**Trends in Body Mass Index Among Individuals with Neurodevelopmental Disorders**

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# Abstract (288/350)

**Importance**: Neurodevelopmental disorders (NDDs) such as autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD) are increasingly common. Individuals with NDDs face heightened obesity risks, but long-term data on body mass index (BMI) trends over time in this population are lacking.

**Objective:** To assess secular BMI changes from 2004-2020 among children with NDDs versus those without NDDs.

**Design, Setting, and Participants**: This population-based cross-cohort study used data from the Child and Adolescent Twin Study in Sweden (CATSS). Children were screened for neurodevelopmental symptoms using the Autism-Tics, ADHD, and other Comorbidities inventory when they were 9/12 years old, assessed between 2004 and 2020.

**Main outcomes and Measures:** BMI percentiles were modeled using quantile regression and compared between youth with and without NDDs. Secular changes in BMI percentiles over time between 2004-2020 birth cohorts were evaluated and stratified by NDD subtype.

**Results**: The cohort included 24,969 Swedish twins (12,681 [51%] boys) born between 1992 and 2010. Of these, 1,103 (4.4%) screened positive for one or more NDDs, including ADHD, ASD or learning disability (LD). Results indicated a greater increase in BMI at the 85th percentile from 2004 to 2020 among youth with NDDs compared with those without NDDs (b=1.67, 95% CI [0.39, 2.90]). The greatest divergence was seen for ASD and LD. Within the latest cohort (2016-2020), the 85th BMI percentile was 1.99 points higher (95% CI 1.08-2.89) among children with NDDs versus non-NDD controls.

**Conclusions and Relevance**: In this repeated cross-sectional study, children with NDDs had significantly greater rises in BMI at the higher end of the BMI distribution versus peers without NDDs over a 16-year period, highlighting an increasing risk of overweight over time in youth with NDDs compared to those without NDDs. Targeted obesity prevention efforts for this high-risk population are needed.

***Keywords****: Neurodevelopmental disorders; body mass index; autism; ADHD; epidemiology.*

# Key Points

**Question**

Has there been a secular change in body mass index (BMI) among those with neurodevelopmental disorders (NDDs) compared to youth without NDDs?

**Findings**

This repeated cross-sectional study found significantly steeper rises in BMI over time between 2004 and 2020 at the upper end of the BMI distribution among 24,969 Swedish children with NDDs versus non-NDD controls.

**Meaning**

Results from this study highlight a need to address an increasing weight-related risk in this vulnerable population through targeted prevention and treatment.

# Introduction

Neurodevelopmental disorders (NDDs), such as autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), and learning disabilities (LD), are characterized by early-onset developmental impairments in cognitive, communicative, motor, and social development. These conditions are highly prevalent, affecting at least 5-10% of children,1 and they frequently persist into adulthood.2

Historically, the focus of research and clinical attention within the realm of NDDs has primarily revolved around the cognitive and behavioral aspects. However, it has become increasingly evident that there are complex interactions between the neurodevelopmental challenges individuals face and their physical health.3 One area of emerging interest is the relationship between NDDs and increased Body Mass Index (BMI). Previous research has consistently found an increased risk of overweight/obesity among children and adults with NDDs (e.g., ASD and ADHD) compared to the general population.4–6 This association has raised important questions about potential contributing factors, such as genetic predispositions, medication effects, dietary patterns, and physical activity levels.7 Nevertheless, the existing body of literature primarily comprises cross-sectional studies, limiting our understanding of longitudinal changes of BMI in individuals with NDDs.

Despite well-established associations between NDDs and increased BMI,8 it is unknown whether the secular trend of increasing BMI observed in the general population over the past decades9 has been more pronounced in individuals with NDDs. Given their vulnerability to weight gain and obesity-related health problems, it is critical to understand whether the obesity epidemic has disproportionately impacted individuals with NDDs compared with the general population. Gaining insight into these trends may inform public health policies and initiatives to increase efforts aimed at preventing and treating obesity specifically in individuals with NDDs, helping to improve their quality of life and health outcomes.

The primary objective of this study was to assess whether there have been differences in secular changes in BMI in individuals with NDDs, including ASD, ADHD, and LD compared with the general population over a 16-year period. By using cross-cohort comparisons of BMI within this population, we aimed to elucidate whether any significant shifts over time have occurred. Quantile regression was used to model different percentiles (15th, 50th, and 85th) of the BMI distribution to examine whether trends differed across the distribution and not just for the mean BMI.

# Methods

This study was approved by the Karolinska Institute Ethical Review Board (2018/960-31-2). We followed the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.10

## Study population

Data for this study were obtained from The Child and Adolescent Twin Study in Sweden (CATSS), an ongoing longitudinal cohort study of all twins in Sweden. CATSS was initiated in 2004 by recruiting families of twins who were turning 9 or 12 years old that year, with an initial participation rate of 80% (see Anckarsäter et al.11 for an in-depth description). The study included all individuals from the CATSS cohort born between January 1, 1992 and December 31, 2010 and assessed between 2004 and 2020.

## Measurements

Neurodevelopmental disorder symptoms were assessed using the Autism-Tics, ADHD and other Comorbidities (A-TAC) inventory,12 a comprehensive screening questionnaire validated in child and adolescent populations covering the most common child and adolescent psychiatric disorders. The A-TAC includes 96 items, with 19 corresponding to ADHD symptoms, 17 to ASD (six for language, six for social interaction, and five for flexibility), and three items related to LD. Each item is scored 0 for ‘*no’*, 0.5 for ‘*yes, to some extent*’, and 1 for ‘*yes’*, yielding a total symptom score ranging from 0 to 19 for ADHD, 0 to 17 for ASD, and 0 to 3 for LD.

Validated clinical cutoffs have been established for ADHD, including a score of ≥12.5 suggesting a high likelihood of an ADHD diagnosis, used as a validated proxy for clinical diagnoses of ADHD (sensitivity=0.28, specificity=0.99).13 The A-TAC ADHD scale has excellent psychometric properties including high inter-rater reliability (ICC 0.89), test-retest reliability (ICC 0.84), and internal consistency (Cronbach's α 0.92).14 The ASD module with a cutoff >=8.5 has a sensitivity of 0.30 and a specificity of 0.99. The LD subscale was validated against ICD-10 definitions of Intellectual disability (F70-F79) and reports a sensitivity of 0.39 and a specificity of 0.99.13,15 ASD, ADHD and LDs subscales have all been validated cross-sectionally and longitudinally in both clinical and large-scale epidemiological samples.13,15

BMI was calculated using parent-reported height and weight for each individual at the time of the CATSS-9/12 telephone interview. Parents provided the current height in centimeters and weight in kilograms. BMI was then computed as weight in kilograms divided by height in meters squared (kg/m2). Individuals with missing data on height or weight (n=3,018) were excluded from the analysis.

## Statistical analysis

Baseline characteristics were summarized using means and proportions for individuals without NDDs and those screening positive for NDDs, including ADHD, ASD, and LD. For descriptive purposes, individuals were classified into five cohorts spanning 2004-2020: 2004-2006, 2007-2009, 2010-2012, 2013-2015, and 2016-2020. Mean BMI was presented for NDD cases and non-NDD controls within each birth cohort and was also presented at the 15th and 85th percentiles to characterize the full BMI distribution.

To visualize secular changes in BMI, a quantile regression model was fitted regressing BMI on year of assessment using a cubic basis spline with four degrees of freedom for those with and without NDDs separately. This was done separately for the 15th, 50th, and 85th percentiles of BMI. The fitted curves from these models were plotted to visualize changes in BMI over time across the distribution. A quantile regression analysis at each BMI percentile (15th, 50th, and 85th) was performed because it allows for understanding the relationship between variables across the distribution of the outcome, not just at the mean. Furthermore, quantile regression analysis is beneficial for outcomes like BMI that may have a skewed or non-normal distribution.16 Importantly, it can characterize associations at the tails of the distribution, for example at higher BMI levels where individuals are at greatest health risk. Thereafter, to assess and quantify differences in the change in BMI over the study period between NDD and non-NDD groups, an interaction term between NDD status (yes/no) and time was included in quantile regression models. Time was scaled to reflect the change from the first study year (2004) to the last (2020). Analyses were stratified by NDD subtype and sex.

Lastly, to quantify differences in BMI between those with and without a NDD more recently, a quantile regression model was fitted using within last cohort (2016-2020). The model included a binary indicator variable for NDD status as a predictor providing an estimate of the difference in BMI between NDD and non-NDD groups at different levels of BMI. This process was repeated separately for individuals with any NDD and for each NDD subgroup (ADHD, ASD, and LD) and sex. Quantile regression models used a sparse implementation of the Frisch–Newton algorithm.17 Standard errors were estimated using the Huber sandwich estimate assuming non-identically distributed errors.18 All analyses were performed using R version 4.2.319 and were conducted between September 27, 2023, and January 30, 2024.

# Results

The study cohort comprised 24,969 individuals born between 1992 and 2010 and assessed between 2004 and 2020, of which 12,681 (51%) were boys and 1,103 (4.41%) had symptoms exceeding the clinical threshold for one or more NDDs (Table 1). Among individuals with NDDs (N=1,103), the most prevalent NDD was ADHD, present in 621 individuals (25%). Across all cohorts, individuals with NDDs showed similar mean BMIs compared with non-NDD controls (e.g., 16.67 vs. 16.79 kg/m2 in the 2004-2006 cohort and 17.48 vs 16.70 kg/m2 in the 2016-2020 cohort; Table 1). However, examinations by BMI percentile revealed diverging trajectories between groups over time, particularly at the upper end of the distribution. For instance, in the 2016-2020 cohort, the 85th percentile of BMI was 20.90 kg/m2 (95% CI 20.30, 21.88) among NDD cases compared with 18.94 kg/m2 (95% CI 18.88, 19.17) in individuals without NDDs, with an estimated BMI difference of 1.99 kg/m2 (95% CI 1.05, 2.93). eTable 1 summarizes the 15th, 50th, and 85th BMI percentiles for those with and without NDDs over time.

Figure 1 displays the predicted 15th, 50th, and 85th percentiles for BMI over time among individuals with and without NDDs. The figure illustrated that BMI has increased across percentiles in both the NDD and non-NDD groups over the study period. However, the rise in BMI percentiles was more pronounced among those with NDDs, particularly after 2016. When quantifying the difference in the change of BMI from 2004 to 2020 between those with and without NDDs, quantile regression showed that, at the 85th BMI percentile, the interaction term between NDD status and time (βint) was significant, indicating the BMI increase over the study period was greater among youth with NDDs compared with non-NDD controls (βint=1.67, 95% CI 0.39, 2.80). When examining specific NDD subtypes, the interaction terms were largest for ASD (βint=2.12, 95% CI 1.26, 3.70) and LD (βint=1.92, 95% CI 0.65, 3.82) compared with individuals without those conditions. The interaction between ADHD status and time did not reach statistical significance (βint=1.37, 95% CI -0.59, 2.53), suggesting less divergence in BMI change over time at the 85th percentile for ADHD versus non-ADHD peers (Table 2).

When stratified by sex, boys with NDDs showed a similar pattern of disproportionate BMI increases over time compared to non-NDD boys, but with a greater magnitude of difference than in the overall sample (eTable 2). For example, the 85th BMI percentile increased by 2.30 more points (95% CI 0.19, 3.27) among boys with NDDs compared with non-NDD boys from 2004 to 2020. In contrast, among girls there were no statistically significant differences in secular trends in BMI over time between NDD and non-NDD groups, except for ASD. Girls with ASD showed steeper BMI increases compared to non-NDD girls (βint=1.39 95% CI 0.11, 4.83), but differences were less pronounced than in boys.

In the latest cohort (2016-2020), there were sizable gaps in the upper BMI percentiles between the NDD and non-NDD groups. The quantile regression analysis demonstrated significantly higher BMIs across the distribution for individuals with NDDs compared with those without NDDs assessed in 2016 or later. The most pronounced differences were evident at the 85th percentile of BMI. For example, individuals with ASD had an 85th percentile BMI that was 2.89 (95% CI 2.14, 3.64) points higher than individuals without ASD. This difference was also large for those with LD at 2.42 (95% CI 1.84, 3.01) points above those without LD. When examining all NDDs together (i.e., without diagnostic subgroup stratification), the 85th percentile BMI was 1.99 (95% CI 1.08, 2.89) points higher compared to non-NDD individuals (Table 3). Significant, albeit smaller, BMI differences were also identified at the 50th percentile across individuals with NDD and NDD subgroups in the quantile regression. Individuals with NDDs had a 50th percentile BMI that was 0.65 (0.19, 1.117) points higher than those without NDDs. Similarly, the difference was 1.13 (95% CI 0.34, 1.91) points higher for those with ASD, 1.13 (95% CI 0.64, 1.61) for LD, and 0.43 (95% CI -0.07, 0.94) for ADHD compared with individuals without those disorders.

Sex-stratified analyses showed similar estimates among boys at the 50th and 85th percentiles (eTable 3). However, the pattern differed in girls. At the 50th BMI percentile, there were no significant differences between girls with and without NDDs in the 2016-2020 cohort. Only at the 85th percentile was BMI significantly higher for girls with any NDD (β=2.40, 95% CI 0.19, 3.59) and specifically LD (β=2.76, 95% CI 1.19, 7.53) compared with girls without NDDs.

# Discussion

This study characterized, for the first time, secular trends in BMI among children and adolescents with NDDs compared with peers without NDDs over a 16-year period. Our results demonstrated significantly steeper increases in BMI over time at the upper end of the BMI distribution for those with NDDs versus non-NDD controls. A significantly higher rise in BMI over time among youth with NDDs was consistently observed across the distribution for boys compared with girls. Boys with NDDs showed BMI increases around 2.3 points greater than non-NDD boys, whereas girls had similar trajectories regardless of diagnostic status, except for those with ASD who showed slightly steeper increases. The disproportionate BMI increase observed across NDDs warrant coordinated efforts to elucidate common mechanisms and develop tailored interventions to mitigate excessive weight gain in these populations.

Notably, this divergence in secular trends in BMI was most pronounced after 2016. The gap was even larger when looking at specific NDD subgroups. When looking at the most recent 2016-2020 cohort, the 85th BMI percentile was 2.85 points higher among children with ASD and 2.43 points higher among those with LD compared with non-NDD controls. When stratified by sex, boys with NDDs showed consistently higher BMIs across the 50th and 85th percentiles compared to non-NDD boys. However, among girls, significant differences were only observed at the 85th BMI percentile for those with any NDD and specifically LD in the most recent cohort. Although coefficient estimates were larger for girls, confidence intervals were also wider, reflecting greater uncertainty. Nevertheless, these preliminary sex-specific findings suggest disproportionate BMI increases may predominantly impact boys across the distribution, whereas girls show divergence mostly at the upper percentiles of BMI. More research is needed to confirm sex patterns as cohorts age.

Several factors may potentially explain the steeper BMI increases among children with NDDs. The increased availability of processed, high-calorie foods in recent decades may especially influence those with NDDs. Moreover, sedentary activities like screen time have increased substantially from 2002.20,21 Symptoms like inattention and hyperactivity in ADHD may make it especially challenging for children with NDDs to limit screen time and sedentary activities compared to peers.7,22 Repetitive behaviors and restricted interests in ASD may also contribute to increased screen time and sedentary behavior. Furthermore, societal shifts like increased working hours for parents may especially impact family routines, diet quality, activity habits, and weight management23 among children with NDDs who require greater structure and supervision around lifestyles.

Our findings have important clinical and public health implications. They suggest that the pediatric obesity epidemic may have disproportionately impacted children with NDDs, further exacerbating health disparities faced by this vulnerable group. The rapid rise in BMI percentiles, especially at the upper end of the distribution, suggests that individuals with NDDs might be at an elevated risk of developing obesity and related cardiovascular health issues. Elevated BMI is a well-established risk factor for various cardiovascular conditions, including hypertension, type 2 diabetes, dyslipidemia, and coronary artery disease.24 The steeper BMI trajectory observed in individuals with NDDs implies a heightened susceptibility to these cardiovascular risk factors, which, over time, can significantly increase the likelihood of developing cardiovascular diseases.25 The continued rise in BMI among individuals with NDDs may lead to a higher risk of premature mortality, particularly in adulthood. This emphasizes the urgency of addressing the factors contributing to this trend to improve the long-term health outcomes of individuals with NDDs.

A recent Swedish population-based study have also reported secular changes in BMI over time among adults with bipolar disorder compared with the general population.26 The parallels in adverse secular trends in BMI between bipolar disorder and NDDs are noteworthy given some evidence that these disorder groups may share common neurodevelopmental origins.27–31 The increasing risk of overweight/obesity in these related diagnostic categories highlight that individuals with early neurodevelopmental vulnerabilities may be most susceptible to obesogenic societal changes.

Increased efforts are warranted to curb excessive weight gain in this high-risk subpopulation. Healthcare providers should prioritize regular BMI screening and counseling on healthy lifestyles. Evidence-based weight management strategies tailored to the needs of children with NDDs are urgently needed. Notably, current guidelines for the management of individuals with NDDs do not provide specific guidance on the management of individuals with or at risk of overweight/obesity or related health conditions, for instance, the management of youth with ADHD and obesity/hypertension is a clinical challenge that requires additional guidance.32,33 Schools must also prioritize resources towards physical activity, nutrition, and obesity prevention in special education programs. Policy-level interventions including taxation of unhealthy foods and improved walkability/public spaces could also be beneficial especially for individuals with NDDs.

## Limitations

This study has some limitations that should be considered when interpreting the results. First, BMI was calculated from parent-reported heights and weights, which could introduce reporting bias. However, previous studies have found high agreement between parent-reported and measured BMI values34, suggesting parent reports are generally accurate representations of true BMI. Future studies should incorporate measured BMI to confirm the trends. Second, our cohort had a limited age range during childhood. Analyses with wider age ranges are needed to characterize BMI changes over time among those with and without NDDs across developmental stages. Third, our study used a sample of twins, which may limit the generalizability of our findings to the broader population of singletons. Fourth, while the sensitivities of the subscales are relatively low, potentially resulting in some individuals with these conditions being misclassified as not having them, the high specificity of 0.99 for both scales ensures accurate identification of true positives. Consequently, any misclassification would likely attenuate the observed associations between NDDs and BMI towards the null hypothesis, suggesting that our findings may underestimate the true strength of the association between these NDDs and BMI. Finally, this Swedish cohort may not fully reflect trends in other nations if rates of obesity risk factors like poor diet and physical inactivity differ across countries. Additional international studies are warranted to determine if similar patterns are observed globally for individuals with NDDs.

Despite these limitations, our study results represent a crucial step toward a more comprehensive understanding of the intersection between NDDs and physical health. The findings highlight the need for multifaceted clinical and public health strategies to address disproportionate obesity risks in this vulnerable population. At the clinical level, providers should prioritize nutrition, activity counseling, and weight management for children with NDDs. Schools and communities must improve accessibility and inclusivity of wellness initiatives. Policy-level interventions including taxation of unhealthy foods and subsidies for nutritious options could also benefit those with NDDs.

## Conclusions

In conclusion, this study found significantly steeper rises in BMI among children with NDDs versus those without NDDs at the upper end of the BMI distribution over the past two decades, reflecting worsening weight-related disparities. Concerted efforts across medical, community and policy sectors are urgently needed to prevent and treat obesity in this high-risk group. Early intervention will be key to avoid a lifetime of obesity-related health complications for those with NDDs.

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Miguel Garcia-Argibay had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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# Role of the Funding source

The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

# Competing interests

Henrik Larsson reported receiving grants from Shire/Takeda Pharmaceuticals during the conduct of the study; personal fees from and serving as a speaker for Shire/Takeda Pharmaceuticals and Evolan Pharma AB outside the submitted work; and sponsorship for a conference on attention-deficit/hyperactivity disorder from Shire Pharmaceuticals outside the submitted work. The remaining authors declare having no conflict of interest.

# Ethical approval

This study was approved by the Karolinska Institute Ethical Review Board (2018/960-31-2).

# Transparency declaration

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

# Author contributions

Conceptualization: Miguel Garcia-Argibay, Henrik Larsson.

Formal analysis: Miguel Garcia-Argibay.

Funding acquisition: Henrik Larsson.

Investigation: Miguel Garcia-Argibay.

Methodology: Miguel Garcia-Argibay

Project administration: Miguel Garcia-Argibay, Henrik Larsson.

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Writing – original draft: Miguel Garcia-Argibay.

Writing – review & editing: All authors

# **Data sharing**

The Public Access to Information and Secrecy Act in Sweden prohibits us from making individual level data publicly available. Researchers who are interested in replicating our work can apply for individual level data at Statistics Sweden: www.scb.se/en/services/guidance-for-researchers-and-universities/.

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# Tables

**Table 1**. Descriptive statistics of the study cohort stratified by NDD status.

|  |  |
| --- | --- |
|  | **Group, n (%)** |
| **Characteristic** | **Without NDD (N = 23,866)** | **NDD (N = 1,103)** |
| *Sex* |  |  |
|     Male | 11,941 (50) | 740 (67) |
|     Female | 11,925 (50) | 363 (33) |
| *Age at assessment, years (IQR)* | 9.06 (8.98, 9.19) | 9.10 (9.00, 9.28) |
| *BMI, kg/m2 (IQR)* | 16.32 (15.09, 17.85) | 16.71 (15.06, 18.66) |
| *Condition* |  |  |
|     ADHD | 0 (0) | 621 (25) |
|     ASD | 0 (0) | 471 (19) |
|     LD | 0 (0) | 392 (16) |
| *N individuals per cohort* |  |  |
| 2004–2006 | 4,531 | 155 |
| 2007–2009 | 6,034 | 256 |
| 2010–2012 | 4,999 | 201 |
| 2013–2015 | 4,168 | 215 |
| 2016–2020 | 4,134 | 276 |
| *Mean BMI by period (15-85th percentiles)* |  |
| 2004–2006 | 16.67 (14.54, 18.92) | 16.79 (14.73, 19.45) |
| 2007–2009 | 16.74 (14.54, 19.02) | 17.45 (14.78, 20.44) |
| 2010–2012 | 16.62 (14.48, 18.88) | 17.18 (14.18, 19.90) |
| 2013–2015 | 16.68 (14.57, 18.93) | 16.76 (14.13, 19.68) |
| 2016–2020 | 16.70 (14.59, 18.94) | 17.48 (14.35, 20.90) |

**Table 2.** Estimated BMI differences from 2004 to 2020 for each NDD compared with individuals without each condition.

|  |  |
| --- | --- |
|  | **BMI Percentile** |
| **Condition** | **15th**  | **50th** | **85th** |
| NDD | -0.65 (-1.15, -0.22) | 0.24 (-0.44, 0.96) | 1.67 (0.39, 2.80) |
| ADHD | -0.51 (-1.21, 0.07) | -0.13 (-0.90, 0.93) | 1.37 (-0.59, 2.53) |
| ASD | -0.59 (-1.33, 0.32) | 0.78 (-0.44, 1.87) | 2.12 (1.26, 3.70) |
| LD | -0.58 (-1.45, 0.52) | 0.71 (-0.21, 1.99) | 1.92 (0.65, 3.82) |

*Note.* Coefficients represent β coefficients for the interaction between NDD status and time.

**Table 3.** EstimatedBMI differences with 95% confidence intervals for each NDD compared with individuals without each condition in the 2016–2020 cohort.

|  |  |
| --- | --- |
|   | **BMI percentile** |
| **Condition** | **15th** | **50th** | **85th** |
| NDD | -0.24 (-0.44, -0.03) | 0.65 (0.19, 1.117) | 1.99 (1.08, 2.89) |
| ADHD | -0.20 (-0.44, 0.04) | 0.43 (-0.07, 0.94) | 0.76 (-0.42, 1.93) |
| ASD | -0.30 (-0.67, 0.06) | 1.12 (0.34, 1.91) | 2.89 (2.14, 3.64) |
| LD | 0.18 (-0.39, 0.74) | 1.13 (0.64, 1.61) | 2.42 (1.84, 3.01) |

# Figures

**Figure 1.** Modeled secular trends in BMI for individuals with and without neurodevelopmental disorders at the 15th, 50th, and 85th percentiles.