Medical Research Archives

European Society of Medicine

OPEN ACCESS

Published: March 31, 2024

Citation: Moncrieff, D., and Mendez, K., R., G., 2024. Prevalence of dichotic deficits in adjudicated adolescents: Implications for language skills and competency within the juvenile justice system. Medical Research Archives, [online] 12(3). https://doi.org/10.18103/mra.v12i3.5099

DOI: https://doi.org/10.18103/mra.v12i3.5099

ISSN: 2375-1924

RESEARCH ARTICLE

Prevalence of dichotic deficits in adjudicated adolescents: Implications for language skills and competency within the juvenile justice system

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ABSTRACT

This study reports the prevalence of dichotic listening weaknesses in 10-18-year-old adjudicated adolescents and its potential impact on their language skills. The findings reveal that 35% of adjudicated adolescents exhibited matched dichotic deficit patterns sufficient to diagnose an APD, a prevalence rate that is higher than the 19% rate among age-matched typically developing children but lower than the 45% rate among age-matched children evaluated clinically for an auditory processing disorder (APD). These rates for all groups are significantly higher than the 2-7% prevalence rate commonly reported for APD in the pediatric population. The study also identified a link between low scores on dichotic listening tests and language deficits, suggesting potentially negative consequences for successful navigation through the juvenile justice system for these adolescents. These results challenge the sustained underestimation of auditory processing risks in children and advocate for early identification and treatment of common processing deficits, emphasizing the need for consensus among researchers and clinicians in identifying and treating them. The implications of untreated auditory processing deficit on educational achievement, language skills, and behavior in adjudicated adolescents are discussed, emphasizing how they contribute to the schools-to-prison pipeline in the United States (U.S.). The study concludes by suggesting that early intervention through an evidence-based short-term auditory training protocol can improve dichotic listening and may alleviate some long-term educational underachievement and dysregulated behaviors associated with juvenile incarceration. The findings underscore the need for increased awareness, screening, and intervention for dichotic listening deficits in general and particularly in the at-risk, underserved pediatric populations world-wide.

Introduction

After the number of children arrested in the United States hit a peak of 2.7 million in the 1990's, major policy changes are credited for steadily declining rates of juvenile arrests, down to 696,620 in 2019. Despite these improvements, violent crime has risen from 5 to 8% of arrests. Males accounted for 80% of youth-related violent crimes with an even higher share of those arrested for murder (92%) and robbery (88%); white youths accounted for half (49%) of those arrests and 57% of the total were arrested for aggravated assault (Puzzanchera, 2022). The number of children placed in the juvenile justice system has also been significantly reduced, but there are still over 40,000 children (about twice the seating capacity of Madison Square Garden) in U.S. detention centers on any given night. Two- thirds of juvenile detainees are children of color (40% Black and over 20% Hispanic), a higher proportion than in the general population (Sickmund & Puzzanchera, 2019). The black/ white racial disparity ranges from a low of 2.2 in Indiana to a high of 17.5 in New Jersey, with several states detaining 9 or more times the number of black youths as white (California, Connecticut, District of Columbia, and Wisconsin). While some states in the U.S. have decreased racial disparities over the past few years, three states have seen their racial disparity grow by at least one-third (South Carolina, Tennessee, and Nebraska) (Puzzanchera, Hockenberry, Sladky, & Kang 2022). The rate of placement for males is 5 times greater than for females and the rate for lesbian, gay, bi, trans and queer (LGBTQ) children at 20% is more than twice the rate of 7-9% in the general population.

Several risk factors that contribute to youth violence include attention deficit, conduct disorder, involvement with drugs, alcohol and tobacco, poor educational achievement, school failure, unemployment, and exposure to violence in the family. A World Health Organization report noted that youth violence is the 4th leading cause of death among young individuals worldwide and that community risk factors include high income inequality, poverty, access to and misuse of alcohol, drugs, and firearms, and limited policies for education and social protection. Poor academic performance, school suspension and expulsion, and school dropout are known risk factors for delinquency and crime (Cuellar & Markowitz, 2015, Lee and Villagrana, 2015, Pettit and Western, 2004). In the U.S., over 5% of schoolchildren experience out-of-school suspension that impacts black students and students with disabilities at higher rates than their white or non-disabled counterparts (Riddle & Sinclair, 2019), especially those who are culturally and linguistically diverse (Snyder de Brey & Dillow, 2016).

Once incarcerated, children are at risk of abuse, assault, suicide, and other harms, including inadequate education. They are exposed to harsh conditions and intensive supervision, widespread violence and maltreatment, overreliance on confinement, and glaring racial and ethnic disparities (Ford, et al., 2007). These conditions are known to exacerbate symptoms for youth with mental health problems or a history of trauma or abuse. It also disrupts schooling and increases the likelihood that the youth will fail classes or drop out. The average length of stay in detention is 27 days, but there is evidence that even a short stay can lead to a greater likelihood of being formally charged, found delinquent, and committed to corrections facilities than if the youth were to remain at home prior to a court hearing. Evidence has also shown that a stay in pretrial detention increases a youth's likelihood of felony recidivism by 33% and misdemeanor recidivism by 11% (Walker, et al., 2020) because youths in detention learn deviant behaviors, experience disruption in important protective influences, and are exposed to traumatic experiences. In a sense, confinement with other youths arrested for offending behavior under the supervision and control of authority figures works as an alternative peer-based classroom for youths to develop counterproductive strategies to continue criminal behavior and avoid arrest.

Despite the requirement that education services be provided for detained and confined youth under provisions of the Elementary and Secondary Education Act of 1965, the highly transient nature of detention together with the complicated mental health and academic needs of incarcerated youth create significant challenges for this requirement. Youth who achieve higher levels of education, either before or during detention, are more likely to experience positive outcomes in the community after release (Blomberg, et al., 2011; Cavendish, 2014), but the detention center's educational services cannot overcome intellectual deficiencies and poor academic achievement that plague many juvenile residents (Krezmien, et al., 2008). Forty-eight percent of youths in custody reported below grade level grades with inferior performance on standardized achievement tests, language and literacy skills, and math scores compared to 28% of youths in the general population (Sedlak & Bruce, 2010).

There are strong links between juvenile delinquency and academic underachievement (Crawford, 1984; Hawkins, Lishner, & Johnson, 1987; Hinshaw, 1992; Hirschi & Hindelang, 1977; Rutter & Giller, 1983) and communication disorders, especially for male students (Stattin & Klackenburg- Larsson, 1993). Early researchers reported a prevalence of language impairment among incarcerated adolescents ranging from 20% (Blanton & Dagenais, 2007; Sanger, Moore-Brown, Magnuson, & Svoboda, 2001) to 40% (Davis, Singer, & Morris-Friehe, 1991), with one study reporting that 66-90% of incarcerated juveniles performed below normal levels on tests of language with 46-67% in the poor to very poor group (Bryan & Freer, 2007). Another study reported that an estimated 70% of the juvenile justice population suffered from a learning disability, with one-third failing to acquire age-appropriate reading skills (Wald & Losen, 2003). Prevalence of learning disabilities among detainees ranges widely with overrepresentation for emotional-behavioral disorders, specific learning disabilities, and other health impairments, disabilities for which eligibility for special education services is weak, but even autism spectrum disorder, developmental cognitive disabilities, physical or sensory impairments, and speech-language impairments that are all eligible for services under the Individuals with Disabilities Education Act (IDEA) are also underrepresented (Kincaid & Sullivan, 2020). As many as one-third of youths in the juvenile justice system has a disability qualifying them for special education services, a rate that is 4 times greater than the rate for youth in public schools, yet fewer than half receive those services while in custody. A mix of adverse childhood experiences, poverty, mental health issues, and school failures may underlie the poor communication, language and literacy skills observed in many adjudicated adolescents (Moncrieff, Miller, & Hill, 2018). When disruptive behavior leads to criminal charges, adolescents are forced into a highly structured system where they must interact with counseling and legal professionals who are trained in mental health and legal issues but who poorly understand or accommodate the juvenile's inability to comprehend and communicate in this unfamiliar and complex environment. The justice system heavily depends on language, beginning with the initial police interview when the adolescent is expected to answer questions and provide a narrative account of events surrounding the crime. Weak narrative production skills in this population (Snow & Powell, 2005) are exacerbated by distracting questions (Agnew et al., 2006) and officers who don't utilize practices for eliciting complete and uncontaminated narratives (Snow et al., 2012). Individuals with language disorders have significant difficulty defining Miranda vocabulary and applying Miranda rights in hypothetical situations (Rost & McGregor, 2012), placing them at risk of being denied their constitutional rights. A language disorder may also interfere with a juvenile's understanding of the conditions and consequences related to bail and parole, leading to subsequent accrual of additional charges (Sprott & Myers, 2011).

A client's ability to process and communicate information effectively is foundational to the attorney-client relationship (LaVigne & Van Rybroek (2011). Standards for competency to stand trial are based on the client's ability to 1) "consult with his lawyer with a reasonable degree of understanding" and 2) have a "rational, as well as factual, understanding of the proceedings against him" (Dusky v.United States, 1960). The Dusky standards have been characterized in a discrete abilities model that characterizes competency to stand trial into three prongs, factual understanding of the proceedings, rational understanding of the proceedings, and ability to consult with counsel. Although not explicitly stated, these standards have been interpreted to regard mental incompetence as primarily a consequence of insanity. Viewing them instead from a cognitive perspective, adequate receptive and expressive language skills are prerequisite as noted by U.S. District Court Judge Jack Weinstein in The United States v. Mosquera (1993) that "effective assistance of counsel is impossible unless the client can provide his or her lawyer with intelligent and informed input." In this light, competency to stand trial requires high-level semantic, syntactic, pragmatic and/or discourse skills, all of which are known weaknesses in individuals with language disorders (Paul, et al., 2017) who demonstrate weak verbal expression, limited vocabulary, an inability to understand figurative language and ask appropriate questions, and difficulty with organizational skills (American Speech Language Hearing Association, 2003). Adjudicated adolescents with language disorders do not understand abstract legal vocabulary and concepts, process complex sentences, provide informative narratives, describe emotional states, or understand expectations and motivations of others. Even in cases when a communication disorder has been identified, most mental health providers are not well-versed in how to modify their interventions for individuals with communication disorders (Hancock, et al, 2023).

Hearing loss and auditory processing disorders have long been linked to poor development of language, reading, and communication skills in children (Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007; Kral, Kronenberger, Pisoni & O'Donoghue, 2016). Children with deficits in hearing sensitivity are eligible for intervention services when identified through mandated universal newborn and school-based hearing screenings, but many children with normal hearing sensitivity may suffer from undiagnosed auditory processing deficits that interfere with their ability to encode complex speech signals that are critical for developing language and literacy skills. Suggested rates of 2-7% dramatically underestimate the prevalence of auditory processing deficits in children for several reasons.

Assessment standards are based on heterogeneous test batteries with standard deviation cutoff measures on results from tests that often do not produce normally distributed results (Strouse & Wilson, 1999; Mattsson, et al., 2017; Moncrieff, 2015; Shaikh, Fox-Thomas, & Tucker, 2016). They also require that a "diagnosis" can be made if the child performs below these normal cutoff scores on any two tests across the battery, regardless of which auditory processing deficit is identified by each test. Dichotic listening and speech recognition in background noise are the most identified auditory processing weaknesses, both of which depend on the integration of speech-based signals through both ears, but current standards do not require weakness in either of these skills to make a diagnosis.

An initial study of 782 adjudicated adolescents reported that over 70% of them showed weakness on at least one dichotic listening test and more than 20% demonstrated consistent patterns of weakness across both dichotic tests (Moncrieff & Wilson, 2009; Moncrieff, 2015). Among a subset of over 400 of these adolescents, half of them fell below age-related criterion on the Clinical Evaluation of Language Fundamentals (CELF) language test (Moncrieff, Miller, and Hill, 2018). A clinical follow-up evaluation of 52 adjudicated adolescents reported that 17% produced matched deficits on both dichotic tests with only 21% demonstrating normal performance, suggesting that there is a critical need for early identification of these deficits (Berken, Miller, & Moncrieff, 2019). The purpose of this study is to summarize results from the final total population of adjudicated adolescents tested at the detention facility and to compare test scores and deficit patterns to results from children of the same age who are typically developing or who were clinically assessed for auditory processing disorder. A second purpose of this study is to further investigate the relationship between dichotic listening scores and language scores in this larger sample of adjudicated adolescents.

Methods and materials

The three groups of 10- to 18-year-old children in the study were adjudicated adolescents residing at a juvenile detention center (n = 1158, 197 females), typically developing children with no previously identified deficits assessed at their school (n= 177, 97 females), and children assessed as part of a clinical evaluation of auditory processing skills (n= 118, 46 females). We assessed hearing and dichotic listening in the juvenile detention center's medical department where the county court system required various screenings. We obtained full-board approval from the Institutional Review Board of the University of Pittsburgh and a memorandum of understanding with the Division of Adolescent Medicine of Children's Hospital of Pittsburgh for procedures at the juvenile detention center. We assessed typically developing schoolchildren in quiet rooms at their schools. Children suspected of auditory processing difficulties were tested in the Auditory Processing Laboratory at the University of Pittsburgh with parental consent and approval by the Institutional Review Board or at the Children's Hospital of Pittsburgh as part of a clinical evaluation for auditory processing disorder. Student clinicians completed all procedures under the direct supervision of the principal investigator of the study as their faculty advisor for clinical training. We screened pure-tone hearing thresholds at the juvenile detention center with a Beltone portable audiometer (Model 120) under supra- aural earphones. We measured hearing thresholds at the hospital and university laboratory through insert earphones attached to a clinical audiometer. Only participants who were able to provide responses to pure tones at ≤ 25 dB HL at 500 Hz and at ≤ 20 dB HL at 1000, 2000, and 4000 Hz in both ears were included in the study with one exception. Because of ambient noise from the heating, ventilation, and air conditioning system in the test room at the juvenile detention center, a biologic calibration performed by the student clinicians on the same Beltone equipment revealed that a correction factor of 10–15 dB was sufficient to compensate for background noise when testing 500 Hz. Therefore, participants were included if they were able to provide a response at ≤ 35 dB for a pure tone at 500 Hz in both ears. Hearing results were validated for an absence of a conductive component by normal peak compliance on tympanometry and present otoacoustic emissions assessed with a Maico ERO-SCAN portable device (ERO-SCAN Pro).

We assessed dichotic listening at the schools and the juvenile detention center with the Randomized Dichotic Digits Test (RDDT; Strouse & Wilson, 1999) and the Dichotic Words Test (DWT; Moncrieff, 2015) at a comfortable listening level through Bose noise-cancelling earphones (Quiet Comfort 15) connected to a laptop computer. We assessed children at the hospital and laboratory with the RDDT and DWT through insert earphones connected to a two-channel audiometer with the output set to 50 dB HL bilaterally. Throughout both dichotic listening tests, we instructed participants to repeat all digits or words heard each time and to guess if unsure. We totaled the number of correctly identified digits or words for each ear under each condition and converted them to percent correct. We then attributed the higher score to the listener's dominant ear and the lower score to the nondominant ear. We calculated the interaural asymmetry for each test as the difference in performance between the listener's dominant and nondominant ears.

Normative data for the RDDT (Moncrieff & Wilson, 2009) and the DWT (Moncrieff, 2015) now include cutoff values for scores that fall below the 25th, 10th and 5th percentiles for children within 5 age groups from age 6 to age 18 (Moncrieff & Wilson, 2009; Moncrieff, 2015; Moncrieff & Ray, in preparation). We compared ear scores and interaural asymmetry for the RDDT two-pair condition (see Moncrieff & Wilson, 2009 for the rationale for using only the 2-pair condition) and for the DWT to the normative cutoff scores for children within the three age groups of children at the juvenile detention center (10 to 12 years, 13 to 15 years, and 16 to 18 years). We interpreted matched deficit patterns from both tests as consistent with 1) amblyaudia (AMB) when the dominant ear was normal and the nondominant ear was below normal and/or the interaural asymmetry was above normal, 2) dichotic dysaudia (DD) when both ear scores were below normal and interaural asymmetry was normal, 3) amblyaudia plus (AMB+) when both ear scores were below normal and interaural asymmetry was above normal, or 4) normal (WNL) if ear scores on both tests were above and interaural asymmetry was below the 25th percentile. Severity rankings for scores from the two tests are displayed in Figure 1.

Scores Test 1	Scores Test 2	Rating	Severity
<5th percentile	< 5th percentile	10	Severe
<5th percentile	< 10th percentile	9	Severe
<5th percentile	< 25th percentile	8	Severe
<5th percentile	> 25th percentile	7	Third test
< 10th percentile	< 10th percentile	6	Moderate
< 10th percentile	< 25th percentile	5	Moderate
< 10th percentile	> 25th percentile	4	Third test
< 25th percentile	< 25th percentile	3	Mild
< 25th percentile	> 25th percentile	2	Third test
> 25th percentile	> 25th percentile	1	Normal

Figure 1. Severity rankings for scores from two dichotic listening tests. Scores below the 5th percentile cut-off are colored in red, scores below the 10th percentile are colored in yellow, and scores below the 25th percentile are colored in green. Scores above the 25th percentile are colored in blue. The final severity rating for the individual is based on the combination derived from the highest severity from each test, i.e. red + red = 10, red + yellow = 9, red + green = 8, red + blue = 7, yellow + yellow = 6, yellow + green= 5, yellow + blue = 4, green + green = 3, green + blue = 2, and blue + blue = 1. Interpretation of overall severity is provided when there are deficits on both tests. When one test result is above the 25th percentile, a third test is recommended.

We also screened 760 of the participants from the juvenile detention center with the Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel, Wiig, & Secord, 2003) and Clinical Evaluation of Language Fundamentals –Fifth Edition (Wiig et al., 2013). As noted in its publication materials, the CELF provides "the only screening measure with research-based criterion scores for older school-age students," with scores obtained from a diverse sample from across the United States. The CELF was administered face- to-face in the same examination room used for hearing and dichotic listening testing. One student clinician administered the test while a second student clinician recorded the participant's responses. The CELF screening score is recorded as an age-related criterion, so comparisons of raw scores could not be made across the range of ages we screened. Therefore, each participant's score was recorded as the number of points above or below the age criterion (or 0 if it matched criterion).

We used Statistical Package for Social Sciences (SPSS) v. 29 to analyze differences in ear scores and interaural asymmetries between the adjudicated adolescents and children within each of the other two groups separately within each of the 3 age groups. Because our results were unequally distributed across different sample sizes, we analyzed scores with the non-parametric Mann-Whitney test to make separate comparisons between adjudicated adolescents and typically developing children and between adjudicated adolescents and children evaluated clinically. Results from statistical comparisons between these groups are shown in Table 1. Statistical results between adjudicated adolescents and typically developing children are shown in the left columns of Table 1 and between adjudicated adolescents and children seen clinically are shown in the right columns of Table 1.

Table 1. Statistical differences between individual ear scores and interaural asymmetry values between adjudicated adolescents and each of the other two groups of children.

			Adjudicated x Typical		Adjudicated x Clinical	
Age Group	Test	Score	U	p	U	p
10 to 12	RDDT	Nondominant	1134.0	**.001**	909.5	.417
		Dominant	1580.0	.203	823.5	.139
		Ear Advantage	2520.0	**.002**	1047.5	.802
	DWT	Nondominant	1611.0	.264	773.0	.062
		Dominant	1557.0	.170	847.0	.193
		Ear Advantage	1955.5	.648	1292.0	**.032**
13 to 15	RDDT	Nondominant	3064.5	**<.001**	4661.0	**.030**
		Dominant	3615.0	**.006**	5029.0	.096
		Ear Advantage	5993.5	**.006**	7540.0	**.037**
	DWT	Nondominant	5903.5	.324	4336.0	**.008**
		Dominant	5721.5	.483	5074.0	.114
		Ear Advantage	4633.5	.289	8202.0	**.002**
16 to 18	RDDT	Nondominant	4621.0	**<.001**	5075.0	.069
		Dominant	6878.5	**.022**	4711.5	**.020**
		Ear Advantage	3237.5	**<.001**	7085.5	.671
	DWT	Nondominant	8063.0	.288	5619.5	.224
		Dominant	8353.5	.428	7162.5	.607
		Ear Advantage	9459.0	.785	8782.0	**.018**

Abbreviations: RDDT = Randomized Dichotic Digits Test; DWT = Dichotic Words Test

Results

Generally, adjudicated adolescents produced poorer ear scores and larger ear advantages than typically developing children, but their scores were not as poor as among children evaluated clinically for an auditory processing disorder. Differences in ear scores across the three groups were larger for the RDDT than for the DWT. The RDDT has a lower linguistic load than the DWT because it uses only the single syllable words for digits from 1 to 10 compared to lists of 25 highly familiar but variable single syllable words on the DWT. The randomized nature of the delivery in the RDDT, however, places a greater demand on the listener's working memory capacity that is considered greatest for the 2-pair condition because the listener's perception of the pairs may be compromised in anticipation of a third pair (Strouse & Wilson, 1996). Compared to typically developing children, adjudicated adolescents produced significantly lower RDDT scores in both ears except for scores for the dominant ear in the youngest group of children as shown in Figure 2. Compared to children seen clinically for an auditory processing evaluation, adjudicated adolescents in the middle age group (13 to 15) produced significantly higher RDDT scores in their non-dominant ear and those in the older age group (16 to 18) produced significantly higher RDDT scores in their dominant ear, also shown in Figure 2. In most cases, adjudicated adolescents produced significantly lower scores than typically developing children that were either as poor as or better than scores produced by children seen clinically.

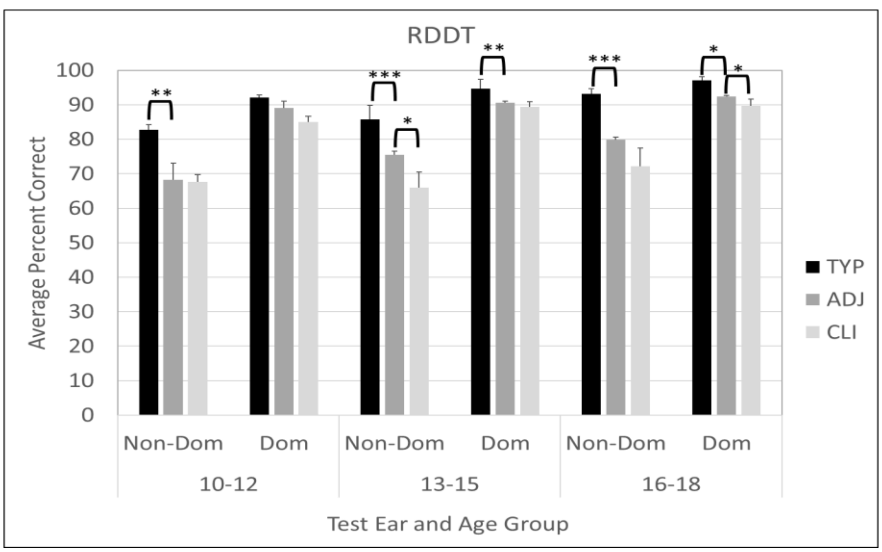

Figure 2. Average non-dominant and dominant ear scores from the Randomized Dichotic Digits Test for participants in each of the three groups (clinical – pale gray, adjudicated adolescents – medium gray, and typically developing – black) within each of the three age groups (10-12 years, 13-15 years, and 16-18 years).

As shown in Figure 3, DWT average scores were non-significantly poorer in the adjudicated adolescents than in the typically developing children except in the middle age group (13 to 15 years) where they were slightly higher. Compared to the children seen clinically, DWT average scores for the adjudicated adolescents were generally higher, achieving significance in the non-dominant ear again in the middle age group.

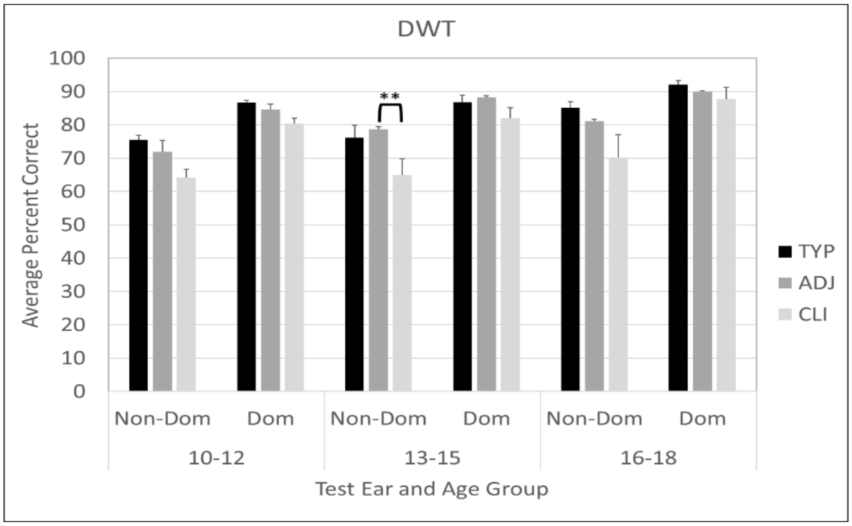

Figure 3. Average non-dominant and dominant ear scores from the Dichotic Words Test for participants in each of the three groups (clinical – pale gray, adjudicated adolescents – medium gray, and typically developing – black) within each of the three age groups (10-12 years, 13-15 years, and 16-18 years).

Ear advantages from the RDDT were significantly larger among adjudicated adolescents than among typically developing children in all three age groups and were significantly lower compared to clinical children only in the middle age group (13-15 years) as shown in Figure 4. There were no significant differences in ear advantages between adjudicated adolescents and typically developing children for DWT, however. Compared to children in the clinical group, DWT ear advantages were significantly lower in all three age groups.

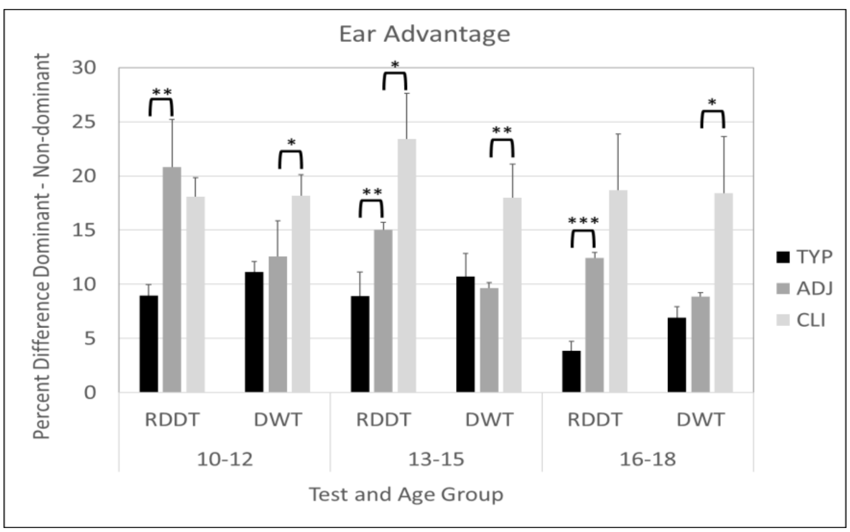

Figure 4. Average interaural asymmetry values for each test, Randomized Dichotic Digits Test and Dichotic Words Test for participants in each of the three groups (clinical – pale gray, adjudicated adolescents – medium gray, and typically developing – black) within each of the three age groups (10-12 years, 13-15 years, and 16-18 years).

Prevalence of Deficit Patterns

The prevalence of matched patterns from the dichotic tests consistent with amblyaudia (AMB), dichotic dysaudia (DD), and amblyaudia plus dichotic dysaudia (AMB+) among the adjudicated adolescents was 7%, 22%, and 6%, respectively, for a total of 35%. Another 8% of the adolescents produced abnormal, unmatched scores on both tests (amblyaudia on one test and dichotic dysaudia on the other), characterized as mixed (MIX). Among the remaining 57% of adjudicated adolescents, 41% produced scores that were normal on one of the tests and abnormal on the other test, identified as undetermined (UND). Only 16% produced consistently normal scores for both tests, based on a stringent criterion of scores better than the 25th percentile for both tests. If we moved the criterion for normal to include those in the UND category with one abnormal test score between the 10th and 25th percentile and the other test score better than the 25th percentile, the prevalence of normal scores would rise to 43%. In comparison, the prevalence of matched patterns from the dichotic tests consistent with amblyaudia (AMB), dichotic dysaudia (DD), and amblyaudia plus dichotic dysaudia (AMB+) among the typically developing children was lower for a total of 19% plus another 10% with the mixed (MIX) pattern. The prevalence among children seen clinically was higher, however for a total of 45% plus another 9% with the MIX pattern.

The prevalence of these deficit patterns across the three groups of children is displayed in Figure 5. The percentage of children with matched deficit patterns and scores below the 5th percentile are represented by the lower, black portion of each bar. Those in the middle, gray portion of each bar are those with scores between the 5th and 10th percentiles and those in the upper, light gray portions are those with scores between the 10th and 25th percentile. As shown by the black portions of the bars, the prevalence of severe dichotic deficits was higher in the adjudicated adolescents than in the typically developing children but lower than in the clinically assessed children for all deficit patterns except dichotic dysaudia.

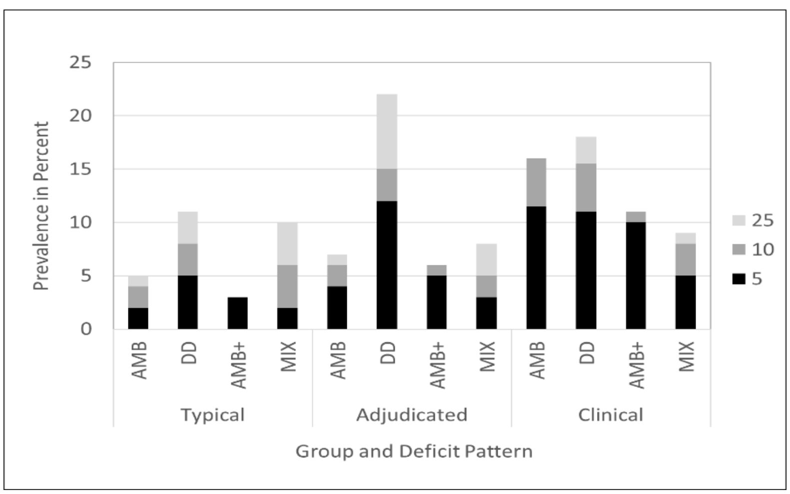

Figure 5. Percent of participants within each group, typically developing, adjudicated, or clinical, demonstrating deficit patterns matched as AMB = amblyaudia, DD = dichotic dysaudia, AMB+ = amblyaudia plus dichotic dysaudia, and MIX = amblyaudia on one test and dichotic dysaudia on the second test. The severity of the deficit pattern within each of the three groups is designated by the stacked color with the percent of participants demonstrating severe deficits (scores below the 5th percentile) in black, those with moderate deficits (scores below the 10th percentile) in gray and those with minimal deficits (scores below the 25th percentile) in light gray.

Relationship between dichotic listening and CELF scores

We used a forward method linear regression to evaluate the effects of age, dominant ear scores on the DWT (DWD) as the primary index for dichotic dysaudia, and nondominant ear scores from the RDDT (RDN) as the primary index for amblyaudia, on the discrepancy scores from the CELF. Results were significant for each variable model, 1) gender $F(1,758) = 11.593$, $p < .001$, $R^2 = .015$, 2) age $F(2,758) = 10.206$, $p < .001$, $R^2 = .026$, 3) RDN $F(3,758) = 36.223$, $p < .001$, $R^2 = .126$ and 4) DWD $F(4,758) = 39.739$, $p < .001$, $R^2 = .136$. Overall, the variables explained 13.2% of the variance, with non-dominant ear scores from the RDDT accounting for most of the variance at 12.6%. The adolescents with the dichotic dysaudia and amblyaudia plus patterns produced the lowest scores on the CELF as shown by their average discrepancy from age criterion in Figure 6. Those with the amblyaudia pattern, mixed results or undetermined results were similarly discrepant from the age criterion and those with normal results produced average scores above criterion.

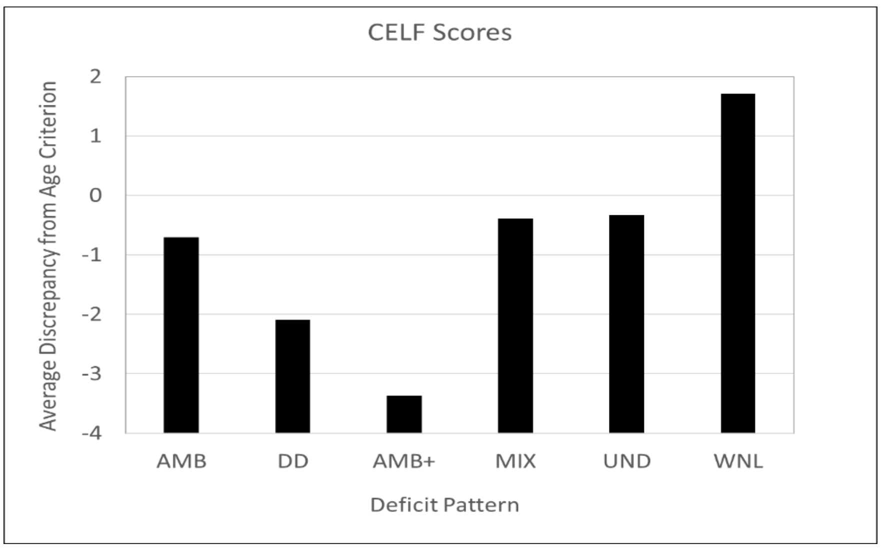

Figure 6. Average discrepancies from age-equivalence for adjudicated adolescents from the Clinical Evaluation of Language Fundamentals (CELF) test. Average discrepancies are shown for those who produced the matched deficit patterns consistent with AMB, DD, AMB+ and MIX as well as those with the UND pattern who demonstrated normal performance on one test and WNL for those who demonstrated normal performance on both tests.

Discussion

Results from this study demonstrated that many children ages 10 to 18 years old are at a substantial risk of auditory processing weaknesses associated with a variety of communication, language, and reading difficulties. We report that 35% of adjudicated adolescents, a rate between 19% of typically developing children and 45% of children evaluated clinically across the same age range, produced matched deficit patterns consistent with AMB, DD or AMB+. Another 8% to 9% of the children in all 3 groups produced the MIX pattern of results (AMB pattern on one test and DD pattern on the other test). In an earlier clinical study, a third dichotic listening test was used as a tiebreaker and two-thirds of the MIX cases (10/15) were converted to AMB, DD or AMB+ deficit patterns when results from two of the three tests matched (Moncrieff, et al., 2017). If we assume that the same two-thirds of results in this study would have resolved to a matched deficit pattern with the use of a tiebreaker test, the rate for matched pattern deficits in adjudicated adolescents would rise to 41% (35% plus 6%). This high rate included severe scores below the 5th percentile, moderate scores below the 10th percentile and borderline scores below the 25th percentile. If we limit our findings to only severe deficits from scores below the 5th percentile, the rate of matched deficit patterns for adjudicated adolescents drops to 24% plus another possible 2% (two-thirds of those with the MIX pattern). This adjusted rate for matched severe deficits is again in-between 12% for typically developing and 38% for children seen in the clinic.

It is important to note that even among typically developing children, these rates are significantly higher than previous predictions that only 2-7% of the pediatric population is at risk of auditory processing disorders.

Scores in the non-dominant ear during the RDDT were highly predictive of discrepancies from age-criteria for the CELF scores among the adjudicated adolescents compared to age, gender, and DWT dominant ear scores. This was unsurprising given the highly significant performance differences observed between the adjudicated adolescents and the children from the other two groups for RDDT scores whereas DWT scores failed in most cases to achieve significant differences. Even though low RDDT scores were highly predictive of weaknesses on this language test, a link between this low-linguistic load dichotic test and language skills seems unlikely. Instead, the RDDT places a high demand on working memory to retain perception of multiple elements prior to repeating what has been heard.

These results suggest that there has been a sustained underestimation of auditory processing risks in the pediatric population for several decades. Earlier prevalence rates were made following administration of a standard, heterogeneous battery of auditory processing test instruments (American Speech Language and Hearing Association, 2005; American Academy of Audiology, 2005) with abnormality based on scores at – 2 S.D. below the age-related mean for the test. Several challenges to this standard have been raised, including insensitivity of sensitized speech tests to adequately assess auditory processing weaknesses (Cacace & McFarland, 1998), intra-individual inconsistencies across a heterogeneous battery of test instruments (DeBonis & Moncrieff, 2008), and inappropriate use of standardized measures with test results that are not normally distributed (Ahmmed & Ahmmed, 2016). Based on these old standards, APD may not be a true clinical entity because it fails to represent 1) uniformly measurable test results, 2) differentiated performance patterns and 3) presence in individuals across a range of severities (Vermiglio, 2016). One study comparing several test batteries and approaches that follow these standards led to a prevalence rate of APD that ranged from 7 to 93% of the children tested (Wilson & Arnott, 2013).

Dichotic listening tests are the most frequently used tool in assessment batteries (Emanuel) and have been known for decades to produce significant weaknesses in children with auditory processing difficulties compared to normal controls (Connors, Kramer, & Guerra, 1969; Obrzut & Mahoney, 2011; Pinheiro, et al., 2010; Reynard, et al., 2023). In this study, only dichotic tests were used to provide consistent measures of weakness in this important auditory processing skill and to identify children with moderate or severe deficits only when their results fell below normal on both dichotic tests. Even with the additional criterion to include only matched performance patterns on both tests, the prevalence rates were higher in typically developing children, higher yet in adjudicated adolescents, and highest among those who sought clinical evaluation. Basing a dichotic deficit on scores below the 5th percentile on both tests is different from the standard deviation rules established by American Speech Language and Hearing Association (2005) and American Academy of Audiology (2010), but the 5th percentile represents an appropriate cut-off score for dichotic test results that are highly skewed and not normally distributed, even after applications of statistical arcsine transformation procedures (Moncrieff & Wilson, 2009; Moncrieff & Ray, in preparation; Strouse & Wilson, 1999; Studebaker, 1985).

Despite decades of research and clinical evidence that auditory processing weaknesses contribute to educational risks, the number of children who receive the services of a clinical audiologist trained to properly identify a problem remains abysmally low. Among many factors that contribute to this underrepresentation has been a failure among researchers and clinicians to reach consensus on a performance practice that adequately assesses and treats auditory processing weaknesses. Concerned parents who use internet search sites to find a service provider rarely locate one close to home, as many pediatric audiology sites do not offer auditory processing assessments. Those that do provide services produce reports that vary widely with long lists of recommendations for accommodations and modifications at home and school, but rarely offer evidence-based treatments to resolve auditory processing difficulties. A growing number of clinicians in the U.S. now identify the specific dichotic listening deficits reported in this study and are trained to use Auditory Rehabilitation for Interaural Asymmetry (ARIA), a treatment protocol with evidence of benefits in dichotic listening performance and word recognition and language skills (Moncrieff & Wertz, 2008; Moncrieff, et al., 2017) and performance listening to speech in background noise (Moncrieff, 2018). Despite the high prevalence of these deficits and reported benefits from auditory training specifically designed, health insurance coverage is rarely available to cover the costs of assessment or treatment.

The typically developing children included in this study were recruited from urban and suburban schools in Connecticut and Pennsylvania, in middle to high socioeconomic areas, and among those for whom race was identified, over 90% of them were white. They were part of a large normative study designed to describe the full range of dichotic performance that would include children who may struggle in school but who were not specifically identified with educational disabilities. Most juvenile detainees, however, were from low to middle socioeconomic areas in Pittsburgh and over

80% of them were Black. The juvenile detention center provided classroom education and additional special educational resources to the adolescents during their residency, but we did not document which participants were eligible for special education services under an Individualized Education Plan (IEP). Each week, the detention center sent a report of these test results to the child's home and for those with severe dichotic deficits, a recommendation for a follow-up evaluation and therapy was made. Only one parent followed through for additional testing but failed to return for therapy when original results were confirmed.

The higher rates of severe deficits among the children seen for clinical evaluations is unsurprising since referrals come from parents, classroom teachers, psychologists, pediatricians, and other related service providers concerned about the child's academic achievements. Many reported family histories of learning disabilities, amblyopia, reading disorders, and attention deficits. Clinical rates of severe dichotic weaknesses were 10% higher among younger children (ages 5 to 9 years), likely due to immaturity in the ascending neural pathways involved in auditory processing and/or in the cortical neural mechanisms involved in attention and working memory that could continue to resolve with development. By age 10, however, neural mechanisms in the brainstem that are responsible for integrating binaural information should be fully mature (Litovsky, 2015), yet between ages 10 and 18, rates of severe deficits were stable from 37-39% in the clinical group and from 21% to 28% in the adjudicated adolescents. The children in the typically developing group produced a 12-13% rate of severe deficits that dropped to zero among those in the 16 to 18-year-old group. That age group was the smallest cohort in the study (n = 18) and by that age, most children characterized as typically developing who remain in school are less likely to struggle with processing deficits and associated learning difficulties.

Race and socioeconomic status are highly related to rates of referrals for clinical evaluation of auditory processing deficits. A study at one large pediatric hospital, in the mid-Atlantic region of the U.S. like this study, noted that only 5.8% of 243 children referred for audiologic assessment were Black or African American (Nagao, et al., 2016). A recent study reported evidence regarding barriers to equity in the provision of hearing health care for children in the U.S. despite implementation of universal newborn hearing screening programs two decades ago (Kingsbury, et al., 2022). Reported barriers to care in urban settings included low socioeconomic status, poverty, caregiver education levels, lack of private or public health insurance coverage, and access to trained service providers. The authors called for long-term changes in policy to remove profit from the privatized health care system to resolve long-standing inequities that they speculate may stem from systemic racism.

In the clinical population used to create a comparison group for this study, the rates of severe deficits were higher at 48% for children ages 5 to 6 and 49% for children ages 7 to 9. This can be attributed to delayed maturation, but the identification of deficits in younger children attending elementary school can lead to provision of rehabilitative treatments and follow-up evaluations that can alleviate associated language, learning and reading disabilities. Unidentified auditory processing deficits can lead to common misunderstandings that children who perform poorly in school suffer from a lack of interest or motivation, deficits in attention or working memory, or an inability to regulate their behavior. Without appropriate identification and treatment of auditory-related learning disabilities, children may underachieve in school, become disinterested, and engage in alternative behaviors that are disruptive to the classroom. Chronic underachievement, especially in male students, is linked to consistent disciplinary action that has been characterized as the "schools-to-prison" pipeline (Hemez, Brent, & Mowen, 2020).

We report a strong relationship between low scores on dichotic listening tests, leading to both the asymmetric AMB pattern and the symmetric DD pattern, with below age-criterion scores from the CELF language assessment among the adjudicated adolescents. They demonstrated significant inability to integrate and understand orally presented information, skills that are needed to help them navigate through the complexities of the court system. Because hearing loss in children also degrades development of speech, language, and literacy and seriously limits educational achievement, social functioning, and higher order cognitive skills including attention and working memory (Lieu, et al., 2020), the US has a federal mandate for universal newborn hearing screening. In addition, 67% of the states in the US require school-based hearing screenings in elementary school with a majority screening at least once beyond 6th grade (Sekhar, Zalewski, & Paul, 2013). Given that auditory processing problems are associated with similar deficits in educational attainment, it seems reasonable that school-age children should be screened for processing deficits as well as for deficits in hearing acuity. It can be argued that the standard battery of auditory processing tests is too large for efficient screening, but student clinicians in this study scored pure tone hearing screenings and the two dichotic listening tests on each participant in approximately 15 minutes. At the least, these dichotic listening tests should be used to screen any child who is struggling in the classroom to perform at grade level.

There are many childhood factors that might contribute to juvenile delinquency, including prenatal and perinatal conditions that lead to poor health, substance abuse, exposure to violence, racism, weak discipline, abuse, neglect, and conflict, many of which could be separate from or co-occur with dichotic listening deficits. Dichotic deficits have been linked to genetics, traumatic brain injury, and to periods of auditory deprivation early in life as in multiple episodes of otitis media, all of which can exacerbate learning disabilities and reading disorders. The results of this study are not intended to suggest that dichotic deficits explain all educational, cognitive, or behavioral differences in adjudicated adolescents but are instead intended to suggest that because dichotic deficits can be remediated through a short-term auditory training protocol, there is a possibility that early identification and treatment of matched deficit patterns might alleviate at least some of the long-term educational underachievement and dysregulated behaviors that are associated with juvenile incarceration.

Conflict of Interest:

The authors have no conflicts of interest to declare.

Acknowledgements

None

Sources of Funding:

Portions of this study were funded by US Department of Education, 84.325K Combined Priority for Personnel Development, Award #H325K100325 to DM.

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