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Auditory processing skills of school-age children diagnosed with dyspraxia

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Abstract

Objective: We aimed to analyse the auditory processing skills of children with developmental dyspraxia (DD) and verify the potential relationships between DD and central auditory processing disorder. *Methods:* 40 children between the ages of 6-8 years, 20 children diagnosed with DD and 20 children with normal development, were included in the study. After the demographic information forms for children were filled out, all participants were given a hearing test. To evaluate the auditory processing skills, filtered words(FW), auditory figured ground (AFG), competing words (CW), and competing sentence (CS) tests, which are the sub-steps of the SCAN-C test, were applied. *Results:* The Scan-C test FW, AFG, CW, CS tests were applied to the groups separately and dichotically for the right and left ears. The number of correct answers was higher in the normally developing control group. A statistically significant difference was found between the FW Right; FW Left; CW Right; CW Left and CS Right; CS Left groups ($p<0.05$).
Conclusion: A delay experienced at the stages of transmission, processing, and perception of the incoming stimuli may lead to functional problems such as attention, learning, and motor and psychosocial effects. To prevent problems to be encountered in the later periods of life, early diagnosis should be made through appropriate tests, and early intervention is necessary to eliminate problems and prevent developmental delays. A multidisciplinary team interaction can be useful for an integrated treatment plan.

Keywords: Auditory processing disorder, Developmental coordination disorder, dyspraxia

INTRODUCTION

Central auditory processing is a function of the central auditory nervous system. It enables the perception and interpretation of audible sounds, and it is responsible for skills such as[1,2] sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition (distribution, masking, integration, ordering), and the ability to identify or recognize degraded or competing acoustic targets.[1,3] Auditory processing skills are important for memory, learning, attention, long-term phonological representation, and other neurocognitive processes at a higher level.[4] Auditory processing occurs along the temporo-parieto-occipital junction area (the area involving the Wernicke area in humans) as well as the superior temporal gyrus (STG) and superior temporal sulcus (STS). In addition, it occurs in the prefrontal and orbital regions of the brain as well as the temporal pole (anterior temporal lobe).[5]

The presence of deterioration in auditory processing skills despite normal hearing and intelligence levels is described as central auditory processing disorder (CAPD). CAPD is a deficiency in the neural processing of auditory stimuli.[3] Its symptoms include difficulty in listening and not being able to track dialogues by focusing attention on the speaker, ignoring the speaker due to their engagement in other activities, sensitivity to sound or noise, and difficulty in understanding complex instructions. In addition to these comorbidities, it may lead to problems in attention, linguistic development, learning skills, being organized, and time management.[1,3]

Developmental coordination disorder (DCD) is a neurodevelopmental disorder that is not associated with a cognitive impairment, cannot be explained by an identifiable physical or neurological disorder, and is characterized by difficulties in the execution, timing, and coordination of motor actions.[6] Recognizing

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the DSM-5 criteria, the definition of DCD is supported by terms such as "Clumsy Child Syndrome" and "Developmental Dyspraxia".[7] Developmental dyspraxia (DD) is characterized by motor learning disorders and negatively affects activities required for daily living. In general, other neurodevelopmental and psychiatric disorders such as specific learning disorders, linguistic disorders, attention-deficit hyperactivity disorder (ADHD), and autism spectrum disorder (ASD) accompany the diagnosis.[8] In an functional magnetic resonance imaging study, cerebellum dysfunction or cerebellar-parietal and low activity in the cerebellar-prefrontal region junctures was found to be the cause of DD.[9] In another study, the DD group displayed low activity in the cerebellar-parietal and cerebellar-prefrontal networks and brain regions associated with visual-spatial learning.[10]

Temporal aspects of hearing are important in the perception and processing of auditory stimuli and planning and producing behaviours. Sensory temporal ability is a prerequisite for controlling motor coordination.[11] Studies have demonstrated the relationship between auditory processing difficulties and inadequate motor coordination, and it has been argued that the underlying cause of auditory processing, sensory function disorder, and motor coordination problems is neural mechanism problems[12] and that timing in auditory processing occurs through interactions between nervous circuits that involve auditory and motor systems.[13]

In line with this information, we believe that auditory processing timing deficiencies can also be the essential features of DD. To elucidate this relationship, we aimed to analyse the auditory processing skills of children with DD and verify the potential relationships between DD and CAPD.

METHODS

The study was evaluated to be suitable in terms of medical ethics by the Ankara Yıldırım Beyazıt University Non-Interventional Clinical Research Ethics Committee with decision number 10-486. The children included in the study and their parents were informed about the purpose and scope of the study, and written consent forms were obtained from the children and their parents. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Participants

Among the children aged 6-9 years who were referred to special child and adolescent psychiatry clinics because of various suspicions by their families, 20 children (9 girls, 11 boys) who had no diagnosis and who were found to be developing normally after examination by the specialist doctor and 20 children (8 girls, 12 boys) who were diagnosed with DCD according to DSM-5 criteria after examination were included in the study. Children were included if they had no diagnosed hearing loss, no concomitant chronic illness or additional neurological disability, and cooperated during testing. Hearing screening and SCAN-C testing were performed on children randomly selected by the audiologist at the clinics they visited.

Based on preliminary data, a G*Power analysis was performed, yielding 95% power, a 0.05 error margin, and an effect size of 1.088. The required sample size for the study was determined to be 40. Consequently, 20 children diagnosed with DCD were included in the study group, while 20 children with typical development formed the control group.

Study protocol

After the demographic information forms for children were filled out, all participants were given a hearing test. To evaluate the auditory processing skills, filtered words, auditory figured ground, competing words, and competing sentence tests, which are the sub-steps of the SCAN-C test, were applied.

Auditory screening

In the school-age hearing screening protocol, applied in our country, children who hear at 20 dB HL at test frequencies of 500–1000–2000–4000 Hz in both ears are considered a "Passed".[14]

Scan-C

In 1974, Jack Willeford published the SCAN-3 auditory processing test battery for diagnosis. The batter was revised in the process and split in two as SCAN-A[15] and SCAN-C.[16] The SCAN-C battery evaluates children's auditory processing skills in the areas of temporal processing, listening in noise, dichotic listening, and listening to filtered stimuli (listening to degraded speech) (Keith, 2000). In the present study, the SCAN-C Turkish Language Version was used.[17]

The SCAN-C screening scale consists of four subtests, including filtered words, auditory figured ground, competing words, and competing sentences. In each subtest, the instructions are given through the recording. Before the test, children prepare for the test by doing two sample exercises. Test stimuli were presented at the best hearing level through supaural headphones in the best listening conditions.[16,17]

Filtered words (FW): This test evaluates the child's ability to understand one-syllable words as speech stimuli degraded with a low-pass filter at 1000 Hz.[16]

Auditory figure-ground (AFG): This test evaluates the child's ability to understand the speech in the presence of background noise(babble noise) at +8 dB S/N rate.[16]

Competing words (CW): This test measures the child's ability to understand simultaneous speech stimuli presented to the left and right ear (presented as one-syllable word pairs) Both words are recorded at equal volumes in stereo. The maximum deviation between word pairs is ±10ms. The child is asked to repeat both words in the order of reciting. (binaural integration test).[16]

Competing sentences (CS): This test is used to evaluate the child's ability to understand sentences presented as irrelevant pairs to the right and left ears. The sentences are presented simultaneously at the same volume. The time difference between the beginning and ending times of both sentences is no more than ± 10 ms. Sometimes, the child is asked to repeat the sentence they hear through one ear and ignore the sentence they hear through the other ear. Sometimes, it can be applied as a binaural separation test.[16]

All subtest words and sentences were voiced with a comprehensible and clear diction by a male speaker. Before the presentation of the word stimuli, "Say" and "The word you will say" were used as carrier sentences. In the FW, AFG, and CW subtests, a 4-second interval was given, and in the CS subtest, a 5-second interval was provided before moving on to a new stimulus. This interval provides children between the ages of 5-11 years with ample time for the response, considering the attention span by keeping the test time short.[16]

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 software (IBM Corp.; Armonk, NY, USA). Sample size was determined using G*Power version 3.1 software (with parameters: correlation of interest $\rho H1 = 0.5$, α error rate = 0.05, power = 0.95). For descriptive statistics, percentages were used for categorical variables. Means ± standard deviations were used for descriptive statistics of variables. Histograms and bell curves were used to assess whether the data followed a normal distribution. When comparing paired samples, the t-test was used to compare normally distributed data. Student's t-test or Mann-Whitney U test was used to compare two groups. A p-value of 0.05 was considered statistically significant.

RESULTS

The study included 40 children with an average age of 7.55±0.73 of these, 20 children diagnosed with dyspraxia (8 girls, 12 boys) constituted the study group, and 20 normally developing children (9 girls, 11 boys) constituted the control group. In our study, stronger and more original groups were created by minimizing the factors that would affect the evaluation results. Demographic information of the children is shown in Table 1.

The Scan-C test FW, AFG, CW, CS tests were applied to the groups separately and dichotically for the right and left ears. The number of correct answers was higher in the normally developing control group. A statistically significant difference was found between the FW Right; FW Left; CW Right; CW Left and CS Right; CS Left groups ($p<0.05$) (Table 2).

DISCUSSION

It has been stated in the literature that the socioeconomic status of the family affects exposure to the stimuli and leads to differences in the results due to the effect of age on neuronal maturation. Considering this information, the groups were homogenously distributed in terms of age, socioeconomic status, and gender.

The accurate processing of the senses arising from the environment, or our bodies affects all developmental areas. Any problem in the neural transmission and cortical and subcortical processing of the stimuli coming to the body may lead to differences in the child's behaviours.[18]

When there is a problem in the processing of the auditory stimuli at the upper centres despite a healthy hearing system, problems are experienced such as not understanding the direction of the sound, tracking the speaker and communicating, temporal organization of incoming stimuli (analysing, masking,

Table 1: Comparison of groups according to their demographic information

		Study Group	Control Group	p
Age (year)	Mean± SD (Min-Max)	7.55±0.61 (6-9)	7.61±0.84 (6-9)	0,82
Gender	Female (n) Male (n)	8 (%40) 12 (%60)	9 (%45) 11 (%55)	0,825
socioeconomic status	High (n) Medium (n) Low (n)	7 (%35) 7 (%35) 6 (%30)	6 (%30) 8 (%40) 5 (%25)	0,732

integration, and sequencing), distinguishing the background noise, understanding, and following. Therefore, this situation experienced at an early period negatively affects the child's memory, learning, attention, speech, and other higher-level neurocognitive processes.

Even if there are no comorbid physical and neurological problems in the developmental coordination disorder, problems in motor skills, coordination, and timing are experienced. This situation negatively affects the child's learning and behaviours in social environments.[11]

Temporal organization is one of the basic requirements for cognitively processing and interpreting the stimuli and transforming them into perceptions. In studies conducted, it has been demonstrated that CAPD and DD may result from a similar neural mechanism at the cortical level.[10] However, in the literature review, no study was encountered in which the auditory processing skills of children with DD were evaluated. In line with our objective to elucidate this relationship, it was determined that there was a significant difference between the auditory processing skills of children with dyspraxia compared to the control group with normal development. Particularly, simultaneous different stimuli were given to both ears in dichotic tests such as CW and CS, and a significant difference was observed in the binaural integration skills. Binaural integration evaluations provide information about the brain stem, cortical lesions, and corpus callosum.[19] They specifically focus on temporal analysis skills. Temporal analysis refers to the skill of noticing the temporal difference between the acoustic stimuli or the gap between auditory stimuli.[20] Deficits in temporal analysis can result in difficulties in the listener's recognizing fast-changing speech sounds, distinguishing them, and interpreting the auditory message.[21] We think that as children with DD experience problems in temporal analysis at the brain stem level, they cannot learn motor skills and experience behavioural problems.

As in the FW subtest which yielded a difference, single-ear low-component speech tests evaluate the skill of complementing the lost component in diminishing signals. The tests in this category cover the skill of complementing the missing components in the stimuli heard.[22] When this skill does not develop, the child will experience difficulties in understanding low or distorted sounds and will not be able to interpret them.

Tablo 2: Comparison of Scan-C between groups

					95% confidence interval		
	Study Group	**Control Group**	**Min**	**Max**	**lower**	**upper**	**p**
FW Right	3.33±0.84	4.61±1.33	2.00	8.00	-2.03	-0.52	**0.02***
FW Left	2.50±0.85	4.22±1.80	1.00	7.00	-1.67	0.223	**.034***
AFG Right	7.55±0.78	7.41±1.46	5.00	9.00	-0.68	0.91	.778
AFG Sol	7.22±1.16	7.88±0.96	5.00	9.00	-1.37	0.038	.063
CW Right	1.77±1.16	2.61±1.62	.00	5.00	-0.78	1.12	**0.03***
CW Left	1.16±0.78	3.95±2.26	.00	8.00	-2.03	0.25	**.012***
CS Right	1.44±0.85	2.48±1.08	.00	3.00	-0.21	1.16	**.018***
CS Left	0.61±0.60	1.66±0.97	.00	3.00	-0.62	0.49	**.038***

Independent t test, $p<0.05$, mean; Mann Whitney U test, min-max
FW, filtered words; AFG, auditory figure-ground; CW, competing words; CS. competing sentences

After some time, problems in attention skills and therefore in learning can be observed. We believe that delays in learning activities among children with DD are a harbinger of poor performance.

When activity performances are delayed due to the delays in skills that need to be learned for participation in life, advanced motor development slows down.[23] The decrease in the level of participation in life may affect the child's internal emotional experiences and have a negative impact on self-confidence development. Considering this, early diagnosis and intervention are of great importance. We would like to emphasize that delays in learning should be recognized at an early period, and interventions to prevent the difficulties to be experienced in activity performance levels should be supported. Identifying the exact cause of the existing delay in learning and adopting a multidisciplinary approach by determining the comorbid factors will facilitate process management.

It is known that motor effects and coordination difficulties of children and young individuals with DD can expose them to various secondary stress factors, which may lead to poor mental health over time.[24] In studies conducted, these secondary effects were exemplified as peer bullying, disrupted social skills, and decreased social behaviors.[25] We believe that situations such as short attention span, inability to maintain a conversation, and not understanding speeches in a crowded environment in individuals with CAPD trigger secondary effects observed in children with DD.

Not to confuse them with neurodevelopmental disorders (ADHD, autism) that show similar findings and symptoms, children should be evaluated in detail with a multidisciplinary approach and personal intervention programs should be prepared for children. Evaluating auditory processing skills in children with DD is also important in terms of identifying the source of the difficulties experienced by children and organizing personal intervention programs, as well as improving their communication skills and quality of life.

A limitation of the present study is that the motor skills of children with DD were not evaluated in detail. As CAPD was determined in % 45 of the children with DD participating in our study, language and speech skills of children with DD can be evaluated in future studies.

İn conclusion, child development occurs through the holistic processing of stimuli from both the environment and the individual's internal systems. Delays in the transmission, processing, and perception of these stimuli can lead to functional issues such as challenges in attention, learning, motor skills, and psychosocial development. At this point, early intervention strategies are critically important for supporting the child's development. Examples of such strategies include auditory rehabilitation, sensory integration therapies, and play-based interventions to enhance the child's interaction with their environment, as well as family education programs to actively involve parents in the process. We emphasize the importance of a multidisciplinary team approach to adopting a holistic perspective on child development.

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DISCLOSURE

Ethics: It has been approved by Ankara Yıldırım Beyazıt University Non-Interventional Clinical Research Ethics Committee with registration number 10-486. Informed, voluntary consent has been obtained from all children and their families.

Data availability: The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

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REFERENCES

1. Buffone FRRC, Schochat E, ed: Sensory profile of children with Central Auditory Processing Disorder (CAPD). *Codas* 2022; 34(1):e20190282. https://doi.org/10.1590/2317-1782/20212019282
2. Crum R, Chowsilpa S, Kaski D, Giunti P, Bamiou DE, Koohi N. Hearing rehabilitation of adults with auditory processing disorder: a systematic review and meta-analysis of current evidence-based interventions. *Front Hum Neurosci* 2024;18:1406916. https://doi.org/10.3389/fnhum.2024.1406916
3. Jerger J, Musiek F. Report of the consensus conference on the diagnosis of auditory processing disorders in school-aged children. *J Am Acad Adiol* 2000;11(09):467-74. DOI: 10.1055/s-0042-1748136
4. Dlouha O, Novak A, Vokral J. Central auditory processing disorder (CAPD) in children with specific language impairment (SLI): Central auditory tests. *Int J Pediatr Otorhinolaryngol* 2007;71(6):903-7. https://doi.org/10.1016/j.ijporl.2007.02.012

5. Kaas JH, Hackett TA. Subdivisions of auditory cortex and processing streams in primates. *PNAS* 2000;97(22):11793-9. https://doi.org/10.1073/pnas.97.22.11793
6. Dannemiller L, Mueller M, Leitner A, Iverson E, Kaplan SL. Physical therapy management of children with developmental coordination disorder: an evidence-based clinical practice guideline from the Academy of Pediatric Physical Therapy of the American Physical Therapy Association. *Pediatr Phys Ther* 2020;32(4):278-313. DOI: 10.1097/PEP.0000000000000753
7. Tunçtürk M, Ermiş Ç, Mutlu C. Developmental coordination disorder. *Comprehensive Med* 2019; 11(Supp: 1):56-68. DOI: 10.5222/iksstd.2019.08831
8. Ferguson G, Jelsma J, Versfeld P, Smits-Engelsman B. Using the ICF framework to explore the multiple interacting factors associated with developmental coordination disorder. *Current Developmental Disorders Reports* 2014;1:86-101. DOI 10.1007/s40474-014-0013-7
9. Pearsall-Jones JG, Piek JP, Rigoli D, Martin NC, Levy F. An investigation into etiological pathways of DCD and ADHD using a monozygotic twin design. *Twin Res Hum Genet* 2009;12(4):381-91. doi:10.1375/twin.12.4.381
10. Zwicker JG, Missiuna C, Harris SR, Boyd LA. Brain activation associated with motor skill practice in children with developmental coordination disorder: an fMRI study. *Int J Dev Neurosci* 2011;29(2):145-52. https://doi.org/10.1016/j.ijdevneu.2010.12.002
11. Trainor LJ, Chang A, Cairney J, Li YC. Is auditory perceptual timing a core deficit of developmental coordination disorder? *Ann N Y Acad Sci* 2018;1423(1):30-9. https://doi.org/10.1111/nyas.13701
12. Tran HT, Li YC, Lin HY, Lee SD, Wang PJ. Sensory processing impairments in children with developmental coordination disorder. *Children* 2022;9(10):1443. https://doi.org/10.3390/children9101443
13. Morillon B, Schroeder CE. Neuronal oscillations as a mechanistic substrate of auditory temporal prediction. *Ann N Y Acad Sci* 2015;1337(1):26-31. https://doi.org/10.1111/nyas.12629
14. Karakoc K, Mujdeci B. Evaluation of balance in children with sensorineural hearing loss according to age. *Am J Otolaryngol* 2021;42(1):102830. https://doi.org/10.1016/j.amjoto.2020.102830
15. Keith RW. SCAN-A: A test for auditory processing disorders in adolescents and adults: Psychological Corporation; 1994.
16. Keith RW. Development and standardization of SCAN-C test for auditory processing disorders in children. *J Am Acad Audiol* 2000;11(08):438-45. DOI: 10.1055/s-0042-1748131
17. Yalçinkaya F, Türkyilmaz MD, Keith R, Harris R. The Scan-C (Children) in testing for auditory processing disorder in a sample of Turkish children. *J Int Adv Otology* 2015;11.
18. Baş B, Gökay NY, Aydoğan Z, Yücel E. Do auditory brainstem implants favor the development of sensory integration and cognitive functions? *Brain Behav* 2024;14(8):e3637. https://doi.org/10.1002/brb3.3637
19. Ma X. Comprehensive assessment of (central) auditory processing disorder in school age children with non-syndromic cleft lip and/or palate. HKU Theses Online (HKUTO). 2014. DOI: 10.5353/th_b5387986
20. Boscariol M, André KD, Feniman MR. Cleft palate children: performance in auditory processing tests. *Braz J Otorhinolaryngol* 2009;75(2):213-20. https://doi.org/10.1016/S1808-8694(15)30780-1
21. Bellis TJ, Chermak GD, Weihing J, Musiek FE. Efficacy of auditory interventions for central auditory processing disorder: A response to Fey et al.(2011). *Lang Speech Hear Serv Sch* 2012; 43(3):381-6. https://doi.org/10.1044/0161-1461(2012/11-0085)
22. Bellis TJ, Bellis JD. Central auditory processing disorders in children and adults. *Handb Clin Neurol* 2015;129:537-56. https://doi.org/10.1016/B978-0-444-62630-1.00030-5
23. Van der Linde BW, van Netten JJ, Otten B, Postema K, Geuze RH, Schoemaker MM. Activities of daily living in children with developmental coordination disorder: Performance, learning, and participation. *Phys Ther* 2015;95(11):1496-506. https://doi.org/10.2522/ptj.20140211
24. Omer S, Jijon AM, Leonard HC. Research review: Internalising symptoms in developmental coordination disorder: a systematic review and meta-analysis. *J Child Psychol Psychiatry* 2019;60(6):606-21. https://doi.org/10.1111/jcpp.13001
25. Rigoli D, Kane R, Mancini V, *et al*. The relationship between motor proficiency and mental health outcomes in young adults: A test of the Environmental Stress Hypothesis. *Hum Mov Sci* 2017;53:16-23. https://doi.org/10.1016/j.humov.2016.09.004