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RESEARCH ARTICLE

Cluster analysis of teachers report for identifying symptoms of autism spectrum and/or attention deficit hyperactivity in school population: EPINED study

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Abstract

An early detection of Neurodevelopmental Disorders (NDDs) is crucial for their prognosis; however, the clinical heterogeneity of some disorders, such as autism spectrum disorder (ASD) or attention-deficit hyperactivity disorder (ADHD) is an obstacle to accurate diagnoses in children. In order to facilitate the screening process, the current study aimed to identify symptom-based clusters among a community-based sample of preschool and school-aged children, using behavioral characteristics reported by teachers. A total of 6894 children were assessed on four key variables: social communication differences, restricted behavior patterns, restless-impulsiveness, and emotional lability (pre-schoolers) or inattention and hyperactivity-impulsivity (school-aged). From these behavioral profiles, four clusters were identified for each age group. A cluster of ASD + ADHD and others including children with no pathology was clearly identified, whereas two other clusters were characterized by subthreshold ASD and/or ADHD symptoms. In the school-age children, the presence of ADHD was consistently observed with ASD patterns. In pre-schoolers, teachers were more proficient at identifying children who received a diagnosis for either ASD and/or ADHD from an early stage. Considering the significance of early detection and intervention of NDDs, teachers' insights are important. Therefore, promptly identifying subthreshold symptoms in children can help to minimize consequences in social and academic functioning.

Lay Summary

It is crucial to efficiently detect and diagnose Autism and attention-deficient hyperactivity disorder from an early stage. Children presenting mild symptoms are often missed, causing delays in diagnosis and treatment. The results of this study demonstrate that teachers can spot these subtle signs in their daily interaction and help identify sub-clinical symptoms, thus providing insight for early assessment and diagnosis.

KEYWORDS
ADHD, autism, cluster analysis, school children, screening, teachers

INTRODUCTION

Autism spectrum disorder (ASD) and attention-deficit hyperactivity disorder (ADHD) are the most common early-onset and chronic neurodevelopmental disorders (NDDs) (APA, 2013). ASD is a heterogeneous disorder mainly identified with social interaction and communication, and restrictive behaviors impairments in the development of children but often accompanied by such other psychopathological comorbidities as ADHD (APA, 2013; Vorstman et al., 2017). ADHD, on the other hand, is defined by the presence of a persistent pattern of inattention and/or hyperactivity-impulsivity (APA, 2013). Both NDDs are highly prevalent worldwide and have multiple implications on individuals and their families as they are known to lower the quality of life (Thapar et al., 2023). The reported prevalence of ADHD in children rate ranges from 5.5% to 9.9% (Bosch et al., 2022; Canals Sans et al., 2021; Zablotsky et al., 2019). In recent years, the prevalence of ASD in children has been increasing and now ranges between 1.5% and 3.6% (Morales Hidalgo et al., 2021; Shenouda et al., 2022). The lifetime prevalence of ADHD in individuals with ASD has been reported to be between 38.5% and 43.2% (Rong et al., 2021). Otherwise, the comorbidity between ADHD and ASD in school-aged children is between 1.2% and 13% (Casseus, 2022; Zablotsky et al., 2020). An apparent association has been seen between the two disorders in terms of social skills, executive functioning, and behavioral disturbances (Ghirardi et al., 2019; Mouti et al., 2019). This could be because an overlap of genetic, biological and environmental risk factors is associated with both disorders (Ma et al., 2021; Xi & Wu, 2021). Therefore, some researchers suggest considering the two disorders as one (Deserno et al., 2022). Since research shows that ASD and ADHD share symptoms and comorbidities, assessment and diagnosis in children may be a challenge in clinical and educational environments (Craig et al., 2015; Melegari et al., 2015). This has led to uncertainties in diagnoses and unattended needs in children and young people who present symptoms of both disorders (Hus & Segal, 2021; Velarde & Cárdenas, 2022).

Challenges in early detection of NDDs

Children's brain develops constantly and rapidly in early childhood. As a result, the process for diagnosing NDD gets complicated, and many interventions can be inappropriate. According to Rivard et al. (2022) this issue is a cause for concern because 2 years can elapse between the first and the final diagnosis. Therefore, it is crucial that children be detected and assessed correctly at an early stage and a clear picture is provided of the possible outcome at later stages of development. The manifestations of neurodevelopmental disturbances may be transitory, but they may also be the first signs of NDDs, which can lead to either over or under-diagnosis (Astle et al., 2022). Astle et al. (2022) suggest that rather than assessing children solely based on their behavior, it would be ideal to incorporate such functional profiles, such as cognitive and language functioning, social development, and even academic achievements to better support the diagnoses of NDDs. Along with other factors, they identified the need to assess the child's family environment and consider socio-economic conditions (SES) (Astle et al., 2022; Hadders-Algra, 2021). Similarly, Kelly et al. (2019) found the existence of SES inequality was a feature of the diagnoses of ASD children and, more specifically, was associated with the mother's educational status. A gender bias has been widely recognized in the diagnosis of disorders such as ASD and ADHD, with an under-diagnosis in the female population (Mowlem et al., 2019; Posserud et al., 2021). Therefore, inconsistencies and not taking into account various risk factors may result in delayed and inadequate diagnoses for NDDs in children (Astle et al., 2022; Rivard et al., 2022).

The role of multi-informant assessment and cluster analysis methodologies

Children spend most of their time at school, where NDDs may be identified due to having difficulties in their social and academic activities. These disorders, therefore, need to be assessed in the school population where teachers are more familiar with each child's behavior. Although the multi-informant assessment is necessary, it can also be challenging because the information provided by teachers and parents is often divergent (DuPaul et al., 2020). Some studies suggest a higher concordance between the information provided by teachers and the diagnosis of ADHD (Canals Sans et al., 2021). In the case of ASD, data from both informants is important for detection and highly correlated with diagnosis (Morales Hidalgo et al., 2021). The fact that the data is collected in a school context allows us to obtain a picture of the dimensionality of the alterations in NDDs.

It is important to understand which clinical and socio-demographic manifestations are most likely to be related to the diagnosis. This understanding can be achieved with cluster analysis or unsupervised machine learning, which provides a transdiagnostic and more individualized approach to alterations in NDD by defining the existence of subgroups (Rivard et al., 2022; Zhang et al., 2022). With the help of clustering, researchers have been able to more accurately suggest that ASD and ADHD cannot be characterized as two separate disorders nor cannot be addressed together (Deserno et al., 2022). In fact, Parlett-Pelleriti et al. (2022) suggested that this type of analyses is particularly useful for analyzing disorders such as ASD which DSM-5 defines as a spectrum, in which individuals present diverse needs based on different symptom profiles and severities. Hence, being able to accurately identify and understand the mechanism underlying disorders at an early stage can enable clinicians to provide specific and more individualized treatment (Parlett-Pelleriti et al., 2022; Stevens et al., 2019).

Objectives and hypothesis

The objective of the current study is to facilitate the screening procedures and provide empirical data on shared functional diversity in NDDs. This will be done by identifying symptom-based clusters in a community-based sample of preschool and school-aged children, using the behavioral characteristics reported by teachers, and analyzing the relation, if any, that these profiles have with sociodemographic and psychopathological variables. The study will focus on four key variables: social interaction and communication, restricted behavior patterns, restless impulsiveness and emotional lability (preschalars), and inattention and hyperactivity-impulsivity (school-aged). We hypothesize that teachers can be good informants of the risk of diagnosis and can detect different NDD profiles. Thus, we expect to find behavior profiles that have different symptom severities and profiles that share symptoms of ASD and ADHD.

METHODS

The current study is part of the Neurodevelopmental Disorders Epidemiological Project (EPINED). The data was gathered from representative schools throughout the province of Tarragona, Spain, between the years 2014 and 2019. The study was conducted in two phases. In the first phase ADHD/ASD, screening was performed by the parents and teachers. In the second phase, children and their families were assessed individually for NDDs. In this stage, we estimate the prevalence of ASD and/or ADHD and examine clinical, cognitive, psychosocial, and environmental factors related to their evolution. The Sant Joan University Hospital's Ethics Committee approved the study protocol (13-10-31/10proj5).

Participants

The sample of our study consisted of 6894 children out of 6921 potential participants from two different age groups: 3374 pre-school-aged children (4–5 years) and 3520 school-aged children (10–11 years). Children were recruited from randomly selected 86 schools (public – 69; private – 17) with a participation rate of 99.6% (6894) for teachers and 53.9% (3727) for parents. A total of 293 teachers (preschool – 139; school – 154) took part in the study. We gathered anonymous information from non-participating children's families on ADHD and ASD risk symptoms in agreement with the Catalan Government. However, only children with a positive screening of ADHD or/and ASD and a control group with the family's consent took part in the first and second phases of the study. A total of 781 children were evaluated individually during the second phase. From this sample, the prevalence of ADHD was 3% in preschoolers and 3% in school-aged children. The prevalence of ASD was 1.3% and 1.8%, respectively (Canals Sans et al., 2021; Morales Hidalgo et al., 2021).

Screening measures

EDUTEA is an 11-item questionnaire for teachers that assesses ASD and social pragmatic communication disorder in school settings (https://psico.fcep.urv.cat/Q4/EduTEA; Morales-Hidalgo, Hernández-Martínez, Vera, et al., 2017; Morales-Hidalgo, Hernández-Martínez, Voltas, & Canals, 2017). It is scored on a Likert scale ranging from 0 to 3 (0 = "never or almost never", 1 = "sometimes", 2 = "often", 3 = "always or almost always") with a minimum score of 0 and a maximum of 33 and a cut-off score of 10. EDUTEA has two factors – social communication impairments (SCI – 7 items) and restricted behavior patterns (RBP – 4 items) and internal consistency in the Spanish population of 0.83. Furthermore, for the cut-off score of 10, sensitivity (87%) and specificity (91.2%) were high (Morales-Hidalgo, Hernández-Martínez, Voltas, & Canals, 2017).

Conners Early Childhood Global Index (EC GI) and Conners 3 ADHD Index (AI) (Conners, 2008; Conners & Goldstein, 2009) assess psychopathology over the previous month in children between the ages of 2–6 and 6–18 respectively. Both indexes are scored on a Likert scale ranging from 0 to 3 (0 = "never", 1 = "occasionally", 2 = "often", 3 = "very often") and provide cut-offs for elevated scores (T = 65–69) and highly elevated scores (T ≥ 7). For the Conners EC GI, we used the two factors labeled by the authors labeled as restless-impulsiveness (RI – comprised of 6 items, Cronbach's $\alpha = 0.88$) and emotional lability (EL −4 items, Cronbach's $\alpha = 0.81$). For the Conners AI, on the other hand, the questionnaire was divided into: hyperactive impulsivity (3 items, Cronbach's $\alpha = 0.97$) and inattention (7 items, Cronbach's $\alpha = 0.99$) (Morales-Hidalgo, Hernández-Martínez, Vera, et al., 2017). The internal reliability of the Spanish versions for parents and teachers was 0.92 and 0.97 (Conners EC GI) and 0.96 and 0.98 (Conners AI), respectively (Morales-Hidalgo, Hernández-Martínez, Vera, et al., 2017).

Diagnosis measures

ASD assessment

To diagnose ASD, we used the DSM-5 criteria, based on the information obtained from the Autism Diagnostic

Interview-Revised (ADI-R; Rutter et al., 2003) and the Autism Diagnostic Observation Schedule, second edition (ADOS-2; Lord et al., 2012). The Gotham et al. (2009) approach was used to determine the ASD severity where a score of 1–3 represent "non-spectrum", a score of 4–5 is "ASD" and a score of 6–10 is "autism". When children reached the cut-off points of the ADI-R diagnostic algorithm and an ADOS-2 calibrated score of severity score ≥4, they were considered positive for ASD. On the other hand, children were considered to have subthreshold autistic traits when two professionally trained psychologists and psychiatrists both awarded them slightly lower on both ADI-R and ADOS-2 tests.

ADHD assessment

To assess fulfillment of DSM-5 criteria for ADHD and severity ratings, information was collected with the Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime version (K-SADS-PL; Kaufman et al., 1997). The Spanish version of the semi-structured interview showed high inter-rater reliability (*kappa* = 0.91; Ulloa et al., 2006). The severity of ADHD was determined on the basis of the number of symptoms present and the level of functional impairment. For mild ADHD, 6 or 7 out of the 9 maximum symptoms were observed in one or both presentations, with low impairment in one or two functional contexts. If 8 or 9 out of the 9 maximum symptoms were present, along with severe impairment in two or three functional contexts, the diagnosis was severe ADHD was given. If symptoms and impairment levels were between mild and severe, the diagnosis was moderate ADHD.

Secondary variables

The parents answered the Child Behavior Checklist (CBCL1½-5, CBCL6-18) a measure to detect emotional and behavioral problems in children (Achenbach & Rescorla, 2000, 2001). Internalizing, externalizing and total problems scores were used, where T-scores between 60 and 64 are considered to be in the borderline clinical range and T-scores ≤65 are considered to be in the clinical range. The inter reliability for preschool and school-aged syndrome scales ranged between 0.65, 0.86, 0.71, and 0.87, respectively (de la Osa et al., 2016; Sardinero García et al., 1997). Neuropsychological functioning was assessed using the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-IV) and Wechsler Intelligence Scales for Children (WISC-IV) (Wechsler, 2005, 2014). The intelligence quotient (≤75) and DSM-5 criteria for adaptive skills, children were used to diagnose with intellectual disabilities. The sociodemographic data of participants were also collected during the first and second phases of the study. Hollingshead (2011) was used to estimate a family's socioeconomic status (SES).

Procedure

In the first phase of the study, teachers and parents provided sociodemographic and psychological information about the children. Teachers completed EDUTEA (Morales-Hidalgo, Hernández-Martínez, Vera, et al., 2017; Morales-Hidalgo, Hernández-Martínez, Voltas, & Canals, 2017) and parents completed the Childhood Autism Spectrum Test (CAST; Scott et al., 2002) to screen for ASD symptoms. To screen for ADHD symptoms, on the other hand, we used teachers' and parents' versions of the Conners Indexes. The screening for ASD was determined to be positive when either one of the informants reported scores above the cut-off. ADHD was determined to be positive only when both the informants scored above the cut-off for elevated symptoms. When children presented a positive screen for ASD or/and ADHD or have a previous ASD/ADHD diagnosis, they were considered positive and continued participating in the second phase together with a control group matched for age, sex, class and school type. Specifically, to maintain an equal ratio, one control child was selected for every two children at risk. Furthermore, to decrease the likelihood of false positives and negatives, in the second phase, qualified clinicians assessed children and their families individually for ASD/ADHD diagnoses, using DSM-5 criteria, in the school setting.

Analyses

The analyses were carried out using JASP 0.16.4.0 and IBM SPSS 28. For the data analyses, four psychopathological variables were used to allocate children to different clusters and identify their behavioral characteristics. Two factors from EDUTEA were used to examine the ASD symptoms: social communication and restrictive repetitive behavior. Likewise, two factors from the Conners EC GI in pre-scholars were used to assess ADHD symptoms: restless-impulsivity and emotional lability. Two more factors were extracted from Conner 3 AI in school-aged children: hyperactivity-impulsivity and inattention. All the factors' scores were transformed into z-scores for the cluster analysis. Children were grouped into appropriate clusters with JASP. A hierarchical clustering approach was used with Ward's minimum variance (D2 linkage) and the Euclidean distance was used with the help of the of elbow method to identify closely related groups of clusters. To ensure robust clustering, *k*-means cluster analysis was conducted to assign each child to their more closely related characteristic cluster. K-mean clustering uses the nearest centroid for multivariate means, thus reducing within-cluster variances. Cluster differences in symptomology, sociodemographic characteristics (age, sex, SES and ethnicity), cognitive and psychopathological data were performed by chi-square (χ^2) for categorical data and analyses of variance (ANOVA) followed by post hoc analyses using Welch and Tamhane's T2, for numerical data. Because of the multiple comparisons, to reduce type 1 error a p correction was applied at a minimum level of significance of 0.005.

RESULTS

The elbow method gave a four-cluster solution. However, to ensure that the subgroups were homogenous, we also examined five clusters with k-means clustering. Finally, in both age groups, a four-cluster solution was found to be most suited to the behavioral profiles of children, evaluated using EDUTEA and Conners Indexes. Figure 1 provides a distribution of mean and standard deviation values obtained regarding ASD and ADHD symptomatology for each cluster and age group. Clusters are identified as follow: for pre-schoolers, Cluster 1 (CP-1; no ASD/ADHD risk), Cluster 2 (CP-2; subthreshold attention deficit hyperactivity disorder; sub-ADHD), Cluster 3 (CP-3-subthreshold autistic symptoms; sub-ASD) and Cluster 4 (CP-4; ASD + ADHD); for schoolers, Cluster 1 (CS-1; no ASD/ADHD risk), Cluster 2 (CS-2; sub-ADHD), Cluster 3 (CS-3; sub-ASD and ADHD) and Cluster 4 (CS-4; ASD + ADHD).

Table 1 presents the results of the identification of clusters of preschool-aged children from ASD and ADHD behavioral data and the sociodemographic characterization of each cluster. The differences in psychopathological profiles of the four clusters were significant ($p < 0.001$). CP-1 consisted of children with no ASD/ADHD symptoms (71%, $n = 2396$). CP-2 consisted of children presenting subthreshold ADHD symptoms (15.8%, $n = 534$; Conners mean T-score = 62.1) and CP-3 consisted of children with subthreshold autistic symptoms (9.8%, $n = 332$; EDUTEA mean score = 9.2). CP-4 consisted of children presenting ASD symptoms and high ADHD (3.3%, $n = 112$; EDUTEA mean score = 19.6, Conners mean T-score = 69.2). The overall sample of preschool-aged children had a balanced number of males and females. However, the clusters of children with ASD and/or ADHD symptomatology were male-dominated, with CP-4 (73.2%), CP-3 (58.7%), and CP-2 (54.7%) having more males than females ($p < 0.001$, both intra and inter groups). The children in the sample were primarily from middle-income families (56.9%) and Spanish ethnicity (77.1%). However, the SES was significantly lower in the clusters of children with ASD and ASD + ADHD symptoms and the proportion of non-Spanish children was also higher.

Table 2 presents the results of identifying of clusters of school-aged children from ASD and ADHD behavioral measures and sociodemographic characterization for each cluster. The differences in psychopathological

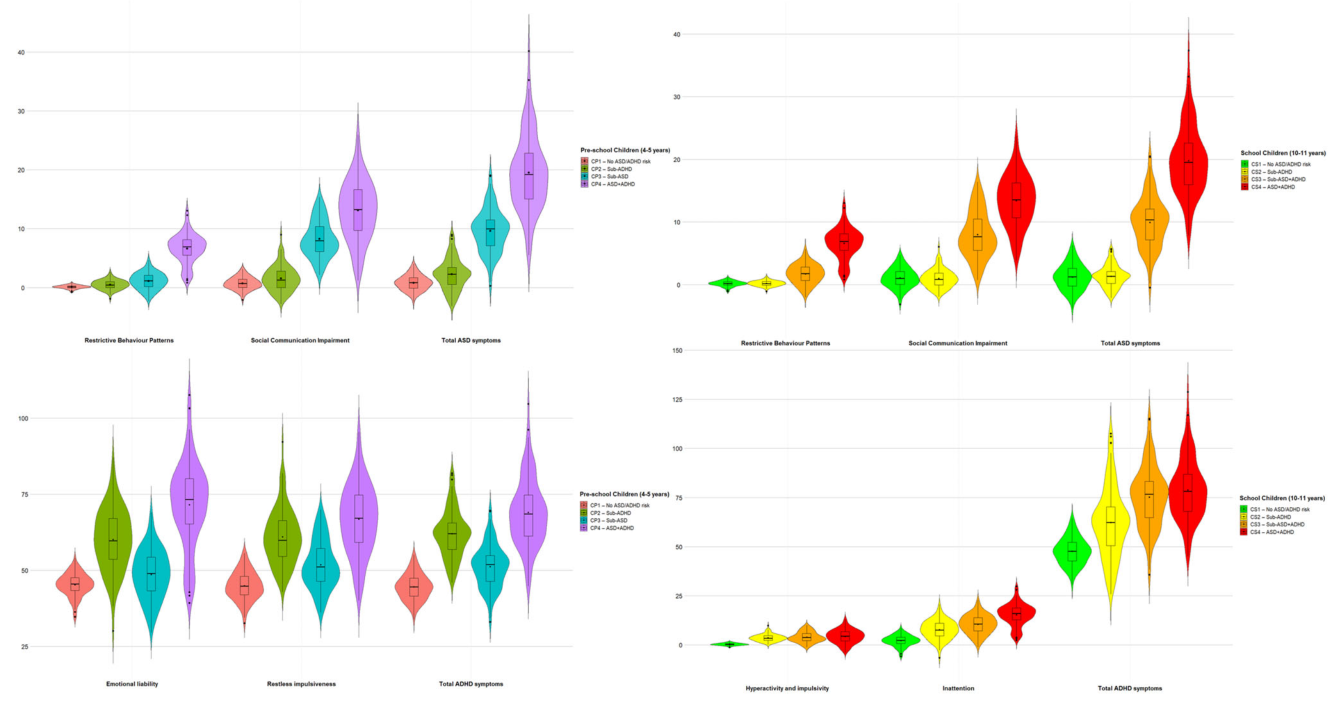

FIGURE 1 Violin plots of the mean and standard deviation of EDUTEA and CONNER EC GI for preschool children and EDUTEA and CONNER 3 AI for school-aged children in each cluster.

TABLE 1 Behavioral and sociodemographic description of the preschool population for each cluster.

PRESCHOOL CHILDREN		Total (N = 3374)		CP-1 No ASD/ADHD (N = 2396)		CP-2 Sub-ADHD (N = 534)		CP-3 Sub-ASD (N = 332)		CP-4 ASD + ADHD (N = 112)		
BEHAVIORAL MEASURES												
EDUTEA		M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)	p*
Social communication impairment		1.9	(3.5)	0.6	(1.2)	1.8	(2.2)	7.9	(3.3)	13.3	(4.9)	<0.001
Restrictive behavior patterns		0.5	(1.4)	0.1	(0.3)	0.5	(0.9)	1.3	(1.4)	6.4	(2.6)	<0.001
Total ASD symptoms		2.4	(4.6)	0.7	(1.2)	2.3	(2.6)	9.2	(3.5)	19.6	(6.4)	<0.001
CONNERS EC GI												
Restless impulsiveness		48.6	(9.8)	44.4	(5.1)	61.9	(9.3)	50.8	(8.3)	67.1	(10.9)	<0.001
Emotional lability		48.6	(9.5)	44.8	(3.8)	60.6	(10.9)	49.8	(7.8)	70.0	(13.9)	<0.001
Total ADHD symptoms		48.4	(9.4)	44.1	(4.8)	62.1	(7.7)	50.3	(6.8)	69.2	(11.1)	<0.001
SOCIODEMOGRAPHIC MEASURES												
Age, M (SD)		4.6	(0.48)	4.7	(0.5)	4.7	(0.6)	4.6	(0.4)	4.7	(0.6)	0.008
Sex, % (n)	Male	50.3	(1697)	47.1	(1128)	54.7	(292)	58.7	(195)	73.2	(82)	<0.001
	Female	49.7	(1677)	52.9	(1268)	45.3	(242)	41.3	(137)	26.8	(30)	
SES, % (n)	Low	19.5	(513)	16.7	(310)	21.6	(94)	33.9	(84)	27.2	(25)	<0.001
	Middle	56.9	(1496)	56.6	(1047)	60.1	(262)	53.6	(133)	58.7	(54)	
	High	23.5	(618)	26.7	(494)	18.3	(80)	12.5	(31)	14.1	(13)	
Ethnicity, % (n)	Spanish	77.1	(2601)	79.6	(1907)	79.4	(424)	58.4	(194)	67.9	(76)	<0.001
	Other	22.9	(773)	20.4	(489)	20.6	(110)	41.6	(138)	32.1	(36)	

***Post-hoc group differences** for all behavioral and sociodemographic measures between clusters (1–2, 1–3, 1–4, 2–3, 3–4) are $p < 0.001$; except for Age – clusters (1–2) $p = 0.10$; (1–3) $p = 0.17$; (1–4) $p = 1.00$; (2–3) $p = 0.004$; (2,4) $p = 0.96$; (3–4) $p = 0.83$.

profiles of the four clusters were significant ($p < 0.001$). CS-1 consisted of children with no ASD or ADHD symptoms (71.3%, $n = 2508$). CS-2 consisted of children presenting sub-ADHD symptoms (14.8%, $n = 523$; Conners mean T-score = 62.7). CS-3 consisted of children with very high ADHD symptoms and mild ASD symptoms (10.2%, $n = 360$; Conners mean T-score = 73.4, EDUTEA mean score = 9.5), whereas CS-4 consisted of children with both evident ASD and ADHD symptoms (3.7%, $n = 129$; Conners mean T-score = 79.1, EDUTEA mean score = 19.9). The overall sample of school-aged children had a balanced number of males and females. However, most of the clusters were male-dominated, and CS-2 (66.9%), CS-3 (66.9%) and CS-4 (77.5%), had more males than females ($p < 0.001$, both intra and inter groups). As in the pre-schoolers, the SES was lower in the clusters of children with NDD symptoms and the proportion of non-Spanish population was higher in the clusters of children with ASD symptoms.

Tables 3 and 4 provide the mean scores of the psychopathological and cognitive measures collected in the second phase of the assessment by clusters for preschool and school-aged children, respectively. Children of both ages in cluster 4 (ASD + ADHD) presented the highest mean scores for measures of ASD (ADI-R/ADOS-2) and ADHD (K-SADS-PL). Post-hoc analyses between clusters 2–4 and 3–4 revealed statistically significant differences only in repetitive behavior for pre-schoolers and in all ASD symptoms for school-age children. This is consistent with the subthreshold ASD label in cluster 3 for both age groups. ADHD severity was high in children of both ages included in clusters with manifestations of ADHD (CP-2 and CP-4 pre-schoolers; CS-2, CS-3, and CS-4 school-children), and there were no significant differences between clusters. All children with ASD and/or ADHD showed more associated psychopathological problems than the children in cluster 1. For preschoolers the comorbidity with ADHD involved a significant increase in externalizing problems. For school-aged children, comorbidity between ASD and ADHD (CS-3 and CS-4) involved significant internalizing problems. As far as cognitive measures are concerned, the scores on the total intellectual quotient and the several scales were lower in pre-schoolers for CP-3 and CP-4. Post-hoc analyses showed no significant differences between CP-3 and CP-4, which included children with ASD symptoms. For the school children, WISC-V scores decreased as the severity of neurodevelopmental problems decreased and were lower in CS-3 and CS-4. Processing speed was significantly lower in CS-4 than in CS-3.

Figures 2 and 3 show the cluster allocation of preschool and school-aged children, respectively, in each diagnostic category in the second phase of the study.

TABLE 2 Behavioral and sociodemographic description of the school population for each cluster.

School children		Total (N = 3520)		CS-1 No ASD/ADHD (N = 2508)		CS-2 Sub-ADHD (N = 523)		CS-3 Sub-ASD + ADHD (N = 360)		CS-4 ASD + ADHD (N = 129)		
BEHAVIORAL MEASURES												
EDUTEA		M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)	p*
Social communication impairment		2.1	(3.7)	0.9	(1.7)	1.2	(1.5)	7.5	(3.9)	13.6	(3.9)	<0.001
Restrictive behavior patterns		0.6	(1.5)	0.1	(0.4)	0.2	(0.4)	1.9	(1.5)	6.3	(2.5)	<0.001
Total ASD symptoms		2.6	(4.9)	1.0	(1.9)	1.4	(1.7)	9.5	(3.9)	19.9	(5.5)	<0.001
CONNERS EC GI												
Restless impulsiveness		1.3	(2.2)	0.3	(0.7)	3.9	(1.8)	3.7	(2.8)	4.5	(3.4)	<0.001
Emotional lability		4.2	(5.3)	1.9	(2.9)	8.0	(5.2)	11.2	(4.7)	14.8	(5.6)	<0.001
Total ADHD symptoms		53.2	(14.6)	47.0	(6.5)	62.7	(17.4)	73.4	(14.7)	79.1	(15.6)	<0.001
SOCIODEMOGRAPHIC MEASURES												
Age, M (SD)		10.6	(0.5)	10.7	(0.5)	10.7	(0.5)	10.7	(0.6)	10.7	(0.9)	0.004
Sex, % (n)	Male	50.5	(1777)	43.3	(1086)	66.9	(350)	66.9	(241)	77.5	(100)	<0.001
	Female	49.5	(1743)	56.7	(1422)	33.1	(173)	33.1	(119)	22.5	(29)	
SES, % (n)	Low	21.4	(572)	18.3	(346)	25.1	(103)	31.5	(87)	37.5	(36)	<0.001
	Middle	59.3	(1585)	60.2	(1139)	50.9	(242)	56.5	(156)	50.0	(48)	
	High	19.3	(516)	21.5	(406)	15.9	(65)	12.0	(33)	12.5	(12)	
Ethnicity, % (n)	Spanish	83.3	(2931)	84.1	(2110)	85.1	(445)	77.5	(279)	75.2	(97)	<0.001
	Other	16.7	(589)	15.9	(398)	14.9	(78)	22.5	(81)	24.8	(32)	

***Post-hoc group differences** for all behavioral and sociodemographic measures between clusters (1–2, 1–3, 1–4, 2–3, 3–4) are $p < 0.001$; except Hyperactivity and impulsivity (2–3) $p = 0.80$; (2–4) $p = 0.29$; (3–4) $p = 0.11$ and Total ADHD symptoms (3–4) $p = 0.002$; and Age – clusters (1–2) $p = 0.96$; (1–3) $p = 0.002$; (1–4) $p = 0.99$; (2–3) $p = 0.44$; (2,4) $p = 1.00$; (3–4) $p = 0.94$.

Some differences were found between age groups. Overall, ASD or/and ADHD were better identified in preschool than school-aged children. Pre-schoolers with ASD were correctly detected by the teachers in 94% of cases (73% from cluster 3, 21% from cluster 4) and 100% of pre-schoolers with ASD + ADHD were identified although only 67% of them were in the CP-4 (ASD + ADHD). Pre-schoolers with ADHD were correctly detected in 86% of cases in two clusters, which included ADHD symptoms (27% from cluster 2, 59% from cluster 4). Of the school aged children, 91% were identified as having ASD + ADHD, either sub-ASD + ADHD (CS-3; 9%) or ASD + ADHD (CS-4; 82%). School-aged children with ASD were correctly identified in 81% of cases (24% from CS-3, 57% from CS-4) and those with ADHD were correctly identified in 79% of cases (33% from CS-2, 31% from CS-3 and 15% from CS-4). However, 9%, 22%, and 9% of school-aged children with ASD, ADHD, and ASD + ADHD were judged to be at no risk.

DISCUSSION

The results of the study indicate that teachers can provide valuable reports on the risk of NDDs and can detect different profiles even at the sub-clinical level. As expected, we detected four behavioral patterns with different severities of ASD and/or ADHD symptoms. The fact that teachers can relate these profiles with diagnoses and clinical and cognitive characteristics shows that they can be good informants of the risk of ASD and/or ADHD. Their reports on, for example, children's behavior in the classroom, their social interaction with their peers and how they perform in terms of the age group, can help identify symptoms of disorders that may not be observable by parents.

Four similar patterns of symptoms were found in both preschool and school-aged groups. A vast majority of the children did not display any symptoms of either ASD or ADHD, which suggests that they are no risk of developing the respective disorders (CP-1/CS-1). We also found clusters of children presenting symptoms of either ASD or ADHD symptoms. The administration of both Conners and EDUTEA questionnaires made it possible to differentiate children with the co-occurrence symptoms of both disorders, which formed specific clusters in both age groups. It should be pointed out that teachers of school-aged children identified different severities of ASD symptoms always along with ADHD symptoms. The ASD and ADHD co-occurrent symptom clusters were strongly associated with comorbid diagnosis in both age groups. From a behavioral perspective, the overlap

TABLE 3 Mean scores of the psychopathological and cognitive measures for preschool children by cluster in the phase-2 assessment.

	CP-1		CP-2		CP-3		CP-4		
	No ASD/ADHD		Sub-ADHD		Sub-ASD		ASD + ADHD		
PRE-SCHOOL	M	(SD)	M	(SD)	M	(SD)	M	(SD)	*p**
ADI-R	***(n = 89)***		***(n = 91)***		***(n = 51)***	***(n = 64)***			
Social interaction	2.09	(2.63)	2.49	(2.79)	4.73	(5.30)	6.95	(6.52)	<0.001
Social communication	1.60	(2.14)	2.02	(2.33)	3.33	(3.81)	5.28	(4.37)	<0.001
Repetitive behavior	0.79	(0.85)	0.90	(1.07)	1.41	(1.68)	2.55	(2.31)	<0.001
ADOS-2 Severity	***(n = 89)***		***(n = 90)***		***(n = 51)***	***(n = 64)***			
Social communication	1.91	(1.37)	1.65	(1.16)	2.98	(2.21)	3.25	(2.21)	<0.001
Repetitive behavior	1.48	(1.39)	1.60	(1.28)	2.41	(2.24)	3.84	(2.69)	<0.001
Total	2.00	(2.57)	1.58	(2.29)	4.57	(4.58)	6.03	(5.84)	<0.001
K-SADS-PL	***(n = 89)***		***(n = 91)***		***(n = 51)***	***(n = 64)***			
Inattention	11.05	(2.84)	14.21	(4.55)	11.56	(3.55)	15.14	(4.94)	<0.001
Hyperactivity	12.23	(4.53)	16.70	(5.87)	12.66	(4.61)	16.03	(5.67)	<0.001
Total	26.03	(7.32)	34.32	(10.24)	27.39	(7.69)	34.69	(10.56)	<0.001
CBCL1½-5	***(n = 85)***		***(n = 89)***		***(n = 49)***	***(n = 63)***			
Internalizing	53.24	(11.87)	60.81	(10.83)	61.24	(11.80)	64.29	(10.12)	<0.001
Externalizing	51.64	(11.95)	62.63	(10.57)	57.16	(10.38)	63.48	(10.68)	<0.001
Total	53.42	(12.60)	62.72	(11.40)	61.06	(12.12)	65.43	(10.96)	<0.001
WPPSI-IV	***(n = 89)***		***(n = 91)***		***(n = 51)***	***(n = 55)***			
Working memory	104.89	(12.52)	98.67	(13.40)	92.51	(13.92)	90.11	(14.97)	<0.001
Speed processing	102.55	(10.52)	96.01	(12.32)	86.92	(14.49)	87.16	(14.54)	<0.001
Verbal comprehension	105.46	(11.81)	97.16	(13.91)	83.49	(15.69)	82.67	(19.54)	<0.001
Perceptual reasoning	111.03	(11.65)	102.60	(13.97)	94.94	(17.11)	95.56	(17.53)	<0.001
Vocabulary acquisition	102.47	(14.56)	96.43	(14.23)	83.83	(17.12)	85.00	(17.65)	<0.001
Full IQ	107.80	(10.87)	97.98	(12.48)	85.72	(14.97)	86.71	(17.18)	<0.001

*Post-hoc group differences can be found in Supplementary Table 1.

of ADHD and ASD symptoms, as perceived by the teachers provides further support for the comorbidity patterns found in previous studies, which suggests that these conditions cannot be differentiated as separate categories (Rau et al., 2020; Zablotsky et al., 2020). One likely reason for the co-existence can be attributed to an overlapping between the symptoms of the two disorders and genetic or non-genetic biological factors may also play a role (Craig et al., 2015; Naaijen et al., 2017). Inattention and hyperactivity-impulsivity are not only shared symptoms between ASD and ADHD, but a structural neuroimaging study conducted by Baribeau et al. (2019) also highlights similarities in social deficits suggesting a biological analogy between the two disorders. The high prevalence of ASD and ADHD found in our study, mainly in older children, may also be attributable to the comorbidity model according to which chances of developing another disorder with similar symptoms become higher- For example, it has been often observed that a few years after being diagnosed with ADHD, children are also diagnosed with ASD (Wei et al., 2021). As suggested by Kentrou et al. (2019) in the presence of comorbidity the severity of ASD was higher than in other groups and the severity of ADHD was higher but not significantly so. Also, these children exhibited more externalizing problems in the preschool age and internalizing in the school group. This is in line with the previous research, which suggests that children with ASD and ADHD have higher rates of emotional and behavioral symptoms (Morales-Hidalgo et al., 2023).

In the preschool age, the teachers were good at identifying children who were diagnosed with ASD or/and ADHD, and false negatives were almost non-existent. Teachers provided a valuable insight into the detection of dysregulated behavior and autistic symptoms in children since they have a great opportunity to observe children's social interaction differentiating the behavior from their peers (Deckers et al., 2020; Martel et al., 2015). In the school-aged group, some children without symptoms of either ASD or ADHD (CS-1) were identified but were diagnosed in the second phase to have one or both conditions. This observation highlights the challenge of diagnosing children with overlapping symptoms of ASD and/or ADHD, which can make the screening process difficult and misdiagnosis or under-diagnosis can occur (Kentrou et al., 2019). It is well-known that NDDs start

TABLE 4 Mean scores of the psychopathological and cognitive measures for school children by cluster in the phase-2 assessment.

	CS-1		CS-2		CS-3		CS-4		
	No ASD/ADHD		Sub-ADHD		Sub-ASD + ADHD		ASD + ADHD		
SCHOOL	M	(SD)	M	(SD)	M	(SD)	M	(SD)	p*
ADI-R	*(n = 207)*		*(n = 107)*		*(n = 112)*		*(n = 56)*		
Social interaction	2.60	(3.28)	1.94	(2.31)	3.28	(3.33)	6.77	(7.03)	<0.001
Social communication	2.10	(2.55)	2.21	(2.47)	2.60	(2.64)	5.95	(5.38)	<0.001
Repetitive behavior	0.80	(1.25)	0.74	(1.08)	0.91	(1.11)	1.80	(2.33)	<0.001
ADOS-2 Severity	*(n = 206)*		*(n = 108)*		*(n = 113)*		*(n = 56)*		
Social communication	1.80	(1.27)	1.70	(1.26)	2.22	(1.64)	4.14	(2.54)	<0.001
Repetitive behavior	1.20	(0.89)	1.13	(0.75)	1.37	(1.21)	3.55	(2.89)	<0.001
Total	1.54	(2.05)	1.31	(1.98)	2.27	(2.58)	6.34	(4.92)	<0.001
K-SADS-PL	*(n = 207)*		*(n = 107)*		*(n = 112)*		*(n = 56)*		
Inattention	13.06	(5.04)	17.96	(5.49)	17.86	(5.68)	18.58	(5.96)	<0.001
Hyperactivity	11.57	(15.77)	15.77	(5.28)	14.75	(5.30)	16.17	(6.26)	<0.001
Total	27.52	(8.48)	37.38	(36.16)	36.16	(10.07)	38.42	(11.43)	<0.001
CBCL6-18	*(n = 202)*		*(n = 100)*		*(n = 110)*		*(n = 53)*		
Internalizing	56.07	(10.16)	54.79	(10.27)	58.65	(9.90)	60.21	(9.77)	<0.001
Externalizing	50.17	(10.15)	56.14	(9.98)	55.51	(9.96)	58.36	(12.30)	<0.001
Total	53.20	(10.15)	57.01	(10.55)	58.75	(9.51)	62.04	(10.35)	<0.001
WISC-IV	*(n = 207)*		*(n = 108)*		*(n = 113)*		*(n = 53)*		
Working memory	99.87	(14.58)	93.91	(13.93)	90.51	(13.75)	87.08	(16.13)	<0.001
Speed processing	104.31	(12.29)	101.16	(12.46)	98.48	(14.06)	90.92	(14.41)	<0.001
Verbal comprehension	106.45	(12.74)	103.59	(11.74)	97.57	(14.77)	94.92	(16.70)	<0.001
Perceptual reasoning	108.78	(14.43)	104.37	(13.58)	98.19	(16.23)	96.23	(18.18)	<0.001
Full IQ	106.11	(13.61)	100.53	(13.32)	94.29	(15.08)	90.48	(16.08)	<0.001

*Post-hoc group differences can be found in Supplementary Table 1.

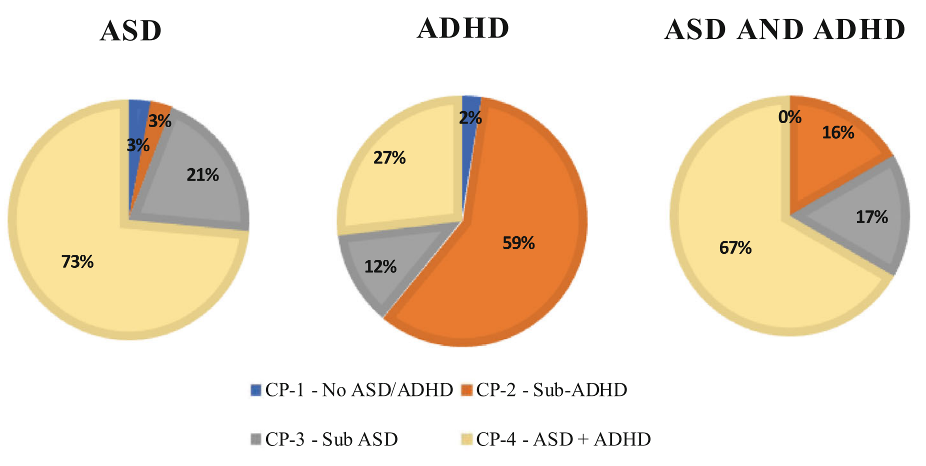

FIGURE 2 Distribution of pre-school aged children across different diagnostic categories based on the cluster allocation in phase-2.

to develop from an early age (Finlay-Jones et al., 2019), so teachers working with preschool-aged children and spending a great time with them are more aware of their evolutions and recognize NDDs symptoms more often than teachers working with school-aged children. As a result, teachers of school-aged children's teachers might not consider NDD symptoms if children have not previously been diagnosed. However, it is worth noting that although some school-age children identified in CS-4 did not meet the diagnostic criteria, teachers were able to recognize withdrawal or behavioral problems and needed to provide them with further assistance. This highlights the importance of teacher observation and their ability to identify potential well-being and behavior issues, which would allow some children to be diagnosed early and others to receive psycho-pedagogical support.

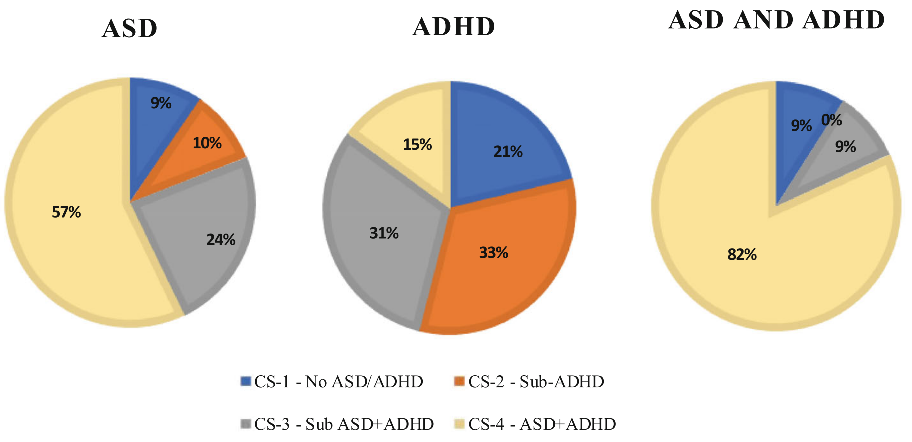

FIGURE 3 Distribution of school aged children across different diagnostic categories based on the cluster allocation in phase-2.

We also observed that some children presented subthreshold symptoms of ADHD and/or ASD in both preschool and school-aged children. Although they did not present clear symptoms of either disorder, they did show some idiosyncratic characteristics of ASD and ADHD. Children presenting subthreshold symptoms are often not considered for diagnosis since they do not fall under the defined criteria for either ASD and/or ADHD. However, the concept of "subclinical variant" was introduced over two decades ago (Scahill et al., 1999). Shah et al. (2022) suggested that ASD and ADHD symptoms can be either extreme while in others the specific traits are not sufficiently "outside the normal variation" for treatment and they often remain undiagnosed. In our study, teachers were able to observe children with varying levels of neurodiversity, which can have consequences on their social, academic, and behavioral functioning. It has long been suggested that identifying subthreshold patterns of ADHD and ASD can prevent further functional decline (Kóbor et al., 2012) and the development of other psychiatric disorders (Lundström et al., 2011; Ruzich et al., 2015).

Some of the children of school age showed symptoms of ADHD and comorbid autistic symptoms. A relevantly substantial number of children with symptoms of ADHD have also been found to present symptoms of ASD, which suggests that the two disorders overlap even though one is more obvious than the other (Hollingdale et al., 2020; Reale et al., 2017). Furthermore, a significant delay between 12 and 20 months has been observed in the diagnosis of ASD with co-occurring ADHD in children over 6 years old, in whom the latter typically being identified first (Sainsbury et al., 2022). Accurate diagnosis is crucial since children with ADHD and sub-ASD are often at greater risk of developing mental health issues over time and decreased psychological development and cognitive functioning, leading to significant challenges in their education and social life (Gargaro et al., 2014).

As far as any association between sociodemographic and psychopathological variables, the data revealed that both ASD or ADHD symptoms are detected more in boys than girls. Moreover, these symptoms are more obvious in school-aged children of low socioeconomic level and non-Hispanics. This is in line with other studies that found that males are more likely to develop ASD and ADHD than females because of complex genetic and environmental factors (May et al., 2019). Our data also show that young children, particularly those with sub-ASD, frequently exhibit dysfunctional behavior, which is more observable in non-Hispanic children. One possible reason for dysfunctional manifestations in children from different ethnic backgrounds is that they might be significantly impacted by their communication skills.

We also observed groups of children displaying NDD symptoms and identified overlaps between some of these disorders. Identifying these patterns is crucial if assessment is to be improved and early intervention in clinical and educational settings is to be made possible. It is worth noting that exhibiting symptoms of ADHD and ASD, they will not necessarily be diagnosed with these disorders. Symptoms may also be an indicator of neurodiversity or predictors of other disorders, requiring further assessment. As teachers are at the forefront of identifying changes in behavior of children, they play an important role in detecting different profiles of NDDs and prove to be reliable informants of the dimensionality of the disorders even at sub-clinical levels.

LIMITATIONS AND RECOMMENDATIONS

The current study is one of the few to have used cluster analysis to identify the groups of children with symptoms of NDDs in a representative school sample. This method can help to identify groups of children with similar characteristics, heterogeneity within a population and subgroups that may have different needs. However, it is also an unsupervised learning method, the results of which need to be used with caution for data based on behavioral characteristics. Another methodological limitation is that the observations made by teachers within the same group (classroom) could be correlated. This could potentially violate the assumption of independence of observations in statistical analyses of clustering. Even though our data included the assessment by multiple teachers and schools, this could have an impact on the results. Despite the limitations of cluster analysis, positive aspects outweigh negative ones and it can significantly improve the clinical screening of children with ASD and/or ADHD. The method allowed us to identify subgroups within different age groups. Furthermore, the objective of the current article focuses on the role of teachers in detecting NDD symptoms. However, for a robust accuracy it would be interesting to consider data from both parents and teachers because, although teachers observe the behavior of children in the class, parents have more information about their behavior at home. This will provide a more comprehensive understanding of the symptoms experienced by children which will ultimately permit clinicians to assess and diagnose children from an early age and provide them with more appropriate treatment.

The present study has given valuable insight into the existence of subgroups from two different age groups of children: 4–5 years and 10–11 years and the severity of ASD and/or ADHD symptoms in different developmental stages. It has shown the importance of adjusting the screening and diagnostic procedure to the age of children. It would be interesting for future research to focus on the sex differences in the various age groups.

CONCLUSION

Using the clustering approach and information provided by teachers in a large sample of schoolchildren, we successfully identified four behavioral patterns related to the neurodiversity population of children. One of these patterns consisted of children with symptoms of both ASD + ADHD while another consisted of children without any underlying pathology. The other two clusters were characterized by subthreshold ASD and/or ADHD symptoms. Some age differences were also identified in our analysis. In the school-age children, the presence of ADHD was consistently observed with ASD patterns. In the preschool age, teachers were more proficient at identifying children who received diagnosis for either ASD and/or ADHD. Considering the significance of early detection and intervention in NDDs, the information provided by the teachers holds great importance. For some children, identifying these patterns will contribute to an accurate diagnosis without delay. For others, identifying subclinical symptoms will make it possible to design tailored support, better address their individual needs and continuously monitor neurodevelopmental progress.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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