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Is There Any Effect of the Chronobiological Profile on Auditory Skills?

Kronobiyolojik Profilin İşitsel Beceriler Üzerinde Herhangi Bir Etkisi Var Mıdır?

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Abstract

Objective: This study aimed to investigate the peripheral and central auditory performance of circadian chronotypes at different times of the day.

Materials and Methods: The participants, whose chronotypes were determined using the morningness eveningness questionnaire, underwent acoustic immittance measurements, Otoacoustic Emission test, Pure Tone Audiometry test, Frequency Pattern test, Duration Pattern test (DPT), Turkish speech in noise (TSiNT) and Auditory Verbal Learning test (AVLT) both in the morning and evening. A total of 63 participants with normal hearing and montreal cognitive assessment score ≥21 were included.

Results: Morning types scored significantly higher on the A7 subtest of the AVLT during the morning session ($p<0.05$). Evening types achieved significantly higher scores on the TSiNT during the evening session ($p<0.05$). In the morning tests, morning types showed significantly better performance on the left ear DPT compared to intermediate types ($p<0.05$). Similarly, in the evening tests, morning types outperformed intermediate types on the TSiNT ($p<0.05$).

Conclusion: The results indicated that the central auditory performance of individuals with the same chronotype varies at different times of the day, influenced by their circadian profile.

Keywords: Auditory perception, chronotype, circadian rhythm, memory, hearing tests

Öz

Amaç: Bu çalışmanın amacı, sirkadiyen kronotiplerin günün farklı saatlerindeki periferik ve santral işitsel performanslarını araştırmaktır.

Gereç ve Yöntem: Sabahçılık akşamcılık anketi ile kronotipleri belirlenen katılımcılara sabah ve akşam saatlerinde akustik immitans ölçümleri, Otoakustik Emisyon testi, Saf Ses Odyometri testi, Frekans Patern testi, Süre Patern testi (SPT), Gürültüde Türkçe Konuşma testi (TKT) ve İşitsel Sözel Öğrenme testi (İSÖT) uygulandı. Normal işiten ve montreal kognitif değerlendirme skoru ≥21 olan toplam 63 katılımcı çalışmaya dahil edilmiştir.

Bulgular: Sabah tipleri İSÖT'nin A7 alt testinde sabah seansında anlamlı olarak daha yüksek puan aldı ($p<0,05$). Akşam tipleri akşam seansında TKT'de anlamlı derecede daha yüksek puan almıştır ($p<0,05$). Sabah testlerinde, sabah tiplerinin sol kulak SPT sonuçları ara tiplerden anlamlı derecede daha iyiydi ($p<0,05$). Akşam testlerinde, sabah tipleri TKT'de ara tiplerden anlamlı derecede daha iyi performans göstermiştir ($p<0,05$).

Sonuç: Sonuçlar, aynı kronotipin günün farklı saatlerindeki santral işitsel performansının sirkadiyen profilden etkilendiğini göstermiştir.

Anahtar Kelimeler: İşitsel algı, kronotip, sirkadiyen ritim, bellek, işitme testleri

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Introduction

Circadian rhythm is the repetition of biochemical, physical, and behavioral routines of an organism at certain intervals and within a certain frequency. The maintenance of the rhythm depends on both exogenous (environmental) and endogenous (biochemical) factors.[1] In this context, the circadian rhythm is part of a very primitive system, considering that the most important and probably most constant zeitgeber in evolutionary terms is the light-dark cycle.[2] The suprachiasmatic nucleus (SCN) is the region of the central nervous system that initiates and maintains the cycle.[3] The process organized by the SCN is supported by neurochemicals from many organs and tissues in the peripheral system: heart, liver, kidneys, lungs, intestine, skin, lymphocytes, esophagus, spleen, thymus, adrenal gland, prostate, olfactory bulb. The levels of neurotransmitters and more hormones required for a healthy circadian rhythm may vary depending on the zeitgebers.[4]

The degree to which the central pacemaker is necessary for maintaining the circadian rhythmicity of various cells, tissues, physiological functions, and behaviors differs across species and tissue types. To ensure synchronization between central pacemaker cells, they are linked by neurotransmitters and neuromodulators.[5]

In particular, serotonin and melatonin are important circadian synchronisers. The decrease in melatonin and increase in serotonin controlled by the SCN are activated by sunlight.[6] Cortisol, another neurochemical, is secreted in the presence of light and causes a decrease in melatonin levels.[7]

Studies have identified the roles of the SCN and the inferior colliculus in the central system, as well as the cochlea in the peripheral system, in regulating circadian rhythms.[3] The majority of studies have aimed to evaluate the effects of noise or ototoxic trauma when applied in the evening and morning. It has been concluded that the startle reflex of rats to sudden and high-intensity acoustic stimuli and their sensitivity to antibiotic-induced ototoxicity are different in light and darkness. Furthermore, the acoustic startle reflex response of mice exposed to a brief acoustic stimulus of 120 dB sound pressure level in the morning was 15% higher than the same sound in the evening.[8-10] Given that mice are nocturnal mammals that hunt at night, it can be inferred that this behavior leads to a reduced startle response during their active periods and an increased startle response during their rest periods. Therefore, it can be hypothesized that humans, as mammals, may be more vulnerable to noise during the day, considering the nocturnal nature of mammals.[2] However, it is important to keep in mind that primates have undergone evolutionary adaptations to be active in daylight, so the biochemical factors in each person vary throughout the day, leading to chronotype bias.[11] In addition to peripheral hearing, studies measuring central auditory processing capacity have shown that the same tests given to the same person at different times of the day produce different results. This difference is thought to be related to age, memory and circadian rhythm.[12] In addition, many studies examining language comprehension and selective attention have found a connection with the time of the test, revealing that individual performance varies based on the person's circadian characteristics.[13] Despite this, little is known about the relationship between the auditory system and circadian rhythms, or how they influence each other.

In the literature, there are experimental studies on animals that investigate the auditory system in relation to circadian rhythms.[14] However, no study has been found that evaluates the human auditory system in detail in relation to circadian rhythms. In addition, although the studies in the literature show comparative results between chronotypes (morning, intermediate and evening types), there is also a need for comparative results between individuals of the same chronotype at different times of the day. Therefore, this study aimed to investigate and compare the auditory performance of circadian chronotypes at different times of the day. In this context, our research is considered a potential pilot study.

Materials and Methods

This study was conducted between February and June 2023 with the approval of the Non-Interventional Research Ethics Committee of Üsküdar University (approval number: 61351342, date: 30.12.2022).

Participants

In this study, G*Power 3.1.9.4 was used to calculate the sample size. According to the program, the minimum sample size was 19, with a significance level of 0.05 and a power of 0.80, assuming a moderate effect. This study included 63 participants, 46 female and 17 male, aged 19-27 years (M: 22.77±1.84). Participants were between the ages of 18-35, had normal hearing, scored within normal limits on the Montreal Cognitive Assessment Scale (MoCA), and were native Turkish speakers. Participants with diagnosed psychological and/or neurological problems, exposure to noise as a hobby and/or occupation, tinnitus, active ear infection, and ototoxicity were excluded. All participants signed an informed consent form.

Participants were determined to have normal hearing using Acoustic Immittance Measurements, Otoacoustic Emission test and Pure Tone Audiometry test. An otoscopic examination was performed prior to Acoustic Immittance Measurements. Tympanometry And Acoustic Reflex testing were performed using the Interacoustics® Titan Handheld (Denmark). Bilateral type A tympanogram (0.3-1.6 cc compliance; ±100 daPa) and bilateral ipsilateral and contralateral reflexes between 500-4000 Hz were considered normal. Otodynamics ILOV6 (UK) equipment was used for the transient evoked Otoacoustic Emission test. A signal-to-noise ratio of 3 dB or more at least three frequencies was considered normal. Participants' air conduction thresholds at frequencies of 500-4000 Hz, were measured with supraaural headphones using an Interacoustics® AC40 clinical audiometer (Denmark). The average of 500-4000 Hz was used for the pure tone average (PTA). Normal hearing was accepted as PTA ≤25 dB HL. Speech tests were performed with speech recognition threshold using a list of 3-syllable phonetically balanced words and speech discrimination (SD)

score using 25 monosyllabic phonetically balanced words.[15] The time of day for initial hearing assessments was randomized and completed at the beginning of sessions.

Participants answered the 19-question Morningness-Eveningness Questionnaire (MEQ), validated in Turkish by Pündük et al.[16] to determine which type they were according to their circadian rhythms. According to the score obtained from the questionnaire, participants were classified as "evening type" (16-41 points), "intermediate type" (42-58 points) and "morning type" (59-86 points). Since the same tests would be administered in both sessions, participants were divided into three groups (group 1: morning types, group 2: intermediate types, and group 3: evening types) to eliminate the experience effect; the first session of individuals in each divided group was randomly scheduled to take place in the morning or evening. According to the MEQ, 30.2% (n=19) of the participants were classified as morning type, 36.5% (n=23) as evening type, and 33.3% as intermediate type (n=21).

MoCA test was performed in the morning for morning types and in the evening for evening types. If the first session for evening types took place in the morning, the MoCA was administered during the second session, i.e., in the evening. In cases where the desired score was not achieved on the MoCA during the second session, the participant was excluded from the study, even though all tests had been conducted in the first session. As a result, two participants were excluded. For intermediate types, there was no restriction on the session in which the MoCA was administered, and it was conducted randomly across sessions.

Data Collection Tools

All evaluations were performed at the Audiology Laboratory of Üsküdar University. Frequency Pattern test (FPT), Duration Pattern test (DPT), and Turkish Speech in Noise test (TSiNT) were administered to assess central auditory processing skills; the Auditory Verbal Learning test (AVLT) was administered to assess cognitive skills and attention performance.

The tests were administered to each participant at 7:30 a.m. and 5:30 p.m. The assessments for all participants were completed within two hours (9:30 a.m. and 7:30 p.m., respectively).

The FPT contains two tones at frequencies of 880 Hz and 1122 Hz on a CD.[17] The duration of each tone is 200 ms and the interval between tones is 150 ms. There are 60 patterns of these sounds in groups of three for each ear. The stimuli were presented to the participant through supra-aural headphones at 50 dB SL in regard to hearing thresholds at 1000 Hz. The participant was asked to identify the sounds in the pattern in terms of high frequency and low frequency according to the order of arrival (e.g. low-low-high). The first 10 patterns presented to each ear were used for trial purposes and were not included in the scoring. The test score was calculated as the percentage of correctly identified patterns.

DPT[17] contains two tones on a CD with durations of 250 ms and 500 ms and a frequency of 1000 Hz. There are 66 patterns of these tones in groups of three for each ear. The stimuli were delivered to participants through supra-aural headphones at 50 dB SL, and participants were instructed to identify the sounds in the pattern based on their length (long versus short) and their order of presentation (e.g., short-short-long). The first 16 patterns presented for each ear were for trial purposes and were not counted. The test score is the percentage of patterns correctly identified.

For the TSiNT, participants were seated at a zero-degree angle to the loudspeaker and a distance of 1 meter from the loudspeaker. This test consisted of 25 isophonic monosyllabic words[15] inserted into multi-speaker babble noise (signal-to-noise ratio = 0 dB). The monosyllabic words spoken by a native Turkish speaker are recorded on a CD and presented through loudspeakers.

The Montreal Cognitive Assessment Scale, validated in Turkish by Selekler et al.[18] assesses cognitive functions such as attention and concentration, executive function, memory, language, visual structuring, abstract reasoning, calculation, and orientation. The maximum score that can be achieved on the test is 30. A score above 21 is considered normal.

The AVLT, validated in Turkish by Genç-Açıkgöz and Karakaş[19], is designed for the comprehensive assessment of verbal learning as well as short- and long-term memory (LTM), based on free recall and recognition functions. The test material consists of A and B lists of 15 different concrete words and a recognition list of 50 words. After the 15 words in List A were read at 1-second intervals, the participants were asked to recall and recite the words they remembered from these 15 words in no particular order. This step of the test was repeated five times with 20-second intervals starting from the last word that the individual recalled (A1-A2-A3-A4-A5-A6-A7 trials). Afterwards, the words in the B list were presented at 20-second intervals, and the individual was asked to repeat what he/she remembered from this list (B1 trial). For list B, the individual was asked to recall the words in list A without reading list A 20 seconds after the last word that the individual recalled (A6 trial). Participants were asked to recall the words from list A (A7 trial) after a 20-minute waiting period. AVLT assesses verbal learning with the A1-A5 average of information processing about verbal materials, verbal learning with the A6 based on free recall, and LTM based on free recall with the A7. The maximum score that can be obtained from the AVLT is 15 for the A list, 15 for the B list, and 30 for the recognition list.[20] In our study, A1-5, A6, A7, and recognition scores were calculated on the AVLT.

Statistical Analysis

First, it was assessed whether the numerical data obtained were normally distributed. Kurtosis and skewness values between ±1.0 are considered perfect, but values between ±2.0 are also acceptable in many cases depending on specific applications.[21] In this study, data were considered to be normally distributed when skewness and kurtosis values were between -2 and +2.

SPSS v.24 was used for statistical analysis. In pairwise comparisons of tests administered to the same group, the Paired Sample t-test was used for data with a normal distribution, while the Wilcoxon Signed Ranks test was applied for data without a normal distribution. For three-group comparisons, the One-Way ANOVA Test was used when the data were normally

distributed, and the Kruskal-Wallis test was used when the data were not normally distributed. Tukey's test was used for post-hoc analyses where appropriate.[21] The significance level was accepted as $p<0.05$.

Results

This study included 63 participants, 46 female and 17 male, aged 19-27 years (M: 22.77±1.84). Since their distribution was not equal, gender differences could not be analyzed. The results and significance values of the tests applied to all three groups in the morning and evening are shown in Table 1 and Figure 1. For morning types, when the results of the morning and evening tests were compared, a significant difference was found only in the A7 subgroup of the AVLT, which assesses LTM ($p<0.05$). Those with the morning type showed higher performance on the AVLT A7 test taken in the morning. No significance was observed between the morning and evening test results of the intermediate-type group ($p>0.05$). The results of the tests administered to this group at both times of day were similar. The results of the morning and evening tests of the evening group were significant only for the TSiNT and MoCA ($p<0.05$); with better performance observed in the tests conducted in the evening (Table 1 and Figure 1).

In the morning and evening sessions, the performances of the morning, evening, and intermediate types were compared, and the significance values obtained are shown in Table 2.

When the performance of the groups was compared in the morning tests, a significant difference was observed only in the DPT-Left side ($p<0.05$). Post-hoc analysis showed that the morning type performed significantly better than the intermediate type. In the other tests performed in the morning, the performance of the groups was similar. A comparison of the performance of the groups in the evening tests revealed a significant difference only in the TSiNT ($p<0.05$). Post-hoc analysis showed that the morning type performed significantly better than the intermediate type. In the other tests performed in the evening, the performance of the groups was similar (Table 2). The data and materials will be available from the corresponding author. This study was not preregistered.

Discussion

Chrono-psychologists refer to the circadian rhythm as the time of the day when a person feels most active, depending on day and night changes. This activity can be observed in various physiological processes, including body temperature, blood pressure, hormone secretion, glucose metabolism, sleep-wake cycles, and the release of neurotransmitters, as well as in mental and physical activities such as attention and short-term memory.[22] All of these factors are directly or indirectly related to the functioning of the auditory system and the overall activity of the nervous system. The above factors can influence processes ranging from the micromechanics of the cochlea-regulated by an adequate blood supply and nutrients essential for the proper functioning of sensory hair cells-to binaural auditory processing, which involves both ipsilateral and contralateral ascending auditory pathways, as well as the functions of the corpus callosum.[23] Although the changes of circadian rhythm in physiological processes are known, there are very few studies on its effect on hearing physiology with behavioral and electrophysiological measurements in audiology. In this study, we aimed to evaluate the effect of circadian chronotype on peripheral and central hearing systems and cognitive skills.

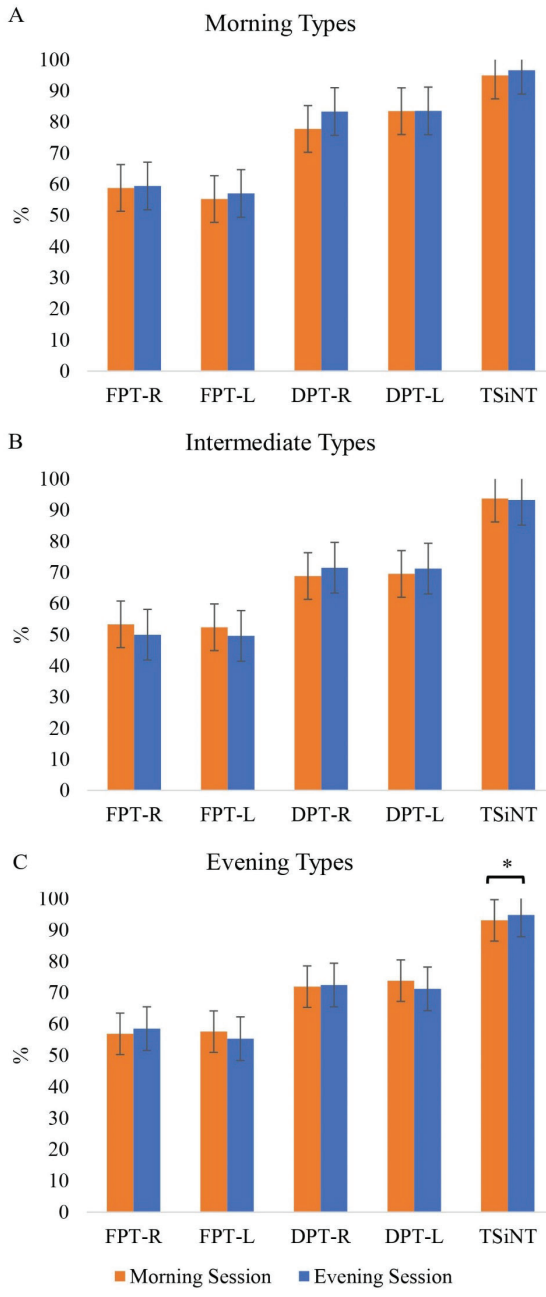

Figure 1. Results of the tests applied to the types in the morning and evening session.
*$p<0.05$: Statistically significant.
FPT-R: Right ear frequency pattern test, FPT-L: Left ear frequency pattern test, DPT-R: Right ear duration pattern test, DPT-L: Left ear duration pattern test, TSiNT: Turkish speech in noise test

Inhibitory controls and the ability to remove irrelevant information from consciousness are necessary for healthy cognitive processes. The inhibitory effect is also thought to be effective on systems such as speech comprehension, selective attention, and working memory.[24] A healthy peripheral and central auditory system is a prerequisite for the proper functioning of these mechanisms. Because of this close relationship between the hearing system and other cognitive systems, we included MoCA in our method. Consequently, the necessity for MoCA results to be within the normal range is paramount, despite the fact that normal hearing findings are included as criteria for inclusion in our study. SD performance in noise, as measured by tests such as TSiNT, necessitates the ability to disregard distracting noises and focus on the relevant speech information. This process may involve the utilization of inhibitory control mechanisms.[25] The effects of the circadian profile on cognitive performance are particularly evident in occupations with shift or flexible working hours. It is not

Table 1. Results and significance values of the tests applied to the types in the morning and evening session

		Morning session (M ± SD)	Evening session (M ± SD)	p
Morning types	PTA-R	2.21±2.80	2.00±2.56	0.680
	PTA-L	1.89±2.20	1.89±2.13	1
	SRT-R	5.78±3.44	5.78±2.50	1
	SRT-L	5.00±3.72	5.26±3.52	0.331
	SDS-R (%)	99.36±2.00	99.78±0.91	0.414
	SDS-L (%)	99.15±1.67	99.36±149	0.331
	AVLT A1-5	11.47±2.23	10.83±1.77	0.217
	AVLT A6	12.05±2.36	10.84±2.91	0.117
	AVLT A7	11.84±2.89	10.15±2.65	**0.017***
	AVLT recognition	22.94±4.39	21.89±4.29	0.153
Intermediate types	PTA-R	2.61±2.22	2.61±1.96	1
	PTA-L	2.09±1.86	2.19±1.77	0.605
	SRT-R	4.52±3.12	4.6±2.94	0.576
	SRT-L	4.04±3.39	3.57±2.80	0.162
	SDS-R (%)	98.85±2.24	98.95±2.24	1
	SDS-L (%)	99.04±1.74	98.85±2.24	0.655
	AVLT A1-5	10.70±2.00	10.33±1.92	0.522
	AVLT A6	12.19±2.06	11.47±2.31	0.237
	AVLT A7	11.00±3.16	11.42±2.29	0.605
	AVLT recognition	22.52±4.46	21.80±3.54	0.441
Evening types	PTA-R	3.08±2.71	3.04±2.51	0.814
	PTA-L	2.60±2.90	3.00±3.24	0.405
	SRT-R	4.78±3.52	4.78±3.19	1
	SRT-L	4.34±3.47	4.34±3.78	1
	SDS-R (%)	99.13±2.07	98.95±2.16	0.317
	SDS-L (%)	99.47±1.83	99.65±1.15	0.655
	AVLT A1-5	10.72±1.49	10.97±2.64	0.598
	AVLT A6	11.56±2.08	11.39±2.33	0.761
	AVLT A7	11.82±2.22	11.39±2.49	0.389
	AVLT recognition	21.69±3.09	22.43±4.02	0.366

*p<0.05: Statistically significant.

M: Mean, SD: Standard deviation, PTA-R: Right ear pure tone average, PTA-L: Left ear pure tone average, SRT-R: Right ear speech reception threshold, SRT-L: Left ear speech reception threshold, SDS-R: Right ear speech discrimination score, SDS-L: Left ear speech discrimination score, AVLT: Auditory verbal learning test

Table 2. Significance values for the performance of morning, evening and intermediate types in the morning and evening session				
	Morning session		**Evening session**	
	Morning vs. intermediate vs. evening types (p values)	Post-hoc (p)	Morning vs. intermediate vs. evening types (p values)	Post-hoc (p)
PTA-R	0.551	-	0.367	-
PTA-L	0.936	-	0.796	-
SRT-R	0.464	-	0.451	-
SRT-L	0.687	-	0.299	-
SDS-R	0.586	-	0.240	-
SDS-L	0.431	-	0.373	-
FPT-R (%)	0.698	-	0.220	-
FPT-L (%)	0.681	-	0.472	-
DPT-R (%)	0.299	-	0.051	-
DPT-L (%)	**0.039***	Morning > intermediate **(0.034)***	0.059	-
TSiNT (%)	0.317	-	**0.049***	Morning > intermediate **(0.038)***
AVLT A1-5	0.358	-	0.602	-
AVLT A6	0.605	-	0.691	-
AVLT A7	0.534	-	0.193	-
AVLT recognition	0.585	-	0.725	-

*p<0.05: Statistically significant.

Vs. Versus, PTA-R: Right ear pure tone average, PTA-L: Left ear pure tone average, SRT-R: Right ear speech reception threshold, SRT-L: Left ear speech reception threshold, SDS-R: Right ear speech discrimination score, SDS-L: Left ear speech discrimination score, FPT-R: Right ear frequency pattern test, FPT-L: Left ear frequency pattern test, DPT-R: Right ear duration pattern test, DPT-L: Left ear duration pattern test, TSiNT: Turkish speech in noise test, AVLT: Auditory verbal learning test

surprising that cognitive performance is affected as a result of circadian disruption or working in a period that does not match the individual's circadian rhythm.[26] Disruption of the cycle, i.e., circadian disruption, can lead to a deterioration in cognitive performance and fluctuations throughout the day. Nevertheless, when assessed according to their circadian rhythms, there is a possibility that the performance of these types may be enhanced. For this reason, the MoCA test scoring, which we determined as inclusion criteria, was conducted at the beginning of the sessions aligned with the participant's preferred type, as determined by the MEQ results.

Psychoacoustic tests such as duration pattern detection and gap detection evaluate the temporal process and are very important for audiology research. Studies in the literature have examined the effects of circadian preference on temporal processing in detail,[27,28] reporting that individuals performed better on duration pattern perception tests conducted during the time period corresponding to their circadian preference. In other words, morning types performed better in the morning than in the evening, while evening types performed better in the evening than in the morning. The results of the studies are consistent with previous studies reporting that participants typically perform best at a certain time of day.[22] In our study, it was observed that the left ear results of the DPT test performed in the morning were significant in morning types compared to intermediate types, which is consistent with the literature. Actually, we expected to see the right ear advantage here. The auditory cortex is dominant in encoding the temporal resolution of the auditory signal in the left hemisphere.[29] The right ear pathway is a more direct pathway to the left hemisphere. In other words, the pathway from the right ear to the left hemisphere is faster than the pathway from the left ear. A message traveling along the left path is at a disadvantage because it has to make more neural synapses. The increased number of synapses slows down the message to reach the center by about 25 msec.[30] However, in our results, contrary to the consensus in the literature, the DPT test in the left ear was significant in morning types. This may be explained by the advantage of the stimuli being sufficiently audible in the spectro-temporal modulation test, which is one of the evaluations for temporal processing of sound.[31-33] In this context, although no significance was observed in the PTA of

the participants included in our study, it may be due to the better hearing sensitivity in the left ear compared to the right ear (Table 1, Figure 1). In the literature, no report was found to support the finding of left ear superiority in our study.

The ability to suppress unnecessary information, or the inhibitory mechanism, may play a leading role in psychoacoustic test results.[28] The inhibitory effect is thought to affect cognitive processes such as speech comprehension, selective attention and working memory.[24] Thus, a change in the inhibitory effect related to the time of day when the test is administered may influence the results of psychoacoustic measures.[27] It has been highlighted that speech perception in noise varies based on the preferred time of day. This may suggest that circadian preference may be less sensitive to distraction.

In studies evaluating the central auditory system according to circadian rhythms[34] it was found that the performance of evening listeners on the filtered speech subtest of the SCAN test improved during the day. In another study of dichotic listening,[35] those in the moderate evening category performed better in the late evening than in the morning. There was no diurnal or nocturnal effect on the listening performance of those in the intermediate category.

The TSiNT results in our study and the evening types showed a significance consistent with the literature when performed in the evening.[28] This significance may not be due to the evening types being very successful in the evening but rather due to their poor performance in the morning. However, the lower performance of evening types on morning tests is in line with,[36] who concluded that the lower performance of evening types on morning tests may be due to lack of sleep and/or effort to wake up in the morning hours. However, no significant differences were found between morning and evening types. Contrary to expectations, the lack of significance for morning types in the morning may be attributed to their high performance in the evening. Morning types with high performance in the evening may have demonstrated their high ability to concentrate on difficult tasks in the evening.[12] At the same time, the relationship between performance on tasks given during test hours outside the boundaries of chronotype preference may depend on the difficulty of the task. There are studies showing that morning people perform better in the evening and evening people perform better in the morning.[34] However, when the evening session of the TSiNT was compared across groups, it was observed that the results of the intermediate types and evening types were similar. However, the significant difference between the intermediate types and morning types favored the morning types. This may be considered an indicator of the advantage of morning people in terms of speech perception in noise, even in the evening.

The AVLT assesses verbal information processing and verbal learning (A1-A5), recall-based verbal learning (A6), and recall-based LTM (A7).[20] In order to achieve high scores on all of these assessments of the AVLT, the peripheral and central auditory systems must function properly. Given that our research question is "does the auditory system show changes according to circadian rhythm?" the cognitive test of the AVLT administered with verbal stimuli should also be reflected in the result. In our study based on this question, significance was found only in the A7 subtest in which LTM was evaluated. A study on the effects of circadian rhythms on memory reported that peak performance on LTM tasks occurs midday, although this may vary depending on the difficulty of the task.[37] This is because[34] found that unit changes were only effective when recalling difficult material, whereas easy material recall tasks were not affected by time of day[38] observed a decrease in LTM performance with increasing time after waking. In our study, it was found that the morning session was higher for the morning types than the evening session, which is consistent with the literature. However, as expected, the AVLT A7 results were not significant in the evening types who were tested in the evening. This result may be attributed to the demands of daily life, which require individuals to start their day early in the morning, leading to increased fatigue as the evening hours approach when they are still expected to remain active. However, in our study, the time the participants spent asleep on the day of the evaluations according to their chronotypes was not taken into account.

Study Limitations

This may be a limitation of the study. The likelihood of being affected by daily changes may also vary depending on whether the tasks and materials are easy or difficult. The extent of the neural networks and sub-functions involved in completing a task, the complexity of the stimulus used, and the level of attention required to perform the task may all influence the degree of susceptibility to diurnal variation.[34] This may be the reason why no significant differences were found in the results of the other subtests (A1-A5, A6), which were easier than the AVLT A7.

Conclusion

There are few studies in the literature that evaluate the human auditory system in detail in relation to circadian rhythms. This study can be considered a pilot effort to address this gap in the literature and to explore the auditory performance of circadian chronotypes at different times of the day.

In conclusion, the results of comparing individuals of the same chronotype at different times of the day revealed the existence of circadian effects on auditory perception. Our findings provide an opportunity for further studies to investigate whether central hearing and auditory processing performance, in particular, vary according to circadian rhythms, using other subjective batteries and auditory electrophysiological testing methods.

Ethics

Ethics Committee Approval: This study was conducted between February and June 2023 with the approval of the Non-Interventional Research Ethics Committee of Üsküdar University (approval number: 61351342, date: 30.12.2022).

Informed Consent: All participants signed an informed consent form.

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Footnotes

Authorship Contributions

Concept: D.Ş.C., Design: D.Ş.C., G.G., Y.S., Data Collection or Processing: D.Ş.C., B.A.A., B.A., Analysis or Interpretation: Y.S., Literature Search: D.Ş.C., G.G., Y.S., B.A.A., B.A., Writing: D.Ş.C., G.G., Y.S., B.A.A., B.A.

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