Impact of Prolonged Electronic Device Use on Auditory Processing Skills

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ABSTRACT

Introduction: The central auditory processing, a complex cognitive function, involves the interpretation and understanding of auditory information. Despite normal hearing, individuals with auditory processing disorder (APD) struggle with these tasks. The pervasive use of electronic devices, including smartphones, tablets, and personal listening devices, has fundamentally altered how humans engage with and process surrounding information. This study investigates the potential impact of electronic device usage on auditory processing in both adults and children in Riyadh, Saudi Arabia, employing APD battery tests.

Methods: Arab adult (aged 18–80 years) and pediatric (aged 5–17 years) participants with diverse backgrounds and normal hearing were included in the study. Of the 160 participants, 100 were adults, and 60 were pediatric participants. The participants underwent a two-stage process involving an online form collecting personal information and appointment scheduling through Google Forms, followed by peripheral hearing evaluation and APD tests.

Results: The study revealed that adults who used electronic devices for more than five hours a day scored significantly lower on auditory processing tests such as gaps-in-noise (GIN), pitch pattern sequence (PPS), duration pattern sequence (DPS), masking level difference (MLD), and random gap detection (RGD) compared to those with less usage. This suggests impairments in auditory processing. Similarly, children with high device usage performed much worse on these tests than their peers with limited usage. The most significantly impacted results were observed in the MLD test for adults ($Z = 7.973$, $p < 0.001$) and the PPS test for children ($Z = 6.550$, $p < 0.001$). Strong correlations between right and left ear scores were detected among young and adult overexposure users, indicating consistent bilateral auditory processing deficits linked to excessive technology use. These findings underscore the potential negative impact of prolonged electronic device usage on auditory processing skills.

Conclusion: This study highlights the need for awareness and further research on the effects of electronic device use on hearing health, emphasizing the importance of balanced technology use to protect auditory processing abilities.

Keywords: *Auditory Processing Disorder (APD), Hearing Loss, Neurobiological Activity, Auditory Processing Tests, Electronic Device Usage.*

INTRODUCTION

The auditory system is a marvel of biological engineering, allowing living organisms to perceive and interpret sound waves in their environment (Hughes, 2001). From the gentle rustling of leaves to the intricate melodies of a symphony, the sense of hearing plays a crucial role in our daily lives, shaping our understanding of the world around us (Kramer, 2021). Our auditory systems can decipher signals distorted by noise, even in challenging listening conditions (Darwin, 2009). A sound's linguistic or acoustic context is one cue that can be utilized to carry out this function (Kujala et al., 2023). Therefore, most sound perceptions that occur in real life are inherently inferential. To comprehend external sounds, one must recognize the fragmented external sound sources as well as the listener's stored expectations and prior knowledge (Lesicko & Llano, 2017). The ways in which top-down mechanisms influencing hearing in noisy environments are influenced by changes in bottom-up signals from the peripheral auditory system (in the context of peripheral hearing loss) remain unclear (Willmore & King, 2023).

The process of hearing involves the conversion of external sound vibrations into nerve impulses that are sent to the brain, where they are translated into sounds (Kunchur, 2023). The decline in hearing quality can significantly impact an individual's overall quality of life. Hearing loss has effects beyond the physical, as emotional and social well-being may be affected (Holman et al., 2023). Reduced hearing sensitivity, which can range from mild to profound, is referred to as hearing loss, and as people age, the frequency and severity of hearing impairments increase. Healthy aging and compensatory mechanisms in the neurodegenerative pathologies impact multiple stages of auditory processing (Henshaw et al., 2023). The type, degree, and configuration variations of hearing loss can be categorized. The outer, middle, and inner ears comprise the peripheral auditory system. These organs receive and process sound waves in order to transform them into data that the human senses can perceive as auditory perceptions (Kunchur, 2023). The tympanic membrane divides the external ear canal from the middle ear, the pinna, the ear canal (external auditory meatus), and the outer ear. The malleus, incus, and stapes are the three ossicles located in the middle ear that begin at the tympanic membrane and transfer sound-induced vibrations of the membrane to the fluid-filled inner ear (Ugarteburu et al., 2022). The inner ear comprises the vestibular system, responsible for balance, and the cochlea, which plays a crucial role in hearing. These anatomical structures are interconnected with the cochlear nucleus in the brainstem through the vestibulocochlear nerve, also referred to as the eighth cranial nerve (Büttner, 2023). The brainstem and cortex contain neural centers that make up the central auditory system, which is the portion of the auditory system that extends past the auditory nerve (Reuss et al., 2023). Sensorineural, conductive, mixed, and central hearing loss are the four main categories of hearing loss. Sensorineural hearing loss is caused by either vestibulocochlear nerve/CN VIII (neural)/auditory dysfunction or cochlear (sensory). Difficulty transmitting sound waves through the tympanic membrane, middle ear (ossicles), or outer ear canal results in conductive hearing loss. Damage to the nerves or sensory hair cells of the inner ear as well as to the conductive pathways of the outer and middle ear, results in mixed hearing loss (ASHA, 2021). Auditory processing disorder, which affects the auditory nerve and auditory pathways in the brain, can result in a hearing impairment known as central hearing loss (Kamali et al., 2022; Shinn, 2012).

Daily in clinical practice, patients complain of communication problems due to hearing loss. The findings of the examination serve to guide audiologic treatment to address these communication challenges or to direct suggestions for many of these patients, for whom the results of an audiologic evaluation are consistent with peripheral hearing loss (Whitelaw, 2008). Nevertheless, according to the results of standard audiometric tests, certain patients who express concerns may demonstrate typical peripheral hearing acuity. Often, individuals' reported worries are dismissed because their audiogram aligns with healthy peripheral hearing (Windle *et al*., 2023) All activities carried out on peripheral auditory inputs that are necessary for the successful and timely formation of auditory precepts, as well as their resolution, classification, and identification, can be referred to as central auditory processing (Fernández Rubio *et al*., 2022). The term auditory processing disorder (APD) has gained popularity in recent years to cover a variety of symptoms that share the difficulties of listening to noises without an audiometric impairment (Moore, 2006).

The following behaviors, including sound localization, auditory discrimination, temporal aspects of audition (including temporal resolution, masking, integration, and ordering), as well as auditory performance skills in the presence of competing acoustic signals and auditory performance skills in the presence of degraded acoustic signals, are all attributed to auditory processes, according to the ASHA (1996) statement (Kyrtsoudi *et al*., 2023). Auditory processing, when used specifically, refers to the central nervous system's perceptual processing of auditory information as well as the neurobiological activity that underlies that processing and results in electrophysiologic auditory potentials (Whitelaw, 2008).

The causes of auditory processing disorder may be linked to a specific lesion or unknown (acquired or congenital) (Malhotra & Kullar, 2023).

In 2022, technology will impact nearly every element of life, including socialization, productivity, access to food and healthcare, and the effectiveness and safety of transportation (Haleem *et al*., 2022). It has facilitated more convenient learning, more accessible access to information, and the natural formation of international communities online (Baughman *et al*., 2022). Technology has improved our lives and made it easier to share ideas and resources. Still, excessive use of it has also been connected to increased social division, privacy concerns, and a decline in mental health (Zara & Monteiro, 2021). This study aimed to determine the effect of electronic device usage on the central auditory nervous system (CANS), (Auditory Processing Skills) and the neurobiological activity of adults and children in the Kingdom of Saudi Arabia (Riyadh) using APD battery tests, which is unprecedented in the region.

METHOD

Participants

A total of 160 participants with different educational and occupational backgrounds were included in this research. The study's inclusion criteria required adult participants to be between 18 and 80 years old, and child participants to be between 5 and 17 years old, as shown in Figure 1. All participants speak Arabic as their native language. Participants should have a normal peripheral hearing as determined by standard hearing assessments and must regularly use electronic devices such as smartphones, tablets, computers, or personal listening devices. Additionally, participants or their guardians must provide informed consent to take part in the study.

Exclusion criteria were developed to eliminate any participant with peripheral hearing loss or auditory diseases, known neurological or cognitive disorders that may impact auditory processing, non-Arabic speakers, children under the age of five, individuals or guardians who do not provide informed consent, and participants who do not regularly use electronic devices or cannot reliably report their usage patterns. As illustrated in Table 1, participants were categorized based on their exposure time to electronic devices.

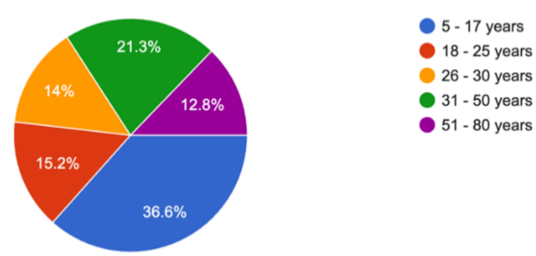
Table 1.

The number of adult and pediatric participants categorized according to time of exposure to electronic devices.

Time of exposure to electronic devices	≤ 5 hours per day	> 5 hours per day
Adults	50	50
Children	30	30

Figure 1.

The Age Categories of Participants in the Study.



Data collection

Stage 1

A structured, closed-ended online form was designed in English and Arabic. It was divided into three sections: 1) personal information and agreement; 2) electronic device type, number of hours used per day, and reasons for usage; and 3) appointment arrangement for the second stage.

Stage 2

All participants underwent five APD tests and a regular hearing assessment to ensure all participants had normal hearing. The equipment requirements for administering the tests included an excellent quality CD player. The stimulus was presented through an audiometer.

The gaps in noise (GIN) test

Is a test of auditory processing designed to measure temporal resolution (Ila et al., 2023). The term temporal resolution describes the capacity to distinguish variations in the length of an auditory event and, in this context, the quiet or gaps incorporated into an auditory stimulus. Speech perception is thought to be significantly influenced by temporal resolution (Lister et al., 2011).

The GIN comprises four lists identified as test 1, test 2, test 3, and test 4. In this study, only test 1 and test 4 were used. Each listening comprised a set of 29–36 segments, or trials, in total. Every segment was made up of six-second bursts of white noise interspersed with zero, one, or three silent intervals (gaps). There was one quiet period (no gaps) or three silent periods (three gaps) in every six-second white noise section. The gaps lasted for 2, 3, 4, 5, 6, 8, 10, 12, 15, or 20 msec. Every interval length was repeated six times. Consequently, there were 60 pauses in total for each exam. Between six-second noise bursts, there was a five-second interstimulus gap. A practice segment was also included at the start of the recording. There were two channels in the GIN recording (Raj-Koziak et al., 2021). The GIN stimuli were found on the left channel, while "gap indication signals" were found on the right channel. Indicators were used to record the right channel, allowing the clinician to see when the gaps in the left channel occurred. In other words, whenever there was a pause in the left (test) channel, a "beep" was audible in the right channel. As a result, isolating the participant (test subject) from the right channel was crucial. The signal was isolated by unplugging the earphone and replacing it with a dummy resistance. Earphones were checked for cross-talk, and the noise gaps could not contain any "beeps." To properly score, participants must be aware of when the gaps are presented. With this method, false positives will be readily apparent. The study subject was informed that short, six-second noise bursts would occasionally be heard, interspersed with brief silence. The participant response switch should be pressed and released quickly for the participant to indicate the existence of the gap. Before starting the test, the participant was given examples of exaggerated gaps by making a hissing noise. The participant should not respond to the large gap between signals. The recording started with a few example practice items. These were used to ensure the participant comprehended how to complete the test.

The GIN test was performed by presenting the indicator "beeps" to channel two after being routed to audiometer channel one. The recording started with a 1 kHz calibration tone, and the VU meter's level was adjusted to 0 dB. To determine the participant's speech reception threshold (SRT), the test was given between a sensation level (SL) of 35 and 50 dB. Test 1 was performed on the right ear, and test 4 was performed on the left ear after administering the practice section and ensuring the participant understood the task. The signal was presented binaurally at a comfortable listening level of 50dB HL.

The noise segment number, "Trial #," appeared in the first column of the score sheet. The gap durations were displayed in the second, third, and fourth columns, with an approximation of where they fell within the noise. In other words, gaps that fell roughly into the first third were categorized as "Early," those that fell into the second third were classified as "Middle," and those that fell into the last third were categorized as "Late." An area was left blank if there was no gap within it. One or two segments (trials) had no gaps listed, and these trials had steady noise (no gaps). The responses were labeled as follows: Xs for erroneous (false) responses, circles for correct responses, and NR for no response when one was expected. The responses were filled in the box in the lower right corner of the score sheet with the total number of responses for each gap length. Two false answers were permitted without consequence for the participant, while further false responses were counted as errors. The false positives were subtracted from the total number of correct answers for each gap, and the results were listed at the bottom right. The calculation of the percentage correct was #correct/60 x 100 = % GIN score. The correct number and percentage were filled in the summary score sheet to determine the overall GIN score. The total GIN score was calculated by dividing the total number of correct answers—60 for one ear or 120 for two ears—by the total number of gaps. This yielded the percentage of answers that were correct. The cutoff score for the percent correct was 52% or less for 8 to 11-year-olds and 54% for adults and 12-year-olds (Musiek et al., 2005).

Frequency pattern

Three-tone burst patterns at two distinct frequencies—"high" and "low"—comprised the exam. The test required correctly identifying the highs and lows in the appropriate presenting order (El-Kholy *et al*., 2022).

There was a total of 60 test items for each ear. The participant was required to recognize and distinguish between the high and low tones to use the first six items for practice. After six practice questions, if the participant was still unable to answer correctly, the test was ended, and new instructions were given. However, the results might be included in the final result if the first six items or five of the six items were correct. The test could be stopped when the participant correctly identified at least 14 of the first 15 items. Thirty items must be finished if more than one of the previous fifteen needed to be corrected. It was optional to provide all sixty items (Musiek, 1994).

The participant was instructed to listen carefully and to report the frequency pattern as they heard it. For example, if he heard high, high, and low tones, the participant responded in the specified order as “Two high and one low." Instructions were given to the participant using examples employing voice and gestures. The administrator motioned with his hands to mimic the high and low harmonies. The signal was presented binaurally at a comfortable listening level of 60 dB HL.

The number of correct responses was counted and converted to a percentage. The reversal responses were not counted because they were not accurate. The response was calculated by dividing the number of correct responses by the overall number of presented tones multiplied by 100: $\left(\frac{\text{correct responses}}{\text{overall number of presented tones (15,30)}} \times 100\right)$ (Musiek et al., 2005). Normative data is shown in Table 2.

Table 2.

The normative data for the Frequency Pattern Test based on Musiek et al. (2005).

Age Range	Percent Correct Bilaterally
8 years through 8 years to 11 months	40 %
9 years through 9 years to 11 months	65 %
10 years through 10 years to 11 months	72 %
11 years and up	75 %

Duration pattern

The test comprised three 1000 Hz tones with two distinct durations—"long" and "short"—. Participants were required to figure out which pattern of longs and shorts was presented in which order. There were a total of 66 test items. The first six items were used as practice. After six practice stimuli, if the participant could not answer correctly, the test was stopped, and the participant was given instructions again (Humes, 2005). However, the results could be included in the final result if the first six items or five of the six items were correct. The test could be stopped if a participant correctly answered at least 14 of the first 15. Thirty items needed to be completed if more than one of the first fifteen were wrong. Not all sixty items were required to be provided. The participants received explicit instructions to attentively listen and accurately report the perceived duration pattern. For instance, if they heard a sequence of long, long, and short tones, they were required to respond in the specified order as “Two long and one short”.

These instructions were conveyed to the participants through illustrative examples using both verbal cues and accompanying gestures. The administrator facilitated understanding by mimicking the long and short harmonies through hand motions (Auditecinfo, 2022). The signal was presented binaurally at a comfortable listening level of 60 dB HL.

The number of correct responses was counted and converted to a percentage. The reversal responses were not considered because they were not correct. The response was calculated by dividing the number of correct responses by the overall number of presented tones multiplied by 100: $\left(\frac{\text{correct responses}}{\text{overall number of presented tones (15,30)}} \times 100\right)$.

For adults, 70% accuracy falls within the normal range. Normative data for children is not available. Therefore, we used the same normative data as adults (Musiek et al., 1990).

Masking level differences

This test contained 33 presentations of brief narrow-band noise bursts that may or may not contain a series of five-tone pulses. The two test variables were the tone level and tone phase. The presentations were punctuated with toneless noise bursts that served as foils. The signal-to-noise ratio of each tone was used to list its level. A typical listener finds it easier to perceive tones when they are out of phase with respect to their ears and the noise is in phase. The tone was presented binaurally at 70 dB HTL. The participant was instructed to listen for a series of tone pulses within the noise bursts and to respond when they were heard. The participant was notified that the tones would not always be audible or might not even be present (Ashrafi & Sakha, 2022).

The scoring form included spaces indicating whether the subject's response was present or absent. The validity of test results was assessed based on the occurrence of excessive positive responses in the 'No Tone' column. In that scenario, it was assumed that subjects might not have fully understood the instructions or were unable to complete the task. The correct responses were tallied in the 'SoNo' and the 'SNo' columns (as detailed in the Appendix). Specifically, for the in-phase ('SoNo') condition, we determined the 'SoNo Threshold' (dB S/N) corresponding to the correct responses. Similarly, for the out-of-phase ('SπNo') condition, we found the 'SπNo Threshold' (dB S/N) corresponding to the correct responses. The variation between these two thresholds represented the masking level difference (MLD), with the 'No Tone' column disregarded for scoring purposes. Mathematically, MLD can be expressed as follows:

[MLD = SoNo Threshold - SπNo Threshold] (Davidson et al., 2023).

The phase was tested by producing a single low-frequency tone in both earphones at equal intensities. Therefore, the tone seems to be in the middle of the skull. A tone would be heard in each ear if the earphones were out of phase. Tones in narrow band noise normally have MLDs of at least 14 dB, if not slightly higher (Mendes et al., 2017).

Random Gap Detection Test

The RGDT is used to diagnose and measure temporal processing disorders (Boboshko *et al*., 2023), also known as timing problems in the auditory system, in both adults and children. The test takes approximately 10 minutes to assess and score. Deficits in phonological processing and issues with auditory discrimination, receptive language, and reading are all linked to temporal processing disorders. The most minor detectable time interval between two closely approximated stimuli is determined in order to assess temporal resolution in the RGDT (Lee & Chermak, 2004). The gap detection threshold is the name given to this range. A listener is asked to focus on a series of stimuli that are presented in pairs in order to determine the gap detection threshold, which is expressed in msec. There is an increase and decrease in the length of the silent interval between every pair of tones. The listener reports whether they hear one tone or two tones in the stimulus pairs as the silent interval changes. The stimulus interval at which two stimuli are perceived as opposed to one is known as the gap detection threshold. A 1000 Hz calibration tone, a practice subtest for tonal stimuli, and four subtests with 7 msec durations at the frequencies 500, 1000, 2000, and 4000 Hz comprised the RGDT recording. A practice test with tone stimuli lasting 230 msec was included in the final subtest, which was followed by a click subtest with clicks presented in random order. The following specific intervals were used to present click pairs with interstimulus intervals ranging from 0 to 40 msec: 0, 2, 5, 10, 15, 20, 25, 30, and 40 msec. A table of randomly assigned numbers was used to record the interstimulus intervals, with gaps assigned at random. The recording of the stimulus pairs was performed at intervals of 4.5 seconds to give the subjects enough time to react (Auditecinfo, 2022).

The participant was instructed to hold up one finger if they heard one tone, or hold up two fingers if they heard two tones. For pediatric participants, cards were used for the responses. Two cards were provided; one had a star and the other had two stars. The participant was instructed to raise the cards depending on the number of tones heard (Auditecinfo, 2022).

Subtest 1: Practice screening was used at the beginning of the test to assess whether the participant was able to participate in the RGDT. The 500 Hz tone pairs used in this section of the test had interstimulus intervals ranging from 0 msec to 40 msec. The interstimulus intervals were 2, 5, 10, 15, 20, 25, 30, and 40 msec and they were arranged in ascending order.

Subtest 2: The interpulse intervals in the standard test spanned from 0 to 40 msec. To prevent the participant from guessing at the next interval, the order of interpulse intervals within each frequency was assigned at random. The first test frequency was 500 Hz, followed by 1000, 2000, and 4000 Hz. The signal was presented binaurally at a comfortable listening level of 55 dB HL.

The frequencies at which the gaps were detected—500, 1000, 2000, and 4000 Hz—were reported. The average of the data reported for each of the four test frequencies was the composite gap detection threshold. For tones, a typical gap detection threshold was thought to be between 2 and 20 msec. (Dias *et al*., 2012).

Results

Study participants

To ensure the study on the impact of technology on auditory processing skills is statistically robust, a total of 160 participants were recruited. This sample size was determined through power analysis to achieve a power of 0.80, ensuring an 80% chance of detecting true effects. The sample includes 100 adults (62.5%) and 60 children (37.5%), allowing for meaningful subgroup analyses. The chosen sample size accounts for expected variability in auditory processing skills and balances practical considerations such as resource constraints and feasibility. This distribution ensures that the study can detect small to moderate effects with a significance level of 0.05, providing reliable and valid results. Table 3 presents the study characteristics of the total participants across adults and children. The median age was 25.0 (range=8–68) years, 51.3% were male and 48.7% were female. Of the total participants, 100 (62.5%) were adults and 60 (37.5%) were children. The median daily usage time of electronic devices was 5.5 (range=2–14) hours. Half of the participants used electronic devices more than five hours a day and were assigned as the subject group, while the other half that used electronic devices less than five hours a day were considered as the control group (Smith et al., 2018). Among total participants, a total of 100 (62.5%) were adults and 60 (37.5%) were children. There were no significant differences across the study groups in terms of gender, electronic device usage time, and all APD test scores (see Appendix, Table 3.).

Of the total participants, the median scores of the GIN tests were 66.6% (range=43.3–86.6) for the right ear and 65.0% (range=41.6–88.3) for the left ear. The median scores of the PPS tests were 90.0% (range=53.3–100) for the right ear and 86.6% (range=56.0–100) for the left ear. The median scores of the DPS tests were 93.3% (range=53.3–100) for the right ear and 93.3% (range=53.0–100) for the left ear. The median score of the MLD test was 14.0 dB (range=-4.0–20.0 dB) and the median of the RGD test was 13.75 msec (range=6.25–22.5 msec).

The differences in APD test outcomes among adults with restricted technology exposure versus those who are overexposed to technology

Among the adult participants, 50% were normal technology users and 50% were over technology users. Table 4 presents the differences in ADP test scores between normal and over technology adult users. The median scores of the GIN were significantly higher among normal technology adult users than over technology adult users for both right ears (73.3% vs 62.3%, z=-6.664, p<0.001, respectively) and left ears (73.3% vs 60.0%, z=-6.987, p<0.001).

For the PPS tests, the median scores were significantly higher in normal technology users compared to over technology users, with recorded medians of 96.7% versus 81.5% for right ears (z=-7.693, p<0.001) and 93.3% versus 83.2% for left ears (z=-7.430, p<0.001). This pattern of superior performance by normal technology users was also evident in the DPS test, where median scores were 93.3% for normal users and 86.6% for over users for right ears (z=-5.675, p<0.001), and both groups recorded a median of 93.3% for normal users compared to 83.3% for over users in left ears (z=-7.562, p<0.001).

Additionally, the MLD test results significantly favored normal technology users, who had a median score of 18.0 dB compared to 12.0 dB for over technology users, indicating a significant difference in auditory sensitivity (z=-7.973, p<0.001). In contrast, the RGD test results were significantly lower among normal technology users, with medians of 11.3 msec, versus 16.3 msec for over technology users, showing the varied impact of extent of technology use on different aspects of auditory processing (z=-4.897, p<0.001). (see Appendix, Table 4.).

Nonparametric correlations for the results of right and left ears in overexposed to technology adults

Table 5 (see Table 5.) presents the nonparametric correlations for right and left ears in adults with over exposure to technology across various ADP tests. There was a very strong correlation between the GIN tests for right and left ears (r=0.692, p < 0.001). There were also strong correlations between right and left ears for PPS tests (r=0.794, p < 0.001), and DPS tests (r=0.565, p < 0.001), indicating a robust relationship between right and left ears.

There were also other random correlations between the GIN for left ears and the PPS for right ears (r=0.331, p=0.019), the PPS for right ears and the DPS for right ears (r=0.313, p=0.027), the PPS for left ears and the DPS for right ears (r=0.351, p=0.013), and the PPS for left ears and the DPS for left ears (r=0.337, p=0.017).

The disparities in APD test results between children with limited technology exposure and those who are overexposed to technology

In the subset of child participants, an equal distribution was observed, with half categorized as normal technology users and the remaining half as over technology users. Table 6 presents the differences in ADP test scores between normal and overexposure to technology users among children.

The median scores on the GIN test were significantly higher among normal technology users compared with over-technology users for both right ears (75.0% vs 60.0%, respectively; z=-5.909, p<0.001) and left ears (74.2% vs 58.3%, respectively; z=-6.237, p<0.001).

Compared to normal technology users, the median scores of PPS were significantly lower among over technology-using children, the right ear medians at 100.0% for normal users compared to 74.7% (z=-6.550, p<0.001) for over users, and left ear medians was 100% for normal users versus 78.3% (z=-6.339, p<0.001) for over users. This suggests a substantial advantage in pitch discrimination for children exhibiting normal technology use.

In addition, the DPS test scores were significantly higher among normal technology-using children compared to those categorized as over-technology users, with right ears showing medians of 93.3% versus 83.2% (z=-5.075, p<0.001), respectively. The medians for the left ears for limited technology users and over technology users were 96.7% versus 83.0% (z=-5.596, p<0.001), respectively. This highlights a notable disparity in duration pattern recognition between the groups.

The MLD scores further emphasized the superior auditory processing capabilities of normal technology users, with a median of 16 dB compared to 12 dB among over-technology users (z=-5.779, p<0.001). Additionally, the RGD test scores were significantly more favorable for normal technology users, presenting a lower median of 12.5 msec versus 17.5 msec for excessive technology users (z=-5.515, p<0.001), illustrating more acute temporal resolution in normal technology users. (see Table 6.).

Nonparametric correlations between the performance outcomes of the right and left ears in children exposed to excessive technology

Table 7 outlines Spearman's rho correlation analysis conducted on over-technology users among children. The analysis uncovered a notably high correlation in the GIN test scores between the right and left ears (r=0.753, p < 0.001). Similarly, the PPS and DPS tests exhibited exceptionally strong bilateral correlations, with r values of 0.922 (p < 0.001) and 0.877 (p < 0.001), respectively. These findings highlight the significant consistency between the auditory processing abilities of the right and left ears in children overexposed to technology.

The correlation between PPS scores for right ears and DPS scores for the same ear yielded an r of 0.390 (p=0.033), while the correlation between PPS for right ears and DPS for left ears was r=0.381 (p=0.038). Additionally, PPS scores for left ears correlated with DPS scores for right ears at r=0.386 (p=0.035), and correlations between PPS and DPS scores for left ears were observed at r=0.422 (p=0.020) (see Table 7.).

Discussion

The current research demonstrated that children's auditory processing skills and technology use correlate significantly. This emphasizes the necessity of focused evaluations and treatments to support children who struggle with auditory processing. The study results indicate that children and adults who use technology often have Auditory Processing Disorder. Thus, a comprehensive strategy is required to address these challenges effectively and adequately.

One hundred sixty participants, including children and adults, who utilized technology daily were examined in the study. According to the study, auditory performance was negatively impacted by excessive use of technology, as evidenced by lower test scores in auditory assessments. The study findings revealed that children with significant technology exposure demonstrated consistent bilateral effects on their auditory processing abilities. Although these effects were less pronounced in adults, similar impacts were observed. These results underscore the importance of comprehensive strategies to mitigate the adverse effects of excessive technology use on auditory health and enhance auditory processing capabilities in affected individuals.

Our investigation found no significant differences between the groups in terms of sex distribution or auditory function normality. This implies that sex does not influence the CANS in different age groups. These findings are consistent with previous studies demonstrating that auditory processing disorder occur equally in men and women (Musiek & Baran, 1999; Burton et al., 2020).

Significant differences were not observed between adult and pediatric groups in terms of auditory test results for the GIN, PPS, DPS, RGD, and MLD tests. This suggests that daily electronic device usage does not exert distinct effects on the specific auditory processing abilities assessed by these tests in children compared to adults. The absence of pronounced differences may be attributed to the brain’s capacity to adapt and reorganize neural pathways, potentially mitigating any adverse effects of electronic device exposure. Additionally, shared developmental patterns in auditory processing may exist across both age groups.

When evaluating these findings, it is critical to examine the role of auditory processing disorder (APD). This disorder can impair an individual's capacity to process auditory information without causing peripheral hearing loss. According to studies, APD impacts various auditory processing skills, including sound localization, discrimination, and speech understanding in noisy circumstances. Furthermore, neurobiological activity within the CANS is believed to influence the processing problems associated with APD (American Speech-Language-Hearing Association, 2024; American Academy of Audiology, 2019). Clinical practice emphasizes the importance of using a broad test battery tailored to individual symptoms when diagnosing APD. This method ensures that the specific areas of difficulty are accurately identified and addressed, which is consistent with our study's approach of using a variety of auditory tests (American Academy of Audiology, 2019).

Furthermore, a study found that extrinsic variables such as a lack of sleep can dramatically impair the brain's ability to interpret auditory information. This demonstrates the intricate nature of the neurobiological processes involved in auditory information processing. Such conditions can negatively impact important cognitive functions such as memory, attention, and perception, which are essential for effective auditory processing (Liberalesso et al. 2012).

The study's findings reveal significant variation in the auditory processing capacity of normal and excessive technology users among adults. Adults who utilized technology within reasonable limits performed better on auditory processing tests than those who overused technology. Therefore, above a certain threshold, prolonged use of electronic devices may damage auditory processing ability. These findings align with previous research indicating that excessive use of electronic devices negatively impacts cognitive and auditory functions. Such usage, especially sound-emitting devices, impairs auditory processing and is linked to lower mental and emotional outcomes (Huang & Lu, 2022; Stavrinos et al., 2020).

The strong connections observed between the right and left ears during various auditory processing tests, such as the GIN, PPT, and DPT tests, suggest that adults with extensive exposure to technology have strong bilateral symmetry in auditory processing. This implies that the auditory processing deficiencies or abilities in this population are often consistent across both ears. These findings are consistent with research emphasizing the linked nature of auditory processing in both ears. According to research, auditory processing capacities are frequently identical in both ears unless a specific injury or disease affects one side more than the other. The substantial correlations across the various tests for each ear indicate that these auditory processing tests accurately evaluate the intended components across different auditory domains. This is crucial for appropriate diagnosis and treatment planning in APD. The observed symmetry and high correlations confirm the concept of auditory processing disorder as a system-wide function within the brain rather than being limited to one or both ears. This supports theories in auditory neuroscience that suggest that the brain integrates information from both ears to create a coherent auditory perception, which is essential for locating sounds in space and understanding complex auditory signals such as speech in noisy environments (Chermak et al., 2017; Gallun et al., 2022). Clinicians should, therefore, conduct comprehensive bilateral assessments when evaluating individuals for potential APD. This approach ensures that diagnosis and subsequent treatment plans address the auditory system as an integrated whole, potentially improving outcomes for individuals with APD (Bellis, 2004; Mayo Clinic, 2024).

The following areas could be explored in future research: the specific aspects of auditory processing most affected by technology overuse, potential differences in impacts from other causes of APD, and the long-term effects of reducing technology use on auditory processing abilities.

The study findings show significant differences in auditory processing abilities between normal and over-technology users among children. Children categorized as limited technology users performed better across various auditory processing tests than their over-using counterparts. This suggests that excessive use of technology may harm crucial aspects of auditory processing, such as gap detection, pitch pattern recognition, and temporal resolution. These results support existing research highlighting the potential negative impacts of excessive electronic device use on auditory processing capabilities. For example, excessive screen time has been linked to poorer cognitive and sensory development, including auditory processing skills. These findings advocate for moderate use of technology, especially during developmental stages (Stavrinos et al., 2020; Bellis, 2004). Another study revealed that mobile phones and video games negatively impact auditory processing abilities, consequently affecting attention, memory, and academic performance (Eissa et al., 2022). From a theoretical standpoint, the differences we observed may be due to neuroplastic adaptations to varying auditory stimulus environments caused by different levels of technology use. High technology use is often accompanied by continuous and sometimes disordered auditory stimuli, which may impede the development of more sophisticated auditory processing abilities required for tasks such as speech recognition in noisy surroundings and sound localization (Reynolds et al., 2016).

The study found significant correlations between the auditory processing capabilities of the right and left ears in children who overuse technology. The high correlation coefficients in the GIN, PPS, and DPS tests across both ears indicate that the impact of technology overuse on auditory processing capabilities is symmetrical. This suggests that the Auditory Processing Disorder processing system is uniformly affected by the overuse of technology, resulting in consistent patterns of auditory processing ability in both ears. This aligns with research that highlights the central nature of APD, where difficulties usually affect both ears rather than being isolated from one ear. Studies have also shown that disorders in auditory processing involve complex brain functions that manage sounds from both ears. This further supports similar performance patterns on tasks that require binaural integration and separation (Liu et al., 2021; Iliadou et al., 2017). In the future, studies should be conducted to explore the causal relationship between overuse of technology and specific types of auditory processing impairments. These studies may differentiate between types of technology exposure, such as headphones and speakers. Furthermore, researchers should look into whether reducing screen usage or implementing focused auditory training therapies can counteract these auditory impacts. Such research could provide a better understanding of the plasticity of auditory processing in response to environmental change (Sharma et al., 2019).

Limitations

The results of this study must be seen in the context of several limitations. First, nonlinguistic tasks were used to assess auditory processing disorder. The lack of examinations that were linguistically appropriate and made especially for Arabic speakers with different dialects made this decision necessary. Second, the information regarding the case histories of participants relied primarily on self-reported data, which can be subject to various biases, including recall bias and social desirability bias, potentially affecting the accuracy and reliability of the information provided. Finally, the advanced nature of the tests presented particular challenges when administered to children. The complexity required repeated instructions and significant effort to ensure the children comprehended the tasks. This necessity for repeated instructions could have influenced the children's performance and the test outcomes, potentially impacting the validity of the findings.

Conclusion

This study emphasizes the need for greater awareness of the potential effects of electronic device use on the auditory system, particularly in developing children. While our findings provide some reassurance about moderate electronic device use, further monitoring and research are needed to fully understand the long-term impacts of our increasingly digitized lifestyles on auditory health. Future research should also investigate the potential recovery of auditory functions with reduced electronic device use to acquire better knowledge of how current technology interacts with neurobiological processes. Further investigation into the specific features of device use that may harm the auditory system will contribute to the establishment of comprehensive health guidelines for both adults and children. Additionally, studies could investigate the effectiveness of targeted auditory training programs in mitigating the impacts of excessive technology use on auditory processing (Van Wilderode et al., 2023).

To maintain the best possible health and function of the auditory system, it is crucial to interact with technology in a responsible and balanced way, as this study clarifies how various degrees of technology use impact auditory processing. The study finds compelling evidence that excessive technology use can impair auditory processing in children, emphasizing the necessity of moderate technology exposure. Effective management of technology use in children's daily routines may be critical to protecting their auditory processing abilities and general sensory development.

The substantial bilateral correlations observed in auditory processing tests among children who use technology excessively suggest that auditory processing systems play a central role in how these children process and respond to auditory stimuli. This could potentially impact their ability to concentrate, understand speech in noisy environments, and develop language skills. This study emphasizes the importance of complete auditory examinations and interventions that holistically address the core auditory processing problems, as well as techniques for mitigating the effects of excessive technology use on auditory health.

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APPENDIX

Table 3.

The study characteristics of all participants across adults and children.

	Total n=160	Adults n=100	Children n=60	p-value
Age in years	25.0 (8–68)	33.0 (18–68)	10 (8–17)	<0.001
Sex, n (%)				0.935
Male	82 (51.3)	51 (51.0)	31 (51.7)	
Female	78 (48.7)	49 (49.0)	29 (48.3)	
Usage time in hours per day	5.5 (2–14)	5.5 (3.0–14.0)	5.5 (2.0–13.0)	0.3847
Normality, n (%)				1.000
Normal	80 (50.0)	50 (50.0)	30 (50.0)	
Abnormal	80 (50.0)	50 (50.0)	30 (50.0)	
Gap in noise				
Right ear	66.6 (43.3–86.6)	67.3 (45–86.6)	65 (43.3–85)	0.4538
Left ear	65.0 (41.6–88.3)	65 (46.6–81.6)	65 (41.6–88.3)	0.8832
Pitch pattern sequence				
Right ear	90.0 (53.3–100)	90 (53.3–100)	93.15 (56.6–100)	0.6862
Left ear	86.6 (56.0–100)	86.6 (56.6–100)	88.3 (56–100)	0.8487
Duration pattern				
Right ear	93.3 (53.3–100)	93.3 (53.3–100)	93.3 (56.6–100)	0.2124

Left ear	93.3 (53.0–100)	93.3 (53–100)	93.15 (53.3–100)	0.7457
Masking level difference in dB	14.0 (-4.0–20.0)	14 (-4–20)	14 (8–20)	0.7944
Random gap detection in msec	13.75 (6.25–22.5)	13.75 (6.25–22.5)	13.75 (10–22.5)	0.1664
All results are presented as median and ranges unless otherwise stated.				

Table 4.

The disparities in auditory processing disorder test outcomes among adults with restricted technology exposure versus those who are overexposed to technology.

Total	Limited exposure users n=50		Overexposure users n=50		z-score	p-value*
	Median (range)	Mean rank	Median (range)	Mean rank		
Usage time	5 (3–5)	25.50	9 (6–14)	75.50	-8.819	<0.001
Gap in noise						
Right ear	73.3 (53.3–86.6)	69.80	62.3 (45–85)	31.20	-6.664	<0.001
Left ear	73.3 (55–81.6)	70.73	60.0 (46.6–73)	30.27	-6.987	<0.001
Pitch pattern sequence						
Right ear	96.7 (73.3–100)	72.51	81.5 (53.3–100)	28.49	-7.693	<0.001
Left ear	93.3 (73.3–100)	71.79	83.2 (56.6–100)	29.21	-7.430	<0.001
Duration pattern						

Right ear	93.3 (86.6–100)	66.54	86.6 (53.3–100)	34.46	-5.675	<0.001
Left ear	93.3 (86.6–100)	71.88	83.3 (53–100)	29.12	-7.562	<0.001
Masking level difference in dB	18.0 (14–20)	73.23	12.0 (-4–16)	27.77	-7.973	<0.001
Random gap detection in msec	11.3 (8.8–17.5)	36.41	16.3 (6.3–22.5)	64.59	-4.897	<0.001
* Mann–Whitney U test						

Table 5.

The outcomes of Spearman's rho correlation tests assessing the relationship between the performance of the right and left ears in auditory processing disorder tests among adult users with overexposure to technology.

	GIN_RE	GIN_LE	PPS_RE	PPS_LE	DPS_RE	DPS_LE
GIN_RE	1.000	0.692 <0.001	0.213 0.137	-0.027 0.855	0.183 0.204	0.129 0.372
GIN_LE	0.692 <0.001	1.000	0.331 0.019	0.091 0.531	0.134 0.352	-0.010 0.946
PPS_RE	0.213 0.137	0.331 0.019	1.000	0.794 <0.001	0.313 0.027	0.229 0.110
PPS_LE	-0.027 0.855	0.091 .531	0.794 <0.001	1.000	0.351 0.013	0.337* 0.017
DPS_RE	0.183 0.204	0.134 0.352	0.313 0.027	0.351 0.013	1.000	0.565 <0.001
DPS_LE	0.129 0.372	-0.010 0.946	0.229 0.110	0.337 0.017	0.565 <0.001	1.000
Spearman's rho test was used.						

** GIN denotes gaps in noise, PPS denotes pitch pattern sequence, DPS denotes duration pattern, RE denotes right ear, and LE denotes left ear.

Table 6.

The disparities in auditory processing disorder test results between children with limited technology exposure and those overexposed to technology.

	Limited exposure users n=30		Overexposure users n=30		z-score	p-value*
	Median (range)	Mean rank	Median (range)	Mean rank		
Usage time	4 (2–5)	15.50	8.5 (6–13)	45.5	-6.720	<0.001
Gap in noise						
Right ear	75.0 (61.6–85)	43.80	60.0 (43.3–70)	17.2	-5.909	<0.001
Left ear	74.2 (60–88.3)	44.53	58.3 (41.6–66.6)	16.5	-6.237	<0.001
Pitch pattern sequence						
Right ear	100.0 (86.6–100)	44.95	74.7 (56.6–93.3)	16.1	-6.550	<0.001
Left ear	100 (83.3–100)	44.72	78.3 (56–93.3)	16.3	-6.399	<0.001
Duration pattern						
Right ear	93.3 (83.3–100)	41.65	83.2 (56.6–100)	19.4	-5.075	<0.001
Left ear	96.7 (83.3–100)	42.90	83.0 (53.3–100)	18.1	-5.596	<0.001
The masking level difference in dB	16.0 (14–20)	43.17	12 (8–16)	17.8	-5.779	<0.001
Random gap detection in msec	12.5 (10.0–20.0)	18.22	17.5 (11.25–22.5)	42.8	-5.515	<0.001

* Mann–Whitney U test

Table 7.

The results of Spearman's rank correlation analyses investigating the association between right and left ear performance in auditory processing disorder assessments among pediatric individuals exposed to excessive technology.

	GIN_RE	GIN_LE	PPS_RE	PPS_LE	DPS_RE	DPS_LE
GIN_RE	1.000	0.753 .000	0.180 0.341	0.143 0.452	0.275 0.141	0.209 0.268
GIN_LE	0.753 <0.001	1.000	0.240 0.201	0.165 0.383	0.259 0.166	0.162 0.392
PPS_RE	0.180 0.341	0.240 0.201	1.000	.922 <0.001	0.390 0.033	0.381 0.038
PPS_LE	0.143 0.452	0.165 0.383	.922** <0.001	1.000	0.386* 0.035	0.422 0.020
DPS_RE	0.275 0.141	0.259 0.166	0.390 0.033	0.386 0.035	1.000	0.877 <0.001
DPS_LE	0.209 0.268	0.162 0.392	0.381 0.038	0.422 0.020	0.877** <0.001	1.000

Spearman's rho test was used.

GIN denotes gaps in noise, PPS denotes pitch pattern sequence, DPS denotes duration pattern, RE denotes right ear, and LE denotes left ear.