Associations between birth weight and attention-deficit/hyperactivity disorder symptom severity: indirect effects via primary neuropsychological functions

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Background: Attention-deficit/hyperactivity disorder (ADHD) has a range of aetiological origins which are associated with a number of disruptions in neuropsychological functioning. This study aimed to examine how low birth weight, a proxy measure for a range of environmental complications during gestation, predicted ADHD symptom severity in preschool-aged children indirectly via neuropsychological functioning.

Methods: A total of 197 preschool-aged children were recruited as part of a larger longitudinal study. Two neuropsychological factors were derived from NEPSY domain scores. One, referred to as ‘Primary Neuropsychological Function,’ was loaded highly with Sensorimotor and Visuospatial scores. The other, termed ‘Higher-Order Function’ was loaded highly with Language and Memory domain scores. Executive functioning split evenly across the two. Analyses examined whether these neuropsychological factors allowed for an indirect association between birth weight and ADHD symptom severity.

Results: As both factors were associated with symptom severity, only the Primary Neuropsychological Factor was associated with birth weight. Furthermore, birth weight was indirectly associated to symptom severity via this factor.

Conclusions: These data indicate that birth weight is indirectly associated with ADHD severity via disruption of neuropsychological functions that are more primary in function as opposed to functions that play a higher-order role in utilising and integrating the primary functions. Keywords: ADHD, neuropsychology, birth weight.

Introduction

The symptoms characteristic of attention-deficit/hyperactivity disorder (ADHD) are often detected in the preschool years (Greenhill, Posner, Vaughan, & Kratochvil, 2008), they are quite stable over time, and predictive of later functional difficulties and persistence of ADHD into the school-age years (Lahey et al., 2004; Riddle et al., 2013). It is associated with a variety of aetiological factors, both environmental and genetic, as well as a range of abnormalities in cortical and subcortical structures that involve the mesolimbic, mesocortical and nigrostriatal pathways (Halperin & Schulz, 2006; Kieling, Goncalves, Tannock, & Castellanos, 2008; Sagvolden, Johansen, Aase, & Russell, 2005; Sonuga-Barke, 2005; Swanson et al., 2007). It is also associated with a range of neuropsychological difficulties. Investigations into the neuropsychological functioning of those with the disorder have focused largely upon executive functioning; where individuals with ADHD are often found to perform poorly on tasks involving behavioural inhibition, set shifting, or working memory (Hall, Halperin, Schwartz, & Newcorn, 1997; Halperin et al., 1993; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Sergeant, Geurts, & Oosterlaan, 2002).

It is unlikely, however, that ADHD can be accounted for solely by dysregulation in executive functioning (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). In a meta-analytic review, Willcutt et al. (2005) found that out of 83 studies, children with ADHD were only differentiated from the typically developing control groups on measures of executive functioning on 65% of comparisons, with effect sizes usually in the medium range (46–69). Children with ADHD also tend to perform worse than their typically developing peers on tasks that involve other areas of neuropsychological functioning. For example, motor coordination (Carte, Nigg & Hinshaw, 1996), perception (Mangeot et al., 2001), visuomotor integration (Raggio, 1999) and intra-individual variability of reaction time (Russell et al., 2006).

Thus, ADHD is associated with deficits in both executive and nonexecutive neuropsychological functioning. This is in keeping with the range of aetiological factors associated with the disorder. One factor found to be associated with the emergence of ADHD is low birth weight (Banerjee, Middleton, & Faraone, 2007). It is likely that low birth weight is associated with ADHD because it is a proxy for a variety of environmental occurrences, such as maternal smoking during gestation and poor maternal nutrition (Kramer, 1987) that have adverse effects on neural development (Weinstock, 2005). Several studies have reported that children with a
low or extremely low birth weight are as much as 3.8 times more likely to meet diagnostic criteria for ADHD (Botting, Powls, Cooke, & Marlow, 1997; Breslau, Chilcoat, DelDotto, Andreski, & Brown, 1996; Mick, Biederman, Prince, Fischer, & Faraone, 2002; Szatmary, Saigal, Rosenbaum, & Campbell, 1993). The association between low birth weight and ADHD remains even after controlling for parental ADHD, parental antisocial behavior disorders, maternal substance abuse while pregnant, social class, and heritability (Hultman et al., 2007; Mick et al., 2002).

While some studies indicate an association between lower birth weight and ADHD, others indicate that children who are born with a low birth weight are also at greater risk of having a range of neuropsychological deficits, many of which overlap with those found in children with ADHD. In particular, low birth weight has been associated with difficulties on verbal fluency, working memory, and cognitive flexibility tasks, which involve aspects of executive functioning as well as other tasks that measure expressive or receptive language, visuo-spatial reasoning and motor control (Aarnoudse-Moens, Weisglas-Kupers, van Goudoever, & Oosterlaan, 2009; Breslau, Chilcoat, Johnson, Andreski, & Lucia, 2000; Breslau et al., 1996). The association between lower birth weight and poorer neuropsychological functioning was found to be present even for children born within the normal birth weight range (Shenkin, Starr, & Deary, 2004).

Given that low birth weight is a risk factor for ADHD, and that both children with ADHD and those born with low birth weight perform worse than controls on a range of neuropsychological tasks, it is plausible that deficits in particular neuropsychological domains at least partially mediate the relationship between birth weight and ADHD symptoms. Following this reasoning, one study using a sample of 823 children aged 6 years children found that perceptual sensitivity, motor speed and motor coordination, partially mediated the association between birth weight and ADHD symptoms (Martel, Lucia, Nigg, & Breslau, 2007). It is of note that this study only included a limited range of neuropsychological measures although, as previously described, children with ADHD or those born with low birth weight perform worse than their peers on a variety of other cognitive domains such as language, working memory and visual-spatial processing.

The variety of neuropsychological dysfunction found amongst those with ADHD has been explained within the framework of a neuropsychological/developmental perspective (Halperin & Schulz, 2006). This view takes into account that, generally, the development of brain regions that underlie primary sensorimotor and visual functions precedes the development of regions that are involved in higher-order cognitive functions (e.g. language, memory). These higher-order functions rely on, as well as integrate, the primary functions (Gogtay et al., 2004). From a developmental view of ADHD, symptoms arise from etiological factors that occur early in development (e.g. genetic expression, gestation, or birth), and thus disrupt neuropsychological functions that develop earlier in life; whereas the persistence or remittance of symptoms is dependent upon the development of regions involved in higher-order neuropsychological functions that could potentially compensate for lower order deficits.

The aim of this study was to examine the associations between the hyperactive/impulsive and inattentive symptoms of ADHD, neuropsychological functioning and birth weight. In this study birth weight was used as a proxy for early environmental insults (e.g. maternal health, smoking). In accordance with a developmental perspective of ADHD it was hypothesized that lower birth weight would be indirectly associated with hyperactivity/impulsivity and inattention via neuropsychological functions that develop earlier, such as visual-spatial and motor coordination, but would not be associated with higher-order neuropsychological functioning, including language and memory, that typically develops later. It was also hypothesized that, while not associated with birth weight, higher-order neuropsychological functioning would be associated with hyperactive/impulsive and inattentive symptom severity.

Methods
Participants

The sample was recruited from the New York City metropolitan area as part of a larger longitudinal study. Of this sample all relevant information was available for 197 children aged 3–4 years (mean age 4.32 years, \( SD = .439 \)) of which 146 (74.1%) were boys. The mother’s Socioeconomic status (SES) was measured using the Nakao–Treas Socioeconomic Prestige Index (Nakao & Treas, 1994) and had a mean of 54.90 (\( SD = 16.77 \)), indicative of a middle-class sample, albeit with some variability. The study excluded children with IQ’s below 80 (measured by the Wechsler Preschool and Primary Scale of Intelligence, 3rd edition; WPPSI-III), a pervasive developmental disorder, post-traumatic stress disorder, a diagnosed neurological disorder (e.g. epilepsy/seizures, hydrocephalus and cerebral palsy), or taking systematic medication for chronic medical conditions (including ADHD). Medication use was exclusionary to allow for a more accurate assessment of the children’s baseline behaviour. Given that the children were 3–4 years-old at the time of recruitment, very few were excluded because of medication treatment for ADHD (\( n < 5 \)). Children participated based upon parent and teacher ratings on the attention deficit hyperactivity disorder-Rating Scale-Fourth Edition (ADHD-RS: DuPaul, Power,
Anastopoulos, & Reid, 1998). The criteria categorised children as ‘at-risk’ for ADHD if at least six symptoms of hyperactivity-impulsivity and/or inattention were rated as ‘Often’ or ‘Very Often’ across parent and/or teacher responses. Children were categorised as ‘typically developing’ if fewer than three symptoms were rated as ‘Often’ or ‘Very Often’ by either parents or teachers. By design these criteria resulted in a sample with a wide range of symptom severity, and although a portion of the at-risk children did not meet diagnostic criteria for ADHD, many of these children were rated as presenting with several symptoms of ADHD in at least one setting. Of the children included in this study, 108 met criteria for a diagnosis of ADHD (10 Inattentive subtype, 45 Hyperactive/Impulsive subtype, 47 Combined subtype and 6 ADHD-NOS). Of the remaining 89 children, 71 were initially recruited as ‘typically developing’ and 18 recruited as ‘at-risk’ for ADHD. It should be noted that these diagnoses are descriptive whereas measures of symptom severity were used for analytical purposes. With regard to race/ethnicity 40.1% of the sample was White, Non-Hispanic; 19.3% White Hispanic; 10.7% Black, Non-Hispanic; 1.5% Black, Hispanic; 10.2% Asian Non-Hispanic and 18.3% reported mixed or ‘other’ ethnicity/race. This distribution was representative of the community from which the sample was recruited. The majority (87.3%) of children had birth weights above 2500 g, 9.7% were within the low birth weight range (1500–2500 g), 1.5% were within the very low birth weight range (1000–1499 g) and 1.5% were within extremely low birth weight range (below 1000 g).

Measures

The measures are described below and descriptive statistics for each of the measures are provided in Table 1.

Neuropsychological functioning. The NEPSY assesses neuropsychological functioning within five domains: Attention/Executive (e.g. ability to inhibit impulsive responses and visual attention), Language, Memory, Sensorimotor (e.g. fine motor coordination) and Visuospatial (e.g. being able to construct two- and three-dimensional designs). While the NEPSY is reliable over time (r = .68–.90), recent revisions and data have led to concerns about the construct validity of some of the domains (Korkman, Kirk, & Kemp, 1998). Thus, we conducted a Principal Components Analysis with Oblimin Rotation and Kaiser Normalization to assess the relations among the five domains in our sample of 3–4 year-old children. This yielded a two-factor solution: Language and Memory loaded onto one factor and Sensorimotor and Visuospatial loaded onto the other; the Attention/Executive domain loaded evenly onto both factors (see Table 2). The regression factor scores for each participant, calculated from all five domains, were saved into variables. We named the first factor ‘Primary Neuropsychological Function’ because it had the greatest loadings of visuo-spatial perception and motor coordination. We named the second factor ‘Higher-Order Neuropsychological Function’ because it had the greatest loadings of memory and language functioning.

Hyperactive/impulsive and inattentive symptom severity. Composite scores were calculated from parent and teacher responses on the ADHD-RS (DuPaul et al., 1998); in accordance with other studies from this cohort (Healey, Gopin, Grossman, Campbell, & Halperin, 2010). This involved summing the highest of either the teacher or parent ratings for symptoms of inattention (termed here as the Inattentive Composite) or impulsivity and hyperactivity (termed here as the Hyperactive/Impulsive Composite). This allowed for the maximum impact of symptoms that only occurred in a single setting (e.g. severe attention difficulties that were reported by the teacher but not by the parent).

Birth weight. The child’s birth weight was obtained from a form completed by parents and reviewed as part of a semi-structured interview.

Procedure

The procedure for data collection for this study were described elsewhere (Healey et al., 2010) and therefore will only be briefly described here. Data were collected in two phases. First, ratings on the ADHD-RS (among other scales) were collected from parents and teachers. Second, information was collected during an assessment session that lasted approximately 4 hr across 2 days. During this session, as parents completed a Kiddie-SADs semi-structured interview (Kaufman, Birmaher, Brent, Rao, & Ryan, 1996), children completed a number of laboratory tasks as well as the WPPSI-III (Wechsler, 2002) and the NEPSY (Korkman et al., 1998). A trained graduate student administered the tests to each child in the same order and in the same testing room.
Table 2  NEPSY principal components derived from factor analysis

<table>
<thead>
<tr>
<th>NEPSY domains</th>
<th>Domain score: mean (SD)</th>
<th>Factor 1: primary neuropsychological functions</th>
<th>Factor 2: higher-order neuropsychological functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention/executive</td>
<td>99.22 (13.38)</td>
<td>0.441</td>
<td>0.449</td>
</tr>
<tr>
<td>Language</td>
<td>101.07 (11.80)</td>
<td>0.018</td>
<td>0.874</td>
</tr>
<tr>
<td>Sensorimotor</td>
<td>92.59 (15.05)</td>
<td>0.890</td>
<td>-0.045</td>
</tr>
<tr>
<td>Visuospatial</td>
<td>105.85 (13.00)</td>
<td>0.871</td>
<td>0.917</td>
</tr>
<tr>
<td>Memory</td>
<td>93.02 (15.13)</td>
<td>-0.099</td>
<td></td>
</tr>
</tbody>
</table>

Statistical analysis

Preliminary analysis of the data was first conducted to examine the associations between variables and examine possible covariates. Based upon the preliminary analysis, path analysis was conducted.

Preliminary data analysis. Intercorrelations were examined among birth weight, neuropsychological functioning and ADHD symptom severity to investigate whether there were necessary significant associations between these variables to warrant conducting path analyses. Pearson correlations were run between age, maternal SES, birth weight, neuropsychological measures and ADHD symptom severity to see whether age and maternal SES should be entered as covariates in further analyses. Age and birth weight were negatively skewed. Thus, before being entered in the Pearson correlations, these variables were square-root transformed so that this skewness was no longer significant (Tabachnick & Fidell, 2006). To determine whether gender should be a covariate, independent sample t-tests were conducted.

Analysis of indirect effects. The hypotheses were tested using path analyses procedures, which tested whether the association between independent and dependent variables was accounted for by other variables (often also referred to as mediation analysis). A requirement for traditional mediation analyses is significant correlations between the independent and dependent variables (Baron & Kenny, 1986). As indicated by our preliminary analysis, no significant correlations were found between birth weight and symptom severity measures. More recently, it was proposed that such a correlation was not necessary (Hayes, 2009; Mackinnon, Lockwood, Hoffman, West, & Sheets, 2002) as there might be multiple paths between the independent and dependent variables that cancelled each other out. Tests of indirect effects that have an optimal balance between maximum power and reducing Type-I error either make use of the distribution of the product of the variables or bootstrapping (MacKinnon et al., 2002). Given that developmental trajectories of mental health typically involved a multitude of factors over time (Hackman, Farah, & Meaney, 2010) the use of such tests to examine the indirect relationships between early etiological factors and later functioning is particularly relevant. A method of analysis for indirect effect was conducted that examines confidence intervals around the indirect effect, with regression-based path analysis and bootstrapping (bootstrapping sample of 5000). This produced path coefficients as well as p-values for total and direct effects, and bias-corrected percentile confidence intervals (in which statistical significance was assumed if zero was not included in the interval) for the indirect effect (Hayes, 2012). This analysis procedure also has the advantage of being robust to violations in variable normality, thus nontransformed variables were entered. Before entering in an analysis of indirect effects all variables (except gender) were converted to standardized z-scores.

Results

Preliminary Analyses

Correlations. Birth weight was significantly and positively correlated with Primary Neuropsychological Functions but not with Higher-Order Neuropsychological Functions or with Hyperactivity/Impulsivity and Inattention. Both Primary and Higher-Order Neuropsychological Functions were significantly negatively correlated with Hyperactivity/Impulsivity and Inattention. Age was significantly negatively correlated with Hyperactivity/Impulsivity. Maternal SES was significantly positively correlated with Higher-Order Neuropsychological Function and significantly negatively correlated with both hyperactivity/impulsivity and inattention (see Table 3).

T-tests. There was a significant difference between boys’ (M = 3347.77 g, SD = 648.94) and girls’ (M = 3115.11 g, SD = 837.66) birth weight; t(195) = 2.04, p < .05. There were no other significant differences between the genders on the other study variables.

Analysis of indirect effects

Analyses of indirect effects were conducted for two models. Because Higher-Order Neuropsychological Functions were not significantly associated with birth weight they were not entered in the models.
Model 1 tested whether birth weight and Inattention were indirectly associated through Primary Neuropsychological Functions. Because Inattention was significantly correlated with maternal SES and because boys had significantly higher birth weights, both maternal SES and gender were entered as covariates. Model 2 tested whether birth weight and Hyperactivity/Impulsivity were indirectly associated via Primary Neuropsychological Functions. Because Hyperactivity/Impulsivity was significantly correlated with maternal SES and age, both were entered as covariates as was gender due to the birth weight differences. Path coefficients, standard errors and 95% bias corrected bootstrap confidence intervals for the models are presented in Table 4.

For Model 1, there was a significant association between birth weight and Primary Neuropsychological Functions (path coefficient = .215, p = .001) and between Primary Neuropsychological Functions and Inattention (path coefficient = -.438, p < .001). The indirect effect of birth weight on Inattention via Primary Neuropsychological Functions was statistically significant [path coefficient = -.094, 95% CI {-.156, -.039}]. This indicates that for each standardized unit increase in birth weight there was a .094 standardized unit decrease in Inattention as a result of the effect of birth weight on Primary Neuropsychological Functions.

For Model 2, there was a statistically significant association between birth weight and Primary Neuropsychological Functions (path coefficient = .213, p = .002) and between Primary Neuropsychological Functions and Hyperactivity/Impulsivity (path coefficient = -.348, p < .001). The direct effect (path coefficient = .136, p = .021) was significant. This indicated that for each standardized unit increase in birth weight there was a significant increase in Hyperactivity/Impulsivity by 0.136 standardized units; that was independent of the effects of Primary Neuropsychological Functions on Hyperactivity/Impulsivity. The indirect effect via Primary Neuropsychological Functions [path coefficient = -.074, 95% CI {-.126, -.032}] was also statistically significant. This indicated that for each standardized unit increase in birth weight there was a .074 standardized unit decrease in Hyperactivity/Impulsivity, as a result of the effect of birth weight on Primary Neuropsychological Functions.

Additional analysis. Because the Attention/Executive function domain split variance across two factors, we tested the models using factors derived

| Table 3 Correlations between study variables and demographic variables |
|-----------------------------|-----------------------|---------------------|---------------------|---------------------|
|                            | Birth weight          | Higher-order        | Primary              | Hyperactive/impulsive |
|                            |          |/neuropsychological|  neuropsychological  |                      |
| Higher-order               | 0.127    | –                   | –                   | –                   |
| Primary                   | 0.155*   | 0.30**              | –                   | –                   |
| Hyperactive/impulsive      | 0.046    | -.23**              | -.33**              | 0.82**              |
| Inattentive               | –.104    | –.39**              | -.46**              | –                   |
| Age                       | –.008    | 0.096               | –0.096              | –0.146*             |
| Maternal SES              | 0.045    | 0.190**             | 0.026               | –0.271**            |

*aEntered in correlation as transformed variable.
*p < .05 level; **p < .01.

| Table 4 Path coefficients and 95% percentile confidence intervals for Model 1 and Model 2 |
|--------------------------------|----------------|-----------------|----------------|----------------|
|                                | Path coefficients | SE   | p value | 95% Bootstrap CI confidence interval |
| Model 1                        |                  |      |        |                                  |
| Path A: birth weight to primary | .215            | .066 | .001   | –                              |
| neuropsychological functions   |                  |      |        |                                  |
| Path B: primary neuropsychological functions to inattentive composite | -.438 | .64   | .000   | –                              |
| Total effect                   | -.117            | .065 | .072   | –                              |
| Direct effect                  | -.023            | .058 | .694   | –                              |
| Indirect effect                | -.094            | .030 | –       | -.156, -.039                   |
| Model 2                        |                  |      |        |                                  |
| Path A: birth weight to primary | .213            | .066 | .002   | –                              |
| neuropsychological functions   |                  |      |        |                                  |
| Path B: primary neuropsychological functions to hyper/impulsive composite | -.348 | .065 | .000 | –                              |
| Total effect                   | .062             | .062 | .318   | –                              |
| Direct effect                  | .136             | .058 | .021   | –                              |
| Indirect effect                | -.074            | .025 | –       | -.127, -.032                   |
from the NEPSY domains but excluding the Attention/Executive Functioning domain. Two factors emerged; one with higher loadings from the Sensorimotor and Visuospatial domains, and one with higher loading from the Language and Memory domains. Like the initial analyses, the Memory/Language domain was not associated with birth weight \( r = .118, p = .099 \) whereas the Sensorimotor/Visuospatial domain was \( r = .248, p < .001 \). Similar to initial analyses birth weight was indirectly associated via the Sensorimotor/Visuospatial domain with Inattention \([\text{indirect path coefficient } = -.080, 95\% \text{ CI } (-.141, -.030); \text{direct path coefficient } = -.037, p = .578]\) and Hyperactivity/Impulsivity \([\text{indirect path coefficient } = -.060, 95\% \text{ CI } (-.112, -.022); \text{direct path coefficient } = .122, p = .070]\).

Although birth weight was used as a proxy for a range of events that could have affected neural development in gestation, it was possible that such factors could affect development without impacting upon birth weight. Similarly, perinatal factors could affect neural functioning without effecting birth weight. Therefore, posthoc analyses of the indirect effects were conducted entering variables pertaining to prenatal/perinatal factors as covariates. In particular, maternal drug use (recreational and medication), tobacco use, alcohol use, maternal illness and c-section (planned or emergency) were entered as dichotomous covariates. For both model 1 and 2 entering these variables did not result in any statistically significant results becoming nonsignificant or vice versa.

**Discussion**

Our primary prediction was that birth weight would be indirectly associated with hyperactive/impulsive and inattentive symptom severity via Primary Neuropsychological Functions; whereas Higher-Order Neuropsychological Functions would not be associated with birth weight, but would still be associated with symptom severity. Analyses of indirect effects supported this, indicating that birth weight was indirectly associated with symptomatology through Primary Neuropsychological Functions. There was a significant direct effect in Model 2 that was not hypothesised. In particular, there was a significant positive association between birth weight and Hyperactivity/Impulsivity when Primary Neuropsychological Functioning was held constant. According to contemporary interpretations of analyses of indirect effects such a finding does not negate the indirect effect, but may be illustrative of multiple indirect associations between birth weight and hyperactivity/impulsivity (MacKinnon, Krull, & Lockwood, 2000).

The Primary Neuropsychological Functions factor had high loadings from the NEPSY Sensorimotor and Visuospatial domains and the Higher-Order Neuropsychological Functions factor had high loadings from the NEPSY Language and Memory domains. It is notable that the Attention/Executive domain split across the two factors. This may be due to a number of factors. First, it is unclear that the two subtests that comprise this domain truly assess executive functioning in this young age range. Second, scores on these subtests are not significantly correlated (Korkman, Kirk, & Kemp, 2007), one primarily assesses visual searching/scanning whereas the other assesses the ability to stand stationary with closed eyes. Thus, it is not surprising that they do not load onto a single factor.

The results of this study were consistent with research indicating that children with ADHD tend to have trouble on a wide range of neuropsychological functions, including basic primary neuropsychological functions such as visuospatial integration (Raggio, 1999), perception (Mangeot et al., 2001), motor control (Carte et al., 1996) as well as higher order functions such as language (Bruce, Thernlund, & Nettelbladt, 2006) and memory (Martinussen et al., 2005). Beyond investigating the neuropsychological correlates of hyperactivity/impulsivity and inattention, this study builds upon previous findings by investigating how neuropsychological functioning relates to birth weight, one of several aetiological factors of ADHD. The findings are similar to those of Martel et al. (2007) who, in a sample of 6 year-olds, found that an association between birth weight and ADHD symptoms was mediated by motor speed, motor coordination and perceptual sensitivity (the ability to distinguish between targets and nontargets on a continuous performance task). By assessing a wider range of neuropsychological functioning in younger children, this study was able to extend these findings. While we found that birth weight was associated with hyperactive/impulsive and inattentive symptomatology via primary neuropsychological functions, birth weight was not associated with higher-order neuropsychological functions, even though these functions were still associated with ADHD symptoms. This is consistent with the view that ADHD arises out of disruptions to the neurobiological systems primarily involved in more basic neuropsychological functions rather than higher order/executive functions (Halperin & Schulz, 2006).

While this study examines some particular examples of indirect effects, these associations are likely to occur within a wider context of other factors and associations. For instance, with regard to aetiology, heritability/genetic mechanisms play a large role in the presentation of ADHD symptoms (Faraone et al., 2005), something not accounted for in the models tested here. It is possible that particular genetic expressions, with or without interactions with environmental factors, lead to the development of ADHD symptomology (Todd & Neuman, 2007). Further, beside hyperactivity/impulsivity and inattention,
there may be other outcome variables associated with birth weight or primary neuropsychological functions. These may be detectable in the younger ages (e.g. symptoms of autism spectrum disorder) or in later years (e.g. learning difficulties).

A number of study limitations need be acknowledged. First, the data regarding birth weight was obtained retrospectively. While this is not as accurate as the collection of birth weight data from health records or at the time of birth, the recollection of birth weight by maternal reports has been found to be a reliable and valid method of data collection (Olson, Shu, Ross, Pendergrass, & Robinson, 1997). Second, although this study was able to consider some particular environmental factors and excluded children with diagnosed neurological problems, there are other prenatal, perinatal or postnatal environmental factors that could be associated with birth weight, neuropsychological functioning and/or ADHD symptom severity that are not accounted for in the model (e.g. perinatal hypoxia, postnatal icterus, catch-up growth, or nutritional interventions). Finally, because neuropsychological functioning and ADHD symptom severity were assessed at the same time point, causal inferences between the two should be interpreted with a level of caution.

Despite these limitations this study has a number of strengths. First, the sample was ethnically diverse and children displayed a wide range of ADHD symptoms, allowing for better generalization of results. Second, by using a bootstrapping approach, path analysis could be conducted in the absence of a direct association between dependent and independent variables. This decreases Type-II error while limiting inflation of Type-I error. Finally, by using continuous measures of birth weight and ADHD symptom severity the study was able to quantify the indirect association birth weight had with symptom severity through neuropsychological functioning.

In conclusion, this study demonstrates that while a range of disruptions to neuropsychological functioning are associated with greater symptomatology in 3–4 year-old children, it is only the disruption of primary functions, rather than higher-order functions, that is associated with birth weight, a proxy for a range of insults to neural development. These findings could be extended in several ways in the future. First, replication is required. Second, the specificity of the aetiological variables should be examined. In particular, birth weight is likely to be a proxy for many different neuronal insults during gestation. Hence, examination of which insults lead to lower birth weight and also cause the most dysregulation to brain development would have obvious benefits with regard to prevention of symptom development (i.e. what events during gestation are most likely to result in ADHD). Third, the models could be extended by the inclusion of other factors associated with ADHD, such as genetics, heritability, and measures of brain physiology.

**Acknowledgements**

This research was supported by grant number R01 MH068286 from the National Institute of Mental Health (NIMH). The authors thank Scott Miller (statistical consultation), staff and students past and present, who have worked on the Queens College Preschool Project. The authors declare that they have no potential or competing conflict of interests.

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**Key points**

- Investigated neuropsychological mediators of the associations between birth weight and ADHD symptom severity in 3–4 year-old children.
- Consistent with previous research, findings indicated ADHD symptom severity was associated with poorer overall neuropsychological functioning.
- Lower birth weight was only associated with lower scores on Primary Neuropsychological Functions but not Higher-Order Functions.
- Lower birth weight was indirectly associated with greater ADHD symptom severity via Primary Neuropsychological Functions.
- Results are consistent with neurodevelopmental theories that suggest etiological factors of ADHD disrupt Primary Neuropsychological Functions whereas the persistence or remittance of symptoms is associated with Higher-Order Functions.
Birth weight, neuropsychological functioning, and ADHD

References


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Accepted for publication: 9 September 2013
Published online: 5 November 2013