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RESEARCH ARTICLE

Türkiye–Anatolia screening and diagnostic tests for auditory processing disorder: A normative data study in young adults

Türkiye–Anadolu sentral işitsel işlemleme bozukluğu tarama ve tanı testleri: Genç yetişkinlerde normatif veri çalışması

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Abstract

Aim: Central auditory processing disorder (CAPD) is an impairment in the processing of auditory information throughout the central auditory system, and it affects the everyday functioning and academic performance of affected individuals. Early identification and management of CAPD are therefore critically important. The aim of this study was to develop CAPD screening and diagnostic tests for native speakers of Turkish and to obtain normative data in healthy adults.

Methods: The Türkiye-Anatolia Central Auditory Processing Disorder Diagnosis and Screening Tests (T-Anatolia CAPDT), comprising screening and diagnostic tests for CAPD, were developed and administered to 90 healthy individuals (45 females, 45 males). The T-Anatolia CAPDT consists of two nonverbal tests, the Bilateral Frequency Tone Pattern Test (BFTPT) and the Dichotic Frequency Tone Pattern Test (DFTPT), and five tests employing verbal stimuli: the Auditory Figure-Ground Test (AFGT), the Dichotic Sentence Test (DST), the Dichotic Word Test (DWT), the Filtered Word Test (FWT), and the Dichotic Monosyllabic Competing Test (DMCT). Differences in test performance between the right and left ears and between sexes were examined. Exploratory factor analysis was performed, and the intercorrelations and reliability of the tests were analyzed.

Results: Exploratory factor analysis (EFA) of the T-Anatolia CAPDT yielded a six-factor structure with eigenvalues above 1.00, accounting for 74.69% of the total variance. All tests examined showed statistically significant reliability and agreement ($p<0.05$). Significant correlations were found within and between the tests ($p<0.05$).

Conclusion: The T-Anatolia CAPDT is a battery capable of assessing central auditory processing in a multidimensional and functional manner. The normative data obtained may serve as a reference in the diagnosis and management of CAPD, and may support the screening and early identification of the disorder as well as the effective planning of treatment.

Keywords: Central auditory processing disorder, behavioral test, dichotic listening tests, screening, diagnosis.

Özet

Amaç: Santral İşitsel İşlemleme Bozukluğu (SİİB) merkezi işitsel sistem boyunca işitsel bilginin işlenmesinde bozukluktur ve bireylerin günlük yaşamını ve akademik becerilerini etkiler. Bu nedenle SİİB'nin erken tanılanması ve tedavisi kritik önem taşır. Çalışmada, anadili Türkçe olan bireylere yönelik SİİB tarama ve tanı testlerinin oluşturulması ve sağlıklı yetişkinlerde normatif verilerin elde edilmesi amaçlandı.

Yöntemler: SİİB tarama ve tanı testlerini içeren Türkiye-Anadolu Sentral İşitsel İşlemleme Bozukluğu Tarama ve Tanı Testleri (T-Anadolu SİİBT) oluşturuldu ve 90 sağlıklı bireye (45 kadın. 45 erkek) uygulandı. T-Anadolu SİİBT; sözel uyaran içermeyen Bilateral Frekans Ton Patern Test (BFTPT) ve Dikotik Frekans Ton Patern Test (DFTPT) ile sözel uyaran içeren Gürültüde Kelime Tespiti (Auditory Figure Ground Test-AFGT). Dikotik Cümle Testi (Dichotic Sentence Test-DST). Dikotik Kelime Testi (Dichotic Word Test-DWT), Filtrelenmiş Kelime Testi (Filtered Word Test-FWT) ve Dikotik Tek Heceli Birleşik Kelime Testinden (Dichotic Monosyllabic Competing Test-DMCT) oluşmaktadır. Test sonuçlarının sağ-sol kulak ve cinsiyete göre farklılıkları değerlendirildi. Açımlayıcı faktör analizi (AFA), testlerin ilişki analizi ve güvenirlik analizi yapıldı.

Bulgular: T-Anadolu SİİBT'de AFA sonucunda özdeğeri (eigenvalue) 1,00 sınırının üzerinde olan ve toplam varyansın %74,69'unu açıklayan 6 faktörlü bir yapı elde edildi. Analiz sonuçlarına göre. incelenen tüm testlerin anlamlı düzeyde güvenilirlik ve uyum gösterdiği tespit edildi ($p<0,05$). Testlerin kendi içinde ve testlerin birbiri ile anlamlı korelasyonlar gösterdiği saptandı ($p<0,05$).

Sonuç: T-Anadolu SİİBT santral işitsel işlemleme süreçlerini çok boyutlu ve işlevsel bir şekilde değerlendirebilen bir bataryadır. Elde ettiğimiz normatif veriler. SİİB tanı ve tedavi sürecinde referans olarak kullanılarak SİİB'nin taranması, erken tanılanması ve tedavi süreçlerinin etkin bir şekilde planlanması sağlanabilir.

Anahtar Kelimeler: Santral işitsel işlemleme bozukluğu, davranışsal test, dikotik dinleme testleri, tarama, tanı.

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INTRODUCTION

Auditory processing disorder is an impairment in the processing of auditory information, a process that involves both bottom-up and top-down flow of information throughout the central auditory system (1). Central auditory processes (CAP) allow the listener to interpret incoming auditory information (2). These processes include sound localization and lateralization, auditory discrimination, temporal aspects of hearing (temporal resolution, temporal integration, temporal ordering and temporal masking, and pattern recognition), the understanding of degraded speech (filtered or time-compressed) and of speech presented against background noise, and performance with competing acoustic signals (3-5).

In central auditory processing disorder (CAPD), peripheral hearing function is normal, yet difficulties arise in the processing of auditory information at the level of the central nervous system (6). A diagnosis of CAPD is made when at least two central auditory processes are impaired, or when a single process is severely impaired, in the absence of hearing loss (1,3). The symptoms reported most often in CAPD include difficulty understanding speech in noisy environments despite normal peripheral hearing, difficulty following complex verbal instructions, difficulty discriminating phonetically similar words, frequent requests for repetition, distractibility, difficulty with reading and writing, poor concentration, and auditory hypersensitivity (7-9). These symptoms may have a considerable effect on an individual's everyday functioning. Because of the broad range of symptoms associated with CAPD, differential diagnosis is of considerable importance (6). Since the 1950s, a substantial number of studies have contributed to the development of tests and test batteries for the assessment of CAPD (10). No universally accepted "gold standard" diagnostic test distinguishes CAPD from other disorders (11). The American Speech-Language-Hearing Association recommends that a CAPD test battery possess high sensitivity and specificity and that it assess auditory categories such as auditory discrimination, temporal processing, dichotic speech, monaural low-redundancy speech, and binaural interaction. Although tests targeting these functions are available in English-speaking countries, many of them incorporate verbal stimuli and cannot be administered to individuals whose native language is not English (3). Because differences in diagnostic criteria may lead to substantial differences in treatment planning, it is essential that diagnosis rest on standardized criteria. No single, valid standard is accepted worldwide. The boundary between normal and abnormal central auditory processing function has not yet been clearly established, and normative values are therefore required for diagnostic purposes (6, 12). In Türkiye, a standard test battery used for diagnosing auditory processing disorder is not currently available. To our knowledge, there is also no auditory processing test battery in Türkiye that features Turkish stimuli designed for native Turkish-speaking individuals, aims to screen and diagnose CAPD, and possesses normative data. Accordingly, the aim of the present study was to establish a standard test battery for the screening and diagnosis of CAPD, the Türkiye-Anatolia Central Auditory Processing Disorder Diagnosis and Screening Tests (T-Anatolia CAPDT), and to determine normative reference values obtained from healthy adults with normal hearing. The intended outcome is that the normative dataset generated with the T-Anatolia CAPDT, which comprises both Turkish verbal tests and nonverbal tests, will provide a basis for the accurate and early identification of CAPD and for the planning of individualized therapy programs in individuals in whom CAPD is identified.

METHODS

Ethical approval for the study was obtained from the Ethics Committee of the Faculty of Health Sciences at Ankara Yıldırım Beyazıt University (Decision No. 08/871).

Participants

Healthy adults aged 18–25 years were enrolled in the study. All volunteers were university students and native speakers of Turkish. Before participation, all participants received detailed information about the study and provided written informed consent. Participants with a Pragmatics Profile score of ≥153 were included in the study (13). The inclusion criteria were: no history of hearing loss, otologic surgery, or head trauma; no use of medication affecting the central nervous system; no prior diagnosis of central auditory processing disorder, attention-deficit/hyperactivity disorder, or a speech and language disorder; absence of any neurological, psychiatric, or developmental condition; no family

Turk J Clin Res. 2026;2(2):158-171
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history of hearing, speech, or central auditory processing disorders; and willingness to take part in the study voluntarily.

Pure-tone audiometry, tympanometry, and ipsilateral and contralateral acoustic reflex measurements were performed in all participants using a TouchTymp MI 36 clinical audiometer and immittance device (MAICO Diagnostics GmbH, Berlin, Germany). Individuals with air-conduction thresholds ≤15 dB HL across 250–8000 Hz in both ears, type A tympanograms (middle ear pressure between +50 and −100 daPa), and normal ipsilateral and contralateral acoustic reflex thresholds (70–100 dB HL) were included in the study.

Data from a total of 90 adults (45 females, 45 males) who met the specified inclusion criteria and completed the behavioral test battery in full were included in the statistical analyses.

The Türkiye-Anatolia Central Auditory Processing Disorder Screening and Diagnostic Tests (T-Anatolia CAPDT)

Participants meeting the inclusion criteria first completed the TAIBTA, a paper-based questionnaire developed by Yalçınkaya et al. (13) that consists of eight illustrated items assessing symptoms of CAPD, and for which the development process and normative data have been published. After the questionnaire had been administered, all participants underwent the T-Anatolia CAPDT. The entire battery was completed in a single session, with rest breaks provided as needed. Administration of all tests took approximately 60 minutes.

The battery was based on the tests most frequently used in clinical practice, most widely preferred internationally, and found to be effective in the diagnosis of CAPD, as well as on the tests described by the American Speech-Language-Hearing Association (ASHA) (3) and the American Academy of Audiology (AAA) (14). The clinical experience of one of the investigators (Yalçınkaya) with children with CAPD played an important role in the selection and construction of the tests. Tests employing both verbal and nonverbal stimuli were included so that the battery would provide a comprehensive assessment. The classification of the subtests within the battery into screening and diagnostic categories was established based on the first author's (Yalcınkaya F.) 20 years of extensive clinical experience in the assessment and management of central auditory processing disorders (CAPD). In accordance with this clinical expertise, the division was determined by analyzing the specific auditory constructs evaluated by each subtest and the inherent psychometric nature of the tools. The screening tests included in the T-Anatolia CAPDT battery are the Bilateral Frequency Tone Pattern Test (BFTPT), which uses nonverbal stimuli, and the Auditory Figure-Ground Test (AFGT), the Dichotic Sentence Test (DST), the Dichotic Word Test (DWT), and the Filtered Word Test (FWT), all of which use verbal stimuli. The diagnostic tests are the Dichotic Frequency Tone Pattern Test (DFTPT), which uses nonverbal stimuli, and the Dichotic Monosyllabic Competing Test (DMCT), which uses verbal stimuli.

Technical Characteristics of the Stimulus Recordings

All auditory stimuli, both verbal and nonverbal, were developed by the investigators and recorded under professional studio conditions. Stimulus preparation was carried out on a computer with 16 GB of RAM, a 512 GB SSD, and an Intel Core i7 processor, together with an SSL12 USB audio interface (12-in/8-out), Sony Vegas Pro Suite software, and an NT2-A multi-pattern large-diaphragm condenser microphone (RØDE, Sydney, Australia). The three-position pad, high-pass filter, and polar pattern controls of the microphone were used during recording, and its ultra-low self-noise, wide frequency response, and internal capsule shock mounting contributed to high-quality recordings.

Construction of the Verbal Stimuli

The verbal stimuli were selected from a word pool developed by Yalçınkaya, in which Turkish words had been classified according to familiarity on the basis of ratings by native Turkish-speaking primary school teachers, preschool teachers, parents, and audiologists. The test materials used the monosyllabic Turkish words rated as having the highest familiarity. To ensure standardization, all verbal stimuli were recorded by a single male speaker in a professional studio environment, and the necessary post-recording audio editing and quality control procedures were completed.

Turk J Clin Res. 2026;2(2):158-171
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Test Equipment

The test stimuli were presented from digital audio files stored on a computer. Auditory stimuli were delivered to the participants through a Creative SB1–100 external sound card and Sennheiser HDA 200 headphones, together with a stereo headphone splitter (Y splitter) that allowed the computer's audio output to be monitored simultaneously by the examiner and the participant. This arrangement enabled the examiner to listen to the test stimuli at the same time as the participant and to record the participant's verbal responses on standard scoring forms in real time.

For the collection of responses in the frequency pattern tests, two wooden sticks were used: a thick stick (10 cm long, 10 mm in diameter) and a thin stick (10 cm long, 4 mm in diameter). Standard scoring forms and the necessary stationery (pencil and eraser) were available throughout test administration.

Test Procedure

All screening and diagnostic tests were administered by the same investigator in a quiet test room at the university. Before testing, participants received a detailed explanation of the purpose of each test, the manner in which the stimuli would be presented, the type of response expected, the approximate duration of the tests, and the availability of rest breaks if needed.

Testing was carried out on an HP ProBook 4510S laptop computer running Windows Professional. Auditory stimuli were presented to participants through Sennheiser HDA 200 headphones via a Creative SB1–100 external sound card. All tests were administered at 50–55 dB HL, based on the participant's most comfortable listening level. Prior to the tests. test-specific stimuli were presented for practice purposes. Completion of the battery took approximately 60 minutes, and short rest breaks were provided between tests according to participant need.

A test–retest reliability analysis was conducted to assess the stability of the battery over time. For this purpose, 20 randomly selected participants were re-tested with the same battery by the same investigator under identical test conditions at least one week after the initial assessment.

Screening Tests

Bilateral Frequency Tone Patern Test (BFTPT)

Purpose: To assess auditory sequencing ability (the perception and ordering of tones differing in frequency).

Test: Low-frequency stimuli were used because they support fundamental processes such as prosody and timing integration (15), and high-frequency stimuli were used because they convey speech clarity and fine-detail analytic information (16). Combinations of three 200 ms sinusoidal tones at low (300 and 350 Hz) and high (3000 and 3050 Hz) frequencies were presented, with a 250 ms interstimulus gap and rise and fall times of 10 ms. The interval between successive test items was 6 s.

Two sticks, one thick and one thin, were placed on the table in front of the participant. The thick stick was 10 cm long and 10 mm in diameter, and the thin stick was 10 cm long and 4 mm in diameter. A stick–frequency correspondence was established by pointing to the thick stick during the presentation of a low tone and to the thin stick during the presentation of a high tone. Once the participant had learned this low–high correspondence, the practice phase began. The test comprises 15 items formed by repeating, in varying numbers, six unique three-tone frequency patterns constructed from low (L) and high (H) frequency tones, with the LLL and HHH patterns excluded. All stimuli were presented bilaterally.

Instructions: Participants were asked to describe the patterns they heard verbally (for example, low–low–high).

Scoring: One point was awarded when all three tones in a pattern were identified correctly. No point was awarded if one or more tones were identified incorrectly. The maximum attainable score is 15.

Auditory Figure-Ground Test (AFGT)

Purpose: To assess the intelligibility of speech presented in the presence of background noise.

Turk J Clin Res. 2026;2(2):158-171
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Test: Thirty frequently used Turkish monosyllabic words spoken by a male speaker were presented separately to the right and left ears, embedded in eight-talker speech babble (±8 dB SNR) presented at an auditorily equivalent level to the background noise.

Instructions: Participants were asked to repeat each word they heard and to guess when uncertain.

Scoring: The number of words repeated correctly in the right and left ears, the interaural difference, and the total number of words repeated correctly were calculated. The maximum score is 30 per ear and 60 in total.

Dichotic Sentence and Dichotic Word Tests

Purpose: To obtain information about binaural integration and binaural separation, attention, maturation of the auditory pathway, executive functions, and hemispheric and interhemispheric function mediated by the corpus callosum.

Dichotic Sentence Test (DST)

Test: Two separate lists were presented, each consisting of 10 different dichotic sentence pairs spoken by a male speaker and delivered dichotically.

Instructions: Participants were told that they would hear two sentences and were asked to repeat only the sentence presented to one ear. For the first list, participants were instructed to repeat only the sentence heard in the right ear; for the second list, only the sentence heard in the left ear.

Scoring: One point was awarded for each dichotic sentence repeated correctly. No point was awarded if one or more words were repeated incorrectly. The number of sentences repeated correctly in the right and left ears, the interaural difference, and the total number of sentences repeated correctly were calculated. The maximum score is 10 per ear and 20 in total.

Dichotic Word Test (DWT)

Test: Two separate lists were presented, each consisting of 25 different dichotic monosyllabic word pairs spoken by a male speaker and delivered dichotically.

Instructions: Participants were told that they would hear a different word in each ear and that they were required to repeat both. For the first list, they were instructed to repeat the word heard in the right ear first and then the word heard in the left ear (Condition 1 = C1). For the second list, they were instructed to repeat the word heard in the left ear first and then the word heard in the right ear (Condition 2 = C2).

Scoring: One point was awarded for each pair in which both dichotic words were repeated correctly and in the required order. No point was awarded if one or both words were repeated incorrectly or in the wrong order (WO). The total number of words repeated correctly in the right and left ears was recorded separately for Conditions 1 and 2, together with the total number of words repeated correctly for each ear across conditions (C1 + C2). For each condition, the number of words repeated in the correct order (CO), the number repeated in the wrong order (WO), the total number repeated in the correct order (C1 + C2), and the interaural difference in the number of words repeated in the correct order were also recorded. The maximum score is 50 per ear and 100 in total.

Filtered Word Test (FWT)

Purpose: To assess the intelligibility of degraded (filtered) speech stimuli.

Test: A low-pass filter with a cutoff of 1000 Hz and a roll-off (rejection rate) of 32 dB per octave was applied, and a series of 30 different monosyllabic words spoken by a male speaker was presented separately to each ear.

Instructions: Participants were asked to repeat each word they heard and to guess when uncertain.

Scoring: The number of words repeated correctly in each ear, the interaural difference, and the total number of words repeated correctly were calculated. The maximum score is 30 per ear and 60 in total.

Diagnostic Tests

Dichotic Frequency Tone Pattern Test (DFTPT)

Purpose: To assess the temporal processing of dichotically presented tonal stimuli.

Turk J Clin Res. 2026;2(2):158-171
https://doi.org/10.63909/1453056

Test: Two sticks, one thick and one thin, were placed on the table in front of the participant. The thick stick was 10 cm long and 10 mm in diameter, and the thin stick was 10 cm long and 4 mm in diameter. Low-frequency (300 and 350 Hz) or high-frequency (3000 and 3050 Hz) tones of 500 ms duration were presented dichotically at 3.5 s intervals. The tones were delivered simultaneously to both ears for 500 ms, and the next stimulus pair followed after 3.5 s. A stick–frequency correspondence was established by pointing to the thick stick during a low tone and to the thin stick during a high tone. Once the participant had learned this low–high correspondence, the practice phase began. Twenty-four dichotic sequences were presented.

Instructions: Participants were asked to describe verbally the frequency heard in the right ear first and then the frequency heard in the left ear. Participants who had difficulty responding verbally were asked to identify the patterns by pointing to the thick and thin sticks.

Scoring: One point was awarded for the right ear when the stimulus presented to the right ear was identified correctly, and one point for the left ear when the stimulus presented to the left ear was identified correctly. No point was awarded if one or more tones were identified incorrectly. The number of tones identified correctly in each ear, the interaural difference, the total number of tones identified correctly, the number of patterns reported in the correct order, and the number reported in the incorrect order were recorded. The maximum score is 24 per ear and 48 in total.

Dichotic Monosyllabic Competing Test (DMCT)

Purpose: To assess the ability to process auditory information across the two ears (binaural integration) and selective attention (binaural separation).

Test: Six lists of dichotic monosyllabic compound words were prepared, each comprising 10 monosyllabic word pairs. Because the number of compound words in Turkish is very limited, familiar monosyllabic compound words were selected (inter-word interval ≤ 5 ms). All compound words had a verb–noun structure and were produced with equal stress on both constituents (for example, çek-yat). One word of each pair was delivered to the right ear and the other simultaneously to the left ear. A 4-second silent interval followed each word pair to allow the participant to respond and the examiner to record the answer.

Instructions: Participants were told that a different word would be presented to each ear and were asked to report the word heard in the right ear first and then to combine the words heard in the right and left ears.

Scoring: The number of words reported correctly for each ear, the interaural difference, and the total number of words reported correctly were recorded. The maximum score is 60 per ear and 120 in total.

Statistical Analysis

Statistical analyses were performed using SPSS 23.0. Descriptive statistics are reported as means, standard deviations (SD), minimum (min) and maximum (max) values, medians, and the 25th, 50th, and 75th percentiles. Skewness and kurtosis coefficients were calculated to examine the normality of the data distributions. Exploratory factor analysis (EFA) with principal components extraction and varimax (orthogonal) rotation was used to determine the construct validity of the newly developed battery. Pearson correlation analysis was used to examine the relationships among test scores. Cronbach's alpha and intraclass correlation coefficient (ICC) analyses, based on a two-way mixed effects, absolute agreement model, were performed to determine test–retest reliability. In the analysis planning, parametric methods-specifically the Independent Samples t-test and Paired Samples t-test-were primarily prioritized because the sample size of the research group (N = 90) substantially exceeds the Central Limit Theorem threshold (N > 30), and parametric tests offer higher statistical power compared to their non-parametric alternatives. Nevertheless, to cross-validate the reliability against potential outliers and micro-level distributional deviations within the sub-dimensions, their non-parametric counterparts, namely the Mann-Whitney U test and Wilcoxon signed-rank test, were also incorporated into the analyses. Statistical significance across all comparisons was evaluated at the $p < .05$ level.

Turk J Clin Res. 2026;2(2):158-171
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RESULTS

Descriptive Statistics

Descriptive statistics for the T-Anatolia CAPDT findings obtained from the 90 healthy participants, including means, medians, SD, min, max and percentiles (25th, 50th, and 75th), together with the skewness and kurtosis values relating to the normality assumptions, are presented in Supplementary Appendix 1. Of the participants included, 45 (50%) were females and 45 (50%) were males (Mean age:20.77; SD:1.40). The mean age was 20.82 years (SD: 0.88) for females and 20.73 years (SD: 1.78) for males. No significant difference in age was found between females and males (p>0.05).

Because the age range of the participants was restricted to 18–25 years, age-related variance within the sample was assumed to be minimal, and no separate normative table was constructed by age. The analyses were therefore performed for the sample as a whole (Appendix 1) and by sex (Appendix 2).

The abbreviations used in the findings are as follows: BFTPT: Bilateral Frequency Tone Pattern Test; AFGT:Auditory Figure Ground Test; RE: Right Ear; LE:Left Ear; DST:Dichotic Sentence Test; DWT: Dichotic Word Test; FWT: Filtered Word Test; DFTPT: Dichotic Frequency Tone Pattern Test; DMCT: Dichotic Monosyllabic Competing Test; C1: Condition 1; C2: Condition 2.CO. Correct Order; WO: Wrong Order. F: Female; M: Male.

Comparison of Test Scores by Sex

The analysis planning, the results of the Independent Samples t-test were primarily prioritized because the sample size of the research group (N=90) substantially exceeds the Central Limit Theorem thresholds (N>30), and parametric tests offer higher statistical power compared to their non-parametric alternatives. Nevertheless, to cross-validate the reliability against potential outliers and micro-level distributional deviations within the sub-dimensions, the non-parametric Mann-Whitney U test was also incorporated into the analyses (Table 1).

In the comparison of behavioral test performance by sex, females performed significantly better on the AFGT-RE and AFGT-LE, the DWT-C1-LE and DWT-C2-RE, DWT-C2-LE and the DMCT-RE, and DMCT-LE (p<.05). Males performed significantly better on the DFTPT-RE and DFTPT-LE. The mean TAIBTA score was 7.60 (SD: 4.00) for females and 8.02 (SD: 3.93) for males.

When Table 1 is examined, although statistically significant differences were found between genders in the AFG-LE [t(88)=2.30, p=0.024] and PFTPT-LE [t(88)=-2.48, p=0.015] variables according to the Independent Samples t-test results, these differences remained at the threshold of significance in the Mann-Whitney U test results (p=0.055 and p=0.064, respectively). Considering our sample size (N=0.90), it was deemed appropriate to base the conclusions on the parametric t-test results for the AFG-LE and DFTPT-LE variables due to the high statistical power and sensitivity of the Independent Samples t-test in detecting small variance differences. Consequently, the difference between genders was accepted as statistically significant for both of these variables. No significant difference in mean TAIBTA score was found between females and males (p>0.05) (Table 1).

Exploratory Factor Analysis (EFA) Findings

To scientifically ground the structural validity of the developed processing test battery and the suitability of the dataset for factor analysis procedures, the Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity were performed. The resulting KMO coefficient (0.692) and Bartlett's test findings ((χ^2) = 574.267, df = 120, p < .001) proved that the data are highly suitable for factor analysis. Accordingly, these findings have been thoroughly integrated into the Methods/Results section of the manuscript.

Exploratory factor analysis with principal components extraction and varimax (orthogonal) rotation was used to determine the construct validity of the behavioral tests of the T-Anatolia CAPDT in adults. The analysis yielded a six-factor structure with eigenvalues above 1.00, accounting for 74.69% of the total variance (Table 2, Figure 1). Factor loadings ranged from .680 to .958 and exceeded the .320 criterion commonly accepted in the literature. Secondary loadings above .30 reached a maximum value of –.461. Overall, the subtests displayed a strong factor structure. Cross-loadings above .30 occurred for the DWT-C2-LE, DWT-C1-LE, and AFGT-

Turk J Clin Res. 2026;2(2):158-171
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Table 1. Comparison of test scores by sex

Variables	Gender	N	Mean	Median	SD	Min	Max	t	df	p (t-test)	Mann-Whitney U	Z
BFTPT	F	45	14.82	15.00	.38	14.00	15.00	0.418	88	00.677	999.000	-.181
	M	45	14.77	15.00	.59	12.00	15.00					
AFG-RE	F	45	24.66	25.00	1.36	22.00	27.00	4.238	88	0.001***	539.500	-3.880
	M	45	23.28	23.00	1.70	20.00	27.00					
AFG-LE	F	45	24.24	24.00	1.52	21.00	28.00	2.304	88	0.024*	778.000	-1.919
	M	45	23.35	24.00	2.09	18.00	27.00					
DST-RE	F	45	9.95	10.00	0.21	9.00	10.00	1.026	88	0.308	966.500	-.859
	M	45	9.88	10.00	0.38	8.00	10.00					
DST-LE	F	45	9.75	10.00	0.52	8.00	10.00	1.039	88	0.301	871.000	-1.466
	M	45	9.64	10.00	0.48	9.00	10.00					
DWT-C1-RE	F	45	23.57	24.00	1.03	21.00	25.00	1.884	88	0.063	853.500	-1.328
	M	45	22.93	23.00	2.05	14.00	25.00					
DWT-C1-LE	F	45	20.46	20.00	1.99	15.00	25.00	2.716	88	0.008**	693.500	-2.609
	M	45	19.17	19.00	2.47	11.00	24.00					
DWT-C2-RE	F	45	21.77	22.00	2.39	14.00	25.00	2.469	88	0.015*	678.500	-2.729
	M	45	20.51	21.00	2.47	14.00	25.00					
DWT-C2-LE	F	45	21.66	22.00	2.03	15.00	25.00	2.475	88	0.015*	676.000	-2.761
	M	45	20.62	21.00	1.96	16.00	24.00					
FWT-RE	F	45	22.37	23.00	2.34	17.00	27.00	0.570	88	0.570	901.500	-.904
	M	45	22.11	22.00	2.08	19.00	26.00					
FWT-LE	F	45	22.28	23.00	2.84	15.00	28.00	-0.354	88	0.724	964.500	-.390
	M	45	22.51	23.00	3.10	14.00	28.00					
DFTPT-RE	F	45	21.17	22.00	3.20	12.00	24.00	-3.110	88	0.003**	721.000	-2.480
	M	45	22.86	24.00	1.72	18.00	24.00					
DFTPT-LE	F	45	21.40	22.00	2.92	14.00	24.00	-2.475	88	0.015*	793.000	-1.849
	M	45	22.66	23.00	1.79	18.00	24.00					
DMCT-RE	F	45	56.06	57.00	3.32	46.00	60.00	3.118	88	0.002**	598.500	-3.364
	M	45	53.31	54.00	4.90	38.00	60.00					
DMCT-LE	F	45	53.08	54.00	4.12	43.00	59.00	3.226	88	0.002**	629.500	-3.102
	M	45	49.62	51.00	5.90	30.00	58.00					

Note: Comparisons between female and male groups were analyzed using the Independent Samples t-test and the Mann-Whitney U test.

LE subtests; these subtests were nevertheless retained in the analysis in order to preserve the integrity of the battery. The differences between primary and secondary loadings exceeded these criterion values, and the subtests grouped successfully under the principal factor to which they were theoretically most appropriate.

The first factor (F1, Verbal-Auditory Memory) comprised the DWT (C1-RE and C1-LE; C2-RE and C2-LE) and DMCT (RE and LE) items and constituted the dominant dimension, accounting on its own for 28.97% of the variance. The second factor (F2, Dichotic Tonal Temporal Processing) consisted of the DFTPT (RE and LE) and accounted for 13.88% of the variance. The third factor (F3, Auditory Closure) brought together the FWT (RE and LE) items (9.59% of the variance), and the fourth factor (F4, Complex Verbal Message Discrimination) grouped the AFGT (RE and LE) and DST (LE) items (8.33% of the variance). The fifth factor (F5, Right Ear Verbal Dominance) was formed by the DST-RE (6.99% of the variance) and the sixth factor (F6, Auditory Sequential Pattern Perception) by the BFTPT (6.91% of the variance), each constituting an independent dimension in its own right (Table 2, Figure 1).

Turk J Clin Res. 2026;2(2):158-171
https://doi.org/10.63909/1453056

Table 2. Results of the exploratory factor analysis for the T-Anatolia CAPDT

Variable	F1 (Verbal-Auditory Memory	F2 (Dichotic Tonal Temporal Processing)	F3 (Auditory Closure)	F4 (Complex Verbal Message Discrimination)	F5 (Right Ear Verbal Dominance)	F6 (Auditory Sequential Pattern Perception)
DMCT-RE	**0.863**					
DWT- C1-LE	**0.796**				0.326	
DMCT-LE	**0.772**					
DWT-C2-RE	**0.771**					
DWT- C1-RE	**0.756**					
DWT- C2-LE	**0.680**				-0.461	
DFTPT-RE		**0.958**				
DFTPT-LE		**0.936**				
FWT-RE			**0.881**			
FWT-LE			**0.827**			
DST-LE				**0.718**		
AFGT-LE			0.321	**0.698**		
AFGT-RE				**0.681**		-0.303
DST-RE					**0.863**	
BFTPT						**0.933**
Eigenvalue	4.346	2.083	1.439	1.250	1.049	1.038
Explained Variance (%)	28.97	13.88	9.59	8.33	6.99	6.91

Note: N=90; To avoid confusion, factor loadings below .30 have been hidden from the table. Main factor loadings including subtests are shown in bold. KMO = 0.692; Bartlett's test $\chi^2(120)=574.267$, p<0.001.

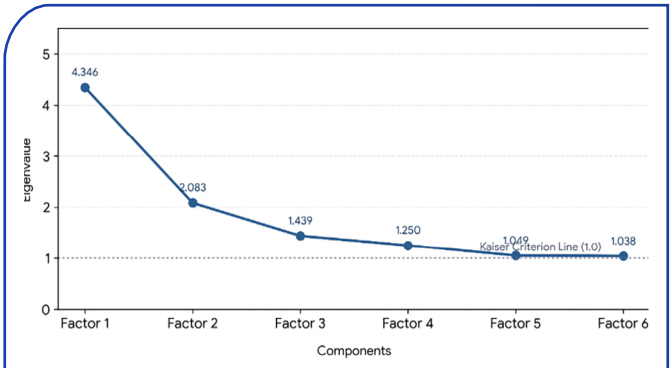

Figure 1. Scree plot of the six-factor structure

Correlation Analysis Findings

Pearson correlation analysis was used to examine the linear relationships among the tests included in the T-Anatolia CAPDT battery. The results of this analysis, together with the sample size (N=90; degrees of freedom, df=88) and significance levels (*p<0.05; **p<0.01), are presented in Appendix 3.

No significant relationships were found between the BFTPT score and almost all of the other tests (p>0.05; r<0.10). The AFGT total score correlated positively and strongly with the other scores of the same test, AFGT-RE (r=0.787, p<0.01) and AFGT-LE (r=0.832, p<0.01). The correlation between the AFGT-RE and AFGT-LE scores was moderate (r=0.312, p<0.01). Positive, weak-to-moderate significant correlations were found between the AFGT scores and the DWT (r=0.20 to 0.35; p<0.05 and p<0.01). The AFGT scores generally showed low or borderline positive correlations (r<0.30) with the DST, FWT, and DMCT scores, most of which were significant (p<0.05).

A positive, low-level significant relationship was found between the DST-LE and AFGT-RE scores (r=0.282, p<0.01). No significant relationships were found between DST-LE and AFGT-LE (r=0.196, p>0.05) or between DST-LE and the AFGT total score (r=0.290, p>0.05).

The DWT scores correlated very strongly and positively with one another (r=0.80 to 0.96, p<0.01). The DMCT

Turk J Clin Res. 2026;2(2):158-171
https://doi.org/10.63909/1453056

total score also correlated highly and positively with its subcomponents, DMCT-RE (r=0.706, p<0.01) and DMCT-LE (r=0.637, p<0.01). Widespread, positive, moderate-to-strong significant correlations were found between the DWT and DMCT scores (r=0.40 to .70, p<0.01).

Although the DFTPT scores correlated very highly with one another (r=0.945 to 0.980 between the DFTPT total score and its RE, LE, and CO subcomponents, p<0.01), they showed no significant relationships with any of the other test scores (BFTPT, AFGT, DST, DWT, DMCT; p>0.05). The FWT scores showed a limited linear relationship only with the DWT scores, at a low-to-moderate level (r=0.25 to 0.41, p<0.05).

When the relationships between the individual TAIBTA items and the behavioral tests were examined, weak negative significant correlations were found between the FWT and item 1 (r=–0.245, p<0.05), between the DST and items 2, 3, 4, 5, 7, and 8 (r=–0.221 to –0.267, p<0.05), between the DFTPT and items 2 and 6 (r=–0.216 to –0.363, p<0.05), and between the AFGT and item 7 (r=–0.284, p<0.05). No significant relationships were found between the TAIBTA total score and the remaining test findings (the DWT, FWT, and DMCT test groups; p>0.05). The strongest relationship was observed with the DST total score (r=–0.345, p=0.001); negative, low-level significant relationships were also found between the checklist and the DST-RE (r=–0.318, p=0.002), AFGT total (r=–0.224, p=0.035), and DST-LE (r=–0.221, p=0.038) scores. A significant relationship was also obtained with the DFTPT-LE score.

Reliability and Intraclass Correlation (ICC)

To comprehensively evaluate the psychometric properties of the developed auditory processing test, both internal consistency and test–retest stability were assessed. Cronbach's alpha coefficient was calculated to evaluate the internal consistency and homogeneity of the test items. Test–retest stability was assessed using the intraclass correlation coefficient (ICC) based on the reassessment of 20 participants.

Cronbach's alpha and ICC analyses, using a two-way mixed-effects, absolute-agreement model for the ICC, were performed for the behavioral tests. All tests examined showed significant reliability and agreement (p<0.05). The DMCT-RE (alpha=0.948; average ICC=0.942), DMCT-LE (alpha=0.952; average ICC=0.912), and all DWT subparameters showed excellent agreement. The BFTPT also showed a high degree of stability (average ICC=0.873, p<0.001). The DST (RE and LE) and FWT (RE and LE) had acceptable, moderate agreement coefficients. The results are presented in Table 3.

Table 3. Internal consistency and intraclass correlation coefficients (ICC) of the subtests

Variable	Number of Measurement	Cronbach's Alpha	Single ICC	Average ICC	95% CI*	p
BFTPT	2	0.869	0.775	0.873	[0.680–0.950]	<0.001
AFGT-RE	2	0.909	0.709	0.830	[0.463–0.932]	<0.001
AFGT-LE	2	0.818	0.596	0.747	[0.228–0.898]	<0.001
DST (RE)	2	0.696	0.523	0.686	[0.236–0.874]	0.006
DST (LE)	2	0.600	0.406	0.578	[0.038–0.831]	0.026
DWT (C1-RE)	2	0.914	0.849	0.918	[0.793–0.968]	<0.001
DWT (C1-LE)	2	0.926	0.851	0.920	[0.795–0.968]	<0.001
DWT (C2-RE)	2	0.907	0.787	0.881	[0.631–0.956]	<0.001
DWT (C2-LE)	2	0.908	0.827	0.906	[0.766–0.962]	<0.001
FWT-LE	2	0.765	0.473	0.642	[–0.066–0.871]	0.001
FWT-RE	2	0.881	0.653	0.790	[0.076–0.934]	<0.001
DFPT-RE	2	0.883	0.794	0.885	[0.712–0.954]	<0.001
DFPT-LE	2	0.789	0.663	0.797	[0.480–0.920]	0.001
DMCT-RE	2	0.948	0.891	0.942	[0.847–0.977]	<0.001
DMCT-LE	2	0.952	0.839	0.912	[0.443–0.974]	<0.001

Note: N=20; CI: Confidence Interval; Intraclass Correlation Coefficients (ICC) and 95% confidence intervals are reported based on the average measures framework under a two-way mixed effects model with absolute agreement.

Turk J Clin Res. 2026;2(2):158-171
https://doi.org/10.63909/1453056

Comparison of Right and Left Ear Performance

The results of the comparison of right and left ear performance across all participants and tests are presented in Table 4. Right ear performance was significantly better than left ear performance on the DST ($p<0.001$), DWT Condition 1 ($p<0.001$), and DMCT ($p<0.001$). No significant differences between right and left ear performance were found for the AFGT, FWT, DFTPT, or DWT Condition 2 ($p>0.05$).

Table 4. Comparison of right and left ear performance across all participants

Variables	Ear	Mean	SD	Median	Min	Max	t	df	p (t-test)	Z (Wilcoxon)	p (Wilcoxon)
AFGT	RE	23.97	1.68	24.00	20.00	27.00	0.807	89	0.422	-0.985	0.324
	LE	23.80	1.87	24.00	18.00	28.00					
DST	RE	9.92	0.30	10.00	8.00	10.00	3.658	89	0.001***	-3.428	0.001 ***
	LE	9.70	0.50	10.00	8.00	10.00					
DWT-C1	RE	23.25	1.64	24.00	14.00	25.00	16.104	89	0.001***	-8.005	0.001 ***
	LE	19.82	2.32	20.00	11.00	25.00					
DWT-C2	RE	21.14	2.50	22.00	14.00	25.00	0.000	89	10.000	-0.322	0.748
	LE	21.14	2.05	21.50	15.00	25.00					
FWT	RE	22.24	2.20	22.00	17.00	27.00	-0.597	89	0.552	-0.701	0.483
	LE	22.40	2.95	23.00	14.00	28.00					
DFTPT	RE	22.02	2.69	23.00	12.00	24.00	-0.077	89	0.939	-0.096	0.924
	LE	22.03	2.49	23.00	14.00	24.00					
DMCT	RE	54.68	4.39	56.00	38.00	60.00	10.967	89	0.001***	-7.677	0.001***
	LE	51.35	5.35	52.00	30.00	59.00					

Note. N=90. Comparisons between the right and left ears were analyzed using the Paired Samples t-test and the Wilcoxon Signed-Rank Test.

DISCUSSION

CAPD, which may occur in children and adults of all ages, is neurobiological in origin and affects both the perceptual processing of auditory information and neural transmission (17). Auditory processing does not depend on the functions of the auditory system alone; it is also influenced by other factors such as memory, attention, phonological skills, learning, and cognition. CAPD may therefore have a substantial effect on abilities and capacities that are important for everyday life and academic performance (18), which makes early identification and management of the disorder critically important.

The central auditory skills relevant to communication include discriminating and recognizing patterns, integrating and discriminating temporal information, the dichotic processing of competing or concurrent stimuli, and localizing or lateralizing sound (19). Understanding how auditory processing contributes to listeners' communication abilities under different conditions is therefore important for both diagnosis and rehabilitation (20).

CAPD tests are designed to assess central auditory function. Performance on speech-based tests may depend on numerous factors that audiologists cannot readily measure, including language skills, speech abilities, and cognitive factors. It has therefore been recommended that performance be assessed across tasks of differing difficulty (21). Accordingly, several tests employing verbal stimuli composed of familiar Turkish words (the DWT, AFGT, DST, FWT, and DMCT) were included in the T-Anatolia CAPDT for use with native speakers of Turkish. Two tests with nonverbal stimuli were also added: the BFTPT, in which combinations of three sinusoidal tones at low (300 and 350 Hz) and high (3000 and 3050 Hz) frequencies are presented, and the DFTPT, in which low (300 and 350 Hz) or high (3000 and 3050 Hz) frequency tones are presented dichotically. These two tests distinguish the present battery from existing test batteries. Within the battery, the BFTPT, AFGT, DST, DWT, and FWT serve as screening tests for

Turk J Clin Res. 2026;2(2):158-171
https://doi.org/10.63909/1453056

CAPD, whereas the DFTPT and DMCT are intended for diagnostic purposes. The data obtained were intended to serve as a reference in the clinical assessment of individuals with CAPD.

It is important that individuals undergo a routine audiometric evaluation before behavioral testing begins (10). In the present study, pure-tone thresholds, middle ear pressure, and acoustic reflexes were therefore assessed in all individuals before the CAPD screening and diagnostic tests were administered, and only those with normal results on these measures were included.

In the present study, the EFA results for the T-Anatolia CAPDT provided supportive evidence for the construct validity of the battery via its factor structure, while the high coefficients obtained indicated excellent reliability and internal consistency. The six-factor structure supported by the exploratory factor analysis suggests that the battery assesses central auditory processes in a multidimensional and functional manner and offers a comprehensive clinical evaluation for the differential diagnosis of CAPD. The factors obtained represent different neurocognitive functions of the auditory system: Verbal-Auditory Memory (F1), Dichotic Tonal Temporal Processing (F2), Auditory Sequential Pattern Perception (F6), Auditory Closure (F3), Complex Verbal Message Discrimination (F4), and Right Ear Verbal Dominance (F5). Although F5 and F6 (contain only one subtest each (DST-RE and BFTPT)—which typically limits statistical stability—they were intentionally preserved as independent factors. Merging or dropping them would compromise the clinical integrity and diagnostic sensitivity of the battery, as both evaluate highly specialized neuro-auditory processes. Future studies with larger clinical samples will be beneficial to further confirm the stability of this specific factor layout.

The reliability and internal consistency findings for the T-Anatolia CAPDT indicate that the tests have a sound psychometric basis capable of yielding stable results in both clinical and research settings. The excellent consistency coefficients obtained for the DMCT and DWT in particular suggest that these tests provide highly reliable measures of auditory processing. The high stability values obtained for the BFTPT likewise support the consistency of this test in the measurement of temporal processes. The acceptable, moderate reliability coefficients observed for the DST and FWT subtests may be explained by the high level of performance achieved by the healthy participants on these tests and the resulting ceiling effect. The well-developed auditory closure abilities and typical short-term memory capacity of healthy individuals may have minimized between-participant variability in DST and FWT scores. The comparatively low agreement coefficients on these two tests may therefore reflect the healthy composition of the sample and the homogeneously high performance it produced, rather than any unreliability of the tests themselves.

The correlation analysis showed that the tests using nonverbal auditory stimuli were unrelated to the other tests, which suggests that temporal processing is governed by distinct neural mechanisms that operate independently of the other processes assessed. Although central auditory functions are interconnected, they need not correlate with one another (20). The weak positive relationship between the Auditory Figure-Ground Test and the dichotic tests suggests that selective attention in noise and the processing of dichotic signals engage partly overlapping but nonetheless different central auditory mechanisms. The relationship between the Dichotic Word Test and the DMCT suggests that the functions assessed by these tests share similar linguistic and hemispheric processes. These findings are consistent with the literature indicating that, in the diagnosis of CAPD, each subtest of a battery is both complementary to the others and of distinct clinical value in its own right (17).

In the present study, the TAIBTA, a questionnaire developed by our group, was administered to all participants before the behavioral screening and diagnostic tests. Self-report questionnaires may yield results consistent with objective assessments and can identify auditory difficulties effectively (22, 23). Of the tests in the battery, the TAIBTA scores showed the strongest negative relationship with the DST scores, and low-level negative relationships with the AFGT, FWT and DFTPT. The finding that poorer questionnaire scores were significantly and negatively related to performance on the DST, FWT, AFGT, and DFTPT supports the view that the questionnaire captures everyday listening difficulties. The strongest relationship, observed with the DST, suggests that subjective complaints become

Turk J Clin Res. 2026;2(2):158-171
https://doi.org/10.63909/1453056

most apparent in the comprehension of complex speech, which imposes the greatest higher-order cognitive and linguistic demands.

When the T-Anatolia CAPDT results were examined by sex, females performed better than males on the AFGT, DWT, and DMCT, all of which use verbal stimuli, whereas men performed better than females on the DFTPT. The human auditory system differs both functionally and structurally between males and females (24). Men have been reported in the literature to outperform females on temporal processing skills such as ordering and patterning, and the ratio of white matter to gray matter (myelinated connective tissue relative to nerve cells) has been found to be higher in the males brain (25). An advantage in favor of women has been reported for situations requiring concentration and listening effort (24). Our findings are consistent with the literature (24,25).

In the comparison of right and left ear performance, right ear performance was significantly better than left ear performance on the DST, the DWT (C1), and the DMCT. No significant differences between ears were found for the remaining tests. This right ear advantage in the auditory processing scores of healthy participants is consistent with the right ear advantage described in the literature. The direct (contralateral) transmission of auditory stimuli from the right ear to the left cerebral hemisphere, which is responsible for speech processing, accounts for the higher performance of this ear in healthy individuals (26). Kimura proposed that auditory input is processed predominantly via contralateral pathways and that speech perception is dominated by the left hemisphere (26). In our study, a right-ear advantage was observed for verbal stimuli in various dichotic tests, whereas similar performance between the two ears was observed in non-verbal tests and the AFGT.

The limitation of the study is the absence of a clinical CAPD group to evaluate the diagnostic utility of the developed test battery, as this study primarily focused on the preliminary standardization and establishment of normative data within a healthy adult population; hence, future studies incorporating clinical CAPD groups are warranted to determine its diagnostic sensitivity and specificity.

CONCLUSION

In this study, normative data and psychometric information regarding healthy young adults were obtained using the T-Anatolia CAPDT, which was developed for screening and diagnosing CAPD. These data obtained with the T-Anatolia CAPDT, which supports a six-factor structure capable of evaluating central auditory processes in a multidimensional and functional manner, will establish a foundation for future clinical validation studies. In the next stage of this work, the battery is to be administered to patient populations with CAPD in order to establish its clinical validation"

Supplementary Materials: Supplementary Appendices 1, 2, and 3 are available at the following link: https://drive.google.com/drive/ folders/1T5LgFiRRhH35jWRzMf3eQLgzij9KKt9s?usp=drive_link

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