Title
Childhood Socioeconomic Status and Auditory Perception in Adults: An ERP Study

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Publication Date
2024

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, MERCED

Childhood Socioeconomic Status and Auditory Perception in Adults: An ERP Study

A Thesis submitted in partial satisfaction of the requirements for the degree of Master of Arts

in

Psychological Sciences

by

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2024

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University of California, Merced
2024

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Acknowledgements

Thank you to my advisor, Dr. Elif Isbell, for your continued dedication to supporting me in my PhD studies. I greatly appreciate your mentorship and guidance as you continue to ensure I am prepared for every milestone throughout graduate school. Your dedicated help in my fellowship writing was very impactful as you taught me early on how to write professionally and how to tailor my writing towards different goals. I look forward to furthering my knowledge and skills even more throughout this journey.

Thank you to Dr. Heather Bortfeld, for your continued support and guidance since the beginning of my undergraduate studies. The Bortfeld-CAN lab meetings helped me practice my presentation skills where I also first learned how to generate scholarly questions in an academic setting. Through your guidance in your professional seminar graduate course, you helped me develop writing skills and learn how to navigate academia. I greatly appreciate your continuous guidance throughout this journey.

Thank you to Dr. Kristina Backer, for your continuous guidance and support throughout my academic journey. You introduced me to my first ever undergraduate research experience and mentored me on my first independent research project with UROC, helping me realize I wanted to pursue graduate school. I greatly appreciate your continued support and guidance, and your valuable feedback on this project.

Thank you to my friends and lab mates in the I.D.E.A. Lab, Nancy Rodas De Leon and Amanda Peters, for their continued support throughout graduate school. I greatly appreciate your support and I look forward to the years to come.

Lastly, thank you to my friends and family back home who continue to support me throughout my journey. Thank you for always being there for me and for your continued encouragement. Finally, thank you to my partner, Diana Cruz Garcia, who has always been there for me. You introduced me to the world of research and graduate school, and gave me the nudge I needed to get my foot in the door. I will forever be grateful, and I am so proud of the work you are doing in your PhD studies at UC Berkeley.

Abstract

Childhood Socioeconomic Status and Auditory Perception in Adults: An ERP Study

by Dylan M. Richardson for the partial satisfaction of the requirements for the degree of Master of Arts in Psychological Sciences, University of California, Merced 2024

Dr. Elif Isbell, Chair

Although previous research demonstrated socioeconomic status (SES) differences in the neurodevelopment of auditory systems throughout childhood, it remains unclear whether such differences persist into adulthood, especially in the absence of attentional or language demands. Here, we administered a passive auditory oddball paradigm with tones to 73 young adults from diverse childhood socioeconomic backgrounds to examine the mismatch negativity (MMN) event related potential (ERP) component as a neural index of auditory perception. As subjective ratings of childhood social status may reflect experiences not fully captured by objective childhood SES, we asked participants about both the highest level of parent education (i.e., objective childhood SES) and their subjective family social status when they were 10 years old. We did not find any links between childhood parent education or subjective family social status and MMN amplitude or latency in adulthood. This research contributes to our understanding of how childhood SES relates to auditory perception, a foundational building block for the auditory system, in young adults.

Introduction

Differences in childhood experiences have been linked to behavioral (Gonzalez-Gomez et al., 2021; Tabone et al., 2017) and neural (Anwyl-Irvine et al., 2021; Hampton Wray et al., 2017; Skoe et al., 2013) differences in the auditory system, demonstrating the system's notable susceptibility to the environment. Childhood socioeconomic status (SES), typically measured through parent income, education, or occupation during childhood, is linked to various characteristics of auditory environments, such as noise exposure (Fidell, 1988; Fyhri & Klæboe, 2006) and language input (Romeo et al., 2018; Schwab & Lew-Williams, 2016), which may give rise to differential neurodevelopment of the auditory system. SES-related differences have been observed in mechanisms that underlie speech perception and auditory attention across childhood (Anwyl-Irvine et al., 2021; Giuliano et al., 2018; Hampton Wray et al., 2017; Tabone et al., 2017). However, it is unclear whether the links between childhood family SES and building blocks of auditory systems persist into adulthood. Here, we examine how childhood SES relates to the brain electrophysiology of a foundational constituent of auditory perception, perception of simple tones, in the absence of attentional and language demands in young adults.

Childhood Auditory Environments

Children from lower SES backgrounds may be at risk for noisy environments, which may give rise to differential auditory system development (Evans, 2004). It has been proposed that lower SES families may be more likely to experience increased and continuous noise exposure due to the lack of resources needed to live in quiet neighborhoods (Fidell, 1988; Fyhri & Klæboe, 2006). Studies with non-human animals demonstrated that prolonged exposure to even non-traumatic noise (i.e., lower levels than what is considered “hazardous” to hearing) may alter the functioning of the auditory cortex and result in sound discrimination deficits, without any observable damage to hearing (Zhou & Merzenich, 2012). In line with these findings, it has been proposed that children who live in noisy environments for prolonged periods of time may adapt to chronic noise exposure, learning to inhibit sounds, even those that are relevant (Evans, 2006).

In addition to the increased risk for prolonged noise exposure, children from lower SES families, especially children with lower parent education levels, may also experience lower quality and quantity language input (Schwab & Lew-Williams, 2016). Children from lower SES backgrounds may hear less child directed speech, a speech style that caregivers typically use with children that contains speech properties that facilitate child language development, and have fewer opportunities to engage in conversation and practice their language skills (Golinkoff et al., 2019; Hart & Risley, 1995; Romeo et al., 2018; Schwab & Lew-Williams, 2016). Specifically, children from lower SES families may receive less conversation eliciting questions and may engage in lower amounts of conversational turn-taking (Hoff & Tian, 2005; Romeo et al., 2018). Conversational interactions may lead to greater conversational engagement by children. In turn, children are more likely to focus on what the other individual is saying while suppressing auditory distractions around themselves. With fewer opportunities for conversational interactions, children from lower SES families may miss out on opportunities to practice their auditory perception and cognition skills. Together, differences in characteristics of auditory environments, such as noise exposure and language input, during childhood may give rise to differential neurodevelopment of the auditory system.

Auditory Systems in the Context of Childhood SES

Developmental differences in the auditory system during childhood are displayed in both auditory perception and attention. Socioeconomic differences in phoneme discrimination can be demonstrated as early as infancy, with infants from lower SES background displaying delayed perceptual narrowing of phoneme discrimination (i.e., delayed acclimatization to phonemes in the native language) compared to infants from higher SES backgrounds (Gonzalez-Gomez et al., 2021). Furthermore, lower family SES has been linked to decreased performance in temporal processing of auditory stimuli in children, which is important for speech perception, potentially giving rise to SES differences in language (Tabone et al., 2017). SES differences in speech perception may persist into later childhood and early adolescence as demonstrated by attenuated neural responses and activation of brain regions that underlie language in response to speech sounds (Anwyl-Irvine et al., 2021; Conant et al., 2017). It is possible that these SES differences continue into middle adolescence as differences in the encoding of speech-specific information was observed in adolescents from lower SES backgrounds compared to higher SES backgrounds (Skoe et al., 2013). Additionally, compared to adolescents from higher SES backgrounds, 13-to-15-year-old adolescents from lower SES backgrounds show noisier auditory brain stem responses even in the absence of sound input, suggesting neurodevelopmental differences in foundations of the auditory systems (Skoe et al., 2013).

Similarly, SES differences have been demonstrated in neurodevelopment of auditory attention. Specifically, children from lower SES backgrounds on average have shown negligible differences between their neural responses to sounds embedded over stories they were asked to attend versus ignore, and these disparities have been observed as early as preschool years and into early school years (Giualiano et al., 2018; Hampton Wray et al., 2017; Stevens et al., 2009). Together these studies on auditory perception and attention suggest SES-related neurodevelopmental differences in the auditory system, from early childhood throughout adolescence. However, it remains unclear whether SES differences are observed in auditory systems that do not involve language or attention, and whether these differences persist into adulthood.

Mismatch Negativity (MMN)

To understand whether childhood SES is linked to neural differences in auditory perception in the absence of language or attentional demands, neural indices can be examined in the auditory mismatch negativity (MMN) event-related potential (ERP) component. MMN is a frontocentral ERP component elicited by any discriminable sound change even in the absence of attention (Näätänen et al., 2019). Prior to MMN elicitation, the auditory system habituates to a reoccurring stream of repetitive sounds, and once an irregularity in this stream is detected, MMN is elicited (Näätänen & Kreegipuu, 2011). More specifically, the auditory system forms an echoic memory trace based on streams of repetitive sounds and MMN reflects the detection of deviance in the presence of the larger auditory context (Sussman et al., 2007; Sussman et al., 2014).

MMN is reflected as a voltage deflection greater in negativity in response to deviant stimuli compared to a voltage deflection greater in positivity in response to frequent stimuli (Näätänen & Kreegipuu, 2011). MMN typically occurs around 125-225 ms post-stimulus onset in neurotypical adults (Kappenman et al., 2021), temporally overlapping with the auditory N1-P2 components (Näätänen & Kreegipuu, 2011). MMN can be observed in typically developing infants (Alho et al., 1990) and throughout childhood into adulthood (Bishop et al., 2011; Shafer et al., 2000), providing a consistent neural index of auditory perception across development (Näätänen et al., 2019). Although MMN is present as early as infancy (Alho et al., 1990; Cheour et al., 2000), the timing and scalp distribution of MMN continues to develop throughout childhood (Cheour et al., 2000; Morr et al., 2002). While there are typically no developmental differences in MMN amplitude (Alho et al., 1990; Morr et al., 2002), MMN latency is prolonged during early childhood (Gomes, 2000; Lovio et al., 2009; Petermann et al., 2009) and becomes more adult-like (i.e., MMN latency becomes earlier) throughout later childhood (Bishop et al., 2011; Glass et al., 2008; Gomes, 2000).

As systems with prolonged development can be more susceptible to environmental influences (Stevens & Neville, 2009), the prolonged development of MMN across infancy and childhood may signify the susceptibility of auditory perception to environmental influences, especially during childhood. Indeed, MMN can be altered after musical and phonetic training among neurotypical children and adults (Putkinen et al., 2014; Tamminen et al., 2015), demonstrating the susceptibility of auditory perception to environmental influences. While musical and phonetic training reflect active auditory experiences, MMN may also be altered in passive auditory experiences (Cheour et al., 2002). For example, Cheour et al. (2002) presented infants with speech sounds during sleep and found that MMN, previously not elicited prior to training, was elicited after training. The malleability of MMN may reflect changes in the allocation of neural resources for auditory perception; specifically, neural resources allocated to the detection of deviance among auditory contexts.

While MMN continues to develop throughout childhood to adulthood and is malleable to experiential influences, it remains unclear whether childhood experiences that may encompass different auditory experiences have enduring links to auditory perception in adulthood. Specifically, childhood experiences from diverse family socioeconomic backgrounds may differ both actively (e.g., language input) and passively (e.g., noise exposure), which raises the possibility for differences in the neurodevelopment of the auditory system. However, capturing childhood SES in adults poses challenges of accurately capturing retrospective indicators of SES.

Measuring Childhood SES in Adults

Childhood SES is typically assessed through retrospective objective measures from adults (e.g., parent education, income, occupation), which may reflect a stable measure of access to financial, educational, and social resources (Diemer et al., 2013). While retrospective information from certain objective indicators, such as parent education, may be sufficient, other SES indicators are at risk for inaccurate recall (e.g., parent income, parent wealth; Diemer et al., 2013). Furthermore, there may be a mismatch between how people report their SES and their actual objective status based on economic indicators (Diemer & Rasheed Ali, 2009), which suggests the potential for inaccurately capturing environmental experiences. In contrast, retrospective assessments of subjective social status (i.e., how individuals perceived their social standing during childhood) may better capture perceptions of living environments and early interpersonal experiences (Diemer et al., 2013). While objective SES indicators may reflect wealth and access to educational and social resources, subjective social status may capture additional factors, such as standard of living, that contribute to an individual's social status but are not captured by objective SES indicators (Diemer et al., 2013, Singh-Manoux et al., 2003). Subjective social status allows individuals to rate their social standing based on factors that they deem are important contributors to their socioeconomic position relative to society (Diemer et al., 2013; Singh-Manoux et al., 2003).

As objective and subjective SES indicators may capture different aspects of childhood experiences, they may act as distinct predictors. For example, parent reports of objective and subjective social status were found to uniquely predict cognitive outcomes in children (Ursache et al., 2015). Furthermore, subjective social status has been linked to cognition in adults while controlling for objective SES indicators (i.e., income, education, occupation) and may even be a stronger predictor (Adler et al., 2000; Singh-Manoux et al., 2005; Wong & Yang, 2022). Subjective social status is also associated with academic achievement in adolescence, reflecting the broader significance of studying it as an individual construct (Destin et al., 2012). However, the developmental literature that has examined subjective social status typically measured how parents currently perceive their own social status, which may capture childhood experiences but not children's perceptions of social status. Similarly, the adult literature typically measured adults' current perceived social status which does not capture childhood experiences that can influence development and persist into adulthood (Last et al., 2018; Ursache et al., 2015; Wong & Yang, 2022). There is no clear superior SES indicator; instead, the choice of objective versus subjective SES indicators depends on study goals, and in general, together they may provide a more comprehensive account of individuals' socioeconomic backgrounds (Diemer et al., 2013).

Current Study

We examined whether childhood family SES relates to neural indices of auditory perception in the absence of attentional and language demands in young adults using both objective and subjective measures of family SES to gain a comprehensive understanding of childhood SES. Event-related potentials (ERPs) were recorded during a passive auditory oddball paradigm and the MMN ERP component was examined as a neural index of auditory perception. We hypothesized that, given socioeconomic differences in childhood auditory environments (Fidell, 1988; Fyhri & Klæboe, 2006; Romeo et al., 2018; Schwab & Lew-Williams, 2016), young adults from lower childhood SES backgrounds may demonstrate a desensitization to irregular sounds, reflected as attenuated MMN amplitude (magnitude of neural responses) and prolonged latency (timing of neural responses). Additionally, if subjective perceptions of socioeconomic experiences capture living environments that parent education does not, such as standard of living (Diemer et al., 2013; Singh-Manoux et al., 2003), then we hypothesized that subjective family social status during childhood would relate to neural indices of auditory perception above and beyond parent education.

Method

Participants

Participants were recruited from the University of California Merced and the Merced community using flyers on campus and at community centers in Merced, California. Participants were included based on the following criteria: normal hearing, normal/corrected-to-normal vision, no history of brain injuries or neurological disorders, no current medication use that could alter brain functioning.

An *a priori* power analysis was conducted in G*Power to determine adequate sample size prior to data collection. With a medium effect size, a minimum sample size of 68 was needed to achieve a power of 0.8. The initial sample included 80 participants; however, 5 participants were excluded due to incomplete demographic information (i.e., participants reported adults they currently lived with rather than parents/legal guardians) and 2 participants were excluded due to excessive EEG noise and poor data quality (criteria described below). The final sample consisted of 73 participants (54.1% female) aged 18 to 30 years old (M_{age} = 21.84, *SD* = 2.70). Of the participants in the final sample, race/ethnicity reports were as follows: 54.8% Hispanic or Latinx, 15.1% Asian/Asian American, 15.1% White/European American, 13.7% more than 1 race/ethnicity, and 1.4% Middle Eastern. Participants' highest level of education ranged from a high school to master's degree (*M* = 13.58, *SD* = 1.79; see Figure 1 for participant education distribution).

Childhood Family SES Measures

Participants were asked to think back to when they were 10 years old and provide retrospective information about their parents' highest level of education completed and their own subjective family social status ratings. These questions were administered at the end of the experiment to avoid any potential influence by prompting participants to think back to their childhood.

Objective Childhood Family SES. Since retrospective accounts of parent occupation and income may be more limited compared to educational attainment (Diemer et al., 2013), the highest level of education completed between the parents/legal guardian was used as an indicator of objective childhood family SES (Diemer et al., 2013). The following coding scheme for years of education was developed and used: less than 1^{st} grade = 0; 1^{st}, 2^{nd}, 3^{rd}, 4^{th} grade = 4; 5^{th} or 6^{th} grade = 6; 7^{th} or 8^{th} grade = 8; 9^{th} grade = 9; 10^{th} grade = 10; 11^{th} grade = 11; high school graduate or GED = 12; some college but less than 1 year = 12; one or more years of college, no degree = 13; associate's degree = 14; bachelor's degree = 16; master's and above = 18. Participant reports of their parent's years of education ranged from 4 to 18 (M = 12.18, SD = 4.30; see Figure 2 for the parent education distribution).

Subjective Family Social Status During Childhood. The MacArthur Scale of Subjective Social Status (Adler et al., 2000) was used to measure subjective social status during childhood. Participants were prompted to think back to when they were 10 years old and indicate where they would place their family in comparison to American society on a ladder, numbered 1 to 10 (1 being at the bottom of the ladder, 10 being at the top). Participant reports of their subjective family social status during childhood ranged from 1 to 10 (M = 4.93, SD = 2.08; see Figure 3 for the distribution of subjective family social status during childhood).

Passive Auditory Oddball Task

The passive auditory oddball task was adapted from ERP CORE (Kappenman et al., 2021), an open resource containing ERP paradigms and processing pipelines to contribute towards the standardization of ERP research across labs. Participants were told they would hear a series of sounds and were instructed to ignore the sounds while watching a silent video. A 700 Hz standard tone was presented at 80 dB for 100 ms and occurred during 80% of trials. A 700 Hz deviant tone was presented at 70 dB for 100 ms and occurred during 20% of trials. Interstimulus intervals were jittered between 450-550 ms. Participants were presented with a total of 350 trials. Presentation Neurobehavioral Systems was used for task design and presentation. The original ERP CORE passive auditory oddball task included 1000 trials (approximately 10 minutes long); however, we reduced the number of trials to 350 trials (approximately 3.5 minutes long) to adapt the task for future studies with different age ranges, including young children. Additionally, we changed the task video to a child-friendly cartoon (Pingu) to increase task engagement. With these changes, a robust MMN was elicited across participants. Participants were seated approximately 95 cm away from the monitor (Dell LCD monitor with a 1280 x 1024 resolution and a 60 Hz refresh rate) and auditory stimuli were presented with noise canceling headphones (Bose QuietComfort 25).

EEG Recording

EEG was recorded with Brain Products antiCHamp Plus, using BrainVision Recorder Version 1.25.0101. For EEG collection, an actiCAP slim active electrode system (32-channel electrode system) was used, mounted on elastic snap caps (Brain Products GmbH, Gilching, Germany). The ground electrode was placed at FPz. Of the 32 electrodes, 5 electrodes were repurposed as follows: 2 electrodes were repurposed as mastoid electrodes, placed behind the left and right ears on the mastoid bones. Three electrodes were repurposed to record electrooculogram (EOG) with the vertical EOG (VEOG) placed below the right eye, and 2 horizontal EOG (HEOG) electrodes placed lateral to the external canthus of each eye. The remaining 27 scalp electrodes were mounted in accordance with the international 10/20 system (see figure 5 for electrode configuration). EEG was sampled at 500 Hz and referenced to Cz. StimTrak (Brain Products GmbH, Glitching, Germany) was used to inspect stimulus presentation delay in the headphones and a 20 ms audio delay was found and was accounted for in the EEG processing pipeline described below.

EEG Processing

EEG and ERP data processing was conducted in MATLAB using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014). Custom scripts and scripts adapted from ERP CORE (Kappenman et al., 2021) and ICLabel (Pion-Tonachini et al., 2019), an automatic independent component classifier, were used. All scripts were designed to be easily adapted for future research that examines other age ranges, including children, and were previously used in research with young children (Isbell and Grammer, 2022).

EEG data was first re-referenced offline to the average of the left and right mastoid channels. Bipolar eye channels were created to detect eye artifacts. The left horizontal eye channel was subtracted from the right horizontal eye channel to create bipolar HEOG. To create bipolar VEOG, Fp2 was subtracted from the right vertical eye channel. DC offset was removed and a band-pass filter with a half-amplitude cutoff of 0.1 and 40 Hz was applied with the EEGLAB default linear finite impulse response (FIR) filter.

Independent component analysis (ICA) was used to estimate and identify artifactual voltages from the continuous EEG data along with the rejection of residual artifacts. In preparation for ICA, recording periods without event codes were removed (defined as periods of 6000 ms or longer without event codes, with a 3000 ms buffer before and after any event codes). Since electrodes with problematic connections can interfere with the connection of nearby electrodes, bad electrode channels were identified prior to applying ICA. Bad channels were identified in the continuous EEG data using a peak-to-peak threshold of ± 300 μV across a 500 ms window moving at 50 ms increments to scalp channels (excluding Fp1 and Fp2). Z-scores were computed, and channels were identified as outliers and excluded if they caused more than 10% data loss and deviated ± 3.29 *SD*, a criterion chosen to be consistent with previous research (e.g., Isbell et al., 2018), compared to other scalp channels. Based on this criterion, 1 bad channel was excluded for 3 participants before pre-ICA artifact rejection. Extreme artifacts were then rejected using a moving window peak-to-peak algorithm with a threshold of ± 300 μV across a 500 ms window moving at 50 ms increments applied to scalp channels, excluding Fp1 and Fp2.

ICA was applied to all channels, excluding bipolar eye channels and mastoid channels, and computed ICA weights were applied to the pre-ICA data files. Eye components were identified using ICLabel. Corresponding eye components were removed if individual components were defined as at least 80% probability “Eye” labels paired with less than 5% probability “Brain” labels, which was a criterion chosen after rigorous comparisons of different labels generated by ICLabel in data with young adults.

To account for the audio stimulus presentation delay in the headphones, stimulus event codes were shifted 20 ms in time. ICA-corrected data was then epoched offline from 200 ms prior to and 800 ms post-stimulus onset, with baseline correction performed from -200 to 0 ms. This is consistent with the MMN epoch window and baseline correction range recommended by Kappenman et al. (2021). ICA-corrected bipolar channels were created for the removal of any remaining eye artifacts. To create ICA-corrected bipolar VEOG, ICA-corrected Fp2 was subtracted from the ICA-corrected vertical eye electrode. To create ICA-corrected bipolar HEOG, the ICA-corrected left horizontal eye electrode was subtracted from the ICA-corrected right horizontal eye electrode. To identify bad channels that may remain in the epoched data prior to additional artifact rejection, a simple voltage threshold algorithm with a ± 200 μV threshold was applied to scalp channels of interest. Z-scores were obtained, and channels were identified as outliers and excluded if they met the threshold of greater than 10% data loss and deviated ± 3.29 *SD* compared to other scalp channels. Based on this criterion, the same 3 electrodes that were excluded from pre-ICA cleaning were excluded from additional artifact rejection. To identify commonly recorded artifactual potentials (Luck, 2022) in the channels of interest, a simple voltage threshold algorithm was applied with a threshold of ± 200 μV, and a moving peak-to-peak algorithm with a threshold of ± 125 μV was applied to the 1000 ms epoch window (-200 to 800 ms) moving at 100 ms increments. Additional artifact rejection for eye artifacts was then performed on ICA-corrected horizontal and vertical EOG channels. To identify horizontal eye movements, a step-like algorithm was applied to the ICA-corrected bipolar HEOG channel with a threshold of 64 μV across a 100 ms window moving at 10 ms increments. To identify vertical eye movements, a peak-to-peak algorithm was applied to the ICA-corrected bipolar VEOG channel with a rejection threshold of 150 μV across a 200 ms window moving at 50 ms increments.

Individual ERP plots were then inspected for data quality. Additionally, analytic standardized measurement error (aSME) was used as a metric of data quality for scores obtained from parent waveforms (Luck et al., 2021). Using a script adapted from Luck et al. (2021), participant aSME values were calculated in EEGLAB for each participant by obtaining the standard deviation for individual EEG trials divided by the square root of total trials (see Table 2 for ERP waveform descriptive). Z-scores were computed, and channel outliers were identified if z-scored deviated ± 3.29 *SD* from other channels. From this criterion, no additional participants were excluded based on aSME scores.

ERP Outcomes and Data Quality Scores

Previous research has chosen a single frontocentral electrode, such as FCz, to measure MMN (Kappenman et al., 2021; Näätänen, 2001). However, the use of an electrode cluster allows for the examination of multiple electrodes of interest while avoiding multiple comparisons at each electrode site (Luck & Gaspelin, 2017). Upon visual inspection of grand average plots, the following electrodes were chosen to cluster: F3, Fz, F4, FC1, FC2, C3, C4. This cluster is in line with a previous frontocentral electrode cluster used to measure MMN (Glass et al., 2008). Four participants had 1 electrode identified as an aSME outlier: Fz, FC1, C3, C4. For these participants, the electrode identified as an aSME outlier was removed from the channel cluster.

It has previously been recommended that the ERP time-window mean amplitude and fractional area latency (50% area latency) scores for MMN be measured between 125 to 225 ms post stimulus onset (Kappenman et al., 2021). However, upon visual inspection this recommended time window was too narrow for our sample as it inaccurately captured most participants' MMN (n = 56). Thus, the measurement time window of 125-300 ms was used for fractional area latency as it best captured most participants' MMN. However, there were 3 remaining participants who did not display MMN in this time window and were excluded from latency analyses due to the absence of a fractional area latency value. Since we observed individual differences in MMN and the typical MMN measurement window recommended by Kappenman et al. (2021) was not sufficient, we conducted two analyses for MMN amplitude: 1) MMN amplitude measured in the recommended measurement window, 150-250 ms post stimulus onset, as MMN has been found to be most pronounced in this time window (Näätänen & Kreegipuu, 2011; Näätänen et al., 2007) 2) MMN amplitude measured in measurement windows that were individually adjusted for each participant (50 ms before and after participants' fractional area latency value). Difference waves were used for analyses to isolate the MMN ERP component as it has been suggested that difference waves demonstrate true experimental effects, with parallel neural processes that may be unrelated to experimental conditions subtracted out (Luck, 2014). Difference waves were created by subtracting the average waveform on the frequent trials from the average waveform on the deviant trials. Since difference waves were computed from averaged waveforms, aSME cannot be used as a metric of data quality for difference waves as it computes standard deviation for each EEG trial. Thus, bootstrapped standardized measurement error (bSME) was used to provide an objective metric of data quality for difference waves (Luck et al., 2021). Using a script adapted from Luck et al. (2021), bSME was computed for each participant by simulated ERP waveforms (10,000 iterations) with difference waves created on each iteration. ERP measurements were obtained in difference waves on each iteration, creating a sampling distribution, and bSME represents the standard deviation of the distribution. Z-scores were computed and the same channels in the four participants with channels identified as aSME outliers were also identified as bSME outliers (z-scores ± 3.29 *SD* compared to other channels): Fz, FC1, C3, C4.

Statistical Analyses

To test whether subjective social status during childhood relates to MMN amplitude and latency while controlling for parent education, hierarchical regressions were performed with parent education entered at step 1 and subjective family social status during childhood entered at step 2. Three separate hierarchical regressions were performed for fixed mean amplitude, adjusted mean amplitude (i.e., mean amplitude measured from time windows individually adjusted per participant), and fractional area latency (50% area latency). SPSS (Version 29) was used for all analyses. Bonferroni correction was performed to control for multiple comparisons, and statistically significant effects were evaluated at $p < 0.017$.

Results

Preliminary analyses were first conducted to inspect potential outliers in the variables of interest. No outliers (defined as scores above 3.29 or below -3.29 *SD* compared to other scores) were detected for parent education, subjective family social status during childhood, MMN mean amplitude, or MMN fractional area latency. Descriptive statistics for demographics and ERP waveforms are reported in Tables 1 and 2, respectively, and zero-order correlations are reported in Table 3. The hierarchical regression analyses did not reveal any links between childhood parent education and any ERP outcomes, and subjective family social status during childhood did not predict any ERP outcomes above and beyond childhood parent education (see Tables 4-6 for the summary of regression analyses for MMN mean amplitude, adjusted mean amplitude, and latency).

Since our sample included a combination of college students, graduate students, and community members, it is possible that differences in participants' years of education may have influenced these results. To account for potential schooling effects, we performed exploratory analyses on fixed mean amplitude, adjusted mean amplitude, and latency excluding participants with a bachelor's degree or above (n = 19). Entered at step 1 in 3 separate hierarchical regression analyses, parent education did not significantly predict ERP outcomes. Similarly, subjective family social status during childhood did not significantly predict any ERP outcomes while controlling for parent education in step 2 (see Tables 7-9 for the summary of regression analyses for MMN fixed mean amplitude, adjusted mean amplitude, and latency results).

Additionally, previous studies conducted analyses with a single frontocentral electrode (Kappenman et al., 2021; Näätänen et al., 2004), making it possible that MMN was not measured in optimal electrode sites in the current study. Thus, we performed further exploratory analyses to examine the correlations between parent education/subjective family social status during childhood and fixed mean amplitude and latency in FC1 and FC2 channels

(Kappenman et al., 2021; Näätänen et al., 2004). Adjusted mean amplitude was not included in these analyses due to the high correlation between fixed mean amplitude and adjusted mean amplitude in the electrode cluster (r = 0.99, p < 0.001). In both FC1 and FC2, parent education and subjective family social status during childhood did not significantly correlate with any ERP outcomes (see Table 10 for zero-order correlations between childhood SES and frontocentral electrodes).

Discussion

In the current study, we examined how childhood parent education and subjective family social status during childhood relate to neural indices of auditory perception in young adults, as measured by the amplitude and latency of the MMN ERP component. Contrary to our hypotheses, we did not find any links between childhood parent education or subjective childhood family SES and the magnitude or timing of MMN.

One possibility for these results is that the links between childhood family SES and auditory perception may not persist into adulthood; however, links with other auditory systems may endure beyond childhood. For example, SES differences in temporal processing, which is foundational for speech perception, were observed during childhood (Tabone et al., 2017) and in adulthood (Aguiar et al., 2019). Similarly, phonological perception, a mechanism that underlies speech perception, has been linked to frequency of parent instruction and availability of reading-related media (i.e., reading-related TV shows and computer games; Foy & Mann, 2003), which may suggest susceptibility to environmental influences in children. Indeed, SES-related differences in neural processes that underlie phonological perception have been observed in children and adolescents (Anwyl-Irvine et al., 2021). Thus, future research should examine whether SES may be linked to specific aspects of auditory perception, such as mechanisms that underly speech perception, and whether such links may endure beyond childhood.

It is alternatively possible that links between childhood SES and auditory systems are specific to auditory attention, which can be measured using an active rather than passive auditory oddball task design. Active auditory oddball tasks are methodologically similar to passive designs with the exception that participants are instructed to attend to the sounds and make a response to the deviant stimuli. Such a design typically elicits the P300 ERP component, which reflects information processing related to attention (Polich et al., 2011). A prolonged development of P300 latency has been observed (Mingils et al., 2023; Riggens & Scott, 2019), suggesting the potential for greater susceptibility to environmental influences. Specifically, it has been observed that P300 latency is shorter in adults compared to children (Mingils et al., 2023; Riggens & Scott, 2019), suggesting faster allocation of attentional resources in adults. While differences are observed in latency, age-related changes in P300 amplitude are relatively ambiguous (Riggens & Scott, 2019). The prolonged neurodevelopment of P300 may suggest possible susceptibility to environmental influences (Stevens & Neville, 2009), especially during childhood. Although there is a lack of research that investigates the links between childhood SES and neural responses during active oddball paradigms, research has suggested the possibility for links between different auditory experiences and P300 measured in active auditory oddball tasks. For example, research that compared musicians and non-musicians showed shorter P300 latency and increased amplitude in musicians compared to non-musicians in an active auditory oddball task (Rabelo et al., 2015), suggesting faster and greater allocation of attentional resources towards sounds.

Despite the lack of research examining links between SES and P300 elicited in active auditory oddball task designs, SES-related differences have been observed from other auditory attention task designs. For example, a dichotic listening task in which participants hear two completing stories simultaneously while instructed to attend to one and ignore the other, has been used to examine SES-related differences in auditory attention. Specifically, negligible differences between neural responses to the attended versus unattended stories have been observed in children from lower SES backgrounds from preschool through early school years (Giualiano et al., 2018; Hampton Wray et al., 2017; Stevens et al., 2009). Neville et al. (2013) further demonstrated that neural indices of auditory attention in 3-5-year-old children from lower SES backgrounds can be improved after an eight-week family-based intervention, demonstrating the malleability of auditory attention, especially during early childhood. Furthermore, a recent study demonstrated neural differences in auditory attention among young adults from rural versus urban environments (Li et al., 2022), suggesting the potential susceptibility of attentional mechanisms in the auditory system to different environmental influences during adulthood. Given the susceptibility of attentional mechanisms in the auditory system to environmental influences across development, future research should examine whether links between SES and auditory attention may be specific to auditory attention rather than automatic perceptual auditory mechanism.

Another possibility for our results may pertain to how objective childhood SES was captured. Childhood parent education may not fully capture childhood auditory environments and may better capture other aspects of socioeconomic experiences. Specifically, higher parent education may relate to parenting beliefs and behaviors that may enrich children's learning environment and developmental outcomes (Davis-Kean et al., 2021). Childhood parent education was found to relate to children's academic achievement through mechanisms such as stimulating parent behaviors in the home (Davis-Kean, 2005; Davis-Kean et al., 2021). While parent education may better capture parenting beliefs and behaviors, other childhood SES indicators, such as parent income during childhood, may better capture auditory environments that may influence the auditory system. For example, lower income was linked to increased neighborhood noise levels (Fyhri & Klæboe, 2006). Greater exposure to noise may alter the auditory cortex (Zhou & Merzenich, 2012) and individuals may adapt to chronic noise, learning to inhibit relevant sounds (Evans, 2006).

Previous research has also obtained a cumulative score of childhood SES, which may more comprehensively capture childhood socioeconomic experiences. For example, childhood SES was linked to executive functions in adults using cumulative scores that included childhood parent education, occupation, and income (Last et al., 2018; Moorman et al., 2018). These findings may suggest that links between childhood SES and adult outcomes may be more accurately captured when multiple childhood SES indicators are considered. However, it should be considered that the multidimensionality of childhood SES may remain too complex to be captured by either single or multiple indicators, each of which may differentially relate to developmental outcomes (Duncan & Magnuson, 2012).

In anticipation that childhood SES may not be best captured by objective indicators and some indicators may be difficult to capture in adults, we further examined whether subjective family social status during childhood may relate to auditory perception. To do so, we modified the MacArthur Scale of Subjective Social Status (Adler et al., 2000), which was originally designed to capture current subjective social status rather than childhood subjective social status. We asked participants to think back to when they were 10 years old when responding to this scale. It is possible that this adaptation did not accurately capture subjective socioeconomic experiences during childhood.

Alternatively, subjective family social status during childhood may have been accurately captured but any enduring links with auditory perception in adults may have been modified by current auditory environments during adulthood. For example, we asked participants to rate their subjective family social status during childhood; however, their current subjective social status may not be the same as how they perceived their childhood social status. It is possible that the auditory system rapidly adapts to current environmental conditions and the influence of factors captured by subjective social status during childhood, such as standard of living during childhood, may not persist across development. Thus, the relationship between adults' current subjective social status and auditory perception should be examined to assess the potential influence of current environments on auditory perception in young adults.

A limitation to consider in the current study is that all participants in our study had at least completed high school and were either enrolled in college or had college degrees. Formal schooling may train auditory systems, such as auditory attention, as students need to focus on task goals while inhibiting irrelevant information, potentially buffering any influence of childhood auditory environments on the auditory system. For example, children from lower SES backgrounds may experience less conversational interactions at home (Hoff & Tian, 2005; Romeo et al., 2018) which may result in less auditory training, but this may be offset by conversational interactions at school. Nineteen participants in the sample also previously obtained a college degree, which may have acted as a buffer if faced with childhood adversity. To attempt to account for this, we excluded participants with a bachelor's degree or higher but did not find links between childhood family SES and auditory perception. Despite childhood socioeconomic backgrounds, schooling may equalize any potential SES inequalities (Raudenbush & Eschmann, 2015). Thus, future research should examine potential links between SES and auditory perception in young children, prior to the introduction of formal schooling, to avoid potential influences from formal schooling.

Conclusion

In summary, the current study did not find any links between childhood parent education or subjective family social status during childhood and auditory perception in young adults. However, future research should examine these links in a population more representative of socioeconomic diversity (e.g., recruiting more adults with lower educational levels) while taking into account potential confounding experiences such as current social status to gain a more accurate understanding of how childhood SES relates to auditory perception. Future work that addresses the current limitations may contribute towards a more comprehensive understanding of the neurodevelopment of auditory perception, a mechanism foundational for auditory systems such as speech perception and auditory attention, in the context of childhood socioeconomic experiences.

References

Adler, N. E., Epel, E. S., Castellazzo, G., & Ickovics, J. R. (2000). Relationship of subjective and objective social status with psychological and physiological functioning: Preliminary data in healthy, White women. *Health Psychology*, *19*(6), 586–592. https://doi.org/10.1037/0278-6133.19.6.586

Aguiar, L. B., Souza, E. K. de, Evangelista, C. K. de S., Nunes, A. D. da S., Lima, K. R. de A., & Balen, S. A. (2019). Influence of the socieconomic level on the temporal resolution hearing skills in adults. *Revista CEFAC*, *21*, e19218. https://doi.org/10.1590/1982-0216/201921419218

Alho, K., Sainio, K., Sajaniemi, N., Reinikainen, K., & Näätänen, R. (1990). Event-related brain potential of human newborns to pitch change of an acoustic stimulus. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *77*(2), 151–155. https://doi.org/10.1016/0168-5597(90)90031-8

Anwyl-Irvine, A. L., Dalmaijer, E. S., Quinn, A. J., Johnson, A., & Astle, D. E. (2021). Subjective SES is Associated with Children's Neurophysiological Response to Auditory Oddballs. *Cerebral Cortex Communications*, *2*(1), tgaa092. https://doi.org/10.1093/texcom/tgaa092

Bishop, D. V. M., Hardiman, M. J., & Barry, J. G. (2011). Is auditory discrimination mature by middle childhood? A study using time-frequency analysis of mismatch responses from 7 years to adulthood. *Developmental Science*, *14*(2), 402–416. https://doi.org/10.1111/j.1467-7687.2010.00990.x

Cheour, M., H.T. Leppänen, P., & Kraus, N. (2000). Mismatch negativity (MMN) as a tool for investigating auditory discrimination and sensory memory in infants and children. *Clinical Neurophysiology*, *111*(1), 4–16. https://doi.org/10.1016/S1388-2457(99)00191-1

Conant, L. L., Liebenthal, E., Desai, A., & Binder, J. R. (2017). The relationship between maternal education and the neural substrates of phoneme perception in children: Interactions between socioeconomic status and proficiency level. *Brain and Language*, *171*, 14–22. https://doi.org/10.1016/j.bandl.2017.03.010

Davis-Kean, P. E. (2005). The Influence of Parent Education and Family Income on Child Achievement: The Indirect Role of Parental Expectations and the Home Environment. *Journal of Family Psychology*, *19*(2), 294–304. https://doi.org/10.1037/0893-3200.19.2.294

Davis-Kean, P. E., Tighe, L. A., & Waters, N. E. (2021). The Role of Parent Educational Attainment in Parenting and Children's Development. *Current Directions in Psychological Science*, *30*(2), 186–192. https://doi.org/10.1177/0963721421993116

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Destin, M., Richman, S., Varner, F., & Mandara, J. (2012). "Feeling" hierarchy: The pathway from subjective social status to achievement. *Journal of Adolescence*, *35*(6), 1571–1579. https://doi.org/10.1016/j.adolescence.2012.06.006

Diemer, M. A., Mistry, R. S., Wadsworth, M. E., López, I., & Reimers, F. (2013). Best Practices in Conceptualizing and Measuring Social Class in Psychological Research: Social Class Measurement. *Analyses of Social Issues and Public Policy*, *13*(1), 77–113. https://doi.org/10.1111/asap.12001

Diemer, M. A., & Rasheed Ali, S. (2009). Integrating Social Class Into Vocational Psychology: Theory and Practice Implications. *Journal of Career Assessment*, *17*(3), 247–265. https://doi.org/10.1177/1069072708330462

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *WIREs Cognitive Science*, *3*(3), 377–386. https://doi.org/10.1002/wcs.1176

Evans, G. W. (2004). The Environment of Childhood Poverty. *American Psychologist*, *59*(2), 77–92. https://doi.org/10.1037/0003-066X.59.2.77

Evans, G. W. (2006). Child Development and the Physical Environment. *Annual Review of Psychology*, *57*(1), 423–451. https://doi.org/10.1146/annurev.psych.57.102904.190057

Fidell, S. (1978). Nationwide urban noise survey. *J. Acoust. Soc. Am.*, *64*(1), 10.

Foy, J. G., & Mann, V. (2003). Home literacy environment and phonological awareness in preschool children: Differential effects for rhyme and phoneme awareness. *Applied Psycholinguistics*, *24*(1), 59–88. https://doi.org/10.1017/S0142716403000043

Fyhri, A., & Klæboe, R. (2006). Direct, indirect influences of income on road traffic noise annoyance. *Journal of Environmental Psychology*, *26*(1), 27–37. https://doi.org/10.1016/j.jenvp.2006.04.001

Giuliano, R. J., Karns, C. M., Link to external site, this link will open in a new window, Roos, L. E., Bell, T. A., Petersen, S., Skowron, E. A., Neville, H. J., & Pakulak, E. (2018). Effects of early adversity on neural mechanisms of distractor suppression are mediated by sympathetic nervous system activity in preschool-aged children. *Developmental Psychology*, *54*(9), 1674–1686. http://dx.doi.org/10.1037/dev0000499

Glass, E., Sachse, S., & Von Suchodoletz, W. (2008). Development of auditory sensory memory from 2 to 6 years: An MMN study. *Journal of Neural Transmission*, *115*(8), 1221–1229. https://doi.org/10.1007/s00702-008-0088-6

Golinkoff, R. M., Hoff, E., Rowe, M. L., Tamis-LeMonda, C. S., & Hirsh-Pasek, K. (2019). Language Matters: Denying the Existence of the 30-Million-Word Gap Has Serious Consequences. *Child Development*, *90*(3), 985–992. https://doi.org/10.1111/cdev.13128

Gomes, H. (2000). The Development of Auditory Attention in Children. *Frontiers in Bioscience-landmark*, 5, 108-120. 10.2741/gomes

Gonzalez-Gomez, N., O'Brien, F., & Harris, M. (2021). The effects of prematurity and socioeconomic deprivation on early speech perception: A story of two different delays. *Developmental Science*, *24*(2), e13020. https://doi.org/10.1111/desc.13020

Hampton Wray, A., Stevens, C., Pakulak, E., Isbell, E., Bell, T., & Neville, H. (2017). Development of selective attention in preschool-age children from lower socioeconomic status backgrounds. *Developmental Cognitive Neuroscience*, *26*, 101–111. https://doi.org/10.1016/j.dcn.2017.06.006

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children* (pp. xxiii, 268). Paul H Brookes Publishing.

Hoff, E., & Tian, C. (2005). Socioeconomic status and cultural influences on language. *Journal of Communication Disorders*, *38*(4), 271–278. https://doi.org/10.1016/j.jcomdis.2005.02.003

Isbell, E., Calkins, S. D., Swingler, M. M., & Leerkes, E. M. (2018). Attentional fluctuations in preschoolers: Direct and indirect relations with task accuracy, academic readiness, and school performance. *Journal of Experimental Child Psychology*, *167*, 388–403. https://doi.org/10.1016/j.jecp.2017.11.013

Isbell, E., & Grammer, J. K. (2022). Event-related potentials data quality in young children: Standardized measurement error of ERN and Pe. *Developmental Psychobiology*, *64*(4), e22245. https://doi.org/10.1002/dev.22245

Kappenman, E. S., Farrens, J. L., Zhang, W., Stewart, A. X., & Luck, S. J. (2021). ERP CORE: An open resource for human event-related potential research. *NeuroImage*, *225*, 117465. https://doi.org/10.1016/j.neuroimage.2020.117465

Last, B. S., Lawson, G. M., Breiner, K., Steinberg, L., & Farah, M. J. (2018). Childhood socioeconomic status and executive function in childhood and beyond. *PLOS ONE*, *13*(8), e0202964. https://doi.org/10.1371/journal.pone.0202964

Li, S., Yang, Z., Wang, C., & Xu, Q. (2022). Rural and urban disparities in selective attention in Chinese young adults: An event-related potential study. *Applied Neuropsychology: Adult*, *29*(5), 1167–1173. https://doi.org/10.1080/23279095.2020.1861617

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, *8*. https://www.frontiersin.org/articles/10.3389/fnhum.2014.00213

Lovio, R., Pakarinen, S., Huotilainen, M., Alku, P., Silvennoinen, S., Näätänen, R., & Kujala, T. (2009). Auditory discrimination profiles of speech sound changes in 6-year-old children as determined with the multi-feature MMN paradigm. *Clinical Neurophysiology*, *120*(5), 916–921. https://doi.org/10.1016/j.clinph.2009.03.010

Luck, S. J. (2014). *An Introduction to the Event-Related Potential Technique, second edition*. MIT Press.

Luck, S. J. (2022). *Applied Event-Related Potential Data Analysis*. LibreTexts. https://doi.org/10.18115/D5QG92

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology*, *54*(1), 146–157. https://doi.org/10.1111/psyp.12639

Luck, S. J., Stewart, A. X., Simmons, A. M., & Rhemtulla, M. (2021). Standardized measurement error: A universal metric of data quality for averaged event-related potentials. *Psychophysiology*, *58*(6), e13793. https://doi.org/10.1111/psyp.13793

Mingils, S. M., Davies, P. L., Stephens, J. A., & Gavin, W. J. (2023). Developmental trends of auditory novelty oddball P3 while accounting for N2 in 7- to 25-year-olds. *Psychophysiology*, *60*(4), e14214. https://doi.org/10.1111/psyp.14214

Moorman, S. M., Carr, K., & Greenfield, E. A. (2018). Childhood socioeconomic status and genetic risk for poorer cognition in later life. *Social Science & Medicine*, *212*, 219–226. https://doi.org/10.1016/j.socscimed.2018.07.025

Morr, M. L., Shafer, V. L., Kreuzer, J. A., & Kurtzberg, D. (2002). Maturation of Mismatch Negativity in Typically Developing Infants and Preschool Children: *Ear and Hearing*, *23*(2), 118–136. https://doi.org/10.1097/00003446-200204000-00005

Näätänen, R., & Kreegipuu, K. (2011). *The Mismatch Negativity (MMN)*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374148.013.0081

Näätänen, R., Kujala, T., Light, G. (2019). *The Mismatch Negativity: A Window to the Brain*. Oxford University Press.

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: A review. *Clinical Neurophysiology*, *118*(12), 2544–2590. https://doi.org/10.1016/j.clinph.2007.04.026

Näätänen, R., Pakarinen, S., Rinne, T., & Takegata, R. (2004). The mismatch negativity (MMN): Towards the optimal paradigm. *Clinical Neurophysiology*, *115*(1), 140–144. https://doi.org/10.1016/j.clinph.2003.04.001

Neville, H. J., Stevens, C., Pakulak, E., Bell, T. A., Fanning, J., Klein, S., & Isbell, E. (2013). Family-based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(29), 12138–12143. https://doi.org/10.1073/pnas.1304437110

Petermann, M., Kummer, P., Burger, M., Lohscheller, J., Eysholdt, U., & Döllinger, M. (2009). Statistical detection and analysis of mismatch negativity derived by a multi-deviant design from normal hearing children. *Hearing Research*, *247*(2), 128–136. https://doi.org/10.1016/j.heares.2008.11.001

Pion-Tonachini, L., Kreutz-Delgado, K., & Makeig, S. (2019). ICLabel: An automated electroencephalographic independent component classifier, dataset, and website. *NeuroImage*, *198*, 181–197. https://doi.org/10.1016/j.neuroimage.2019.05.026

Polich, J. (2011). Neuropsychology of P300. In E. S. Kappenman & S. J. Luck (Eds.), *The Oxford Handbook of Event-Related Potential Components* (p. 0). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374148.013.0089

Putkinen, V., Tervaniemi, M., Saarikivi, K., de Vent, N., & Huotilainen, M. (2014). Investigating the effects of musical training on functional brain development with a novel Melodic MMN paradigm. *Neurobiology of Learning and Memory*, *110*, 8–15. https://doi.org/10.1016/j.nlm.2014.01.007

Rabelo, C. M., Neves-Lobo, I. F., Rocha-Muniz, C. N., Ubiali, T., & Schochat, E. (2015). Cortical inhibition effect in musicians and non-musicians using P300 with and without contralateral stimulation. *Brazilian Journal of Otorhinolaryngology*, *81*, 63–70. https://doi.org/10.1016/j.bjorl.2014.11.003

Raudenbush, S. W., & Eschmann, R. D. (2015). Does Schooling Increase or Reduce Social Inequality? *Annual Review of Sociology*, *41*(1), 443–470. https://doi.org/10.1146/annurev-soc-071913-043406

Riggins, T., & Scott, L. S. (2019). P300 development from infancy to adolescence. *Psychophysiology*, *57*(7), e13346. https://doi.org/10.1111/psyp.13346

Romeo, R. R., Segaran, J., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., Yendiki, A., Rowe, M. L., & Gabrieli, J. D. E. (2018). Language Exposure Relates to Structural Neural Connectivity in Childhood. *Journal of Neuroscience*, *38*(36), 7870–7877. https://doi.org/10.1523/JNEUROSCI.0484-18.2018

Schwab, J. F., & Lew-Williams, C. (2016). Language learning, socioeconomic status, and child-directed speech. *WIREs Cognitive Science*, *7*(4), 264–275. https://doi.org/10.1002/wcs.1393

Singh-Manoux, A., Adler, N. E., & Marmot, M. G. (2003). Subjective social status: Its determinants and its association with measures of ill-health in the Whitehall II study. *Social Science & Medicine*, *56*(6), 1321–1333. https://doi.org/10.1016/S0277-9536(02)00131-4

Singh-Manoux, A., Marmot, M. G., & Adler, N. E. (2005). Does Subjective Social Status Predict Health and Change in Health Status Better Than Objective Status?. *Psychosomatic Medicine*, *67*(6), 855–861. https://doi.org/10.1097/01.psy.0000188434.52941.a0

Skoe, E., Krizman, J., & Kraus, N. (2013). The Impoverished Brain: Disparities in Maternal Education Affect the Neural Response to Sound. *Journal of*

Neuroscience, *33*(44), 17221–17231. https://doi.org/10.1523/JNEUROSCI.2102-13.2013
Stevens, C., Lauinger, B., & Neville, H. (2009). Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: An event-related brain potential study. *Developmental Science*, *12*(4), 634–646. https://doi.org/10.1111/j.1467-7687.2009.00807.x
Sussman, E. S. (2007). A New View on the MMN and Attention Debate: The Role of Context in Processing Auditory Events. *Journal of Psychophysiology*, *21*(3–4), 164–175. https://doi.org/10.1027/0269-8803.21.34.164
Sussman, E. S., Chen, S., Sussman-Fort, J., & Dinces, E. (2014). The Five Myths of MMN: Redefining how to use MMN in basic and clinical research. *Brain Topography*, *27*(4), 553–564. https://doi.org/10.1007/s10548-013-0326-6
Tabone, N., Said, J., Grech, H., & Bamiou, D.-E. (2017). *The impact of socioeconomic status on auditory processing skills in Maltese children*. https://doi.org/10.14614/AUDIPROC/8/17
Tamminen, H., Peltola, M. S., Kujala, T., & Näätänen, R. (2015). Phonetic training and non-native speech perception—New memory traces evolve in just three days as indexed by the mismatch negativity (MMN) and behavioural measures. *International Journal of Psychophysiology*, *97*(1), 23–29. https://doi.org/10.1016/j.ijpsycho.2015.04.020
Ursache, A., Noble, K. G., & Blair, C. (2015). Socioeconomic Status, Subjective Social Status, and Perceived Stress: Associations with Stress Physiology and Executive Functioning. *Behavioral Medicine*, *41*(3), 145–154. https://doi.org/10.1080/08964289.2015.1024604
Wong, Y. P., & Yang, H. (2022). The influence of subjective socioeconomic status on executive functions in middle-aged and older adults. *Aging, Neuropsychology, and Cognition*, 1–18. https://doi.org/10.1080/13825585.2022.2055738
Zhou, X., & Merzenich, M. M. (2012). Environmental noise exposure degrades normal listening processes. *Nature Communications*, *3*(1), Article 1. https://doi.org/10.1038/ncomms1849

Table 1

Descriptive Statistics

Variables	n	*Mean*	SD	Min	Max
Demographics					
Age	73	21.84	2.70	18.58	30.12
Parent education	73	12.33	4.12	4	18
Subjective family social status during childhood	73	4.93	2.08	1	10
Fixed mean amplitude (μV)	73	-2.34	1.53	-6.06	1.28
Adjusted mean amplitude (μV)	73	-2.47	1.54	-6.12	1.25
Fractional area latency (ms)	70	195.37	14.97	160	228

Note. Age and childhood parent education are reported in years.

Table 2

ERP Waveform Descriptive Statistics

	Trials				Mean Amplitude (μV)				SME
Waveform	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	
Standard	191.14	5.19	170	196	0.54	1.28	-2.90	3.52	0.61
Deviant	68.56	2.18	60	70	-1.93	1.82	-6.47	2.10	1.02
Difference	259.84	7.00	230	265	-2.34	1.53	-6.06	1.28	1.18

Note. aSME (analytic standardized measurement error) was used for standard and deviant waveforms. bSME (bootstrapped standardized measurement error) was used for the difference waveform.

Table 3

Zero-order correlations

Variable	1	2	3	4	5	6	7	8
1. Childhood parent education in years	--							
2. Subjective family social status during childhood	**0.49**	--						
3. Fixed mean amplitude (µV)	-0.12	0.08	--					
4. Adjusted mean amplitude (µV)	-0.13	0.07	**0.99**	--				
5. Fractional area latency (ms)	0.02	-0.01	-0.15	0.05	--			
6. aSME standard waveform	0.18	0.08	-0.21	-0.19	0.06	--		
7. aSME deviant waveform	0.06	0.01	-0.12	-0.11	0.03	**0.78**	--	
8. bSME difference waveform	0.09	0.03	-0.14	-0.12	0.04	**0.86**	**0.99**	--

Note. Boldface font indicates $p < 0.05$. aSME represents analytic standardized measurement error. bSME represents bootstrapped standardized measurement error.

Table 4
Summary of hierarchical regression results for fixed mean amplitude in the electrode cluster (n = 73)

Variable	*B*	*SE B*	*β*	*p*	R^2
Step 1					0.00
Parent education	-0.04	0.04	-0.12	0.32	
Step 2					0.01
Parent education	-0.08	0.05	-0.20	0.14	
Subjective social status during childhood	0.13	0.10	0.18	0.20	
					$\Delta R^2 = 0.02$

Note. Childhood parent education is reported in years.

Table 5

Summary of hierarchical regression results for adjusted mean amplitude in the electrode cluster (n = 73)

Variable	*B*	*SE B*	*β*	*p*	R^2
Step 1					0.00
Parent education	-0.05	0.04	-0.13	0.29	
Step 2					0.04
Parent education	-0.08	0.05	-0.21	0.12	
Subjective family social status during childhood	0.13	0.10	0.18	0.19	
					$\Delta R^2 = 0.02$

Note. Childhood parent education is reported in years.

Table 6

Summary of hierarchical regression results for fractional area latency in the electrode cluster (n = 70)

Variable	*B*	*SE B*	*β*	*p*	R^2
Step 1					0.00
Parent education	0.07	0.42	0.02	0.87	
Step 2					0.00
Parent education	0.11	0.49	0.03	0.83	
Subjective family social status during childhood	-0.15	0.97	-0.02	0.88	
					$\Delta R^2 = 0.00$

Note. Childhood parent education is reported in years.

Table 7

Summary of hierarchical regression results for fixed mean amplitude excluding participants with a bachelor's degrees or above (n = 54)

Variable	*B*	*SE B*	*β*	*p*	R^2
Step 1					0.01
Parent education	-0.03	0.05	-0.07	0.61	
Step 2					0.01
Parent education	-0.04	0.06	-0.11	0.47	
Subjective family social status during childhood	0.08	0.12	0.09	0.55	
					$\Delta R^2 = 0.01$

Note. Childhood parent education is reported in years.

Table 8

Summary of hierarchical regression results for adjusted mean amplitude excluding participants with a bachelor's degree or above (n = 54)

Variable	*B*	*SE B*	*β*	*p*	R^2
Step 1					0.01
Parent education	-0.03	0.05	-0.08	0.56	
Step 2					0.01
Parent education	-0.05	0.06	-0.12	0.45	
Subjective family social status during childhood	0.07	0.13	0.09	0.58	
					$\Delta R^2 = 0.01$

Note. Childhood parent education is reported in years.

Table 9
Summary of hierarchical regression results fractional area latency excluding participant with a bachelor's degrees or above (n = 52)

Variable	*B*	*SE B*	*β*	*p*	R^2
Step 1					0.01
Parent education	0.33	0.52	0.09	0.53	
Step 2					0.03
Parent education	0.57	0.57	0.16	0.32	
Subjective family social status during childhood	-1.32	1.23	-0.16	0.29	
					$\Delta R^2 = 0.02$

Note. Childhood parent education is reported in years.

Table 10

Zero-order correlations between childhood SES and outcome variables in frontocentral electrodes

Variable	1	2	3	4	5	6
1. Parent education	--					
2. Subjective family social status during childhood	**0.49**	--				
3. FC1 fixed mean amplitude (μV)	-0.04	0.08	--			
4. FC2 fixed mean amplitude (μV)	-0.10	0.07	**0.82**	--		
5. FC1 fractional area latency (ms)	0.04	0.02	**0.03**	-0.97	--	
6. FC2 fractional area latency (ms)	0.03	0.02	-0.08	-0.11	**0.91**	--

Note. Boldface font indicates $p < 0.05$. Parent education is reported in years.

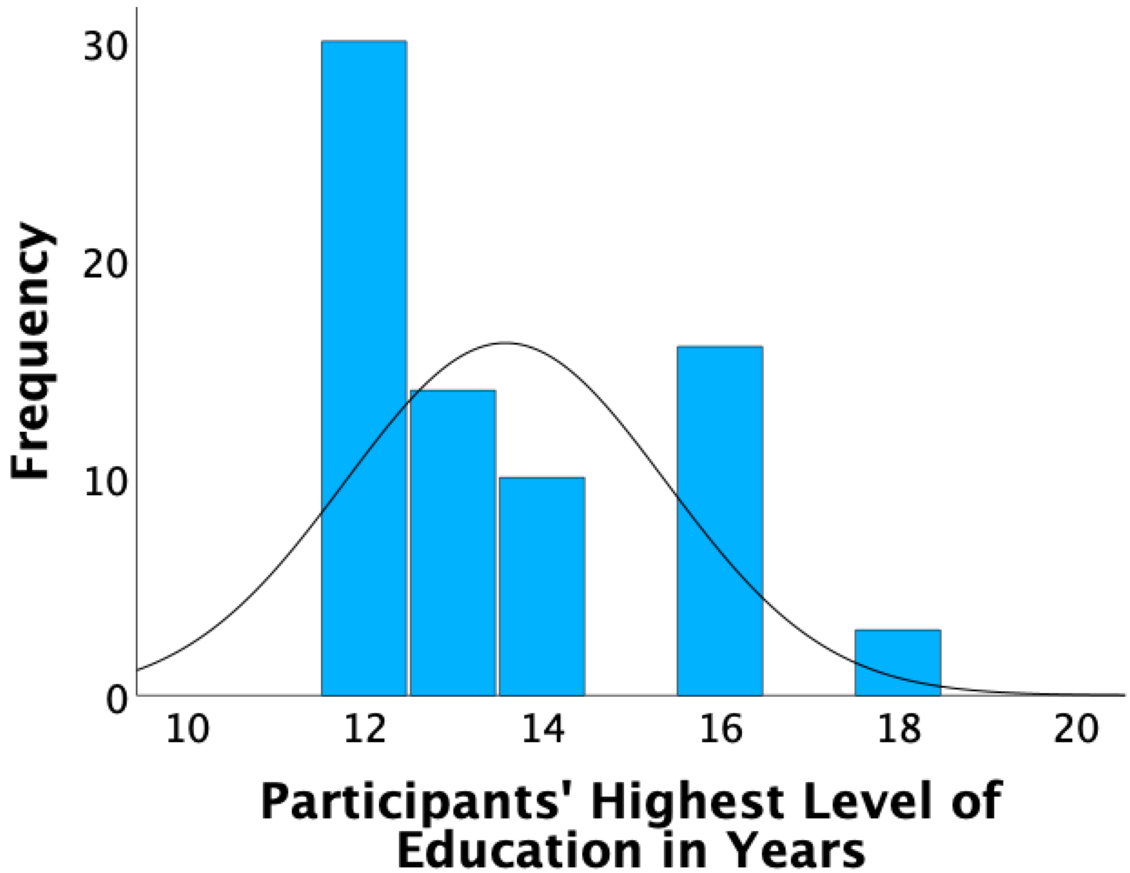

Figure 1. Histogram of participants' highest level of education they completed (n = 73).

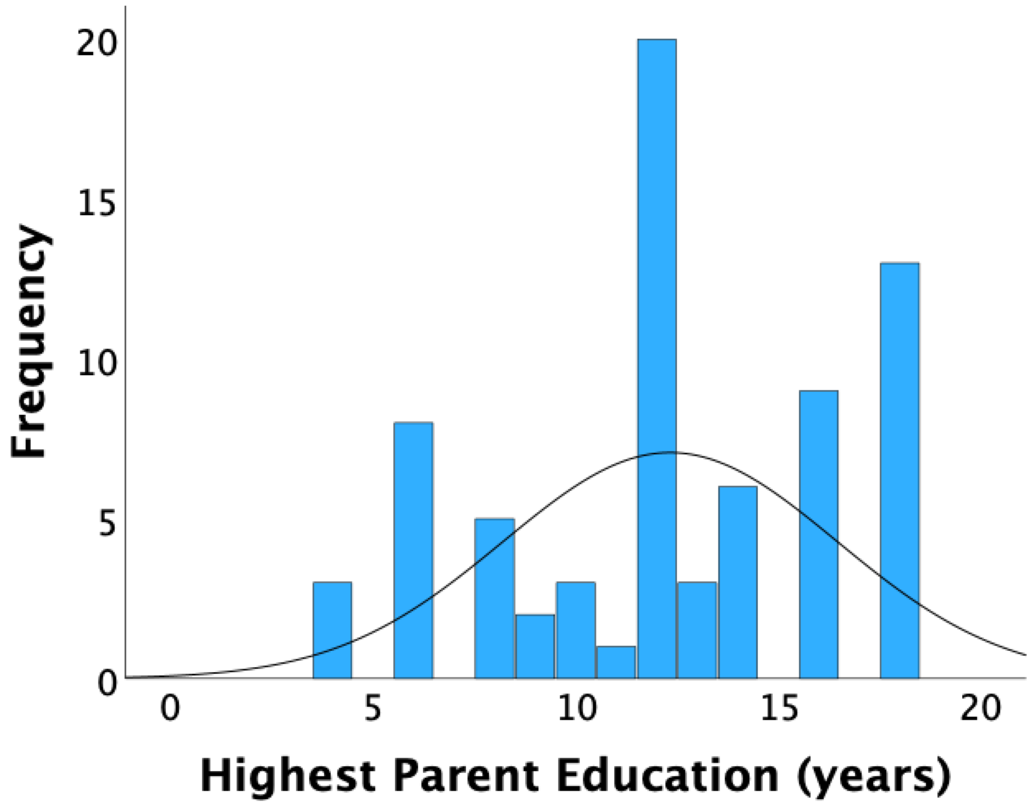

Figure 2. Histogram of highest childhood parent education (n = 73)

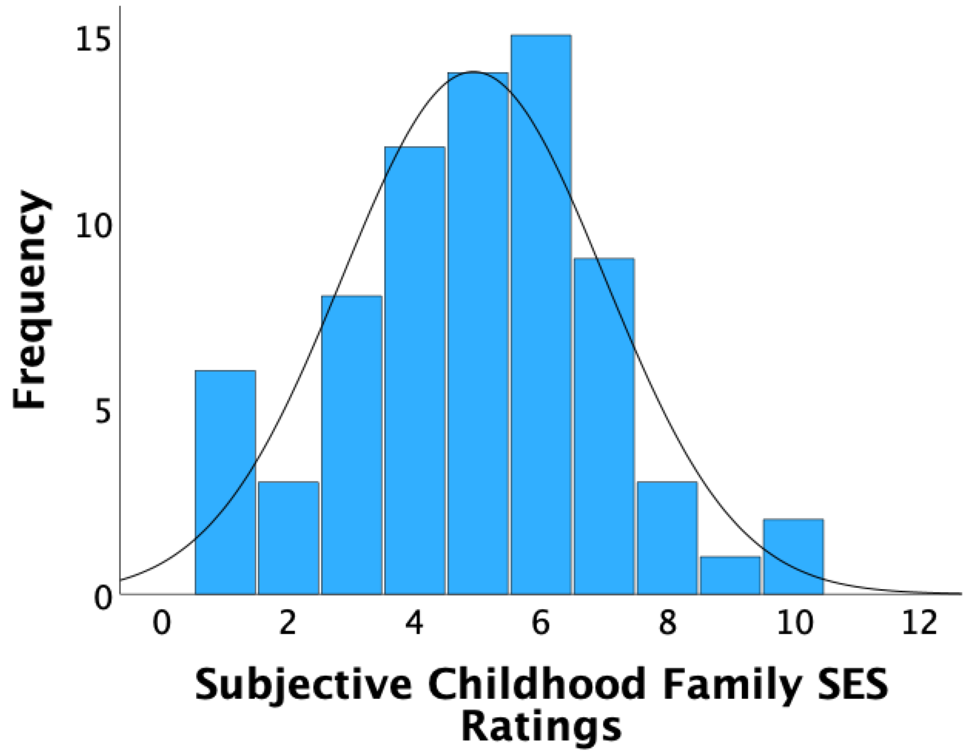

Figure 3. Histogram of participants' ratings of subjective family social status during childhood as answered on the MacArthur Scale of Subjective Social Status (n = 73; Adler et al., 2000).

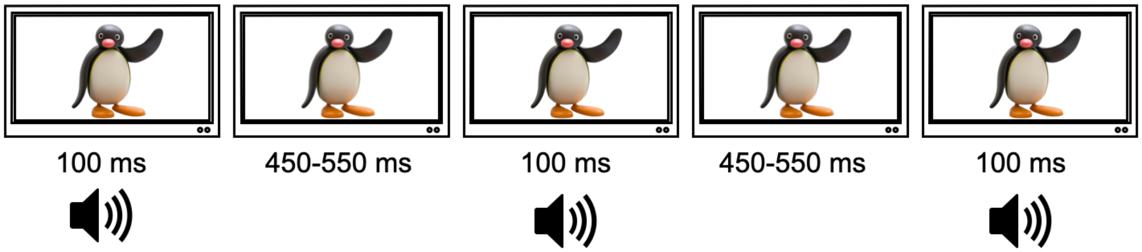

Figure 4. Passive auditory oddball paradigm illustration. Tone stimuli were presented for 100ms with a 450-550 ms interstimulus interval.

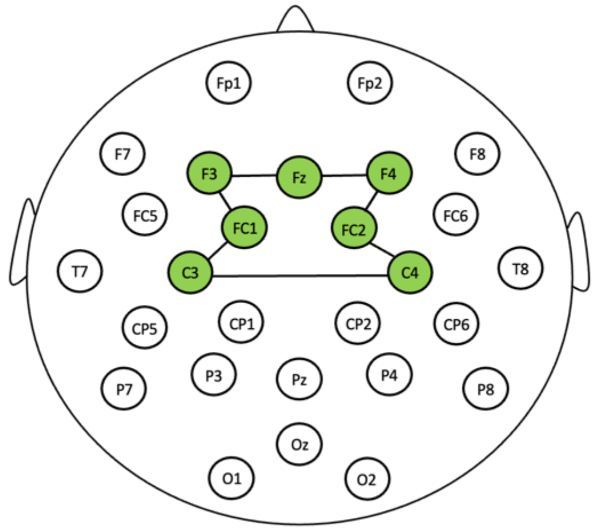

Figure 5. Electrode configuration with electrodes included in the MMN cluster highlighted in green.

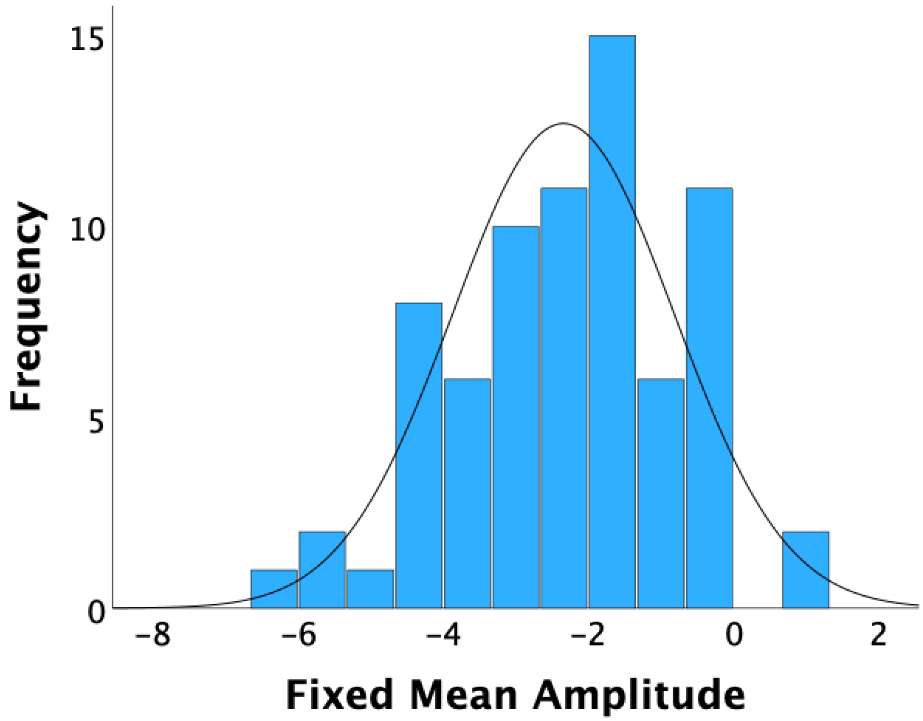

Figure 6. Histogram of mean amplitude (μV) in the MMN electrode cluster measured between 150-250 ms post stimulus onset (n = 73).

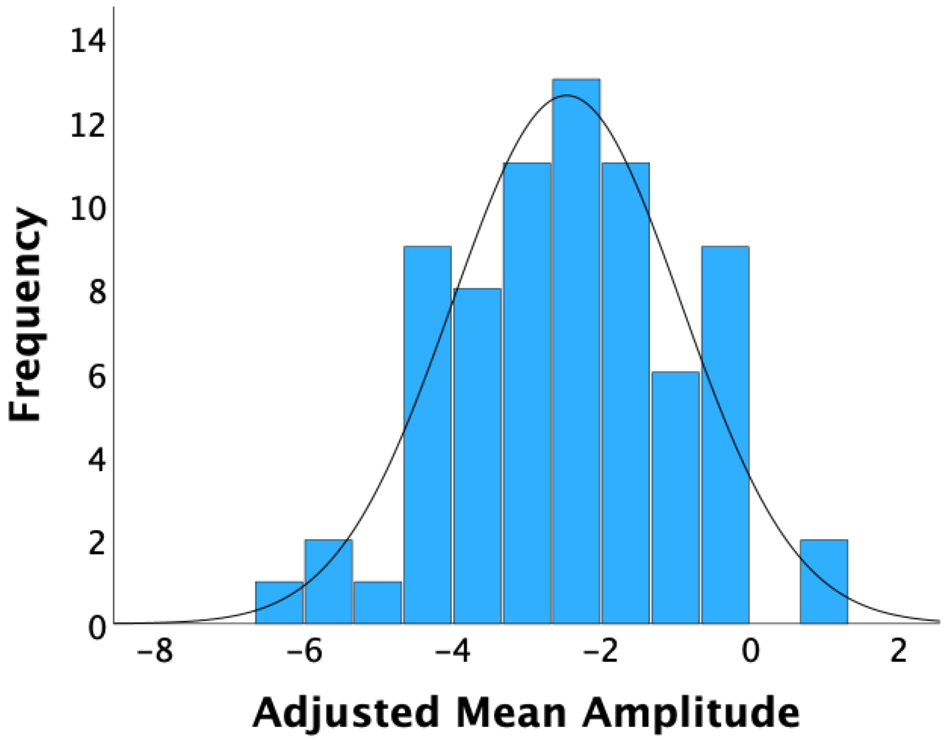

Figure 7. Histogram of mean amplitude (μV) in the MMN electrode cluster measured from measurement windows individually adjusted for each participant (n = 73).

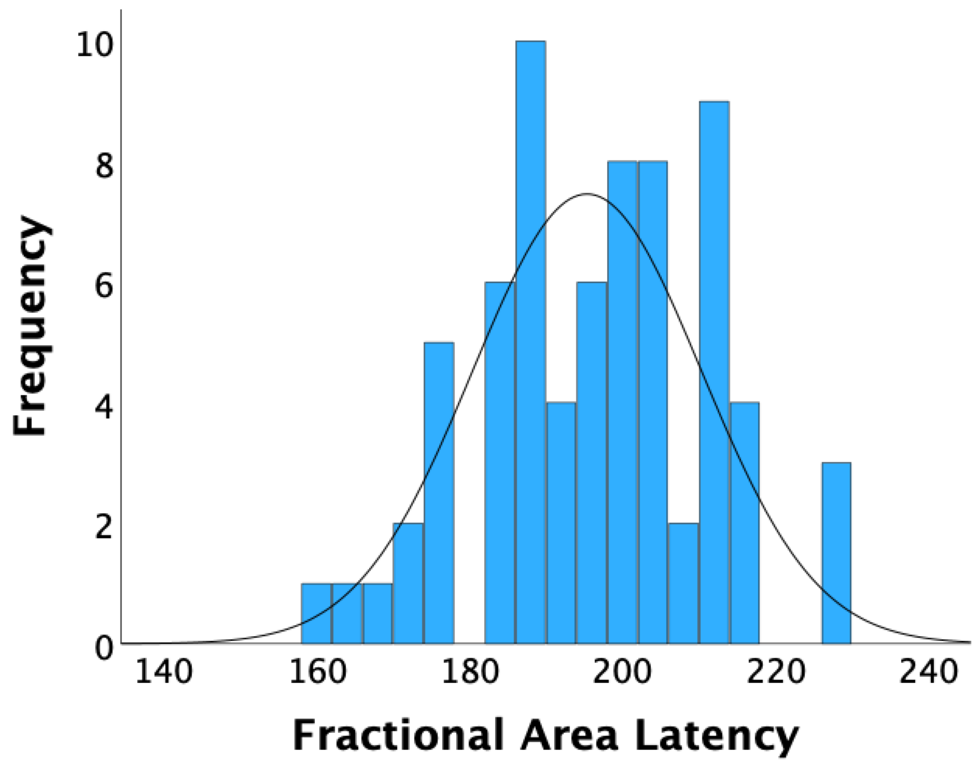

Figure 8. Histogram of fractional area latency (ms) in the MMN electrode cluster measured between 125-300 ms post stimulus onset (n = 70).

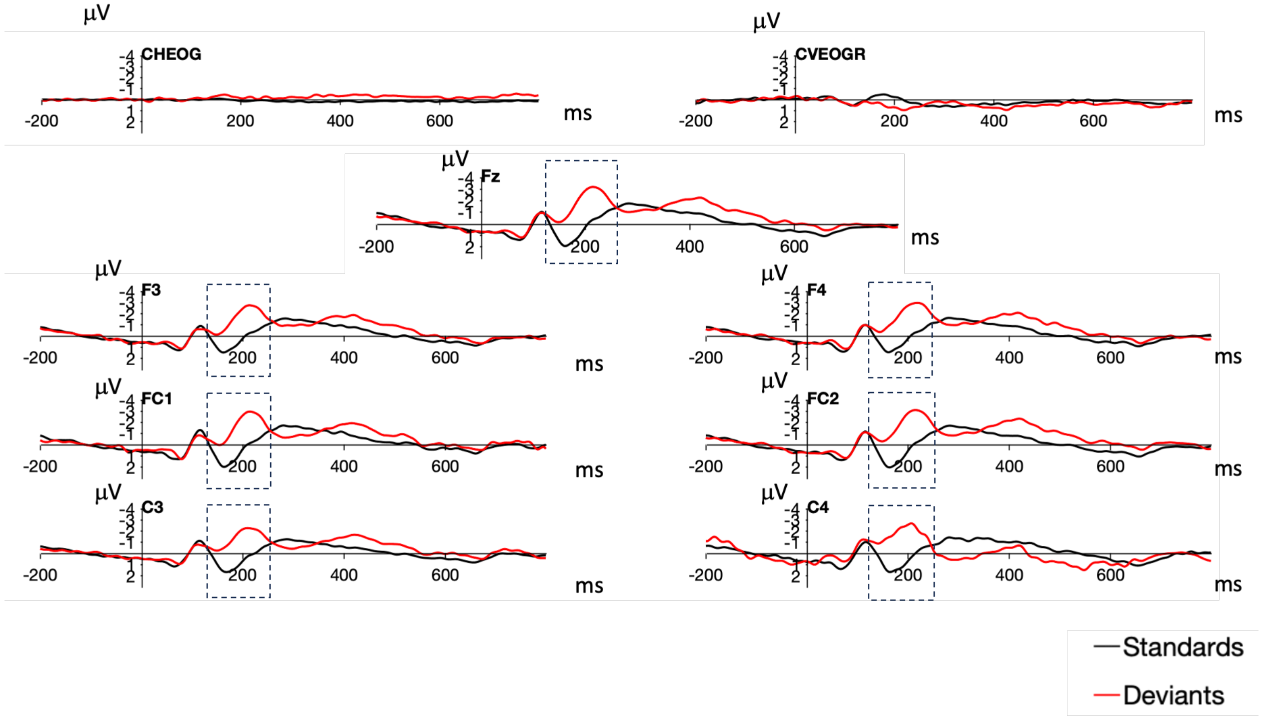

Figure 9. Grand average ERP plots (n = 73) for the standards (black waveform) and deviants (red waveform) over bipolar EOG channels and the individual electrodes that were clustered together. Negative is plotted upward by convention. The dotted outline shows the 150-250 ms MMN measurement time window measured in the electrodes of interest.

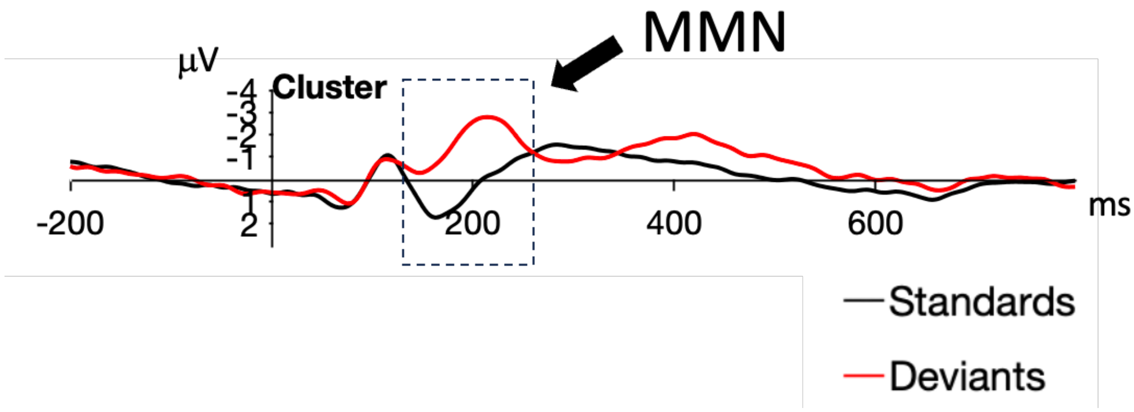

Figure 10. Grand average ERP plot (n = 73) for the standards (black waveform) and deviants (red waveform) over the electrode cluster (F3, Fz, F4, FC1, FC2, C3, C4). Negative is plotted upward by convention. The dotted outline shows the 150-250 ms MMN measurement time window.