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Predicting ADHD-related symptoms in primary school children from developmental characteristics assessed at the preschool health examination.

Results of IPSUM, a prospective cohort study at German Steiner schools

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ABSTRACT. *Background*: Children with attention-deficit/hyperactivity disorder (ADHD) and ADHD-related symptoms perform poorer at school and have lower educational attainment. Early identification, diagnosis, and appropriate treatment may avoid poorer educational outcomes in these children. We investigated whether developmental characteristics assessed prior to school entry independently predict ADHD-related symptoms later in primary school.

Methods: A multi-centre prospective cohort study including 1,345 children (mean age at study entry: 6.1 years; 50 % girls) from 87 German Steiner schools (Waldorf schools) was conducted. Developmental characteristics were assessed by a standardized preschool health examination addressing six domains: gross and fine motor skills, cognitive/sensory skills, auditory memory, anthropometric measures, and second dentition. ADHD-related symptoms were obtained with the hyperactivity/inattention subscale of the Strengths and Difficulties Questionnaire (SDQ) at three time points: prior to school entry by parent reports and in 2nd and 4th grade by teacher reports. Relationships between developmental characteristics and ADHD-related symptoms were evaluated by multivariable linear mixed model analysis and adjusted for baseline symptoms and potential co-predictors.

Results: Scores on the cognitive/sensory skills subscale were negatively related to scores on the SDQ hyperactivity/inattention subscale. Regarding the single items of this subscale, independent associations for three of seven subscale items were observed.

CONCLUSIONS: Developmental characteristics such as cognitive/sensory skills assessed prior to school entry may independently predict teacher-reported ADHD-related symptoms later in primary school. Performance ratings of these skills may contribute to an early identification of children at risk for developing ADHD and related educational problems later in school.

Keywords: attention-deficit/hyperactivity disorder, assessment at school entry

Vorhersage von ADHS-Symptomen bei Grundschulkindern durch schulrelevante Merkmale und Fähigkeiten, die bei der Schuleingangsuntersuchung erhoben werden. Ergebnis einer prospektiven Kohortenstudie an deutschen Waldorfschulen

ABSTRAKT. *Hintergrund*: Kinder mit einer Aufmerksamkeitsdefizit-/Hyperaktivitätsstörung (ADHS) oder ADHS-Symptomen können geringere Schulleistungen und schlechtere Bildungsabschlüsse aufweisen als nicht betroffene Kinder. Eine frühe Identifikation, Diagnose und Behandlung der ADHS könnte das Bildungsrisiko bei betroffenen Kindern verringern. Wir haben untersucht, ob vor der Einschulung erhobene schulrelevante Merkmale und Fähigkeiten später in der Grundschulzeit auftretende ADHS-Symptome vorhersagen können.

Methode: Aus einer multizentrischen prospektiven Kohortenstudie an 87 deutschen Waldorfschulen wurden Daten von 1345 Schulkindern analysiert (mittleres Alter bei Studieneintritt: 6,1 Jahre; 50 % Mädchen). In der standardisierten Schuleingangsuntersuchung wurden sechs Entwicklungsbereiche beurteilt: Grob- und Feinmotorik, kognitive/sensorische Fähigkeiten, auditives Gedächtnis, anthropometrische Größen und Stand des Zahnwechsels. ADHS-Symptome wurden zu drei Zeitpunkten mit der Subskala Hyperaktivität/Unaufmerksamkeit des Strengths and Difficulties Questionnaire (SDQ) erfasst: vor Schulbeginn durch die Eltern und im 2. und 4. Schuljahr durch die Lehrkräfte. Der Zusammenhang zwischen den schulrelevanten Merkmalen und den ADHS-Symptomen wurde mittels linearer gemischter Regressionsmodelle analysiert und nach Symptomen vor Schulbeginn und potentiellen Co-Prädiktoren adjustiert.

Ergebnisse: Es zeigte sich ein negativer Zusammenhang zwischen den Werten der Subskala Kognitive/sensorische Fähigkeiten und den Werten der SDQ-Subskala Hyperaktivität/Unaufmerksamkeit. Die Analyse der einzelnen Items ergab für drei der sieben Items der Subskala Kognitive/sensorische Fähigkeiten signifikante Assoziationen.

Schlussfolgerung: Schulrelevante Merkmale wie kognitive/sensorische Fähigkeiten, die vor der Einschulung erhoben werden, könnten für die Vorhersage von später in der Grundschulzeit auftretenden ADHS-Symptomen genutzt werden. Damit könnte die Beurteilung dieser Fähigkeiten dazu beitragen, Kinder mit einem Risiko für die Entwicklung einer ADHS und eine damit verbundene spätere Bildungsbenachteiligung frühzeitig zu erkennen.

Schlüsselwörter: Aufmerksamkeitsdefizit-/Hyperaktivitätsstörung, Schuleingangsuntersuchung

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is one of the most prevalent mental health disorders in childhood and adolescence. The second wave of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS; Gobel et al., 2018) found that 4.4 % of children and adolescents aged 3 to 17 years have been diagnosed with ADHD. Affected children present with attention problems, restlessness, and impulsivity and are commonly diagnosed at school age. It has been repeatedly shown that children with ADHD or ADHD-related symptoms perform poorer at school and have lower educational attainment, which may have long-lasting effects on their occupational and economic status later in adulthood (Polderman et al., 2010). For the educational outcomes, the level of attention problems rather than hyperactivity may play a mediating role (Schmiedeler & Schneider, 2014). ADHD is a multicausal condition and several contributing risk factors such as premature birth, low birth weight, and prenatal tobacco exposure have been described (Galera et al., 2011).

In Germany, the developmental status, health problems, school-relevant skills, and school readiness are assessed in all preschool children in the year prior to school entry at a compulsory preschool health examination (PHE) to ensure that they will be able to meet the school requirements (Oldenhage et al., 2009). The PHE is performed by school health physicians employed at the schools or at the regional public health department. Children with developmental deficits or health problems that may affect their readiness for school are identified so that special health care can be initiated and/or school entry can be deferred. That way, school adjustment problems should be prevented, educational disadvantages reduced, and differences in development between the children starting school diminished (Horstschräer & Muehler, 2014). Researchers have also proposed flexible school enrolment rules to allow children to wait until they are adequately prepared for school entry (e.g., Halldner et al., 2014; Holland & Sayal, 2018; Schwandt & Wuppermann, 2016).

However, no concepts or strategies for PHE have been developed and established in order to identify, manage, and treat children at risk for developing ADHD or ADHD-related symptoms later in primary school. Such strategies may be beneficial by preventing potentially negative outcomes due to delayed detection and treatment of ADHD. However, known risk factors may be not sufficient to accurately identify children with or at risk for ADHD and to initiate diagnostic work-up steps for ADHD, special education, or school deferral. Therefore, identifying predictors of later ADHD and combining them with evidence-based rules may support the development of effective preventive strategies. This approach is supported by prior studies that suggested that developmental characteristics may serve as potential predictors of later ADHD (Kalff et al., 2002; Perrin et al., 2019).

To investigate the benefits of a structured PHE and its relevance for school health and performance outcomes, the IPSUM research project was initiated in 2004 (Patzlaff et al., 2006). Details of the project have been published elsewhere (Diefenbach et al., 2018; Patzlaff et al., 2006; Wendt et al., 2018). In brief, the project comprised a nation-wide population-based multicentre prospective cohort study at German Steiner schools and the development and validation of a PHE suitable for Steiner schools. Following extensive pretests of the PHE and supplementing questionnaires, cohort enrolment started in 2008. After a baseline assessment prior to school entry that involved the PHE and a parental questionnaire, two follow-up assessments were conducted in 2nd (2010) and 4th grade (2012). These assessments included each one questionnaire for parents and one for class teachers. The study protocol was approved by the ethics committee of the Federal Physician Chamber in Frankfurt/Main (Hesse; Germany). Written informed consent was obtained from parents/legal guardians prior to study enrolment.

Previous reports from that project covered the risks of being relatively young at school entry (Wendt et al., 2018) and the psychometric evaluation of the final PHE version (Diefenbach et al., 2018). In the present report, we investigated the associations between developmental characteristics assessed in the PHE and ADHD-related symptom reports later in primary school to address whether these characteristics may serve as potential predictors of ADHD.

Methods

Analysis sample

All preschoolers registered for the PHE in 2008 at a participating school underwent the PHE and of these, 2,100 children were initially included in the present study. Children, who were finally not enrolled in the 1st grade of a Steiner school or did not take part in at least one of the follow-up assessments were later excluded (n=193). In addition, children born outside the regular school entry cut-off dates of the respective German federal state were also removed from the analysis (n=417). This exclusion of older children with deferred school entry or younger children who were not obliged to attend school should prevent bias in the results. Children were also excluded if teacher reports of ADHD-related symptoms were available neither for the 2nd nor for the 4th grade (n=142) and if data on their family structure were missing (n=3), which was an important confounding variable in our analysis. Accordingly, the final analysis sample comprised 1,345 participants (679 boys) from 87 schools. Their mean age was 6.1 years at PHE (range 5.3-7.0 years), 8.3 years at the teacher assessment in 2nd grade (range 7.6-9.5 years), and 10.1 years at the teacher assessment in 4th grade (range 9.4-11.4 years). The distribution of sample characteristics related to ADHD is given in Appendix Table S1. The analysis sample was largely representative of the underlying group of study participants, apart from a few minor selection effects: It included fewer boys (but towards a more balanced gender ratio) and fewer children from families with low socio-economic status compared to the total number of study participants.

Instruments and procedures

Preschool health examination. In order to assess the children`s developmental status for school entry, the PHE was standardized, repeatedly improved, and validated (Diefenbach et al., 2018). The final version of the instrument comprised six domains with a total of 35 items. The PHE was performed by a special school team of the respective Steiner school. Teams usually consisted of a school health physician, a teacher, and/or a therapeutically working staff member. As a result of the PHE, the school team rated the preschooler as being school ready, not school ready, or having a questionable school readiness status.

The PHE items covered the following developmental domains: The gross motor skills subscale consisted of 8 items referring to motor skills performed with legs. The fine motor skills subscale included 4 items referring to motor skills performed with hands. The cognitive/sensory skills subscale comprised 7 items covering instant recognition of quantities, counting, working memory (remembering quantities), visual perception (grasping a form), and visual-spatial integration (copying figures). The auditory memory subscale consisted of 6 items that required repeating rhythm patterns and sequences of syllables. The anthropometric measures subscale contained 5 items that indicated the state of physical development. The second dentition subscale contained five items registering whether the change of teeth has started. However, two items were later removed due to low inter-rater reliability and poor discriminatory power. More detailed information on the items, the factor structure, and the psychometric evaluation of the instrument have been described elsewhere (Diefenbach et al., 2018).

The parental questionnaire. At baseline and follow-up assessments, a parental questionnaire investigated the child`s individual health status. The presence of ADHD-related symptoms was assessed by the hyperactivity/inattention subscale of the German version of the Strengths and Difficulties Questionnaire (SDQ) for parents (Goodman, 1997; Woerner et al., 2004). The SDQ is a widely used, valid, and reliable screening questionnaire (Becker et al., 2004), which addresses behavioural problems and strengths of children and adolescents across five domains. The hyperactivity/inattention subscale consists of five items, which are rated as being not true (0), somewhat true (1), or certainly true (2), resulting in subscale scores ranging from 0 to 10 points (higher scores reflect more ADHD-related symptoms). Other items of the parental questionnaire covering gestational age at birth, birth order, family structure, socio-economic status, and migration background were mainly retrieved from the parental questionnaire of the KiGGS (Kurth et al., 2008).

The teacher questionnaire. In the follow-up assessments in 2nd and 4th grade, the teachers completed a questionnaire about each child's school-related behaviour. Similar to the parental questionnaire, the child`s ADHD-related symptoms were assessed by the hyperactivity/inattention subscale of the German version of the SDQ for teachers. Teacher ratings were used to improve validity on externalizing behaviour problems such as school-associated ADHD symptoms, as they are more sensitive to detect ADHD than parent ratings (Goodman et al., 2000), while both parents and teachers rate the same construct as shown in similar construct validity (Hall et al., 2019).

Statistical analysis

Missing values for PHE data on child development in ratio-scaled items were imputed using single imputation by regression with the independent variables gender and age at PHE. Since PHE items have different result scales, all item values were z-transformed in order to obtain a standardized result scale (with mean = 0 and standard deviation = 1). The subscale scores that resulted from averaging the corresponding item scores were also z-transformed. Higher item or subscale scores mirror higher levels of developmental skills. Detailed information on the calculation of PHE subscale scores is given elsewhere (Diefenbach et al., 2018).

Age at school entry was computed for each child as the difference (in years) between the date of the first day at school and the date of birth. Gender, gestational age at birth, birth order, family structure, socio-economic status, and migration background were considered as co-predictors since they have been found to be associated with ADHD (Galera et al., 2011; Hjern et al., 2010; Montes, 2018; Schneider & Eisenberg, 2006). Gestational age at birth (preterm vs. term birth) and family structure (nuclear family vs. single-parent family, foster parents, or children`s home) were dichotomized. Missing values for gestational age at birth (16.7% of the sample) were set to term birth. Based on the birth order, a child was classified as an only child, a child with older siblings, or an oldest child with younger siblings. The socio-economic status was defined based on the CASMIN classification (Comparative Analyses of Social Mobility in Industrial Nations; Brauns et al., 2003) by using information about parents` highest school-leaving qualification (general education) and vocational education. The total CASMIN score ranged from 0.5 (still in education) to 7.0 (highest socio-economic status). Based on the definition of the German Federal Ministry of Justice and Consumer Protection, children were classified as being from an immigrant family, if at least one of the parents had a non-German nationality or was born outside Germany. Parent-reported ADHD-related symptoms at baseline were used to adjust for pre-existing symptoms prior to school entry. Missing values in these baseline symptoms (23.5% of the sample) were completed with a full multiple imputation procedure using the Monte Carlo Markov chain method (SAS procedure MI).

A linear mixed model analysis for repeated measures was fitted with an unstructured covariance structure and restricted likelihood maximization. The teacher-reported SDQ hyperactivity/inattention subscale scores in 2nd and 4th grade were used as the dependent variable and the standardized scores of the six PHE subscales as independent variables. The school of the children was included as random effects variable. Effect estimates (non-standardized regression coefficients B) and standard errors (SE) were adjusted for age at school entry, parent-reported SDQ hyperactivity/inattention subscale scores at baseline, and the co-predictors mentioned above, by including them as fixed effects variables. As gestational age at birth and birth order showed no association with the dependent variable ($p > .1$), they were later excluded from the final model.

A sensitivity analysis was performed in order to determine whether the child`s age at PHE, which is also reflected in the PHE subscale scores, affected the association between developmental characteristics and ADHD-related symptoms. Thus, the analysis described above was repeated with age-standardized PHE subscale scores. The influence of age at PHE was removed from the PHE subscale scores by running separate regression analyses for each subscale with age at PHE as independent variable and stratified by gender. The standardized residuals from these regression models (instead of the standardized scores of the PHE subscales) were then entered into the final regression model as independent variables.

To determine which PHE items are most important for predicting the development of ADHD-related symptoms, the items of those subscales that were significant predictors of teacher-reported SDQ hyperactivity/inattention subscale scores were investigated with z-transformed item values as independent variables. Apart from that, this analysis was identical to the main analysis.

All statistical analyses except the multiple imputation procedure were performed with IBM SPSS Statistics version 23. A two-sided p-value < .05 was considered statistically significant. No adjustments for multiple testing were performed for this exploratory analysis.

Results

Relationship between PHE subscales and SDQ hyperactivity/inattention subscale

In the linear mixed model analysis only the cognitive/sensory skills subscale had a statistically significant association with the SDQ hyperactivity/inattention scores in 2nd and 4th grade. The association was negative at both time points (Table 1), indicating that the lower the cognitive/sensory skills at PHE, the more ADHD-related symptoms are reported by the teachers in primary school. This association appeared to be slightly stronger in 2nd compared to 4th grade. Similar results were obtained for the fine motor skills, but the association was not significant. There were no discernible associations for the remaining subscales. The association between the scores of the cognitive/sensory skills subscale and ADHD-related symptoms is shown in Figure 1 with subscale scores being grouped into quartiles of the empirical distribution. The figures for the remaining PHE subscales are given in the Appendix (Figure S1, Figure S2, Figure S3).

Table 1

Relationship between the SDQ hyperactivity/inattention subscale (dependent variable) and the subscales of the preschool health examination as assessed by linear mixed model analysis (N = 1,345)

Independent variable[a]	Second grade			Fourth grade		
	B[b]	SE	p	B[b]	SE	p
Gross motor skills	0.02	0.09	.85	0.05	0.08	.51
Fine motor skills	-0.15	0.09	.074	-0.14	0.08	.095
Cognitive/sensory skills	-0.42	0.09	<.001	-0.36	0.08	<.001
Auditory memory	0.04	0.08	.61	0.01	0.08	.86
Anthropometric measures	-0.13	0.08	.11	0.06	0.08	.47
Second dentition	0.06	0.08	.44	-0.11	0.08	.18

[a] Standardized subscale scores.

[b] Non-standardized regression coefficient for fixed effects; the model includes school as random effect; results are adjusted for age at school entry, gender, family structure, migration background, socio-economic status, and parent-reported hyperactivity/inattention score at baseline.

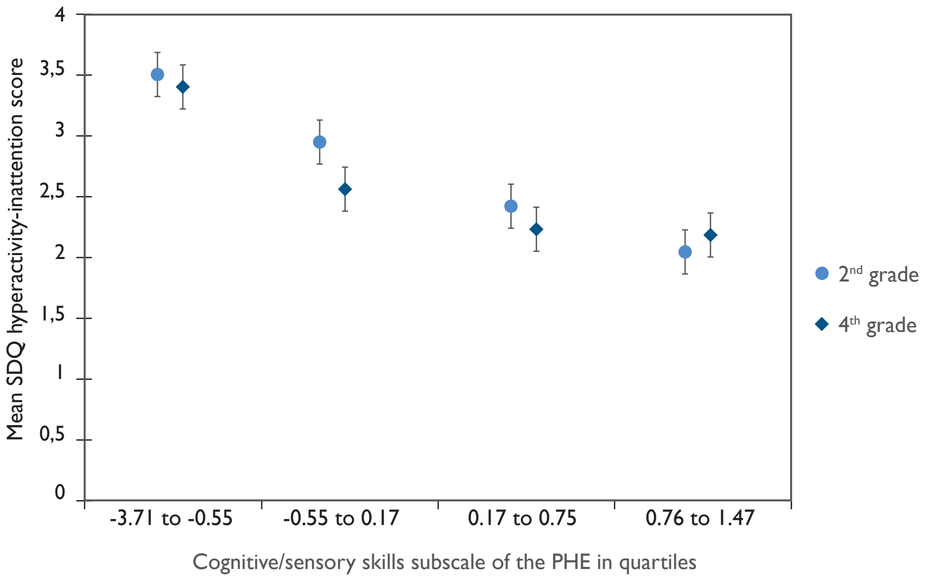

Figure 1. Mean SDQ hyperactivity/inattention scores as a function of cognitive/sensory skills subscale scores of the preschool health examination. Subscales scores are divided into quartiles. Error bars indicate standard errors.

Sensitivity analysis

The linear mixed model analysis with age-standardized subscale scores confirmed the results of the main analysis: a highly significant negative association between the cognitive/sensory skills subscale and the SDQ hyperactivity/inattention subscale in 2nd and 4th grade (see Appendix Table S2).

Relationship between items of the cognitive/sensory skills subscale and the SDQ hyperactivity/inattention subscale

Results for the single items of the cognitive/sensory skills subscale are reported in Table 2. Only the number memory item showed a significant association with ADHD-related symptoms at both time points. This item requires the child to remember the total amount of hidden beads that were presented before an intermediate task to determine their quantity. The association appeared to be stronger in 4th compared to 2nd grade. The second strongest association with ADHD-related symptoms was observed for the copying of the shape of a Maltese cross. Scores on this item were significantly associated with the SDQ hyperactivity/inattention subscale in 4th grade but not in 2nd grade. The item referring to the instant recognition of the quantities of differently coloured beads was also significantly associated with SDQ hyperactivity/inattention scores, but only in 2nd grade and not in 4th grade. In all these cases, the association was negative, meaning that children with lower skill levels exhibit more ADHD-related symptoms later in primary school. For the other items of the cognitive/sensory skills subscale, no significant associations were observed.

Table 2

Relationship between the SDQ hyperactivity/inattention subscale (dependent variable) and the items of the cognitive/sensory skills subscale as assessed by linear mixed model analysis (N =1,345)

Independent variable[a]	Second grade			Fourth grade		
	B[b]	SE	p	B[b]	SE	p
Recognition of quantities	-0.19	0.09	.027	-0.05	0.08	.56
Continuing counting	-0.08	0.08	.36	0.04	0.08	.62
Number memory	-0.17	0.08	.043	-0.25	0.08	.001
Remembering quantities	-0.05	0.08	.57	-0.11	0.08	.15
Grasping a form	-0.13	0.08	.13	-0.13	0.08	.1
Copying a figure (cross)	-0.15	0.09	.082	-0.19	0.08	.022
Copying a figure (fish)	-0.05	0.08	.52	-0.01	0.08	.93

[a] Standardized values.

[b] Non-standardized regression coefficient for fixed effects; the model includes school as random effect; results are adjusted for age at school entry, gender, family structure, migrant background, socio-economic status, and parent-reported hyperactivity/inattention score at baseline.

Discussion

We investigated whether developmental characteristics prior to school entry that were assessed by a PHE at Steiner schools are related to the extent of teacher-reported ADHD-related symptoms later in primary school. In our study, scores on a cognitive/sensory skills subscale and in particular scores on items referring to working memory, quantity-number competencies, and visual-spatial integration were significantly associated with teacher-reported SDQ hyperactivity/inattention subscale scores in 2nd and/or 4th grade. In children with lower performance regarding these cognitive/sensory skills, more ADHD-related symptoms were later reported. This association was present while adjusting for the level of ADHD-related symptoms prior to school entry, age at school entry, gender, and other potential ADHD-related risk factors. A sensitivity analysis with age-standardized scores yielded the same results, which further indicates that the association between the lower cognitive/sensory skills and later ADHD-related symptoms could not be attributed to the child`s actual age at the PHE but to their age-adjusted skills in this domain.

Working memory has been frequently examined in studies on the relationship between deficits in executive functions as precursors or early signs of later ADHD. A meta-analysis (Pauli-Pott & Becker, 2011) evaluated, among other neuropsychological deficits, the evidence of an association between early working memory and ADHD risk. Results of included studies were found to be not consistent and the estimated mean effect size – although statistically significant – was small compared to effect sizes for response inhibition, interference control, delay aversion, vigilance/arousal, and flexibility. In the present study, there were also no consistent associations between working memory at PHE and later ADHD-related symptoms. Symptoms were predicted only by number memory, that is, by remembering the total number of presented beads (10 pieces). In contrast, no significant association was found for remembering the quantity of the differently coloured subsets of these beads (4 blue, 6 red) as well as for the immediate recall of rhythm patterns and sequences of syllables within the auditory memory test. Unlike the auditory memory items, the number memory item included a distracting task (the continuing counting item) before the recall, which may have been more difficult for children at risk for developing ADHD-related symptoms later in school.

Surprisingly, remembering the total number of presented beads was associated with ADHD-related symptoms but remembering the subsets was not, although both contained the distracting task. This finding could be related to noisier representations of number magnitude in children with ADHD as suggested by Kaufmann and Nuerk (2008). The authors refer to Dehaene (1997), who proposed that access to the magnitude representation of a given number becomes more variable as the magnitude of the number increases. According to their results, this variability in accessing representations of number magnitude seems to be even larger in children with ADHD. If this larger variability is already present in preschool children at risk for ADHD, they could have had greater difficulties in accessing the exact number representation of the total quantity than that of the smaller subsets compared to children without risks for ADHD. In line with this assumption, there is evidence that preschoolers at risk for ADHD have lower quantity-number competencies than children who are not at risk (Schmiedeler & Schneider, 2014). In particular, this affects the ability to enumerate objects (Schuchardt et al., 2013), which requires the linking of number words to quantities (Krajewski & Schneider, 2009) and was also found to be impaired in primary school children with ADHD (Kuhn et al., 2016). This, in turn, is consistent with our result that children with more ADHD-related symptoms in primary school had performed worse in the PHE item that captured instant recognition of quantities. Again, the reason for this finding could be a more difficult activation of the exact number representation that corresponds to the quantities presented.

Another finding of our study was that children with lower scores on the copying of the shape of a Maltese cross exhibited more ADHD-related symptoms later in primary school. This item measures visual-spatial integration, which involves both visual processing and fine motor skills. Its association with ADHD is in line with previous research: Preschool children that were later diagnosed with ADHD showed poorer performance in copying geometric forms compared to children without later ADHD (Kalff et al., 2002). In a recent study, school children with ADHD have been found to show impairments of visual-spatial integration (copying figures) and visuomotor ability (line tracing) (Fenollar-Cortes et al., 2017). In our study, however, no association with ADHD-related symptoms was observed for our PHE item referring to the copying of the figure of a fish. The reason for this discrepancy is unclear, but this task may be too easy to accurately differentiate between children with and without risk for developing ADHD-related symptoms later.

There is also evidence for deficits in other fine motor skills such as the sequential finger-thumb opposition in children with ADHD (Mendes et al., 2018). This task was also included in our PHE as part of the fine motor skills subscale, but the association of the total subscale with later ADHD-related symptoms was not significant. We, hence, refrained from analysing individual items of this subscale. However, as summarized by Mendes et al. (2018), findings on impairments of motor abilities in children with ADHD are not consistent and further research on this topic is needed.

Strengths and limitations

Strengths and limitations of the IPSUM study (e.g., setting, study design, participants` selection, accuracy of ADHD measurements, external validity) have been discussed in detail elsewhere (Diefenbach et al., 2018; Wendt et al., 2018). For the current study, it was important to take into account baseline levels of ADHD symptoms, because developmental deficits during preschool could simply be epiphenomena of early ADHD and may not contribute independently to the prediction of later ADHD symptoms (van Lieshout et al., 2013). The same holds for the age at school entry, which appears to be an important and independent risk factor for later ADHD. Since we adjusted for baseline symptoms and age at school entry, performances in the mentioned cognitive/sensory skills items appear to be still relevant and independent predictors of later ADHD-related symptoms. Thus, the prospective longitudinal design and the adjustment for baseline symptoms and other important co-predictors in the analysis are definitively strengths of the study.

ADHD is more sensitively predicted by teacher rather than by parent ratings (Goodman et al., 2000). In our study, teacher ratings were available for 2^{nd} and 4^{th} grade, but not for baseline (i.e., prior to school entry). Thus, effect estimates were adjusted for parent reports at baseline instead of teacher reports at baseline. Although, parent and teacher ratings converge due to criterion validity (Hall et al., 2019), the adjustment for parent reports was not appropriate and might have led to residual bias. Future studies should try to gather nursery school teacher assessments of ADHD-related symptoms prior to school entry.

The PHE data collection took place in a real-world setting, that is, under less controlled and standardized conditions compared to usual laboratory-based psychometric testing. Nevertheless, we found comparable effects as under controlled conditions.

Certain developmental characteristics that may be important for the early identification of children at risk for ADHD, such as measures of different executive functions (e.g., Pauli-Pott & Becker, 2011), were not covered by the present PHE. For an improved identification of at-risk-children, more appropriate items should be considered for future revisions of the PHE. The present PHE has been designed to reflect developmental aspects that are relevant for the judgement of school readiness from the perspective of Steiner education. This is somewhat different from the view of school readiness underlying the PHEs at German public schools. However, item selection was based on already established instruments and the relevant cognitive/sensory skills subscale overlaps considerably with other widely used and validated German school entrance tests such as the GSS (Göppinger sprachfreier Schuleignungstest; Kleiner, 1998) or the WTA (Weilburger Testaufgaben für Schulanfänger; Hetzer & Tent, 1994). In addition, a recent psychometric evaluation of the present PHE instrument and its subscales confirmed a sufficient reliability and validity (Diefenbach et al., 2018).

We interpreted the scores of the hyperactivity/inattention subscale of the SDQ as indicators of the extent of ADHD-related symptoms and not as proof of an ADHD diagnosis. In fact, this SDQ subscale is not a specific ADHD scale, but assesses hyperactive, inattentive, and impulsive behaviour that may also occur for other reasons than ADHD (e.g., sleep problems with daytime sleepiness). However, a validation study showed that the hyperactivity/inattention subscale of the German version of the SDQ was able to discriminate between patients with and without a diagnosis of ADHD and that it is useful for screening purposes (Becker et al., 2004). Therefore, we felt that it is justified to use the term "ADHD-related symptoms" for measures of this subscale.

Conclusions

The present study demonstrated that items of a PHE, a compulsory examination of all preschool children in Germany, may be useful to identify children at risk for developing ADHD-related symptoms (and perhaps ADHD) during primary school. Aside from other important risk factors, children with underperformance in cognitive/sensory skills may be particularly at risk.

Further research should focus on the ability of further developmental domains such as inhibition, cognitive flexibility, and delay aversion to predict ADHD-related symptoms and ADHD diagnosis later in primary school. Based on such characteristics and other established ADHD risk factors, prediction rules and models should be developed and validated in prospective studies. The incorporation of predictions from these models into the consideration of school readiness may have the potential to prevent ADHD-related symptoms (and perhaps ADHD) later in school.

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Appendix

Table S1

Sample characteristics of children enrolled in the study (participants) and children in the analysis sample: Total numbers (N) and frequencies (%) of relevant variables, unless otherwise stated

Characteristics	**Study participants N = 2,100**	**Analysis sample N = 1,345**
Male	1,122 (53.4 %)	679 (50.5 %)
Family structure: Single-parent family or other relatives	394 (18.8 %)	257 (19.1 %)
Migrant background	365 (17.4 %)	231 (17.2 %)
Socio-economic status (CASMIN classification)		
Low	461 (22.0 %)	261 (19.4 %)
Medium	678 (32.3 %)	440 (32.7 %)
High	961 (45.8 %)	644 (47.9 %)
Gestational age at birth		
Preterm	115 (5.5 %)	76 (5.7 %)
Term	1,574 (75.0 %)	1,045 (77.7 %)
Missing	411 (19.6 %)	224 (16.7 %)
Age at school entry (M, SD)	6.69 (0.39)	6.61 (0.28)
SDQ hyperactivity/inattention score (M, SD)		
Baseline (Parent reports)	2.01 (1.82)	1.94 (1.81)
Second grade (Teacher reports)	2.79 (2.91)	2.69 (2.84)
Fourth grade (Teacher reports)	2.64 (2.76)	2.56 (2.71)

Table S2

Sensitivity analysis: Relationship between the SDQ hyperactivity/inattention score (dependent variable) and the age-standardized subscale scores of the preschool health examination as assessed by linear mixed model analysis (N = 1,345)

Independent variable	Second grade			Fourth grade		
	B[a]	SE	p	B[a]	SE	p
Gross motor skills	0.02	0.09	.85	0.05	0.08	.55
Fine motor skills	-0.16	0.09	.062	-0.14	0.08	.081
Cognitive/sensory skills	-0.42	0.08	<.001	-0.36	0.08	<.001
Auditory memory	0.04	0.08	.61	0.01	0.08	.88
Anthropometric measures	-0.12	0.08	.11	0.05	0.07	.50
Second dentition	0.06	0.08	.43	-0.10	0.07	.15

[a] Non-standardized regression coefficient for fixed effects; the model includes school as random effect; results are adjusted for age at school entry, gender, family structure, migrant background, socio-economic status, and parent-reported hyperactivity/inattention score at baseline.

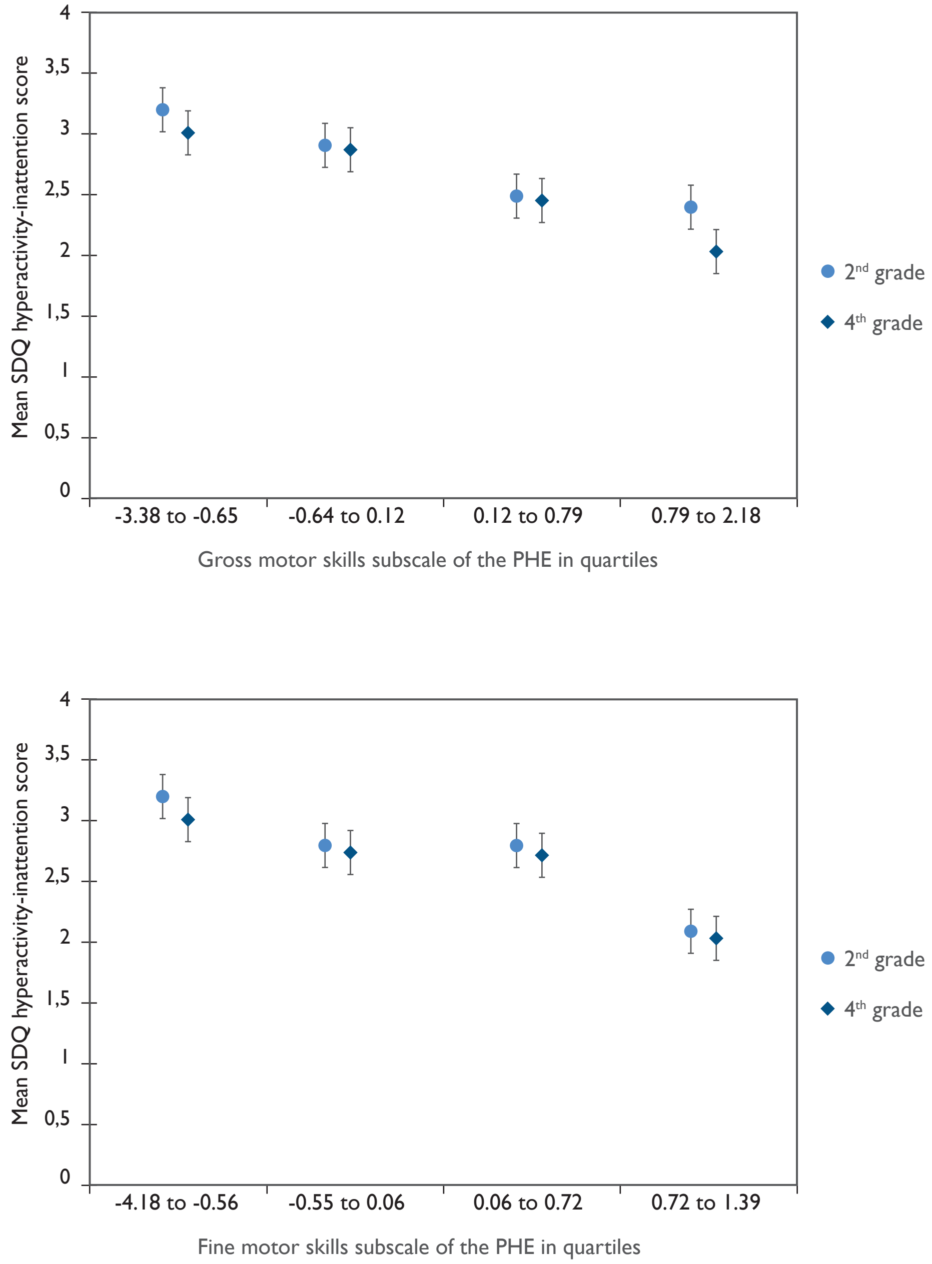


Figure S1. Mean SDQ hyperactivity/inattention scores as a function of gross motor skills subscale scores (top panel) and fine motor skills subscale scores (bottom panel) of the preschool health examination (PHE). Subscales scores are divided into quartiles. Error bars indicate standard errors.

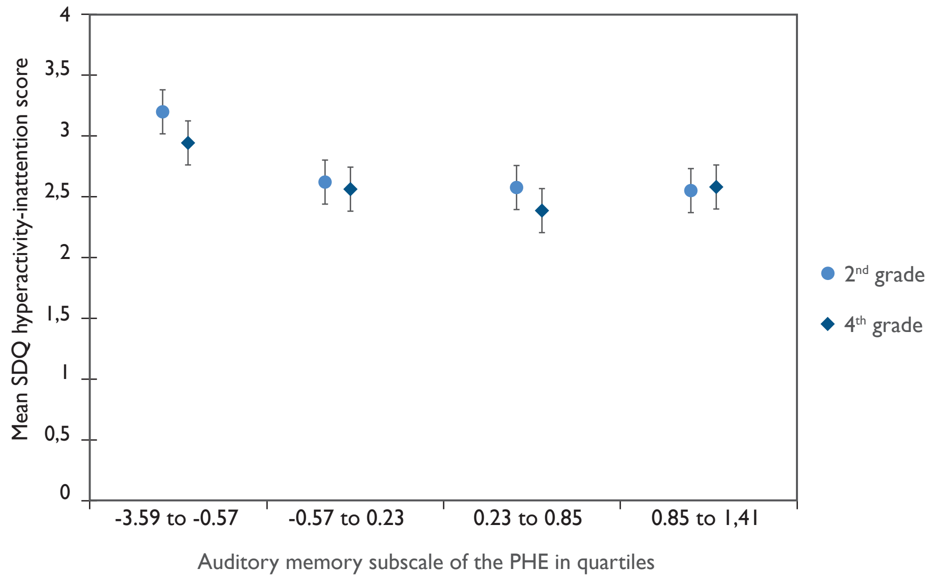
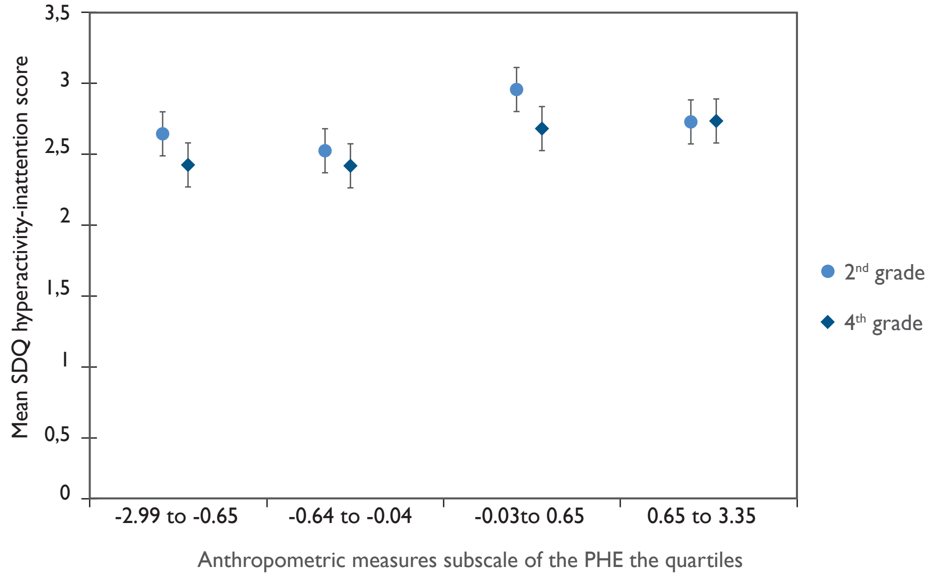


Figure S2. Mean SDQ hyperactivity/inattention scores as a function of auditory memory subscale scores of the preschool health examination (PHE). Subscales scores are divided into quartiles. Error bars indicate standard errors.



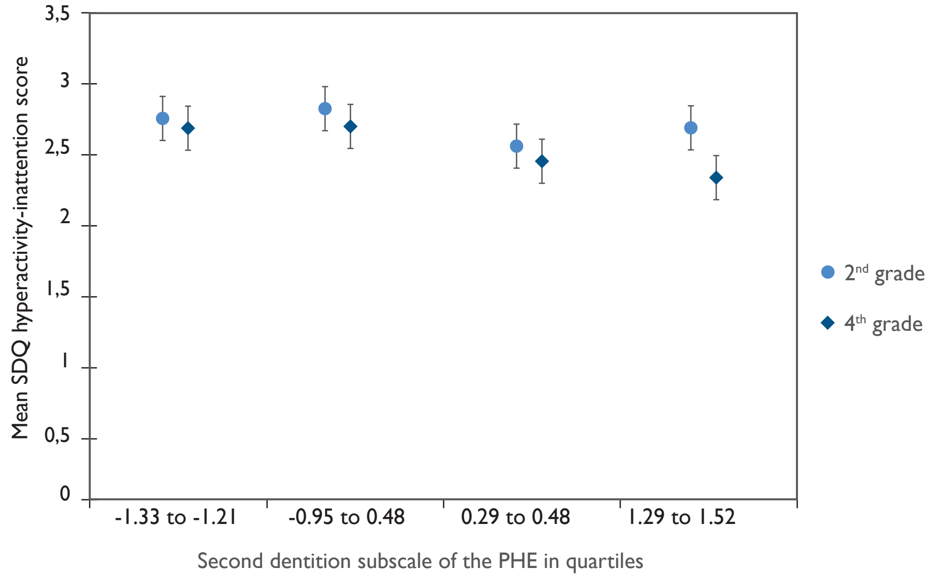


Figure S3. Mean SDQ hyperactivity/inattention scores as a function of anthropometric measures subscale scores (top panel) and second dentition subscale scores (bottom panel) of the preschool health examination (PHE). Subscales scores are divided into quartiles. Error bars indicate standard errors.