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Mechanism-based groups of children with ADHD are associated with distinct domains of impairment

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Abstract

Person-oriented analyses are commonly used to identify subgroups of children with mental health conditions in the hopes that they will meaningfully inform the taxonomy, assessment, and treatment of psychological disorder. However, whether these data-driven groups are demonstrably better at predicting important aspects of adaptive functioning than standard DSM taxonomy has not been established. Using Attention-Deficit-Hyperactivity-Disorder (ADHD) as a model condition, we utilized dimensions of personality and cognitive ability to identify person-centered profiles of school-aged children (N=246) and evaluated the association of these profiles with critical areas of adaptive functioning. A single profile ("Conscientious") represented non-ADHD controls and was characterized by faster drift rate and higher executive functioning scores. Three profiles ("Disagreeable," "Negative Emotionality," and "Extraverted") were identified for children with ADHD. Drift rate, but not executive functioning, distinguished among ADHD profiles, which were also distinctly associated with comorbid externalizing and internalizing psychopathology, social skills, and academic achievement. In contrast, the Diagnostic and Statistical Manual (DSM) presentations were not informative and showed similar patterns of impairment across domains. Person-centered profiles of children with ADHD are associated with distinct adaptive functioning deficits and may be useful in informing clinical practice.

Keywords

ADHD; Latent Profile Analysis; Impairment; Nosology; Assessment

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none

1. Introduction

The diagnostic and statistical manual for the classification of mental disorders (DSM; American Psychiatric Association, 2013) has dominated the classification of psychopathology for nearly four decades. DSM's success is largely due to the use of observable behaviors to improve diagnostic reliability. However, the validity of DSM's classification system has been criticized due to widespread comorbidity between disorders, heterogeneity within disorders, and the failure to identify unique mechanisms (Wiecki et al., 2015). Person-oriented analyses have become popular as a way to identify subgroups within a population to increase homogeneity within groups. If replicable and predictive subgroups based on a given set of vulnerabilities are found, then they can in turn be used to isolate genetic or other markers that contribute to the disorder, develop new taxonomies based on mechanism, and improve treatment specificity (Kapur et al., 2012).

Attention-Deficit-Hyperactivity-Disorder (ADHD) is one prominent example of problematic heterogeneity with a single DSM category. Although the content and number of profiles have been somewhat variable, studies using temperament and the Big-5 dimensions of personality framework (Caspi et al., 2005) have identified a small number of person-centered profiles, consistent with theoretical accounts hypothesizing ADHD can result from multiple temperamental pathways (Rabinovitz et al., 2016). Those studies suggest that children with ADHD are likely to be associated with membership in groups exhibiting: 1) low conscientiousness (often accompanied by low agreeableness and average or lower neuroticism); 2) high neuroticism, accompanied by average or lower extraversion and conscientiousness, 3) and high extraversion, accompanied by low neuroticism and average or lower conscientiousness (Karalunas, Fair, et al., 2014; Martel, 2016; Martel et al., 2010; Smith & Martel, 2019). Notably, group differences in extraversion have not been consistently identified in variable-centered analyses (Gomez & Corr, 2014), highlighting the person-centered approach's ability to identify patterns that do not emerge in variable-centered analyses.

The understanding that children with ADHD vary considerably along temperamental and personality dimensions exists alongside a similar recognition of the substantial cognitive heterogeneity in the disorder (Nigg et al., 2005). Person-centered studies of ADHD conducted to reduce cognitive heterogeneity have identified several distinct cognitive profiles. As with person-centered studies using personality variables, the content and number of cognitive profiles have varied across studies, reflecting variations in tasks and the type of person-centered analytic approach adopted. Nonetheless, multiple studies have found some convergence, with groups characterized by: 1) poor executive function (EF) (Karalunas et al., 2017; Mostert et al., 2018; Van Hulst et al., 2015); 2) arousal or vigilance deficits (Fair et al., 2012; Rommelse et al., 2016); and 3) high response time variability (Fair et al., 2012; Van Hulst et al., 2015).

These findings are consistent with multiple lines of research identifying cognitive deficits associated with ADHD. First, EF deficits have long been central to etiologic theories and mechanism of the disorder (Barkley, 1997; Castellanos & Tannock, 2002; Oosterlaan & van der Meere, 1999; Swanson et al., 1998) with a large body of empirical work finding that a sizable portion of children with ADHD exhibit broad EF deficits (Alderson et al., 2013; Bonham et al., 2021; Nigg, 2017; Patros et al., 2016; Pauli-Pott & Becker, 2011). More recently, there has been a shift towards using computational psychiatry approaches to better pinpoint the causal cognitive mechanisms contributing to development of psychopathology (Huys et al., 2016). Diffusion modeling, a mathematical model of cognition, has featured prominently in these new endeavors because it provides a more plausible model of cognition than traditional theories of EF which rely upon the invocation of a homunculus (Verbruggen et al., 2014; Wiecki et al., 2015). Applied to ADHD, the most consistent and substantive finding is the presence of ADHD-related slow drift rate (Karalunas, Geurts, et al., 2014; Ziegler et al., 2016), which refers to the rate of information accumulation during forced choice decision making, and is also related to the high response time variability often observed in speeded performance in ADHD. Slow drift rate accounts for a significant proportion of unique variance in both inhibitory control and working memory capacity (Karalunas & Huang-Pollock, 2013; Weigard & Huang-Pollock, 2017), has been successfully used to explain ADHD-related deficits on a variety of EF and non-EF tasks (Feldman & Huang-Pollock, 2021a; Huang-Pollock et al., 2012; Shapiro & Huang-Pollock, 2019), and predicts unique variance in ADHD symptomology over and above EF (Feldman & Huang-Pollock, 2021b).

Importantly, however, studies have demonstrated that cognitive skills and trait-like behavioral profiles have bidirectional effects on each other (Papachristou & Flouri, 2020). Therefore, identifying profiles based on *both* cognitive *and* personality domains might identify the most nuanced subgroups. That being said, even if such groupings were more scientifically accurate, they might not be more clinically useful. The movement to reform existing psychiatric categories using data-driven person-centered strategies would be considerably strengthened if it could be demonstrated that mechanism-based groups were more informative of impairment (e.g., social skills, academic achievement, and/or co-occurring psychiatric syndromes) compared to groups derived from DSM presentations. Conversely, if they are not, then the argument to move towards such groupings would be weakened. In fact, such groupings would be even less useful than DSM ADHD presentations. The current ADHD presentations do not predict unique problems in specific domains of adaptive functioning (Lee et al., 2008; Owens et al., 2009), but they are at least simple to implement and more intuitive to clinicians, parents, and teachers, even if the reduction in heterogeneity is only symptomatic.

The current study utilizes a data-driven approach to identify variations in temperament and cognition that may be more useful for capturing important variations in children with ADHD that could be used to improve current ADHD taxonomy and treatment. It is anticipated that adaptive functioning will be better predicted by these data-driven groups than by standard DSM ADHD presentations. That is, membership in one (or more groups) would be expected to show greater specificity in identifying domains of maladaptive functioning than when groups are compared using traditional DSM ADHD presentations.

2. Methods

2.1. Participants

To avoid biasing the sample towards greater symptom severity (Goodman et al., 1997), children ages 8-12 (*N*=246; 41.5% girls) were community-recruited from local schools, newspaper/social media ads, and distributed flyers in the Centre, York, and Dauphin counties in Pennsylvania. The demographic makeup was 72.8% Caucasian/non-Hispanic, 9.3% African American/non-Hispanic, 4.9% Caucasian/Hispanic, 1.2% African American/Hispanic, .8%, Asian, 8.1% Mixed, and 2.0% other or unknown.

To be included, either: (a) both parent and teacher report of behavior on the Attention, Hyperactivity, or ADHD subscales of the Behavioral Assessment Scale for Children (BASC-2: Reynolds & Kamphaus, 2004) or the Conners' Rating Scales (Conners, 2008) had a t-score>60, or, (b) both parent and teacher report on the same indices had t-score≤58). Children were excluded if they were currently treated with non-stimulant medication, had a pervasive developmental disorder, autism spectrum disorder, intellectual or sensorimotor disability, psychosis, parent-reported neurological disorder, and/or Full-Scale-IQ (IQ)<80. Children prescribed psychostimulant medications ceased taking their medication 24-48 hours in advance.

For the purpose of variable-centered analyses, a diagnosis of ADHD (*N*=167) was determined using the DSM criteria for ADHD including age of onset, duration, symptom count, cross situational severity, and impairment reported by a parent or guardian on the Diagnostic Interview Schedule for Children (DISC-IV: Shaffer et al., 2000). At least one parent *and* one teacher report of behavior on the above listed rating scales also had a t-score≥60.

Non-ADHD controls (*N*=67) had never been diagnosed/treated for ADHD, did not meet criteria for ADHD on the DISC-IV, and had t-scores≤58 on the same rating scales. Among non-ADHD controls, a bias towards high average or gifted intellectual functioning based on national norms was observed. To protect against volunteer bias, controls were required to have IQs<115. An upper IQ limit was not required for children with ADHD.

Only children with DSM-5 ADHD or non-ADHD controls (*n*=234) were included in the variable-centered DSM-based analyses. However, a small number of participants (*n*=12) did not meet criteria for ADHD but had higher symptomology than acceptable to be included as a non-ADHD control. To maximize power, these children were included in person-centered analyses which are independent of ADHD status (*n*=246). Primary results did not change when they were removed from analyses.

2.2. Procedure

Children completed measures of cognition and academic achievement over the course of two visits as part of a larger study examining neurocognitive processes in childhood ADHD. Parents completed a diagnostic interview and rating forms.

2.3. Measures

2.3.1. Group indicators

2.3.1.1. Child personality traits: Parents were asked to sort 100 cards of the common language version of the California Child Q-sort (CCQ: Caspi et al., 1992). Analyses were conducted using mean scores on scales of the "Big Five" personality traits (i.e., Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism). The validity and reliability of the CCQ-based FFM scales are adequate (John et al., 1994; Robins et al., 1994), 1-year test-retest reliabilities have been found to range from .67 for Openness to .85 for Conscientiousness, with an overall mean test-retest reliability of .72 (Abe & Izard, 1999).

2.3.1.2. Executive functioning

Verbal Working Memory (Reading Span Task).: Children read simple sentences aloud and made true/false decisions with a right/left mouse click. A to-be-remembered letter appeared after each response. The number of sentence/letter pairs increased from two to seven; after all pairs were presented, children recalled the letters in the order they were presented. Three items were presented per set size; the task was discontinued when children failed all items of a set size. Children were given a point for each letter recalled in the correct position within a trial. Children demonstrate good 1-year test-retest reliability (r = .71) on this measure (Hitch et al., 2001)

Inhibitory control (Stop Signal Reaction Time Task).: A fixation point appeared at the center of the screen (500ms) followed by an "X" or an "O" target (3000ms). On 75% of trials, children indicated the identity of the target with a key press. On 25% of trials, an auditory stop tone was given. The stop signal delay decreased following unsuccessful inhibits and increased following successful inhibits. Subtracting the mean delay from the mean go reaction time formed the Stop-Signal Reaction Time (SSRT). Studies have found that children with ADHD demonstrate adequate to good (*pr=.33; ICC=0.72)* test-retest reliability (Kindlon et al., 1995; Soreni et al., 2009)

Set shifting (Navon Task).: Children viewed small geometric shapes (circle, triangle, square, or cross) grouped to form a larger, different geometrical shape. Children pressed one of four buttons corresponding to the smaller shape when the background was yellow. When the background was blue, they indicated the identity of the larger shape. In switch trials, children identified a different type of shape (i.e. small or large) than the previous trial (72 switch, 144 no switch trials). Response times from the switch trials were regressed on the No-Switch trials, and unstandardized residual scores were used as a measure of set-shifting, which has been found to have good 3-week reliability (ICC = .74; Hedge et al., 2018).

A latent Executive Functioning factor was subsequently created for analyses using Mplus 8.3, with higher factor scores representing better EF. A maximum likelihood estimator with robust standard errors was used (Brown, 2015). Variables were allowed to load on a single factor and a factor score was obtained for each participant.

2.3.1.3. Drift rate: Drift rate was obtained from responses on a mental rotation task (Feldman & Huang-Pollock, 2021a). Children were shown one comparison and one target stimulus. The target stimulus appeared on the right of the comparison and was rotated 0°-315°. Children made a keypress to indicate whether the comparison was the same or different as the target. Stimuli remained on the screen until a response was made, at which point visual feedback (i.e., "Right!" or "Wrong!") appeared for 1000ms. Half the targets were congruent; the other half were a mirror image/incongruent. Unusually fast (<200ms) and slow trials (>7000ms) were excluded. When evaluating a similar version of the task, test-retest reliability was found to be fair (ICC = .51) when evaluating response accuracy but not response times. The *fast-dm* version 30.0 program (Voss et al., 2015) was used to estimate drift rate. Although the diffusion model also produces two other primary parameters (boundary separation and non-decision time), the centrality of these parameters to both EF and ADHD is not as robust (Karalunas et al., 2014; Schmiedek et al., 2007).

2.3.2. Adaptive areas of functioning

2.3.2.1. Intellectual Ability and Academic Achievement: A two-subtest short form (Vocabulary, Matrix Reasoning) of the Wechsler Intelligence Scale for Children-IV (WISC-IV: Wechsler, 2003) provided an estimated IQ for participants. The Word Reading, Spelling, and Numerical Operations subtests of the Wechsler Individual Achievement Test (WIAT-III: Wechsler, 2009) provided estimates of academic achievement.

2.3.2.2. Psychopathology and Social Functioning: Internalizing, Externalizing, and Social Skills composite scores from parent and teacher report of behavior and socioemotional functioning on the BASC-2 provided indices of psychopathology and social functioning.

2.3.2.3. ADHD Symptomology: Following DSM field trials (Lahey et al., 1994), the "or" algorithm was used to integrate parent and teacher report of ADHD symptomology. A symptom was counted as present if either the parent on the DISC-IV (Shaffer et al., 2000) or the teacher on the ADHD-Rating Scale (ADHD-RS: DuPaul et al., 1998) indicated that a symptom was present "often" or "very often."

2.3.3. Data analysis—First, a latent profile analysis (LPA) was conducted. Mean score for each personality scale, the EF factor score, and drift rate as continuous indicators were used to identify profiles. Missing data values (Table S6) were directly accounted for using a maximum likelihood estimator.

Model selection was conducted using the Akaike information criterion (AIC; Akaike, 1974), Bayesian information criterion (BIC; Schwarz, 1978), sample-size adjusted BIC (a-BIC; Sclove, 1987), entropy (Celeux & Soromenho, 1996), and a bootstrapped likelihood ratio test (BLRT; McFachlan, 1987). Lower AIC, BIC, and a-BIC values reflect better model fit; higher entropy suggests improved classification; significant BLRT values indicate model fit is improved relative to a model with one fewer profile. Model selection emphasized the theoretical interpretation of possible solutions. Class-specific means were free to vary across all indicators and class-specific variances were constrained to be equal for all models. Model identification was checked with 10000 initial and 1000 final stage starts. Models were estimated using Mplus version 8.3. Profile membership was then used to predict adaptive functioning using the Bolck-Croon-Hagenaars (BCH) approach (Bakk & Vermunt, 2016). This approach provides an overall test indicating whether significant differences exist among all latent profiles, and pairwise tests to identify whether differences exist between any two profiles.

3. Results

3.1. Variable Centered Analyses

Table 1 provides group analyses by presentation type. Children with ADHD had more difficulty than non-ADHD controls on multiple indices of psychosocial functioning. Math achievement did not differ between presentations but was lower among children with ADHD-I than non-ADHD controls. Any presentation-based differences were consistent with a severity model of ADHD (i.e. ADHD-C with the greatest number of symptoms were worse than ADHD-I). Supplemental Table S1 provides first-order correlations among primary variables.

3.2. Latent Profile Analysis

Table 2 provides model fit information. Models with 1-9 profiles were evaluated. The BIC minimized for the 4-profile model; the AIC and a-BIC did not minimize but eventually plateaued at the 6-profile model. Entropy ranged from .75-.85, with values generally increasing for models with a greater number of profiles. Given three to five classes, entropy in these ranges are associated with classification accuracies greater than 90% (Wang et al., 2017). The BLRT remained significant across all models. Models with four, five, and six profiles were therefore considered. Identified groups in the 4-profile solution were adequately sized and theoretically meaningful. The 5 and 6-profile solutions were redundant with the existing 4-profile groups and the number of children in the 5th and 6th profile solutions was also very small (n=19 in the 5th profile, n=15 in the 6th; Supplemental Tables S2a and S2b). Consequently, the 4-profile model was selected for additional analyses.[1]

Table 3 provides parameter estimates for the 4-profile model. Profile 1 (28% prevalence, “Conscientious”) was characterized by better than average (relative to the sample mean) EF, faster than average drift rate, high conscientiousness/agreeableness, and low extraversion/neuroticism/openness. Interestingly, whereas faster drift rate distinguished between the three more “impaired” profiles (i.e. profiles 2 and 3 were slower than the mean drift rate while profile 4 was faster), EF did not. Profile 2 (10% prevalence, “Disagreeable”) was characterized by average EF, slow drift rate, high neuroticism/agreeableness, and low conscientiousness, extraversion and openness. Similarly, Profile 3 (24% prevalence, “Negative Emotionality”) was characterized by average EF, slow drift rate, high neuroticism/agreeableness, and low extraversion/conscientiousness/openness. Profile

[1]Excluding the 12 children with subclinical ADHD produced a similar 4-Group solution and similar patterns of impairment across groups. See Tables S3–S5

4 (37% prevalence, “Extraverted”) was characterized by average EF, fast drift rate, high extraversion/agreeableness/openness, and low conscientiousness/neuroticism.

3.2.1. Profiles—

Profile membership was then used to predict adaptive functioning (Table 4). To control for Type I error, $\alpha \leq .001$ was used for significance tests. Relative to all others, the Conscientious group was better adjusted and had negligible ADHD symptomology and rates of ADHD diagnosis. In contrast, profiles 2-4 exceeded the symptom threshold for an ADHD diagnosis but did not conform well to DSM-5 ADHD presentations. Whereas an absence of important differences in adaptive functioning was noted across DSM presentations (Table 1), a more nuanced pattern of impairment emerged across LPA profiles. The Disagreeable group had high levels of externalizing and social problems, whereas the Negative Emotionality group had the highest internalizing psychopathology and poorest math skills. Notably, although the Extraverted group were reported to have greater problems than the Conscientious group, they did not exceed clinical cut-offs on measures of adaptive functioning.

Because EF represents both a unitary concept and discrete abilities, we conducted an additional analysis in which we replaced the EF factor score with the three manifest variables used to derive the EF score. We again found (Tables S7) support for a 4-group model using these manifest variables, which were highly similar in structure (Table S8) to those groups identified using the latent EF variable. We again found that a Conscientious group tended to perform better than other groups across measures of EF and the extraverted group tended to perform slightly above the mean. Again, as in our original 4-group model, the Disagreeable and Negative Emotionality groups both performed below the mean, with the Disagreeable group performing worst on measures of EF.

4. Discussion

Prior person-centered research has identified subgroups of children along temperament/personality or cognitive dimensions to reduce the well-known heterogeneity in childhood ADHD. However, these dimensions interact throughout development, so identifying profiles based on both cognitive and personality traits arguably provides the most accurate and nuanced groupings. If such novel groupings were also uniquely informative of impairment and treatment, then their clinical utility would also surpass that of the current DSM presentations.

Using standard DSM-5 taxonomies, children with ADHD had lower math achievement, greater externalizing and internalizing problems, and poorer social skills. However, only minor presentation-based differences were found between children with Inattentive and Combined presentations (i.e., children with ADHD-C had more externalizing problems than children with ADHD-I). The overwhelming evidence of the absence of any meaningful differences across ADHD presentations (Willcutt et al., 2012) is why in 2013, DSM altered the nomenclature from “subtype,” which suggested distinct *types*, to *presentation*, which better reflects the presence of a single disorder.

In contrast, the LPA identified four groups of children (Conscientious, Disagreeable, Negative Affect, and Extraverted), which were similar to those identified in previous studies (Karalunas, Fair, et al., 2014). Differences in measurement likely account for the minor discrepancies between prior and current work; Karalunas and colleagues employed a three-factor measure of temperament (broadly corresponding to extroversion, conscientiousness, and neuroticism) whereas the current work was based in the 5-Factor Model of personality. The profiles identified in the current manuscript correspond most consistently to studies which utilized similar personality measures as indicators (e.g. Martel, 2016).

The Conscientious group had the strongest cognitive functioning and temperamental traits commonly associated with positive socioemotional functioning. This profile showed no impairment and negligible ADHD symptom scores. The latter three groups were composed of children with elevated ADHD symptomology and were associated with unique patterns of impairment not evident using DSM-based nosology. The Extraverted group was the largest of the groups associated with elevated ADHD symptomology, but functioning remained within normal limits for national norms in all other domains. The presence of ADHD is a well-documented risk factor for a range of negative outcomes, but the heterogeneity of the disorder means that many still do function well in one or more domains. Protective factors include the presence of peer acceptance, positive parenting, and positive self-perceptions (Dvorsky & Langberg, 2016). In contrast, membership in the Disagreeable and Negative Emotionality groups was associated with elevated and unique patterns of impairment. Children in the Negative Emotionality group had the highest and clinically significant parent-rated internalizing problems, as well as relatively worse math skills. The latter is consistent with a large body of work documenting the negative influence of anxiety on mathematics (Pekrun et al., 2017), a relationship that is believed to be due to the compromising effects of anxiety on working memory (Ashcraft, 2002). Compared to the Negative Emotionality group, parent-rated externalizing and social problems were greatest in the Disagreeable group.

The association of profiles with specific impairment is notable for several reasons. First, the data-driven profiles were not consistent with DSM presentations, which were not uniquely predictive of impairment. Instead, person-centered ADHD-related groups differed on the presence/absence of co-occurring externalizing and internalizing psychopathology, (i.e., Extraverted= uncomplicated ADHD, Disagreeable= ADHD+Externalizing, and Negative Emotionality= ADHD+Internalizing). The conceptual overlap of temperament and psychopathology is well known (Hyatt et al., 2019). Proposals that ADHD presentations may be better defined by the presence/absence of co-occurring externalizing/internalizing psychopathology rather than the presence/absence of hyperactivity/impulsivity (Jensen et al., 1997) are consistent with our findings. Nonetheless, the indicators used in the current study were measures of cognition and temperament, not psychopathology. Future work using comorbid pathology as class indicators would be needed to formally test such a proposal.

The existence of the Extraverted profile, which was only associated with impairing inattentive and hyperactivity/impulsivity suggests that a sizeable proportion of children with ADHD would most benefit from treatment that focuses on symptom reduction alone. Indeed, in the absence of comorbidities, ADHD can be effectively and cost-efficiently treated using either low-intensity behavioral interventions (Pelham & Altszuler, 2020) or rigorously dosed and monitored medication management (Jensen et al., 2005). However, the combination of behavioral interventions and stimulant medication together has long been established as the best approach to address functional impairments associated with ADHD and comorbid conditions (Jensen et al., 2001). Consequently, treatment components for anxiety, depression, and academic underachievement should be considered for children in the Negative Emotionality group, whereas children in the Disagreeable group may benefit from the addition of treatment addressing conduct problems and social skills.

In general, personality traits were more salient and discriminating markers than cognitive ability. Notably, while drift rate distinguished between ADHD profiles (i.e. Extroverted vs. Disagreeable and Negative Emotionality), EF did not, suggesting drift rate is a more sensitive marker of profile belongingness than EF. However, it could also be that our choice to use a latent factor score to represent EF reduced its sensitivity. We chose to use a latent factor score following seminal work repeatedly finding a bifactor model to best represent the underlying structure of EF across development (Karr et al., 2018; McKenna et al., 2017). However, studies that have identified cognitive subgroups have typically employed measures of specific abilities, so the choice to use a latent variable could have reduced EF's ability to identify more nuanced profiles.

4.1. Limitations

First, data was cross sectional, and results of any data-driven approach is of course restricted by the variables included in those analyses. Findings would be strengthened by demonstrating the utility of these profiles in predicting outcomes longitudinally, or by replication in another sample. Nonetheless, we are encouraged by other work which has found similar, temporally stable groupings to predict future outcomes. A related concern is that heterogeneity in personality and cognitive configurations is present in non-ADHD children as well as children with ADHD; the lack of such heterogeneity in our profiles of children with few ADHD symptoms likely reflects the common practice of excluding diagnostically ambiguous individuals (e.g. Karalunas & Nigg, 2020). Therefore, future studies would benefit from the inclusion of a broader sample of children, including a greater number of those with subthreshold ADHD, which is likely to include greater variability in cognitive abilities and personality traits. Fourth, it is possible that cognitive functioning within the profiles we identified would be more nuanced or that alternative profiles would have emerged had we used multiple latent factors to reflect the bifactor model of EF. Finally, we note that children with ADHD in our study performed in the average range on measures of intellectual ability. Studies have previously found that children with ADHD tend to perform slightly worse than their peers (d = 0.61, representing ~9-point difference; Frazier et al., 2004). It is possible that our results may not generalize to lower-performing children with ADHD. However, we feel this possibility is somewhat unlikely given that no low-IQ group emerged, and no differences in IQ were found among the groups we identified.

4.2. Conclusion

We utilized cognitive and personality variables to identify four groups within a sample of children with and without ADHD. Results suggest that children with few ADHD symptoms were primarily identified by a single profile, whereas children with many ADHD symptoms were identified by three profiles. Evaluating the relationship between these profiles and functional domains found unique associations of profiles with impairment in different domains. In contrast, group comparisons based on DSM nosology were uninformative. Adopting an alternative classification of ADHD based on profiles is not only more accurate representation of groups, but also useful to informing treatment.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Profiles of children with and without ADHD were identified using personality traits and cognitive ability
- Children with ADHD were best identified by three profiles whereas those without ADHD were identified by a single profile. Drift rate, but not EF, distinguished between ADHD profiles.
- ADHD profiles were associated with distinct patterns of adaptive functioning; in contrast, DSM presentations were not informative and demonstrated similar patterns of impairment across domains.
- Mechanism-based profiles are a useful taxonomy to inform treatment planning

Table 1.

Adaptive domains across controls and ADHD presentations

	Control	*ADHD-I*	*ADHD-C*	*F (dfw,dfb),p,η²*
n (234, 44% girls)	67, 40%	69, 39.1%	98, 41.8%	F(2,231)=0.04,0.96 ,<0.001
Full Scale IQ	103.81(7.91)	101.65(11.80)	105.36(14.24)	F(2,231)=1.93,0.15,0.02
WIAT-WR	105.27(10.12)	102.71(14.59)	102.84(14.13)	F(2,231)=0.84,0.43,0.01
WIAT-S	101.00(14.04)	98.93(13.21)	99.29(14.77)	F(2,229)=0.43,0.65,<0.001
WIAT-NO	105.43(15.00)[a]	98.30(12.10)[b]	101.02(16.17)	F(2,231)=4.06,0.02,0.03
TBASC-Ext	42.99(2.09)[c]	51.49(8.21)[b]	57.64(10.77)[a]	F(2,228)=61.04,<0.001,0.35
TBASC-Int	43.70(5.34)[b]	53.55(12.80)[a]	52.34(10.30)[a]	F(2,228)=20.05,<0.001,0.15
TBASC-SocSk	55.11(7.87)[a]	44.09(9.36)[b]	45.12(8.41)[b]	F(2,227)=35.15,<0.001,0.25
PBASC-Ext	42.97(4.85)[c]	55.90(10.42)[b]	63.70(11.33)[a]	F(2,230)=92.26,<0.001,0.44
PBASC-Int	44.40(8.66)[b]	56.51(12.99)[a]	54.92(15.17)[a]	F(2,231)=19.09,<0.001,0.13
PBASC-SocSk	53.66(10.36)[a]	43.26(9.97)[b]	43.36(8.38)[b]	F(2,231)=28.60,<0.001,0.19
#Attn Sxs	.43(.58)[b]	8.14(.97)[a]	7.74(1.90)[a]	F(2,231)=710.55,<0.001,0.86
#H/I Sxs	.22(.49)[c]	2.91(1.52)[b]	7.59(1.11)[a]	F(2,231)=908.80,<0.001,0.89

Note. Mean standard score or t-scores presented with standard deviation in parentheses.

WR=Word Reading, S=Spelling, NO=Numerical Operations, TBASC=Teacher BASC, PBASC=Parent BASC, Ext=Externalizing Problems, Int=Internalizing Problems, SocSk=Social Skills, Attn=Attention, H/I=Hyperactive/Impulsive, Sxs=Symptoms. Superscripts indicate significant differences with other groups (a>b>c). 12 subclinical children who did not meet criteria for the ADHD or control groups were not included in this analysis.

Table 2.

Fit statistics

Profiles	Free parameters	Log-Likelihood	AIC	BIC	a-BIC	Entropy	BLRT
1	14	−3340.796	6709.592	6758.667	6714.288	--	--
2	22	−3260.569	6565.138	6642.255	6572.516	0.751	0.0000
3	30	−3221.394	6502.789	6607.948	6512.850	0.743	0.0000
4	**38**	**−3194.118**	**6464.235**	**6597.438**	**6476.980**	**0.782**	0.0000
5	46	−3174.165	6440.331	6601.576	6455.758	0.808	0.0000
6	54	−3158.319	6424.637	6613.925	6442.747	0.823	0.0060
7	62	−3144.368	6412.735	6630.066	6433.528	0.838	0.0250
8	70	−3131.214	6402.429	6647.802	6425.905	0.839	0.0360
9	78	−3117.133	6390.266	6663.681	6416.425	0.853	0.0120

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Table 3.

Sample mean and parameter estimates for the 4-profile model

	Sample Mean	**Conscientious (n=70)**	**Disagreeable (n=25)**	**Negative Emotionality (n=60)**	**Extraverted (n=91)**	***Sig. Differences***	χ^2, *p*
Membership probability		.28	.10	.24	.37	--	--
Indicator							
Drift Rate	8.84	9.33[b]	7.56[a]	8.68[a]	8.95[b]	-	14.76, .002
Executive Function	0.00	2.34[b]	−2.62	−2.26	.44	C>N	19.86, <.001
Extraversion	5.70	5.29[a]	6.10[b]	5.37[a]	6.14[b]	E>N,C; D>C	822.01, <.001
Agreeableness	6.55	7.23[b]	4.43[a]	6.58[b]	6.62[b]	D<C,N,E; C>N,E	211.58, <.001
Conscientiousness	4.75	6.62[b]	3.16[a]	3.60[a]	4.50[a]	C>D,N,E; E>D,N	305.85, <.001
Neuroticism	4.31	3.42[a]	4.69[b]	5.95[b]	3.79[a]	N>C,D,E; D>C,E	60.14, <.001
Openness	5.88	5.75[a]	5.53[a]	5.38[a]	6.43[b]	E>C,D,N	38.43, <.001

[a]Significantly below sample mean

[b]Significantly above sample mean

Table 4.

Within profile means for demographic and functional domains

	Sample Mean (SE)	**Conscientious**	**Disagreeable**	**Negative Emotionality**	**Extraverted**	***Sig. Differences***	χ^2, ***p***
Sex	.41 (.31)	.51 (.06).	.31 (.11)	.47 (.08)	.34 (.06)	-	4.43,0.218
Full Scale IQ	104.00 (.78)	104.99 (1.22)	101.81 (2.87)	98.65 (1.87)	107.51 (1.69)	-	12.92,0.005
WIAT-WR	103.50 (.85)	106.20 (1.42)	102.36 (2.60)	100.20 (2.18)	103.90 (1.81)	-	6.28,0.099
WIAT-S	99.64 (.92)	102.97 (1.90)	96.81 (3.19)	95.45 (1.94)	100.69 (1.87)	-	9.28,0.026
WIAT-NO	101.55 (.94)	106.23 (2.01)	101.49 (2.50)	93.32 (1.60)	103.38 (1.99)	N<C,E	29.47,<.001
TBASC-Ext	51.39 (.65)	43.58 (.68)	60.09 (2.47)	52.02 (1.55)	54.88 (1.29)	C<D,N,E	107.87,<.001
TBASC-Int	50.04 (.69)	43.54 (.77)	56.67 (3.31)	53.75 (1.86)	50.93 (1.22)	C<D,N,E	59.31,<.001
TBASC-SSk	47.93 (.62)	55.28 (1.10)	40.80 (2.08)	43.29 (1.18)	47.22 (47.22)	C>D,N,E	77.74,<.001
PBASC-Ex	55.29 (.82)	43.26 (.74)	77.03 (2.75)	57.37 (1.59)	57.09 (1.36)	C<D,N,E; D>N,E	246.12,<.001
PBASC-Int	52.22 (.87)	44.29 (1.08)	57.04 (2.57)	65.93 (2.32)	47.82 (1.43)	N>C,E; C<D	89.61,<.001
PBASC-SSk	46.40 (.67)	53.77 (1.32)	35.07 (1.61)	42.73 (1.17)	46.35 (1.24)	C>D,N,E; D>N,E	91.93,<.001
# Attn Sxs	5.68 (.23)	.81 (.31)	8.38 (.20)	8.31 (.24)	7.00 (.36)	C<D,N,E	502.01,<.001
#H/I Sxs	4.04 (.21)	.63 (.26)	6.76 (.46)	4.19 (.45)	5.92 (.5.92)	C<D,N,E; D>N	220.69,<.001
ADHD	.71 (.03)	.05 (.05)	1.00 (.00)	.97 (.03)	.93 (.04)	C<D,N,E	376.58,<.001

Note. Sex was coded as a dichotomous variable with 0=boy, 1=girl. ADHD was coded as a dichotomous variable with 0=control, 1=ADHD, and for this comparison alone, ADHD status was marked as Missing for the 12 children with subthreshold ADHD. WR=Word Reading, S=Spelling, NO=Numerical Operations, TBASC=Teacher BASC, PBASC=Parent BASC, Ext=Externalizing Problems, Int=Internalizing Problems, SSk=Social Skills, Attn=Attention, H/I=Hyperactive/Impulsive, Sxs=Symptoms. C=Conscientious, D=Disagreeable, N=Negative Emotionality, E=Extraverted.