTENDED HIGH-FREQUENCY THRESHOLDS, AUDITORY FIGURE-GROUND DISCRIMINATION, AND WORKING MEMORY IN FEMALES WITH POLYCYSTIC OVARY SYNDROME (PCOS)

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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

Abstract

Introduction: Polycystic ovary syndrome (PCOS) affects up to 10% of reproductive-age women, yet its impact on auditory function remains underexplored. This study aimed to compare auditory and cognitive functions between PCOS patients and age-matched controls.

Material and methods: Participants were 60 normal-hearing individuals aged 20–25 years, evenly split into two groups: Group 1 (control) consisted of unmarried females with regular menstrual cycles, and Group 2 (clinical group) comprised unmarried females diagnosed with PCOS. Auditory assessment involved extended high-frequency audiometry and speech perception in noise (SPIN) tests. Auditory working memory was evaluated through digit span and digit sequencing tasks.

Results: Results showed significantly poorer extended high-frequency audiometry thresholds and SPIN scores in the PCOS group compared to controls. Additionally, PCOS participants performed significantly worse on the digit span task, indicating poorer auditory working memory.

Conclusions: Extended high-frequency audiometry and reduced auditory figure-ground discrimination at low signal-to-noise ratios could potentially serve as early indicators of cochlear abnormalities at the basal end of the cochlea. Future research is needed to investigate the interplay of hormonal milieu and central processing in PCOS.

Keywords: PCOS • working memory • speech perception in noise • extended high-frequency thresholds

PRZEKROJOWE BADANIE PROGÓW W ZAKRESIE ROZSZERZONYCH WYSOKICH CZĘSTOTLIWOŚCI, DYSKRYMINACJI SŁUCHOWEJ FIGURA–TŁO I PAMIĘCI ROBOCZEJ U KOBIET Z ZESPOŁEM POLICYSTYCZNYCH JAJNIKÓW (PCOS)

Streszczenie

Wprowadzenie: Zespół policystycznych jajników (PCOS) dotyka do 10% kobiet w wieku rozrodczym, jednak jego wpływ na funkcje słuchowe jest jeszcze niedostatecznie zbadany. Niniejsze badanie miało na celu porównanie funkcji słuchowych i poznawczych między pacjentkami z PCOS a dobraną wiekowo grupą kontrolną.

Materiał i metody: Uczestniczkami badania było 60 prawidłowo słyszących kobiet w wieku 20–25 lat podzielonych na dwie równe grupy: grupa 1 (kontrolna) składała się z niezamężnych kobiet z regularnymi cyklami menstruacyjnymi, a grupa 2 (kliniczna) składała się z niezamężnych kobiet, u których zdiagnozowano PCOS. Ocena słuchowa obejmowała audiometrię w rozszerzonym paśmie wysokich częstotliwości i testy percepcji mowy w hałasie (SPIN). Słuchowa pamięć robocza została oceniona za pomocą testów rozpiętości i sekwencjonowania cyfr.

Wyniki: Wyniki wykazały istotnie niższe progi audiometrii w rozszerzonym paśmie wysokich częstotliwości i wyniki SPIN w grupie PCOS w porównaniu z grupą kontrolną. Dodatkowo osoby z PCOS osiągały istotnie gorsze wyniki w teście sekwencjonowania cyfr, co wskazuje na gorszą słuchową pamięć roboczą.

Wnioski: Audiometria w rozszerzonym paśmie wysokich częstotliwości i zmniejszona dyskryminacja słuchowa figura-tło przy niskim stosunku sygnału do szumu mogą potencjalnie służyć jako wczesne wskaźniki nieprawidłowości funkcjonowania ślimaka w obszarze jego części podstawnej. W przyszłości należałoby zbadać wzajemne oddziaływania środowiska hormonalnego i centralnego przetwarzania słuchowego w PCOS.

Słowa kluczowe: PCOS • pamięć robocza • percepcja mowy w hałasie • progi w zakresie rozszerzonych wysokich częstotliwości

Key for abbreviations	
AWM	auditory working memory
CRP	c-reactive protein
CVD	cardiovascular diseases
DPOAEs	distortion product otoacoustic emissions
EHF	extended high-frequency
IMT	intima-media thickness
LEAP-Q	Language Experience and Proficiency Questionnaire
MCRs	message to competition ratios
MOC	medial olivocochlear (reflex)
OAE	otoacoustic emissions
PCOS	polycystic ovary syndrome
QuickSIN	Quick Speech Perception in Noise (test)
SD	standard deviation
SNR	signal to noise ratio
SPIN	Speech Perception in Noise (test)
VWM	Visual Working Memory (test)
WM	working memory
WMC	working memory capacity
WRS	word recognition score

Introduction

Polycystic ovary syndrome (PCOS) is a common metabolic disorder that impacts around 10% of women in their reproductive years [1,2]. It is a chronic condition marked by wide array of clinical manifestations that can vary in severity throughout a woman's life [3,4]. Key features include irregular menstrual cycles (oligo-amenorrhea), hyperandrogenism, and polycystic ovaries [5,6]. The development and exacerbation of PCOS involve both intrinsic factors such as insulin resistance, inflammation, and altered hormone production, and extrinsic factors including environmental pollutants, epigenetic influences, diet, and stress [7,8]. Environmental and epigenetic factors play critical roles in regulating genetic expression associated with PCOS [9].

PCOS sufferers are often prone to multiple morbidities, such as coronary heart disease, type 2 diabetes, hyperinsulinemia and dyslipidemia [10–12], infertility, gestational hypertension, miscarriage or premature delivery, non-alcoholic steatohepatitis, metabolic syndrome, sleep disorders, depression, anxiety, eating disorders, and endometrial cancer [13]. Predisposing women to endothelial damage are hyperinsulinemia, insulin resistance, dyslipidemia, and low-grade chronic inflammation [11]. Diseases that cause endothelial damage often lead to early high-frequency hearing loss. Oghan and Coksuer [4] were the first to identify high-frequency hearing loss, specifically in the 4–8 kHz range, in patients with PCOS. Later, Kucur et al. [14] found that hearing impairment in PCOS patients extend to even higher frequencies (8–14 kHz).

Moreover, young PCOS cohorts often have increased carotid intima-media thickness (IMT) in comparison to those without hyperandrogenism [4]. Carotid IMT is a subclinical indicator used to evaluate atherosclerosis and cardiovascular diseases (CVD). Research has demonstrated that endocrinal and biochemical changes associated with PCOS can affect blood flow, potentially contributing to sensorineural hearing loss caused by vascular abnormalities [4]. Sundararaj et al. [15] reported that endocrinal and biochemical changes, hyperandrogenism, cardiovascular problems, insulin resistance, and endothelial damage impact auditory function in females with PCOS.

Studies indicate that individuals with PCOS are more likely to experience hidden hearing loss at high frequencies (8–20 kHz) than at lower frequencies (0.25–4 kHz) [14]. This type of hearing loss, due to cochlear damage, can hinder speech understanding in noisy environments. Shaw et al. [16] suggested that reduced speech perception in the presence of noise may result from extended high-frequency (EHF) hearing loss. Motlagh et al. [17] found that young adults in their 20s with normal standard audiometric results still showed reduced speech perception in challenging conditions due to EHF hearing loss. Thus, it is essential to study how high-frequency hearing loss affects auditory figure-ground discrimination (speech perception in noise, SPIN) in young women with PCOS. Fluctuations in ovarian hormones like estrogen and progesterone can affect inner ear homeostasis and overall auditory function. Estrogen, in particular, is known to protect the auditory system by activating the medial olivocochlear (MOC) reflex [18,19]. Kumar et al. [19] compared MOC function between PCOS patients and age-matched males using QuickSIN (quick speech perception in noise test) in Malayalam [20], finding that PCOS participants had significantly poorer scores.

High-frequency hearing loss is well-documented in females with PCOS [4,14,15]. Further research is needed to investigate auditory figure-ground discrimination ability in young women with PCOS. A study by Apeksha et al. [21] explored this in middle-aged women with PCOS, highlighting the need for additional research focused on younger populations to better understand the relationship between EHF hearing loss and auditory figure-ground discrimination.

In the general population, reproductive and metabolic disturbances each affect cognitive function separately [22]. Physiological and pathological alterations in the levels of testosterone and estrogen hormones can lead to changes in cognitive function [23,24]. In women with PCOS, cognitive function may be influenced by hyperandrogenism and hyperestrogenism [12]. However, there are limited studies that have explored cognitive function in women with PCOS [22,25–28]. Barnard et al. [25] conducted an online study involving 221 women with PCOS (some of whom were on antiandrogenic treatment) and 442 control participants, and found that women with PCOS had

notably slower reaction times and reduced word recognition. Additionally, those undergoing antiandrogenic treatment showed improved performance compared to those not receiving such treatment. Schattmann and Sherwin [22] found that women with high free testosterone levels from PCOS performed less effectively on tasks typically associated with female-oriented skills, such as verbal memory, fluency, and visuospatial working memory compared to control women. However, these women did not exhibit superior performance on tasks generally favored by men.

Working memory (WM) plays a significant role in higher cognitive functions [29–32]. The hippocampus, situated in the medial temporal lobe, is rich in androgen and estrogen receptors and plays a vital role in WM [33]. Working memory capacity (WMC) can be evaluated through simple tasks (forward, backward, ascending, and descending digit span, along with visual and spatial span) as well as complex tasks (including reading span, operational span, rhyme judgment, and visual letter monitoring) [34]. Sundararaj et al. [15] assessed auditory working memory in 20 women with polycystic ovarian syndrome using digit span and sequencing tasks. The study found that women with PCOS performed poorly on backward digit span and both ascending and descending digit sequencing tasks. These deficits may be linked to hormonal irregularities such as hyperandrogenism and imbalances in testosterone and estrogen levels in PCOS [35,35a].

WM encompasses the selection and processing of stimuli from a single sense as well as the integration of information from different senses, such as vision and hearing [36,37]. Research combining these sensory modalities is of considerable scientific interest. To evaluate higher cognitive functions, the brain might have to adjust and integrate information from both visual and auditory inputs [38]. We hypothesized that impaired auditory working memory due to hormonal variation might also be reflected in the visual modality. Therefore, this study examined the auditory and visual working memory of women with PCOS and compared them to age-matched controls. The objectives of the study were to assess EHF thresholds, speech perception in noise (SPIN), as well as auditory and visual working memory in individuals with PCOS.

Material and methods

Using the purposive sample method we recruited 60 final-year graduate students aged between 20–25 years from our allied health science university. These participants had normal/corrected vision, hearing, and intelligence and had no history of mental or neurological diseases. All participants provided written consent and voluntarily agreed to take part.

Inclusion criteria

All the participants were bilingual individuals with Malayalam as the primary language and English as a second language. Language proficiency was assessed using the Language Experience and Proficiency Questionnaire [39] (LEAP-Q score > 80% for Malayalam and English). Participants were evenly divided into two groups, with 30 in each. Group 1, the control group, comprised unmarried females with regular menstrual cycles with a mean age of 22.3 years ($SD = 1.57$), while Group 2, the clinical group, included unmarried females diagnosed with PCOS with a mean age of 22.0 years ($SD = 1.56$). All participants had air conduction thresholds < 15 dB HL and bone conduction thresholds < 10 dB HL at octave frequencies, as well as speech recognition scores of > 90% in quiet. Bilateral ipsi and contra reflexes were within normal limits, and participants also had type A tympanograms using a 226 Hz probe tone. DPOAEs were detected in all participants, with signal to noise ratio (SNR) > 6 dB over 2–5 kHz.

Participants in the clinical group were recruited after being diagnosed with PCOS according to Rotterdam's criteria [40]. All selected individuals had been diagnosed with PCOS for at least 3 years prior to the study and were currently receiving treatment. Despite their medication, all participants exhibited clinical symptoms of PCOS such as irregular menstrual cycles, hirsutism, and acne during the data collection period.

Exclusion criteria

History or complaints of loss of hearing in one or both ears, neurological diseases, endocrine diseases such as diabetes, androgen-secreting tumors and thyroid dysfunctions, hypertension, exposure to ototoxic drugs, noise exposure, autoimmune diseases, and intake of any medications which could alter sex hormones.

Ethical standards

Participants were briefed on the study's objectives and procedures before commencement, and informed consent was obtained from each participant. All procedures were non-intrusive and adhered to the Ethics committee of the Institute (approval number AWH/EC/02/2022) and complied with the Declaration of Helsinki.

Instrumentation

A calibrated Maico MA 42 dual-channel diagnostic audiometer in conjunction with TDH 39 headphones fitted with MX-41/AR cushions and a Radioear B-71 bone vibrator were used to perform pure tone and speech audiometry. A Malayalam high-frequency wordlist was delivered to the ear with better hearing from the same audiometer during an auditory figure-ground discrimination test. The middle ear condition was evaluated using a GSI Tympstar Pro middle ear analyzer. A Smart DPOAE Intelligent Hearing System was used to measure DPOAEs. Auditory and visual working memory was evaluated using Smriti Shravan software, a customized tool for assessing working memory [40a]. The stimulus was delivered via a Dell Inspiron Core i3 laptop calibrated with TDH-49 headphones.

Test environment

Tests were conducted in an acoustically treated and well-lit air-conditioned room with ambient noise levels within ANSI S.3 (1991). Pure tone audiometry and SPIN tests at various MCRs were performed in a two-room setup, while OAE measurements and working memory assessments were conducted in a single room.

Procedure

Hearing evaluation

Each subject underwent an otoscopic examination to ensure the absence of earwax, foreign objects, and abnormalities in the tympanic membrane. Pure tone and speech audiometry tests were conducted using the modified Hughson and Westlake procedure [41] to determine thresholds. Spondees were used for speech reception threshold assessment [42], while monosyllabic wordlists were employed to measure speech identification scores [42]. Stimuli were presented in real-time at 40 dB SL. DPOAEs were recorded using a Maico Ero Scan.

Acquisition of EHF thresholds

Sennheiser HAD 300 circumaural headphones were used to provide pure tones to measure EHF hearing thresholds at 9, 10, 11.2, 12.5, 14, and 16 kHz. The thresholds were obtained using the modified Hughson and Westlake technique.

SPIN test

Speech perception in noise was assessed at different message competing ratios (–5, 0, and +5 dB MCRs), and a Malayalam high-frequency word list [43] was utilized alongside multitalker babble controlled by custom-written Matlab code. The stimuli were delivered to the right ear at a comfortable level from a Dell Inspiron Core i3 laptop through a clinical audiometer. The right ear advantage is not specific to the dichotic condition and has been observed with monaural presentations in normal healthy adults [44]. Among healthy normal children and adults, the word recognition score (WRS) in the right ear has been reported to be slightly better than that of the left ear in the noise condition [45]. Hence the auditory figure-ground discrimination test was only administered to the right ear.

Recordings were conducted in a sound-proof room, adhering to noise level guidelines specified in ANSI S3.1-1991. Each word list, randomized for presentation, was spoken by a female native speaker of Malayalam (who was a voice professional) and recorded in Praat software. The speaker was instructed to pronounce words naturally, clearly, and with neutral intonation while maintaining consistent vocal effort. Post-recording, each word was normalized to 0 dB using Adobe Audition v. 3.0. Additionally, a 1 kHz calibration tone normalized to 0 dB was generated in Adobe Audition and added at the beginning of each word list.

Working memory tests

The assessment of auditory and visual working memory utilized Smriti Shravan software, a tool designed for this purpose [40a].

Auditory working memory

Stimuli consisted of sets of digits from the auditory module of the software, which were presented simultaneously to both ears of each participant. In the forward span task, participants were asked to arrange the digits in the exact order they were heard in English. Similarly, in the backward, ascending, and descending spans, participants were instructed to sequence the digits in reverse, ascending, and descending orders, respectively. During each trial, digits were presented sequentially with a 1 s interval between each digit. After completing a full trial, the participant had 5 s to input the heard digits in a particular sequence according to each task's instructions. Before the actual testing, each task included a trial for familiarization, with instructions displayed on the computer screen. The examiner provided supplementary verbal instructions as required.

The number of digits in each trial depended on the participant's responses. Correct responses resulted in an increase of one digit in subsequent trials, while incorrect responses led to a reduction of one digit. The stimulus trials included digits from 1 to 9, with the exception of 7, which had a longer duration than the others. Stimuli were presented through a Dell Inspiron Core i3 laptop paired with Sennheiser HD 206 headphones, at an intensity of 40 dB SL (relative to the speech recognition threshold) for all participants, in a quiet, distraction-free environment. Scoring utilized a one-up, one-down adaptive procedure, and the final score was determined as the average of the midpoints of the last four reversals. The software computed scores for each task and the scores from the midpoint of the last three reversals were extracted for ascending, descending, forward, and backward spans. These scores were then compared between the groups using suitable statistical methods. The software computed the scores achieved for each task. Scores from the midpoint of the last three reversals were obtained for ascending, descending, forward, and backward spans, and were compared between groups using appropriate statistical methods.

Visual working memory

In this task, participants were required to memorize and subsequently recall visual stimuli (numbers) presented in the forward, backward, ascending, and descending span tasks using the visual module. The remaining test procedure and scoring were identical to those described earlier. Test results were automatically recorded and saved in an Excel spreadsheet.

The obtained data were tabulated and analyzed by using Statistical Package for Social Sciences (SPSS, v. 26.0). A Shapiro–Wilk test of normality was administered to verify the normal distribution of the obtained data and findings showed that data was not normally distributed. Hence non-parametric tests were administered. Descriptive statistics were done to estimate the mean and standard deviation (SD) of extended high-frequency audiometry, SPIN, and working memory assessment for all participants. Mann–Whitney *U*-tests were done to compare the EHF thresholds for right and left ears between groups. Mann–Whitney *U*-tests were conducted to test whether there was any significant difference between the experimental and control groups for SPIN scores at various MCRs. The auditory working memory results for digit span and digit sequencing were compared using Mann–Whitney *U*-tests between control and experimental groups.

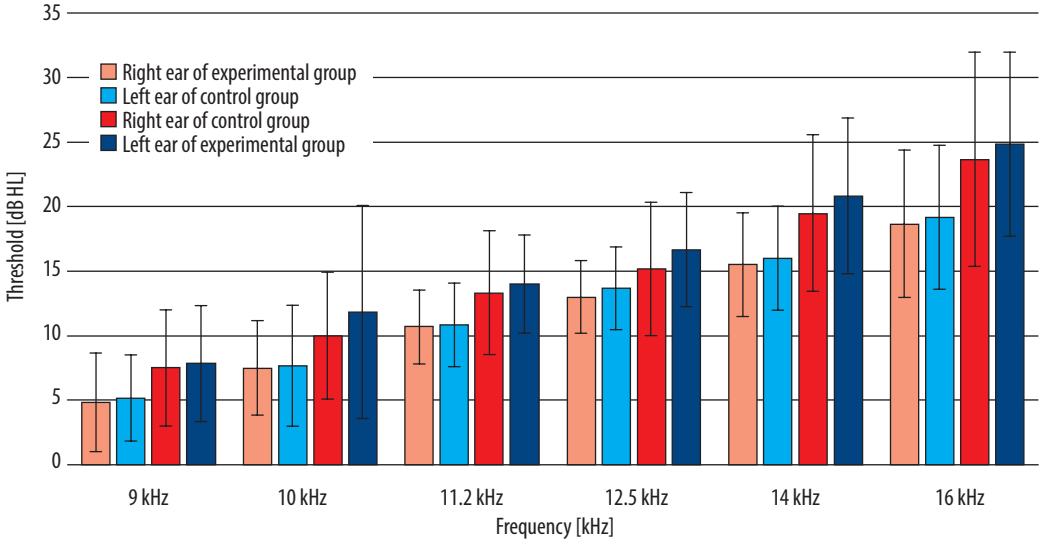

Figure 1. Mean and standard deviation of EHF thresholds in control and experimental groups

Table 1. Comparison of EHF thresholds across the groups

	9 kHz	10 kHz	11.2 kHz	12.5 kHz	14 kHz	16 kHz
Mann–Whitney *U*	299.5	311	285.5	345.5	272.5	290
Z	−2.4	−2.2	−2.6	−1.7	−2.8	−2.4
Asymp. Sig. (2-tailed)	**.019**	**.030**	**.009**	.090	**.005**	**.014**

Results

EHF thresholds

Figure 1 shows the mean and standard deviation of EHF thresholds in PCOS females (saturated colours) compared to age-matched healthy controls (light colours). PCOS females returned significantly poorer mean scores in both ears than in controls, although both groups showed a right ear advantage.

Mann–Whitney *U*-tests were used to compare the EHF thresholds between groups across frequencies. A statistically significant difference was obtained ($p < 0.05$) across all frequencies except at 12.5 kHz (**Table 1**).

Speech Perception in Noise Test (SPIN)

Figure 2 shows the mean and standard deviation of SPIN scores across different MCR levels (5, 0, −5 dB SNR) in PCOS females compared to age-matched healthy individuals. Across all MCRs, PCOS females exhibited lower mean scores, with statistically significant differences observed, particularly at 0 and −5 dB MCR.

Mann–Whitney *U*-tests were administered to check if there were any significant differences between scores of SPIN at 5, 0, and −5 dB MCR in both the control group and the experimental group. A statistically significant difference

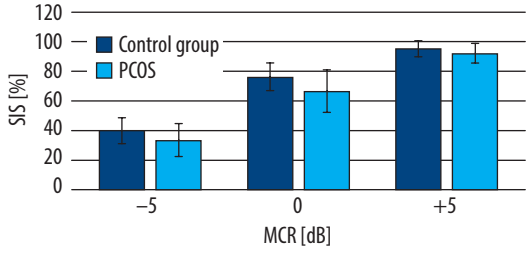

Figure 2. Means and standard deviations of speech in noise (SPIN) in both groups

was obtained in all MCRs except at +5 dB for both the control group as well as the experimental group (**Table 2**).

Working memory assessment

Auditory digit span and sequencing tests

Figure 3 depicts the mean and *SD* of forward digit span tests, backward digit span, ascending sequence, and descending sequence test of both groups. Females with PCOS had lower mean scores overall, with the forward digit span test yielding the highest mean score and the descending sequence test the lowest. This was true for both groups.

Table 2. Comparison of different MCRs in both groups

	SPIN scores at various MCRs [%]		
	–5 dB	**0 dB**	**+5 dB**
Mann–Whitney *U*	298	280	333
Z	–2.3	–2.5	–1.8
Asymp. Sig. (2-tailed)	**0.023**	**0.011**	0.071

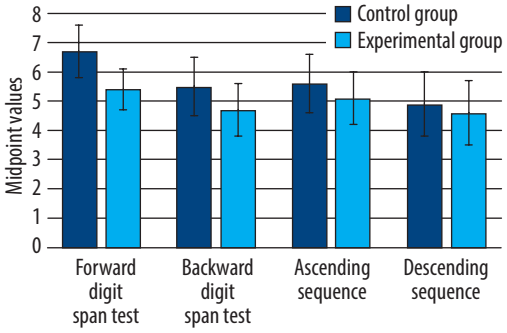

Figure 3. Mean and standard deviation of auditory working memory tests in both groups

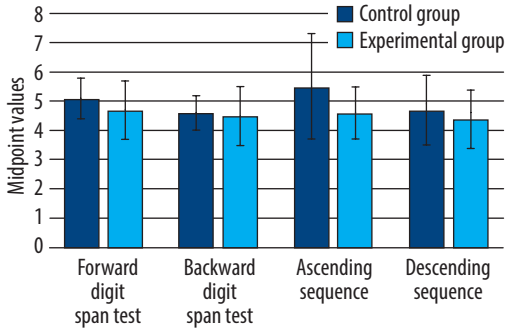

Figure 4. Mean and standard deviation of visual working memory tests in both groups

Table 3. Comparison of auditory working memory tests between both groups

	Forward digit span test	Backward digit span test	Ascending sequence	Descending sequence
Mann–Whitney *U*	119	239.5	335.5	360.5
Z	–4.9	–3.1	–1.7	–1.3
Asymp. Sig. (2-tailed)	**< 0.001**	**0.002**	0.090	0.186

Table 4. Comparison of visual working memory tests between both groups

	Forward digit span test	Backward digit span test	Ascending sequence	Descending sequence
Mann–Whitney *U*	319.5	437.5	294.0	412.0
Z	–1.930	–0.185	–2.307	–0.562
Asymp. Sig. (2-tailed)	0.054	0.853	**0.021**	0.574

Comparison of AWM between groups

Mann–Whitney *U*-tests were administered, and a statistically significant difference was present only for forward and backward digit span tests (**Table 3**).

Visual digit span and sequencing tests

Visual working memory was evaluated using digit span and sequencing tasks, analogous to those used for auditory assessment. Females with PCOS had overall lower scores, with the forward digit span test producing the highest scores and the descending sequence test the lowest. In the control group, the ascending sequence test had the highest scores, while the backward digit span test had the lowest. Mean scores are plotted in **Figure 4**.

Comparison of VWM tests between groups

Mann–Whitney *U*-tests were administered and only the ascending sequence span tests showed a statistically significant difference (**Table 4**).

Correlation between AWM and VWM in PCOS females

To evaluate the correlation between auditory working memory with visual working memory in the experimental

Table 5. Correlation between auditory and visual working memory in the experimental group

			AWM				VWM			
			F.S	B.S.	A.S.	D.S.	F.S	B.S.	A.S.	D.S.
AWM	F.S.	correlation coefficient	1.00	0.47	–0.16	–0.36	–0.10	0.17	–0.12	–0.29
		Sig. (2-tailed)		**0.01**	0.39	0.05	0.60	0.36	0.53	0.11
	B.S.	correlation coefficient	0.47	1.00	–0.07	0.01	–0.19	0.09	–0.02	–0.36
		Sig. (2-tailed)	**0.01**		0.71	0.94	0.32	0.63	0.90	**0.048**
	A.S.	correlation coefficient	–0.16	–0.07	1.00	0.60	–0.26	–0.13	0.48	0.49
		Sig. (2-tailed)	0.39	0.71		**< 0.001**	0.17	0.49	**0.01**	**0.01**
	D.S.	correlation coefficient	–0.36	0.01	0.60	1.00	–0.23	–0.17	0.49	0.53
		Sig. (2-tailed)	0.05	0.94	**< 0.001**		0.23	0.36	**0.01**	**< 0.001**
VWM	F.S.	correlation coefficient	–0.10	–0.19	–0.26	–0.23	1.00	0.68	–0.13	–0.09
		Sig. (2-tailed)	0.60	0.32	0.17	0.23		< 0.001	0.51	0.62
	B.S.	correlation coefficient	0.17	0.09	–0.13	–0.17	0.68	1.00	0.11	–0.11
		Sig. (2-tailed)	0.36	0.63	0.49	0.36	**< 0.001**		0.55	0.56
	A.S.	correlation coefficient	–0.12	–0.02	0.48	0.49	–0.13	0.11	1.00	0.50
		Sig. (2-tailed)	0.53	0.90	**0.01**	**0.01**	0.51	0.55		**0.01**
	D.S.	correlation coefficient	–0.29	–0.36	0.49	0.53	–0.09	–0.11	0.50	1.00
		Sig. (2-tailed)	0.11	**0.048**	**0.01**	**< 0.001**	0.62	0.56	**0.01**	

Abreviations: AWM, auditory working memory; VWM, visual working memory; F.S., forward span; B.S., backward span; A.S., ascending span; D.S., descending span

group, Spearman's rank correlation was used. **Table 5** shows the correlation between auditory and visual working memory and it shows that there is a low positive significant correlation between forward and backward digit span tests in auditory working memory (correlation = 0.47, $p = 0.01$), ascending and descending sequence span in auditory working memory (correlation = 0.60, $p < 0.001$), ascending sequence span in both auditory and visual working memory (correlation = 0.48, $p = 0.01$), ascending sequence span in auditory and descending sequence span in visual working memory (correlation = 0.49, $p = 0.01$), descending sequence span in auditory and ascending sequence span in visual working memory (correlation = 0.49, $p = 0.01$), descending sequence span in both auditory and visual working memory (correlation = 0.53, $p = 0.01$), forward and backward digit span in both visual working memory (correlation = 0.68, $p = 0.01$). There is a low negative significant correlation between backward digit span tests in auditory and descending sequence span in visual working memory (correlation = –0.36, $p = 0.048$).

Discussion

The study aimed to assess hearing and cognition in PCOS individuals. EHF audiometry and SPIN tests were used to assess hearing, while cognition was evaluated using tests for auditory and visual working memory.

EHF audiometry

Results of the current study revealed that young women with PCOS had poorer EHF thresholds (9–16 kHz), which is in accordance with previous findings. Both Oghan and Coksuer [4] and Kucur et al. [14] reported that the hearing thresholds of their PCOS groups were higher at EHF compared to controls. The cause of the loss could be insulin resistance, hyperandrogenemia, or elevated serum CRP as an inflammatory marker of PCOS.

A recent study on PCOS cohorts aged 18–40 years reported similar findings [21]. Elevated thresholds were attributed to vascular obstructions in the arteries which feed the inner ear with oxygen. Hearing in the low and mid frequencies may improve if blood flow returns to normal, but hearing in the higher frequencies may not [46]. Increased carotid intima-media thickness in young women with PCOS results in endocrinal and biochemical changes, which could affect the blood flow and potentially contribute to hearing loss. The current study on young PCOS females observed signs of hyperandrogenism such as hirsutism, acne, alopecia, and irregular menstrual cycles, and there was elevated body weight even under medication. Turan et al. [47] proposed that a rise in testosterone levels, primarily associated with hirsutism, could contribute to elevated hearing thresholds.

SPIN

Poorer SPIN scores for the Malayalam high-frequency word list were obtained at lower SNRs (–5 and 0 dB) by the young PCOS females. Apeksha et al. [21] noted reduced SPIN scores among PCOS-afflicted women at –3, –6, and –9 dB SNR. The hidden high-frequency hearing loss resulting from cochlear damage might therefore hinder the perception of high-frequency words in the presence of noise. Other researchers have suggested that fluctuations in estrogen levels in the ovaries may influence SPIN scores, while progesterone may also have an impact [48]. Thus, the reduced SPIN scores in PCOS females may stem from fluctuations in female reproductive hormones. This study supports the suggestion that the diminished SPIN performance in PCOS cohorts could result from disturbances in hormonal equilibrium, together with possible auditory and neural impairments linked to vascular constriction.

AWM in PCOS females

Women with PCOS demonstrated lower mean scores on auditory working memory tests such as digit span and sequence tasks. A statistically significant difference was noted in the forward and backward digit span test whereas no such difference was observed in the sequence tasks. A previous study [15] reported a significant difference in all tasks except the forward task. From these findings, it is clear that auditory working memory is affected in these individuals, and can possibly be attributed to elevated levels of testosterone and estrogen associated with hyperandrogenism in PCOS. An alternative explanation suggests that women with PCOS show increased activation in brain regions such as the superior and inferior parietal lobes and the superior temporal lobe. However, such an increase in activation is not associated with working memory storage or attentional processes compared to women in the control group [49].

The lack of a significant difference in the sequencing task between groups might be attributed to their younger age and ongoing hormonal treatment. Collectively, these factors help mitigate significant declines in working memory in PCOS cohorts, since Soleman [49] noted that hormonal treatment could potentially alleviate memory issues and concluded that antiandrogenic treatment improves cognitive performance.

VWM in PCOS females

The mean and standard deviation of visual working memory digit span and sequence tasks revealed that females had poorer mean scores, even though the difference was statistically significant only in the ascending sequence test. Lai et al. [50] conducted a cross-sectional study on 21 PCOS cohorts and reported decreased activities of brain regions responsible for visuospatial working memory such as the left inferior temporal and occipital gyrus. The literature suggests that the parietal region acts as a storage buffer for visual information [51]. Reduced efficiency in working memory processing may lead to the need for compensatory parietal activity. But this may not be observed in women with PCOS, due to suboptimal processing. The above literature supports the contention that VWM is affected in young PCOS females, even though in the current study there was no significant differences across various digit tasks. The lack of a significant difference may be attributed to the inherent difficulty and time needed to complete each task, which led to generally low scores across both the experimental and control groups. Future research may aim to reduce these difficulties. Despite these limitations, this study serves as an initial exploration into understanding the impact of PCOS on visual working memory.

The correlation observed between auditory and visual working memory tasks suggests that the cognitive effects of PCOS are not isolated to specific modalities but rather involve broader cognitive domains. Future research could delve deeper into the intricate interplay between hormonal balance and central cognitive processing in this complex condition.

There are a number of limitations in the current study. The result of visual working memory tasks can be taken as preliminary findings from which a future study could be designed with greater control on extrinsic variables. Also, this study cannot say whether specific hormonal treatments might mitigate cognitive deficits.

Conclusions

Young women diagnosed with PCOS exhibited poorer extended high-frequency thresholds in both ears. Furthermore, their speech discrimination scores in noisy environments were also adversely affected. Cognitive function was assessed with tasks that evaluated working memory in both the auditory and visual domains, and revealed lower performance in PCOS. Moreover, extended high-frequency audiometry and reduced auditory figure-ground discrimination at low signal-to-noise ratios could potentially serve as early indicators of cochlear abnormalities at the basal end of the cochlea. Future research is needed to investigate the interplay of hormones and central processing in PCOS.

Statements and declarations

The authors state there are no conflicts of interest. Data and materials can be provided upon request.

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