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Odds of Autism at 5 to 10 Years of Age for Children Who Did Not Pass Their Automated Auditory Brainstem Response Newborn Hearing Screen, but were Diagnosed with Normal Hearing

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Abstract

Background: Research has found atypical auditory brainstem response (ABR) activity in some children with Autism Spectrum Disorder (ASD). The current study examined whether an association may also be found between ASD and pass/refer results obtained via automated auditory brainstem response (AABR) screening. As stewards of large-scale AABR data, an AABR–ASD association may be of interest to EHDI programs.

Methods: State EHDI data for children born in Maine between 2003 and 2005 were linked with education records, including special education status, for the 2010-2011 and 2013-2014 school years.

Results: Children who did not pass their AABR screen but were later documented to have typical hearing were at more than eight times the odds of being identified with ASD at 5 to 7 years of age, and over six times the odds at 8 to 10 years of age.

Conclusion: Newborns who did not pass their AABR screen but were subsequently diagnosed with typical hearing, experienced higher rates of ASD 5 to 10 years later. With further research evidence, this may create opportunities for EHDI programs to support and facilitate the work of colleagues in the ASD community, as well as further assist families already touched by EHDI systems.

Keywords: Automated Auditory Brainstem Response, Autism Spectrum Disorder, Special Education, Newborn Hearing Screening, ASD, AABR

Acronyms: AABR = automatic auditory brainstem response; ABR = auditory brainstem response; ASD = autism spectrum disorder; EHDI = Early Hearing Detection and Intervention

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Auditory Brainstem Response (ABR) and the more limited Automated Auditory Brainstem Response (AABR) are familiar to many in the Early Hearing Detection and Intervention (EHDI) community as tools for screening (AABR) and diagnosing (ABR) hearing loss in children. Although commonly used for audiological evaluations, prior research (e.g., Cohen et al., 2013; Rosenhall et al., 2003; Roth et al., 2011) has shown that some individuals diagnosed with or suspected to have Autism Spectrum Disorder (ASD) demonstrate atypical results for ABR testing. The purpose of this study was to examine whether the evidence of a possible association between ASD and ABR using ABR testing—which provides detailed data regarding ABR activity—may be detectable using AABR screening that only provides *pass* or *refer* results. Although AABR screening provides more limited data than ABR testing, it is used in many EHDI programs and thus already available for many young infants.

Autism Spectrum Disorder

ASD is a neurodevelopmental disorder characterized by persistent communication impairments related to social communication and social interaction; and behavioral symptomatology described as restricted, repetitive patterns of behaviors, interests, and activities (American Psychiatric Association, 2013). Children diagnosed with ASD typically demonstrate functional performance deficits directly related to these characteristics in the areas of adaptive skills, communication and social engagement with peers and adults, and behavioral regulation (Volkmar et al., 2014).

A particular concern with ASD is the steadily increasing number of cases that have been identified over the last few decades—an observation that has received widespread attention by families, health care professionals, and policy makers (Maenner et al., 2020; Shaw et al., 2020). Since 2007, the American Academy of Pediatrics has recommended that all children be screened for ASD at 18 and 24 months of age (Johnson et al., 2007). In the past decade, the age for a reliable diagnosis of ASD has decreased to as early as 14 months with the recommended age for early diagnosis at 18 months (Hyman et al., 2020; Pierce et al., 2019). This trend leads to an increased demand for early intervention services for children as young as 12 months who demonstrate ASD symptomatology (Chawarska et al., 2014). Barriers to screening for ASD include physician time and resources to screen, as well as lack of confidence in screening tools (Khowaja et al., 2018; Siu & the U.S. Preventive Services Task Force, 2016).

Automated Brainstem Response and Autism Spectrum Disorder

Multiple studies have observed atypical ABR results in children with ASD. For example, 101 Swedish children with typical (i.e., *normal*) hearing who were diagnosed with ASD (mean age = 8.38 years, range = 4 to 20 years) were found to have abnormal ABR results when compared to a typically hearing control group (Rosenhall et al., 2003). In another study of younger children with suspected ASD and typical hearing, 26 Israeli youth (mean age = 32.5 months, range = 24 to 45 months) exhibited abnormal ABRs when compared to a matched sample of children with language delay, as well as when compared to clinical norms (Roth et al., 2011). More recently Miron and colleagues (2016) examined ABRs of infants (mean adjusted age of 1.6 months) who were later diagnosed with ASD. Compared to ABRs from a case matched control group, the ASD diagnosis group had increased interpeak latency I-V and wave V latency. When the same authors compared ABRs from 1.5 to 3.5 year olds with ASD to clinical norms, increased interpeak latencies were seen in I-III, III-V, and I-V along with increased latencies in I, II, and V.

Such differences may vary based on age (Miron et al., 2018; Roth et al., 2011), and may be evident in the latency and amplitude of the waveform. For example, increased latencies have been observed in children with ASD suggesting slower conduction and/or longer conduction pathways, particularly in waves I, II and V (Miron et al., 2018; Miron et al., 2016; Rosenhall et al., 2003; Roth et al., 2011; Talge et al., 2018) and in those children under 8 years of age (Miron et al., 2018; Miron et al., 2016; Talge et al., 2018). Children with ASD may also be more likely than children with other language delays to have increased interpeak latencies with I-III, III-V, and I-V (Miron et al., 2016; Rosenhall et al., 2003; Roth et al., 2011; Talge et al., 2018). In addition to latency, other studies have examined wave amplitude and found greater amplitude in waves I and III among children with ASD, versus age-matched controls (Claesdotter-Knutsson et al., 2019; Santos et al., 2017). It is unknown whether such atypical ABR activity existed at birth or developed over time for these individuals. However, based on a small histopathology study of 2-year to 36-year-old decedents with ASD that showed changes in the auditory brainstem nuclei, some have proposed that it may be possible to use ABR testing to screen for ASD (Smith et al., 2019).

Of course, an association between ASD and AABR may reflect other mechanisms or processes. For example, in studies of infants referred due to atypical newborn hearing screening tests, 39%–60% had middle ear effusions (Adachi et al., 2010; Weber et al., 2018). The effusions occurred along with other sensorineural hearing loss in many infants, while others had typical hearing once the effusion was cleared. (Adachi et al., 2010; Weber et al., 2018). A slightly increased frequency of otitis media with effusion was seen in children with typical hearing and ASD (Adams et al., 2016; Myne & Kennedy, 2018), suggesting that an association with ASD may also reflect other, more fundamental mechanisms that are also related to middle ear effusions at birth.

Automated Auditory Brainstem Response Screening

As a screening tool for hearing loss, AABR does not provide the breadth and depth of information available in ABR diagnostic testing. Nevertheless, these findings based on ABR data raise the question of whether similar associations may be seen between the pass/refer results obtained via AABR newborn screening and subsequent identification of ASD. For clarity, AABR screening technology used by the equipment employed in this study

> …delivers thousands of soft click sounds at 35 dB nHL ('normal hearing level' scale) to a newborn's ears through disposable earphones. Each click evokes a series of identifiable brain waves from a special area of the baby's brain called the auditory brainstem. This brain wave activity is called the auditory brainstem response (ABR)…The instance in which the screener delivers a click and receives a response to that click is called a sweep. Sensors on the baby's skin pick up the brain wave signals and transmit the signals to the screener. The screener uses advanced signal processing technology to separate the ABR waves from background noise and other brain activity. These brain waves are averaged and checked to see if they are consistent with a pattern called a template. The template is derived from ABRs of normal-hearing infants. The screener must detect the ABR waveform with high statistical confidence to determine that a response is present…The screener will generate a PASS result when it collects sufficient data to establish with > 99% statistical confidence that an ABR signal is present and consistent with the template at a minimum of 1000 sweeps…If it has not established with > 99% statistical confidence that the ABR signal is present at 15,000 sweeps, the screener will generate a REFER result. (Natus Medical Incorporated, 2014, p. 9)

An association between AABR screening results and ASD would potentially be valuable given the use of AABR in many EHDI programs across the United States and other countries. In 1993, the U.S. National Institutes of

Health recommended that all newborns be screened for hearing loss. Subsequent position statements by the Joint Committee on Infant Hearing (Joint Committee on Infant Hearing, 1995, 2000, 2007, 2019) and Healthy People 2010 (U.S. Department of Health and Human Services & Office of Disease Prevention and Health Promotion, 2000) and 2020 (U.S. Department of Health and Human Services & Office of Disease Prevention and Health Promotion) called for universal screening of all newborns by one month of age—preferably prior to hospital discharge. AABR is widely used in many EHDI programs, and as such provides access and data for a large portion of births.

To that end, we conducted two sets of population-based archival analyses by linking newborn hearing screening results at birth, with public school records from kindergarten through fifth grade. Specifically, we were interested in those children who did not pass their newborn hearing screen using AABR but were subsequently diagnosed with typical (i.e., normal) hearing. The goal was to determine the prevalence rate of ASD among these children and compare it to overall rates. Given that prior studies (Cohen et al., 2013; Rosenhall et al., 2003; Roth et al., 2011) found that children who were diagnosed with or suspected to have ASD were more likely to show abnormal ABR activity, we hypothesized that newborns *with typical hearing* who nevertheless did not pass their AABR hearing screen would be more likely to be identified with ASD in elementary school. Although we anticipated such an association would also exist among children with diagnosed hearing loss, we focused solely on those with typical hearing to avoid any confounds with hearing loss, such as a possible inflated risk of being identified with ASD due to a child with hearing loss receiving a more careful evaluation upon school entry.

Method

This archival study was based on statewide newborn hearing screening and diagnostic data obtained from the Maine Newborn Hearing Program (EHDI), and statewide education data obtained from the Maine Department of Education. The Maine Newborn Hearing Program was established in 2000 and has been collecting newborn hearing screening and diagnostic evaluation data for all children born in the state since 2003. Coincidentally, all birthing hospitals in Maine used AABR for screening from the inception of the Maine Newborn Hearing Program, with all equipment provided by a single supplier (Natus). Relevant for this study, it is worth noting that the Maine Newborn Hearing Program data also includes information obtained from the electronic birth certificate, the Maine Birth Defects Program, and the Maine Newborn Bloodspot Screening Program.

The Maine Department of Education maintains the State Longitudinal Data System, which stores educational data for all children attending public school (and many large private schools) from preschool through the 12th grade. In addition to educational outcome data, the system includes the disability identification, such as ASD, for children receiving special education services. The existence of these two independent data systems creates a unique opportunity to investigate the potential correlation between the newborn hearing screening results and identification of ASD at a later age.

Measures

Eight childhood characteristics or variables were examined including child sex, age, reported birth defect, NICU status, birth weight, AABR/hearing status, special education status, and ASD status. Definitions for each variable can be found in Table 1.

Sample

Within the newborn hearing screening data, we identified all births in Maine from 2003 to 2005 (N = 41,493). Given that special education identification may change over time, these records were then linked to the Maine Department of Education records for the 2010 and 2013 school years (Time 1 and Time 2, respectively). By examining two different time-periods corresponding to early and later elementary school years, it would be possible to observe age-related variation within the same cohort of children. Record linkage was based on the child's name (first, middle, and last) and date of birth using an iterative, probabilistic linkage algorithm (Tu & Mason, 2004; Tu, Mason, & Song, 2007). Summaries of the data-flow from the original birth and school records, through data linkage, to special education enrollment and ASD identification are presented in Figure 1 (for Time 1) and Figure 2 (for Time 2), as well as in the following section.

All analyses were conducted using a de-identified data set, and the project was approved by the University of Maine Institutional Review Board (IRB), the Maine Center for Disease Control and Prevention (Maine CDC), and the Maine Department of Education.

Results

Time 1: Automated Auditory Brainstem Response at Birth Predicting Autism Spectrum Disorder at Age 5–7 Years

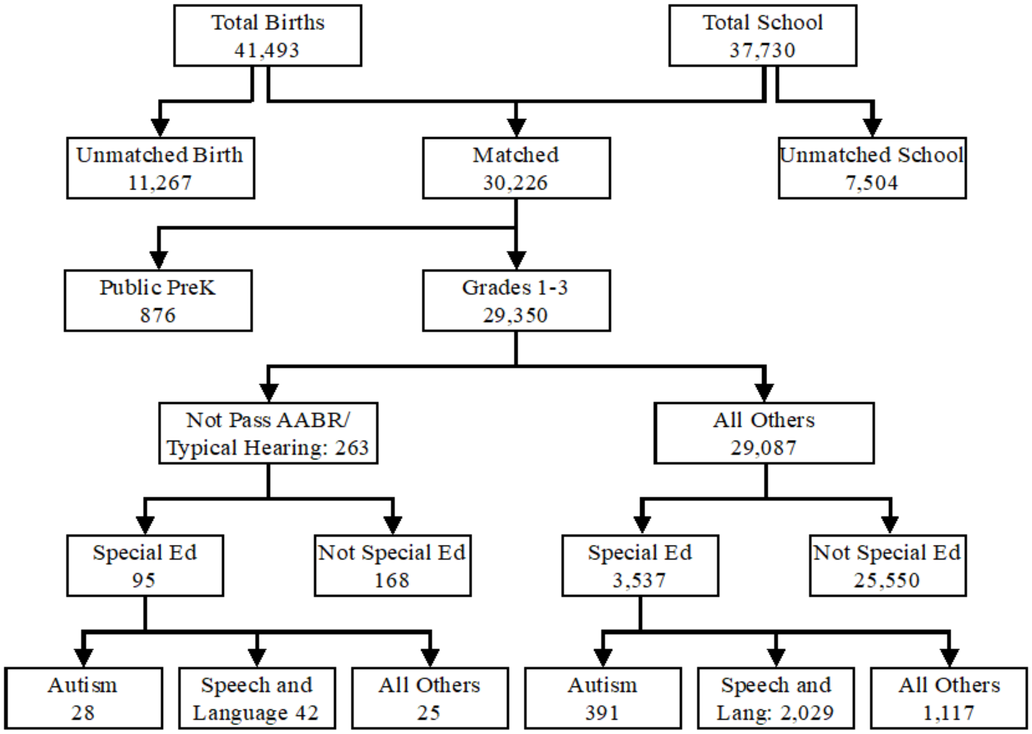
Record Linkage

Newborn records (AABR screening, diagnostic evaluation, birth data) for 41,493 children born in Maine from 2003 to 2005 were electronically linked to 2010/2011 school records for 37,730 children born in 2003 to 2005. A total of 30,226 matches were found, reflecting 72.8% of the newborn and 80.1% of the 2010/2011 school records. Non-matched birth records included children who moved out of state or were not attending public school in 2010/2011, as well as those who died or had a name change. Non-matched school records included children born out of state as well as those with a name change. A summary of the data-flow from birth and school records to special education enrollment and ASD identification is presented in Figure 1.

Table 1
Measures Used to Investigate Potential Correlation between Automated Auditory Brainstem Response (AABR) and Autism Spectrum Disorder (ASD)

Variable	Definition
Child Sex	A dummy variable indicating child sex (Female = 0, Male = 1).
Age	Child age in years.
Reported Birth Defect	A dummy variable indicating the documented presence of any of the 57 birth defects covered by the Maine Birth Defects program (0 = No documented birth defect, 1 = Documented birth defect).
NICU Status	A dummy variable indicating that a child's birth hospitalization included time in the neonatal intensive care unit (0 = No NICU placement at the birth hospitalization, 1 = NICU placement at the birth hospitalization).
Birth Weight	Birth weight, as recorded on a child's electronic birth certificate, was coded as one of four categories—extremely low birth weight (< 1000g), very low birth weight (1000g up to 1500g), low birth weight (1500g up to 2500g), and normal birth weight (2500+g). Note that although all analyses used the 4-category birth weight variable, due to suppression rules, birth weight is reported in tables as < 2500g and 2500+g.
AABR/Hearing Status	A dummy variable coded "1" if a child had a final AABR newborn screening result of "refer" for one or both ears **and** a formal diagnosis of typical/normal hearing reported to the state EHDI program. Children with diagnostic testing that was in process, missing, or unknown were not considered to have a diagnosis of typical hearing and were coded as "0".
Special Education Status	A dummy variable indicating whether a child was enrolled in special education during the specified academic year (0 = Not enrolled in special education, 1 = Enrolled in special education).
ASD Status	A dummy variable indicating whether a child was identified as having ASD based on their special education category (0 = Not enrolled in special education *or* enrolled in special education with a category other than ASD, 1 = Enrolled in special education with the category of ASD).

Figure 1
Case-Flow from Birth and School Records, Through Data Linkage and Time 1 Special Education Status



Note. Information regarding the counts for children enrolled in special education (Special Ed) under the specific category of speech/language impairment is provided for context, but not analyzed separately. AABR = automated auditory brainstem response.

Sample Characteristics

Of the 30,226 matched records, 876 were for children enrolled in public preschool at that time. Most children do not attend public preschool, which is neither required nor offered uniformly across the state; therefore, these children were excluded to avoid potential sampling bias. This resulted in a final sample of 29,350 matched records, for whom 8,080 were five years of age, 10,577 were six years of age, and 10,693 were seven years of age. Slightly more than half were male (n = 15,134) and 6.5% (n = 1,903) were placed in the NICU during their birth hospitalization. Eighty-one were extremely low birth weight (< 1000g), 161 were very low birth weight (1000g up to 1500g), and 1,615 were low birth weight (1500g up to 2500g) when born. In addition, 1,038 had a known birth defect.

Characteristics of Children Who Did Not Pass Their AABR Screen, But Were Diagnosed with Normal/Typical Hearing

Of the 29,350 matched records, 263 were children who did not pass their AABR hearing screening, but were later documented to have normal/typical hearing. As summarized in the first pair of columns in Table 2, they were nevertheless more likely to have a birth defect (OR = 2.40, 95% CI: 1.53–3.76; $\chi^2(1, N = 29{,}350) = 15.39$, $p < .001$), be in a lower birth weight category ($\chi^2(3, N = 29{,}337) = 17.55$, $p = .001$), have been in the NICU at birth (OR = 2.02, 95% CI: 1.39–2.93; $\chi^2(1, N = 29{,}350) = 14.14$, $p < .001$), and be male (OR = 2.05, 95% CI: 1.58–2.66; $\chi^2(1, N = 29{,}350) = 30.27$, $p < .001$).

Table 2

Frequencies of Various Child Characteristics at Time 1 Based on Automated Auditory Brainstem Response (AABR) Status and Autism Spectrum Disorder (ASD) Status

	All Others	Not Pass AABR Typical Hearing	Not ASD	ASD
No Birth Defect	28,070	242	27,906	406
Birth Defect	1,017	21	1,025	13
Normal BW	27,247	233	27,095	385
Low BW	1,827	30	1,824	33
Not NICU Birth	27,216	231	27,060	387
NICU Birth	1,871	32	1,871	32
Female	14,133	83	14,151	65
Male	14,954	180	14,780	354

Note. BW = birthweight; NICU = Newborn Intensive Care Unit.

Birth Factors Related to ASD at 5–7 Years Age

Of the 29,350 children in the final dataset, 3,632 (12.4%) were enrolled in special education, and 419 (1.4%) were specifically identified as having ASD at five to seven years of age. As summarized in the second pair of columns in Table 2, males were at higher risk for ASD during this age period (OR = 5.21, 95% CI: 4.00–6.80; $\chi^2(1, N = 29{,}350) = 184.48$, $p < .001$), as were older children ($\chi^2(2, N = 29{,}350) = 23.22$, $p < .001$), with rates of 0.9% for five-year-olds, 1.6% for six-year-olds, and 1.7% for seven-year-olds. Presence of a birth defect ($\chi^2(1, N = 29{,}350) = 0.23$, $p = .63$), birth weight category ($\chi^2(3, N = 29{,}337) = 2.32$, $p = .51$), and NICU status ($\chi^2(1, N = 29{,}350) = 0.93$, $p = .33$) were unrelated to ASD at five to seven years of age.

Preliminary Analyses: Predicting Age 5–7 Special Education Placement Based on AABR Screening Results and Hearing Status

As a preliminary test, analyses first examined the overall rate of special education placement—any special education category—among children who did not pass an AABR screen, but were diagnosed with typical hearing. Results found that the 263 children who did not pass their AABR hearing screen but had documented typical hearing experienced higher rates of special education five to seven years later—36.1% versus 12.2% for all other children (OR = 4.08, 95% CI: 3.17–5.27; $\chi^2(1, N = 29{,}350) = 138.01$, $p < .001$).

To address additional possible confounds, a logistic regression examined this same relationship controlling for sex, age, reported birth defect, birth weight category, and NICU status. As summarized in Table 3, children who did not pass their AABR newborn hearing screen, but were subsequently diagnosed with typical hearing continued to exhibit higher levels of enrollment in special education when five to seven years of age (OR = 3.35, 95% CI: 2.58–4.35), even after controlling for these other factors. Although not presented in Table 3, results were similar when controlling for school grade-level instead of age (OR = 3.49, 95% CI: 2.70–4.53).

Primary Analyses: Predicting Age 5–7 ASD Identification Based on AABR Screening Results and Hearing Status

These same analyses were then repeated, specifically focusing on ASD classification at age 5 to 7 years. The 263 children who did not pass their AABR hearing screen but had documented typical hearing were again found to experience higher rates of ASD five to seven years later—10.6% versus 1.3% for all other children (OR = 8.74, 95% CI: 5.84–13.10; $\chi^2(1, N = 29{,}350) = 160.27$, $p < .001$).

As summarized in Table 4, this result remained even after controlling for sex, age, reported birth defect, birth weight category, and NICU status. Children who did not pass their AABR newborn hearing screen but were diagnosed with typical hearing continued to exhibit higher levels of ASD when five to seven years old (OR = 6.94, 95% CI: 4.59–10.48), even after controlling for these other factors. Although not presented in Table 4, similar results were found controlling for school grade-level instead of age (OR = 7.34, 95% CI: 4.86–11.07).

Table 3

Logistic Regression Predicting Special Education Status (S.E.) at 5–7 Years of Age Based on Newborn Automated Auditory Brainstem Response (AABR) Screen and Child Characteristics

Variable	*b*	S.E.	Wald	*p*	OR [95% CI]
Constant	-4.103	0.148	764.69	< .001	0.017
Male	0.838	0.038	476.86	< .001	2.311 [2.144, 2.491]
Age	0.253	0.023	117.54	< .001	1.287 [1.230, 1.347]
Any Birth Defect	0.514	0.095	29.08	< .001	1.671 [1.387, 2.014]
ELBW	0.280	0.275	1.03	0.310	1.323 [0771, 2.269]
VLBW	-0.005	0.216	0.00	0.982	0.995 [0.651, 1.521]
LBW	0.383	0.075	26.13	< .001	1.466 [1.266, 1.698]
NICU	0.357	0.072	24.53	< .001	1.429 [1.241, 1.646]
Not Pass AABR w/TH	1.209	0.133	82.91	< .001	3.351 [2.583, 4.347]

Note. Special Education Status (0 = Not enrolled in special education, 1 = Enrolled in special education); Male (0 = Female, 1 = Male); Any Birth Defect (0 = No record of monitored birth defect, 1 = Presence of a monitored birth defect); ELBW (Extremely low birth weight under 1000g, 0 = No, 1 = Yes); VLBW (Very low birth weight, 1000g to 1500g, 0 = No, 1 = Yes); LBW (Low birth weight, 1500g to 2500g, 0 = No, 1 = Yes); NICU (Presence in NICU during birth hospitalization, 0 = No, 1 = Yes); Not Pass AABR w/TH (Child with typical hearing who did not pass their newborn AABR screening, 0 = Passed screening, 1 = Did not pass screen but later diagnosed with typical hearing). All Wald tests have one degree of freedom.

Table 4

Logistic Regression Predicting Autism Spectrum Disorder (ASD) Identification at 5–7 Years of Age Based on Newborn Automated Auditory Brainstem Response (AABR) Screen and Child Characteristics

Variable	*b*	S.E.	Wald	*p*	OR [95% CI]
Constant	-6.966	0.424	270.37	< .001	0.001
Male	1.620	0.136	142.23	< .001	5.052 [3.871, 6.593]
Age	0.249	0.065	14.71	< .001	1.283 [1.129, 1.456]
Any Birth Defect	-2.30	0.332	0.48	0.487	0.794 [0.415, 1.521]
ELBW	0.114	1.069	0.01	0.915	1.120 [0.138, 9.103]
VLBW	0.081	0.794	0.01	0.919	1.084 [0.229, 5.140]
LBW	0.320	0.211	2.30	0.129	1.377 [0.911, 2.083]
NICU	0.006	0.213	0.00	0.979	1.006 [0.662, 1.527]
Not Pass AABR w/TH	1.937	0.210	84.80	< .001	6.940 [4.595, 10.481]

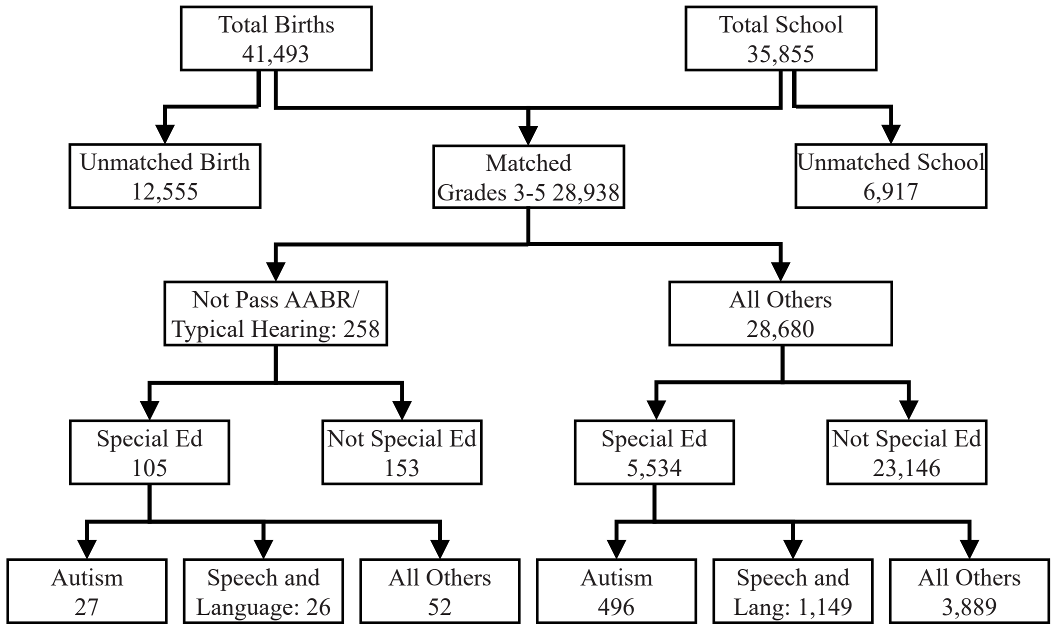
Note. ASD Identification (0 = Not identified as having ASD, 1 = Identified as having ASD); Male (0 = Female, 1 = Male); Any Birth Defect (0 = No record of monitored birth defect, 1 = Presence of a monitored birth defect); ELBW (Extremely low birth weight under 1000g, 0 = No, 1 = Yes); VLBW (Very low birth weight, 1000g to 1500g, 0 = No, 1 = Yes); LBW (Low birth weight, 1500g to 2500g, 0 = No, 1 = Yes); NICU (Presence in NICU during birth hospitalization, 0 = No, 1 = Yes); Not Pass AABR w/TH (Child with typical hearing who did not pass their newborn AABR screening, 0 = Passed screening, 1 = Did not pass screen but were later diagnosed with typical hearing). All Wald tests have one degree of freedom.

Time 2: Automated Auditory Brainstem Response at Birth Predicting Autism Spectrum Disorder at Age 8–10 Years

As children age, more in any given cohort will tend to be identified with ASD. Consequently, ASD and special education rates also change with age throughout the elementary school years. Therefore, the previous analyses were repeated using the same birth cohort linked with school records at a later point in time. Although largely overlapping the children included in Time 1, the underlying samples are not identical due to factors such as out-migration (children leaving the state) and sample-specific in-migration (children who were born in Maine, but not enrolled in public school at Time 1). A summary of the data-flow from birth and school records to special education enrollment and ASD identification using Time 2 data is presented in Figure 2.

Figure 2

Case-Flow from Birth and School Records, Through Data Linkage and Time 2 Special Education Status



Note. Information regarding the counts for children enrolled in special education (Special Ed) under the specific category of speech/language impairment is provided for context, but not analyzed separately. AABR = automated auditory brainstem response.

Record Linkage

Newborn records for the 41,493 children born from 2003 to 2005 were electronically matched to 2013-2014 school records for 35,855 children born those same years. Second grade students who were in preschool in 2010-2011 and not included in Time 1 analyses were excluded to continue with the same potential cohort. A total of 28,938 matches were found, reflecting 69.7% of the newborn records and 80.7% of the 2013-2014 school records. Non-matched birth records included children who moved out of state or were not attending public school in 2013-2014, as well as those who died or had a name change. Non-matched school records included children born out of state as well as those with a name change.

Sample Characteristics

Among matched records, 8,066 were eight years of age, 10,395 were nine years of age, and 10,477 were ten years of age. Slightly more than half were male (n = 14,984) and 6.5% (n = 1,890) had been in the NICU during their birth hospitalization. Seventy-nine were extremely low birth weight (< 1000g), 157 were very low birth weight (1000g up to 1500g), and 1,601 were low birth weight (1500g up to 2500g) when born. In addition, 1,013 had a known birth defect.

Characteristics of Children Who Did Not Pass Their AABR Screen, But Were Diagnosed with Normal/Typical Hearing

Two hundred fifty-eight children who did not pass their AABR hearing screen were later found to have documented normal/typical hearing. As summarized in the first two columns of Table 5 they were also more likely to have a birth defect (OR = 2.47, 95% CI: 1.58–3.88; (χ^2(1, N = 28,938) = 16.58, p < .001), be in a lower birth weight category (χ^2(3, N = 28,927) = 18.56, p < .001), have spent time in the NICU at birth (OR = 2.04, 95% CI: 1.41–2.97; χ^2(1, N = 28,938) = 14.70, p < .001), and be male (OR = 2.08, 95% CI: 1.60–2.72; χ^2(1, N = 28,938) = 30.89, p < .001). This is generally consistent with the results from Time 1.

Birth Factors Related to ASD at 8–10 Years Age

Of the 28,938 children in the final dataset, 523 (1.8%) were identified as having ASD at eight to ten years of age. As summarized in the second pair of columns of Table 5, males

Table 5

Frequencies of Various Child Characteristics at Time 2 Based on Automated Auditory Brainstem Response (AABR) Status and Autism Spectrum Disorder (ASD) Status

	All Others	Not Pass AABR Typical Hearing	Not ASD	ASD
No Birth Defect	27,688	237	27,424	501
Birth Defect	922	21	991	22
Normal BW	26,862	228	26,619	471
Low BW	1,807	30	1,786	51
Not NICU Birth	26,822	226	26,574	474
NICU Birth	1,858	32	1,841	49
Female	13,874	80	13,864	90
Male	14,806	178	14,551	433

Note. BW = birthweight; NICU = Newborn Intensive Care Unit.

continued to have higher rates of ASD during this age period (OR = 4.58, 95% CI: 3.65–5.76; $\chi^2(1, N = 28{,}938) = 205.16$, $p < .001$) and presence of a birth defect continued to be unrelated at this later age ($\chi^2(1, N = 28{,}938) = 0.79$, $p = .38$). In contrast to results three years earlier, higher rates of ASD at eight to ten years of age were observed among those born below normal birth weight (2.8%), compared to those born at normal birth weight (1.7%; $\chi^2(3, N = 28{,}927) = 14.17$, $p = .003$). NICU births also had higher rates of ASD (OR = 1.49, 95% CI: 1.11–2.01; $\chi^2(1, N = 28{,}938) = 7.03$, $p = .008$) compared to non-NICU births (2.6% vs. 1.8%). In contrast, while age continued to be related to ASD, rates now *declined* slightly with age ($\chi^2(2, N = 28{,}938) = 7.87$, $p = .02$) reflecting a potential peak rate of 2.2% around eight years of age, versus 1.6% for nine-year olds, and 1.7% for ten-year olds.

Preliminary Analyses: Predicting Age 8–10 Special Education Placement Based on AABR Screening Results and Hearing Status

A preliminary pair of analyses first examined the overall rate of special education placement—in any special education category—among children age 8 to 10 years, who did not pass an AABR screen, but were diagnosed with typical hearing. Results found that the 258 children who did not pass their AABR hearing screen but had documented typical hearing experienced higher rates of enrollment in special education eight to ten years later—40.7% versus 19.3% for all other children (OR = 2.87, 95% CI: 2.24–3.69; $\chi^2(1, N = 28{,}938) = 74.65$, $p < .001$).

This effect continued to be present in a logistic regression controlling for sex, age, reported birth defect, birth weight category, and NICU status. As summarized in Table 6, children who did not pass their AABR newborn hearing screen and were nevertheless diagnosed with typical hearing continued to exhibit higher levels of enrollment in special education when eight to ten years of age (OR = 2.52, 95% CI: 1.95–3.25), even after controlling for these other factors. Although not presented in Table 6, results were similar using grade-level in school in place of age (OR = 2.69, 95% CI: 2.07–3.49).

Table 6

Logistic Regression Predicting Special Education Status at 8–10 Years of Age Based on Newborn Automated Auditory Brainstem Response (AABR) Screen and Child Characteristics

Variable	*b*	S.E.	Wald	*p*	OR [95% CI]
Constant	-0.994	0.174	32.77	< .001	0.370
Male	0.794	0.031	635.27	< .001	2.21 [2.079, 2.352]
Age	-0.107	0.019	31.65	< .001	.0899 [.0866, 0.933]
Any Birth Defect	0.392	0.084	21.83	< .001	1.480 [1.255, 1.744]
ELBW	0.807	0.247	10.67	0.001	2.242 [1.381, 3.638]
VLBW	0.119	0.194	0.38	0.539	1.27 [0.770, 1.648]
LBW	0.446	0.064	48.68	< .001	1.562 [1.378, 1.771]
NICU	0.339	0.063	29.28	< .001	1.403 [1.241, 1.587]
Not Pass AABR w/TH	0.923	0.131	49.94	< .001	2.516 [1.948, 3.249]

Note. Special Education Status (S.E.; 0 = Not enrolled in special education, 1 = Enrolled in special education); Male (0 = Female, 1 = Male); Any Birth Defect (0 = No record of monitored birth defect, 1 = Presence of a monitored birth defect); ELBW (Extremely low birth weight under 1000g, 0 = No, 1 = Yes); VLBW (Very low birth weight, 1000g to 1500g, 0 = No, 1 = Yes); LBW (Low birth weight, 1500g to 2500g, 0 = No, 1 = Yes); NICU (Presence in Neonatal Intensive Care Unit during birth hospitalization, 0 = No, 1 = Yes); Not Pass AABR w/TH (Child with typical hearing who did not pass their newborn AABR screening, 0 = Passed screening, 1 = Did not pass screen but later diagnosed with typical hearing). All Wald tests have one degree of freedom.

Primary Analyses: Predicting Age 8–10 ASD Identification Based on AABR Screening Results and Hearing Status

The 258 children who did not pass their AABR newborn hearing screen but had documented typical hearing continued to exhibit higher rates of ASD at eight to ten years of age—10.5% versus 1.7% for all other children (OR = 6.64, 95% CI: 4.41–9.99; $\chi^2(1, N = 28{,}938) = 109.95$, $p < .001$). The decrease in the odds-ratio reflects the relative increase in the overall number of identified cases of ASD as children grew older.

Finally, a logistic regression examined this same relationship controlling for sex, age, reported birth defect, birth weight category, and NICU status. As summarized in Table 7, children who did not pass their AABR newborn hearing screen but were diagnosed with typical hearing continued to exhibit higher rates of ASD when eight to ten years old (OR = 5.70, 95% CI: 3.76–8.63), even after controlling for these other factors. Results were similar when substituting school grade-level for age (OR = 5.98, 95% CI: 3.85–9.28).

Table 7

Logistic Regression Predicting Autism Spectrum Disorder (ASD) Identification at 8–10 Years of Age Based on Newborn Automated Auditory Brainstem Response (AABR) Screen and Child Characteristics

Variable	*b*	S.E.	Wald	*p*	OR [95% CI]
Constant	-3.784	0.513	54.42	< .001	0.023
Male	1.508	0.117	166.90	< .001	4.519 [3.595, 5.681]
Age	-0.146	0.056	6.85	0.009	0.864 [0.775, 0.964]
Any Birth Defect	-0.434	0.303	2.05	0.152	0.648 [0.358, 1.174]
ELBW	1.434	0.609	5.55	0.019	4.195 [1.272, 13.836]
VLBW	1.132	0.524	4.68	0.031	3.102 [1.112, 8.656]
LBW	0.395	0.183	4.68	0.031	1.484 [1.038, 2.122]
NICU	0.131	0.182	0.51	0.473	1.140 [0.797, 1.629]
Not Pass AABR w/TH	1.740	0.212	67.34	< .001	5.696 [3.759, 8.631]

Note. ASD Identification (0 = Not identified as having ASD, 1 = Identified as having ASD); Male (0 = Female, 1 = Male); Any Birth Defect (0 = No record of monitored birth defect, 1 = Presence of a monitored birth defect); ELBW (Extremely low birth weight under 1000g, 0 = No, 1 = Yes); VLBW (Very low birth weight, 1000g to 1500g, 0 = No, 1 = Yes); LBW (Low birth weight, 1500g to 2500g, 0 = No, 1 = Yes); NICU (Presence in Neonatal Intensive Care Unit during birth hospitalization, 0 = No, 1 = Yes); Not Pass AABR w/TH (Child with typical hearing who did not pass their newborn AABR screening, 0 = Passed screening, 1 = Did not pass screen but later diagnosed with typical hearing). All Wald tests have one degree of freedom.

Discussion

Based on previous research that found atypical ABR results among some children with ASD (Miron et al., 2018; Rosenhall et al., 2003; Roth et al., 2011; Talge et al., 2018), this study examined whether state-wide, child-level AABR pass/refer results collected by an EHDI program would be related to identification as having ASD at 5 to 10 years of age. By linking newborn hearing screening records and educational records, we were able to identify a cohort and explore the relationship between newborn hearing screening results and identification of ASD at a later age. Results found that newborns who did not pass their AABR hearing screen but were diagnosed with normal/typical hearing were at more than eight times the odds of being identified with ASD at 5 to 7 years of age, and over six times the odds at 8 to 10 years of age.

This study adds to the existing research base in several key ways. First, previous research involved older, clinical-based samples of children and young adults with ASD. In this study we have extended the age-range down to newborn infants. Second, this is the first study to use a population-based sample, suggesting the possibility to further examine a relationship between ABR activity—albeit as more limited pass/refer results—and ASD on an epidemiological, population-level, using data from existing EHDI programs in the United States or elsewhere. Third, while prior research drew on the more rich and detailed data available through ABR testing, this study found a statistically significant association was evident even with the more limited information available in simple pass/refer results provided by AABR screening.

The results are particularly noteworthy because the newborn AABR data and data on ASD status were collected independently and years apart by two different systems, health and education, that do not usually share information. Furthermore, the five to ten year delay between AABR screening and ASD identification, as well as the focus on children with typical hearing, minimizes the potential for some variation of confirmation bias (i.e., schools were somehow aware that a child with normal/typical hearing did not pass an AABR at birth, and this knowledge influenced their decision to identify the child as having ASD).

It should be noted that this effect continued to be observed after controlling for various early childhood characteristics, including child sex, age, presence of another known birth defect, birth weight, and presence in a NICU during birth hospitalization (which served as a marker for other high-risk birth factors that may be related to both hearing loss and ASD). Although large, the effect size did decrease with age from an adjusted odds ratio of 6.94 at 5 to 7 years of age to an adjusted odds ratio of 5.70 at 8 to 10 years of age. This reflects the relative increase in the number of children identified with ASD as they became older, but it is also possible that these specific children exhibited more clear or severe ASD-related behaviors that resulted in earlier identification. Furthermore, although this study focused on ASD as an outcome, analyses also examined whether an association was seen more broadly based on whether a child was or was not enrolled in any special education classification when 5 to 10 years old. Consistent with the ASD findings, children who did not pass their newborn AABR but were subsequently diagnosed with typical hearing, were significantly more likely to be enrolled in special education in elementary school. This further suggests that although AABR screening compares ABR activity against a template derived from normal-hearing infants, there may be additional signal in the *noise* associated with an AABR refer/pass result that goes beyond hearing loss and may potentially tap into other important areas of child development.

As we note throughout this paper, AABR only provides binary results of pass or refer, and does not provide detailed information regarding wave forms that is available through ABR testing. Clearly, additional research that examines specific waveform patterns in connection with subsequent ASD identification would be valuable. Furthermore, the current study cannot shed light on specific mechanisms or processes through which the observed association between AABR screening at birth and ASD five to ten years later operates. Additional research examining such possible mechanisms would also be valuable.

The widespread availability of AABR screening data via EHDI programs may have a role in these efforts—for example, this may create opportunities for EHDI programs to support and facilitate the work of colleagues in the ASD community, as well as further assist families already touched by EHDI systems. In this regard, we must be perfectly clear that we are not suggesting a change in practice or policy based on a single study, and we are certainly not suggesting that AABR be seen as a diagnostic tool for ASD. However, when a child who did not pass an AABR screen is subsequently diagnosed with typical hearing, it is currently standard practice within the EHDI community to *close the case* and move on. If the findings in this study are supported by additional research, parents and primary health care providers may want to continue to monitor language, behavioral, and cognitive developmental milestones for these children, even after they are diagnosed with typical hearing.

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