Mediterranean Journal of Clinical Psychology

MJCP

ISSN 2282-1619

Volume 11, n 1, 2023

Articles

Predictive Neurocognitive Model of Attention Deficit Hyperactivity Disorder Diagnosis

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Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental clinical entity associated with a reduction in brain maturation mainly at the frontotemporal level, generating neurocognitive deficits. This disorder usually presents in a comorbid form. Our research aimed to identify the neurocognitive characteristics of ADHD (combined, hyperactive/impulsive and inattentive) of pure presentation or with comorbidity with oppositional defiant disorder, specific learning disorder or autism spectrum disorder. We used a sample of N=712 school children with a diagnosis of ADHD, aged between 6 and 13 years, using non-probability sampling. We built predictive models to establish probabilistic rules with different types of variables (total IQ, working memory index, perceptual reasoning index, processing speed index, phonological/semantic fluency, attention, visuoverbal memory, verbal memory, working memory, visual memory, visual perception, constructional praxias), we used the automatic learning technique of Decision Trees (DTCM) in Rcran 4.2.1 software, which allowed us to establish a clinical hierarchy. The data for the analysis were obtained from the results of the psychometric tests provided to the sample (WISC-IV, Verbal Fluency, TMT, Visuoverbal Memory Scale, Verbal Memory Curve, Wechsler Memory Scale, Rey/Osterrieth Complex Figure). We conclude that children with pure ADHD present poor performance on tasks assessing the working memory index and perceptual reasoning that are not explained by deficits in IQ. Deficits in working memory are generalizable to all presentations and comorbidities of ADHD. One of the main advantages of DTCM over other predictive machine learning techniques is the possibility of differentiating the hierarchy of importance of the dependent variables, in this case, allowing the identification of the most important variables in four different populations of children diagnosed with ADHD.

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Keywords:
ADHD; Clinical Profiles; Decision trees; Neurocognition; Predictive modeling.

Received: 8 November 2022
Accepted: 12 April 2023
Published: 30 April 2023

Citation: Quintero-López, C., Gil-Vera, V.D., Landinez-Martínez, D.A., Vargas-Gaviria, J.P., Gómez-Muñoz, N. (2023). Predictive Neurocognitive Model of Attention Deficit Hyperactivity Disorder Diagnosis. *Mediterranean Journal of Clinical Psychology 11*(1). https://doi.org/10.13129/2282-1619/mjcp-3606

Abbreviations

American Psychological Association (APA); Attention Deficit Hyperactivity Disorder (ADHD); Specific Learning Disorder (SLD); Autism Spectrum Disorder (ASD); Decision Tree Classification Model (DTCM); DSM (Diagnostic and Statistical Manual of Mental Disorders); Female (F); Group (G); Male (M); Mean (M); Oppositional Defiant Disorder (ODD); Standard Deviation (SD); Intelligence Quotient (IQ); Trail Making Test (TMT); Wechsler Intelligence Scale (WISC-IV).

1. Introduction

ADHD is grouped within the nosological conditions of neurodevelopment, the symptoms of this clinical condition become evident and persistent from preschool age; it can generate patterns of attentional deficit and hyperactive and impulsive behaviors, which negatively impact the successive evolution of the areas of development and functioning in the academic, family and social environment (American Psychiatric Association [APA], 2021; Operto et al., 2021). At the attentional level the presence of this diagnosis can generate difficulties to focus on tasks that involve mental effort for a prolonged time, in activities that are considered unrewarding could appear inconvenient to follow instructions and execute them (Nejati, 2020; Patros et al., 2017).

The clinical manifestations of ADHD associated with hyperactivity are evident in some cases by the exacerbation of movements in situations where it is not appropriate; symptoms of impulsivity could generate anticipation of responses and the appearance of maladaptive behaviors to obtain rewards; commonly, this diagnosis is related to a low tolerance to frustration and poor regulation at the emotional level (Berger et al., 2021; Ownes et al., 2021). There are three subtypes of this clinical condition: inattentive type (predominance of symptomatology associated with attentional failures), hyperactive/impulsive type (predominance of motor restlessness, deficits in behavioral regulation and inhibitory failures) and combined type (predominance of attentional and behavioral deficits).

ADHD has become a public health problem in several countries (Fayyad et al., 2017), given the high worldwide occurrence of this clinical condition (7.2%) and the negative social impact that can be generated if a person with ADHD is not intervened in time, due to the high probability of concomitance with an antisocial personality structure (APA, 2021; Dayan et al., 2022). In European and Asian countries, a prevalence of 6.8% is reported (Catalá-López et al., 2012; Carballal Mariño et al., 2018; Kofler et al., 2016), in Latin America from 8 to 18% being the main cause of neuropsychological care in children (Cervantes-Henriquez et al., 2021). In children a 2:1 ratio has been reported, with females being more likely than males to present inattentive type ADHD (Rusca & Cortez, 2020; Soriano & Echegaray, 2019). Prenatal risk factors that have been related to the genesis of ADHD are tobacco or alcohol use, lead exposure, metabolic and nutritional deficits, and infections; it has a heritability of 74% (Elkins et al., 2018; Justin Thenmozhi et al., 2022).

Imaging studies indicate that at the neurobiological level in ADHD cortical and subcortical neuroanatomical alterations are observed, mainly in the orbitofrontal lobe and cingulum (He et al., 2015; Hermosillo et al., 2020); neurophysiological investigations report a delay in cephalic maturation with a decrease in total brain volume of approximately 5% compared to typically developing children (Castellanos & Proal, 2012; Greven et al., 2015); neuronal activity to generate inhibitory responses is deficient in the cortex and corpus callosum, there is a deviation of gray matter tracts in frontotemporal structures, cerebellum, basal ganglia and striatal networks (Pitzianti et al., 2017); these neurobiological conditions negatively impact the effective functioning of neurocognitive processes in individuals diagnosed with this neurodevelopmental disorder (Ludyga & Ishihara, 2022; Pineda-Alhucema et al., 2018).

Attentional problems in ADHD generate a reduced capacity to store information, which affects academic performance (Einav & Margalit, 2022). The most neurologically sensitive function is memory and abnormalities in working memory are present in 67% of children with ADHD and continue into adulthood, being considered a neuropsychological endophenotype of this neurodevelopmental condition (Ackermann et al., 2018; Fabio 2017; Wang et al., 2018). Research has reported that the linguistic and pragmatic component of language is affected by low regulation in inhibitory control and impulsive behaviors: some children with a diagnosis of impulsive-predominant ADHD speak in an anticipatory manner, without respecting turns in conversations, may generate interruptions in others' dialogues, and might present logorrhea (Baixauli-Fortea et al., 2019; Guntuku et al., 2019; Helland et al., 2016). ADHD symptoms can lead to difficulties in planning and ordering daily activities, as well as in the analysis of visual tracking, localization, and visuospatial position tasks (Alabdulakareem & Jamjoom, 2020; DeCarlo et al., 2016).

Between 30% and 50% of ADHD cases coexist with oppositional defiant disorder (ODD), research reports that this concomitance increases the likelihood of offending in adolescence and adulthood (Hilton et al., 2019; zbaran et al., 2018). Comorbidity with other neurodevelopmental or behavioral disorders is present in 70% of children diagnosed with ADHD (Harvey et al., 2016; et al., 2018). SLD is a neurodevelopmental condition that causes persistent difficulties in learning to read, write, or calculate; it shares a 30% comorbidity rate with ADHD (Lonergan et al., 2019; Vacas et al., 2020). A dual diagnosis of ADHD and autism spectrum disorder (ASD) is now possible according to the Diagnostic and Statistical Manual of Mental Disorders [DSM-V] - APA (2013). This modification was the result of clinical evidence of concomitance and conformity.

There is a vast scientific production that has been devoted to the neurocognitive analysis and comorbidities of ADHD (Arnett et al., 2022; Bergwerff et al., 2019; Parke et al., 2020). Few studies address the relationship between these constructs, and there are even divergences and contradictions in published findings (Groves et al., 2020; Romani et al., 2018), which prevents establishing a standardized profile that facilitates mental health professionals in characterization, profiling and intervention; it has been proposed that neurocognitive deficits persist into adulthood (Fabio & Caprì, 2017). In this research, we present a predictive study that aimed to identify the neurocognitive characteristics of ADHD (combined, hyperactive/impulsive, inattentive) of pure presentation and with comorbidity with ODD, SLD and ASD. We constructed probabilistic rules with different types of variables (total IQ, working memory index, perceptual reasoning index, processing speed index, phonological/semantic fluency, attention, visuoverbal memory, verbal memory, working memory, visual memory, visual perception, constructional praxias), using DTCM which allowed us to establish a clinical hierarchy.

2. Materials and methods

2.1 Participants

From a population of 799 participants with neurodevelopmental disorders, the clinical history, family history of ADHD, presence or absence of neurological risk and delays in the successive evolution of developmental areas were analyzed. N=712 schoolchildren with a diagnosis of ADHD, n=564 boys and n=148 girls, aged between 6 and 13 years, were included in the sample and non-probability sampling was used (Ni et al., 2018). The 87 excluded had intellectual disabilities or sensory deficits. Eleven groups (G) were formed with the selected sample: G1 ADHD combined (n=73), G2 ADHD hyperactive/impulsive (n=77), G3 ADHD inattentive (n=61), G4 ADHD combined comorbid with ASD (n=51), G5 ADHD inattentive comorbid with ASD (n=72), G6 ADHD combined comorbid with NDD (n=68), G7 ADHD hyperactive/impulsive comorbid with NDD (n=88), G8 ADHD inattentive comorbid with NDD (n=46), G9 ADHD combined comorbid with ASD (n=57), G10 ADHD inattentive comorbid with ASD (n=67) and G11 ADHD hyperactive/impulsive comorbid with ASD (n=52). Table 1 presents the characterization of the selected sample.

Table 1. Sample characterization

Group	Age		Gender		Schooling level		Family Background		Neurological Risk		Developmental Areas Delays		Laterality		
	M	SD	M	F	Elementary	High School	Yes	No	Yes	No	Yes	No	RH	LH	A
G1	8.49	2.01	59	14	61	12	51	22	34	39	19	54	72	0	1
G2	7.86	1.59	55	22	73	4	56	21	22	55	18	59	70	7	0
G3	8.91	2.06	45	16	51	10	46	15	17	44	15	46	56	5	0
G4	8.20	2.68	51	0	31	20	39	12	30	21	20	31	51	0	0
G5	8.78	2.17	72	0	69	9	61	17	52	26	52	26	69	9	0
G6	8.23	1.96	58	10	63	5	48	20	52	16	11	57	68	0	0
G7	8.00	2.65	59	29	88	0	70	18	59	29	30	58	88	0	0
G8	9.50	2.67	35	11	17	29	36	10	6	40	7	39	46	0	0
G9	8.78	1.51	42	15	51	6	44	13	21	36	21	36	57	0	0
G10	8.95	2.01	46	21	58	9	49	18	15	52	12	55	58	9	0
G11	9.00	1.58	42	10	42	10	37	15	0	52	31	21	52	0	0

Key: Mean (M), standard deviation (SD), Male (M), Female (F), Right-handed (RH), Left-handed (LH), Ambidextrous (A).

2.2 Assessments

2.2.1 Wechsler Intelligence Scale (WISC-IV) (Wechsler, 2005)

It evaluates the cognitive and intellectual competencies of persons between 6 and 16 years of age. It consists of 15 tests (10 essential and 5 complementary), and the application is individual. The 10 essential tests were applied to the study sample to establish the index of verbal comprehension, working memory, perceptual reasoning, processing speed and total IQ. The verbal comprehension index evaluates the ability to structure verbal conceptualizations, establish relationships between morphemes and measure precision and agility in verbal decoding; the tests applied in this index were: Similarities/Vocabulary/Comprehension. The perceptual reasoning index estimates constructive competencies, classifications used for non-verbal concepts, visual analysis and data processing simultaneously; the tests used were: Cubes/Concepts/Matrices. The working memory index determines information retention, manipulation and transformation competencies; this index was assessed using two tests: Digits/Letters-Numbers. The processing speed index measures the skills of attentional focus, exploration, ordering and discrimination of visual data quickly; the sample included the Symbol/Key Search tests. The scale has content validity and reliability.

2.2.2 Verbal Fluency Test (Portellano Pérez & Martínez Arias, 2020)

It is a test that performs a rapid global assessment of language and executive functions and is applied individually from 6 to 90 years of age. It consists of two verbal fluency tasks with a set time of one minute: phonological fluency (rapid naming of words beginning with the letters F, A, S), and semantic fluency (rapid naming of words belonging to the same semantic category, animals and fruits). The test shows content validity, criterion and pre-test and post-test reliability. This test has a sensitivity level of 0.79 and a specificity of 0.82.

2.2.3 Trail Making Test (TMT) (Tombaugh, 2004)

The purpose of the test is to assess visual setting speed, sustained/divided attention, cognitive flexibility, working memory and motor function. It consists of two parts, A (twenty-five numbers randomly placed in circles are to be joined with a line) and B (twelve numbers and twelve letters are to be joined with a line, which are within circles in ascending sequential order, alternating a number and then a letter). The test has face validity and pre-test reliability.

2.2.4 Visuoverbal memory scale (Ardila et al., 1994)

The person being tested is shown a template with 10 drawings and is asked to pronounce the names of each design before removing the visual template, after which the person being tested must recall the drawings immediately. The test allows up to 10 attempts. The number of words evoked after up to 10 trials are measured by the maximum volume. Delayed recall measures the number of words spoken after 20 minutes. The test has stability coefficient reliability and content validity.

2.2.5 Verbal memory curve (Ardila and Rosselli, 2007)

The test consists of 10 words that must be pronounced to the test subject, allowing up to 10 attempts so that the test subject can obtain the maximum volume (10), after each trial (listening to the words) the test subject evokes the ones he/she remembers (immediate evocation). The number of items that the test subject can recall 20 minutes after the last exposure is represented by the score obtained in delayed recall. The test has pure internal consistency reliability and content validity.

2.2.6 Wechsler Memory Sca (Wechsler, 1945)

This is a separate test that assesses the fundamental components of memory in different age groups (information, orientation, mental control, logical memory and associated pairs). The information and orientation tests use very basic questions about orientation in space, time and person, and general culture to assess the level of awareness. Three activities make up Mental Control, which assesses mechanized and controlled processing (counting backward from twenty to one, repeating the alphabet and counting by threes starting from four up to forty). To assess logical memory, two stories are read to the tested subject for immediate recall. The associated pairs consist of giving the patient a pair of words to learn and having him/her read them in order.

2.2.7 Rey/Osterrieth complex figure test (Rey, 1980)

It evaluates the level of development of the ability of constructive praxis and long-term visual memory. It consists of two tasks, the first evaluates the immediate copying of a drawing and the second the evocation of the drawing without resorting to the sample. The test has a reliability of 0.83 for copying and 0.78 for delayed recall.

2.3 Procedure

The study protocol was endorsed and approved by the University Research Ethics Committee of Luis Amigo Catholic University with file number 65136. The informed consent complies with the requirements that classify the project in the "minimal risk" research category, given that the behavior of the participants will not be manipulated. The evaluation sessions were conducted individually with a duration of two hours. The psychometric scales were provided by neuropsychologists from a Neuropsychology Specialized Care Center in the city of Medellín-Colombia.

2.4 Data analysis

We used an empirical analytical research design, relational in scope; this structure allowed us to reduce the bias of the results so that they could be generalized. We began with the statement of the problem, formulating the objective and the criteria for selecting the research units. The selected sample were children diagnosed by pediatric neurology, pediatric psychiatry and child neuropsychology professionals, the neuropsychological evaluation performed assessed various neurocognitive processes (IQ, IQ indices, language, attention, perceptual reasoning, memory and executive functions); the tests applied had the following psychometric principles: direct score, standard score, reliability, validity and sensitivity. The inclusion criteria of the selected sample were: a) schooled population, b) aged between 6 and 12 years, c) without a diagnosis of intellectual disability, d) without sensory deficits.

Measures of central tendency for the selected sample and DTCMs were produced in the statistical computing software RCran 4.2.1. A decision tree is a nonparametric supervised learning algorithm, which is used for both classification and regression tasks (Fletcher & Islam, 2019). This machine learning technique starts with a root node, which has no incoming branches, the outgoing branches from the root node feed the internal nodes (decision nodes), based on the available features, both types of nodes perform evaluations to form homogeneous subsets, which are indicated by leaf nodes or terminal nodes, the leaf nodes represent all possible outcomes within the dataset (Chen, et al., 2021). In total, four DTCMs were constructed, the first of which corresponds to children with ADHD without any other clinical condition (G1, G2 and G3), the second to children with the diagnosis of ADHD and ASD (G4 and G5), the third to children with ADHD and NDD (G6, G7 and G8) and the fourth to children with ADHD and ASD (G9, G10 and G11). For each decision tree, probabilistic rules were identified to determine membership in an ADHD type (combined, hyperactive/impulsive, inattentive) and the hierarchy of neurocognitive variables was identified.

2.5 Conflict of interest

This study is a byproduct of the project "Computerized Working Memory Training Program in Patients with ADHD diagnosis", funded by the Luis Amigo Catholic University, cost center No. 05020299124, which doesn´t present any type of conflict of interest.

3. Results

Table 2 presents the structure of the database, the first column indicates the variables included, the second the nomenclature used in the DTCMs and the third the description. In total, N= 712 children with ADHD were analyzed.

Table 2. Database description

Variable	Nomenclature	Description
Target variable - ADHD	V0.	Combined=1, Hyp/Imp=2, Inattentive=3
Gender	V1.	Male=1, Female=2
Age	V2.	Integer
Schooling	V3.	Ordinal
Neurological Risk	V4.	
Developmental Delays	V5.	
SLD	V6.	Dichotomic
ODD	V7.	Yes=1 , No=0
ASD	V8.	
Emotional Disturbances	V9.	
Laterality	V10.	Right-handed (RH), Left-handed (LH), Ambidextrous (A).
Verbal-Comprehension (Index)	V11.	
Perceptual-Reasoning (Index)	V12.	
Working-Memory (Index)	V13.	
Processing-Speed (Index)	V14.	
Total IQ	V15.	
Semantic Fluency	V16.	
Phonological Fluency	V17.	
Attention TMT A	V18.	
Attention TMT B	V19.	
Attention - Cues	V20.	
Attention - Symbol Search	V21.	
Visuoverbal Memory Scale Maximum volume	V22.	
Visuoverbal Memory Scale Delayed Evocation at 20' (20')	V23.	Standard score
Verbal Memory Scale Maximum Volume	V24.	
Verbal Memory Scale Delayed Evocation at 20' (20' delayed recall)	V25.	
Information	V26.	
Orientation	V27.	
Mental Control	V28.	
Logical Memory	V29.	
Digits	V30.	
Associated pairs	V31.	
Complex figure of King-Osterrieth (evocation)	V32.	
Perception-Concepts	V33.	
Perception-Matrices	V34.	
Complex figure of King- Osterrieth (copying)	V35.	

Key: Variable (V), 35 V were analyzed.

With the information obtained from the selected sample, four DTCMs were elaborated. Figure 1 shows, in order of importance, the variables with the greatest weight in the identification of the predominant type of ADHD (combined, hyperactive/impulsive, inattentive) in children without another comorbid diagnosis (G1, G2 and G3). The first three variables were the total working memory index, matrix test and total IQ.

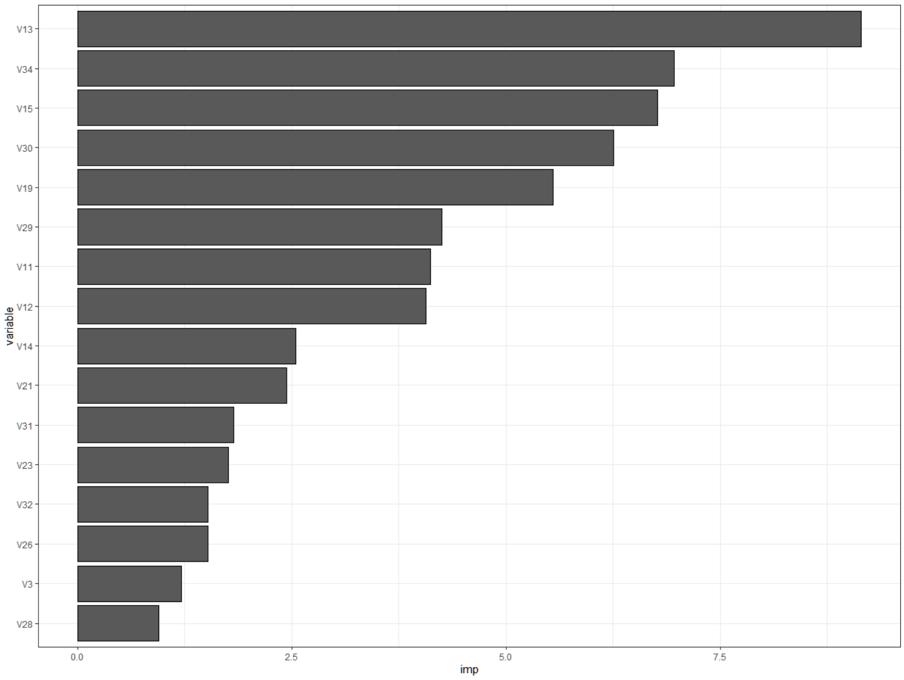

Figure 1. Importance order of predictor variables - Case 1

From the DTCM presented in Figure 2, the following results can be deduced: if the child obtains a score in the Matrices test lower than 13, he has a probability of 0.61 of having ADHD of the combined type, if he obtains a score higher than 13 in this same test, he has a probability of 0.18 of having ADHD of the Hyperactive/Impulsive type. If the patient scores below 146 on the Attention TMT B test, he/she has a 0.83 probability of having ADHD of the combined type, if he/she scores above 146 on this same test he/she has a 0.51 probability of having ADHD of the combined type. If the patient obtains a score lower than 93 in the working memory index the probability of having ADHD of combined type is 1, if he obtains a score higher than 93 in the working memory index he has a probability of 0.43 of having ADHD of Hyperactive/Impulsive type. If the patient scores above 60 on the working memory index he/she has a 0.40 probability of having ADHD of the Hyperactive/Impulsive type. If the patient scores equal or higher than 9.3 on the logical memory test, he/she has a 0.71 probability of having ADHD of the combined type, if he/she scores less than 9.3 he/she has a 0.23 probability of having ADHD of the Hyperactive/Impulsive type.

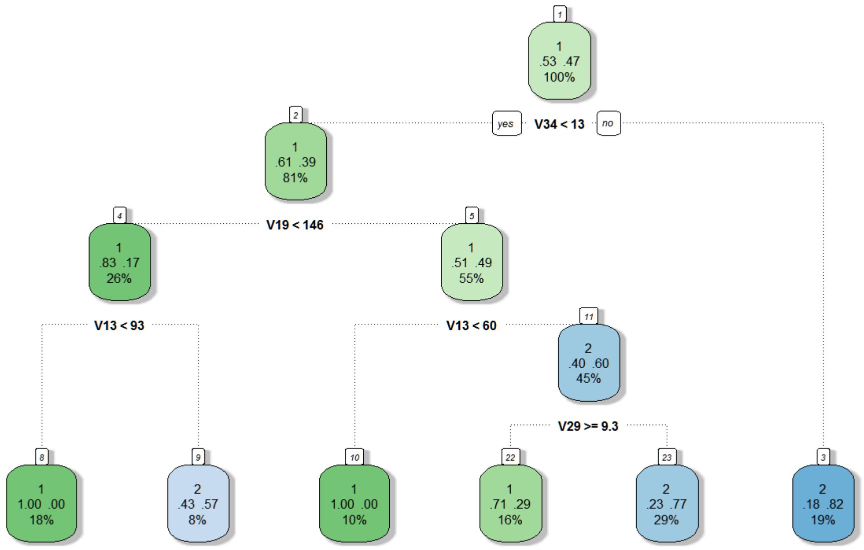

Figure 2. Decision Tree – Case 1

Figure 3 presents in order of importance the variables that have greater weight in the identification of the type of ADHD (Combined or Inattentive) with comorbidity with ASD (G4 and G5). The first three variables were Attention Cues, processing speed index and working memory index.

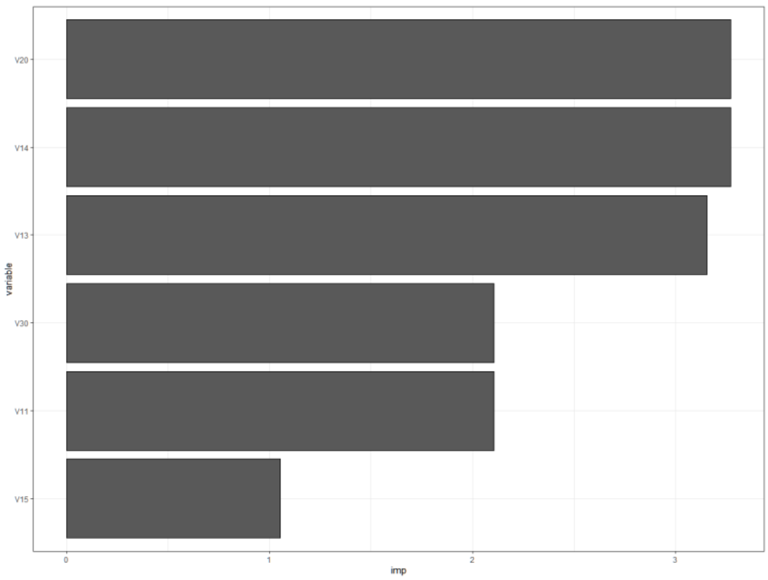

Figure 3. Importance order of predictor variables – Case 2

From the DTCM presented in Figure 4, the following results can be deduced: if the child with a diagnosis of ASD obtains a score on the working memory index lower than 59 he/she has a probability of 1.0 of having ADHD of the combined type. If the child with ASD scores greater than 59 he has a 0.18 probability of having inattentive ADHD, if he scores greater than or equal to 96 on the processing speed index he has a 1.0 probability of having combined ADHD, if he scores less than 96 he has a 0.0 probability of having inattentive ADHD.

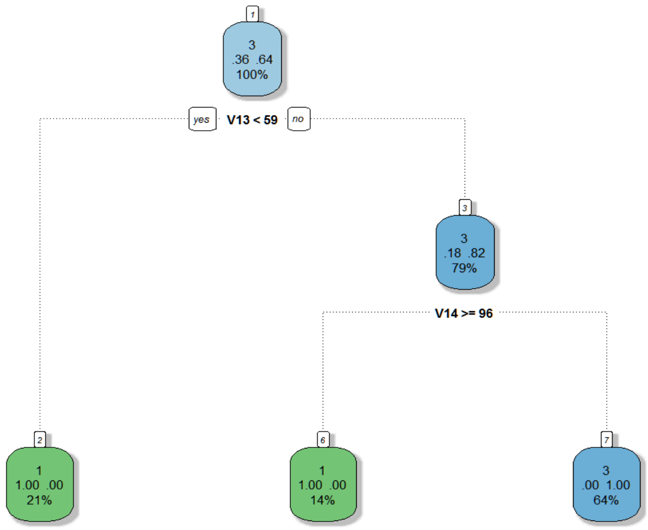

Figure 4. Decision Tree – Case 2

Figure 5 presents in order of importance the variables with the greatest weight in the identification of the type of ADHD (combined, hyperactive/impulsive, inattentive) with comorbidity with NDD (G6, G7 and G8). The first three variables were the perceptual reasoning index, matrices and concepts.

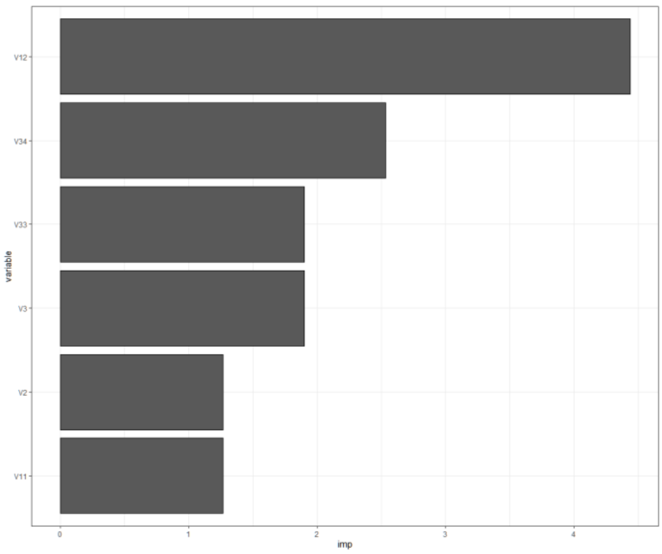

Figure 5. Importance order of predictor variables – Case 3

From the DTCM presented in Figure 6, the following results are deduced: if the child obtains a score on the perceptual reasoning index greater than or equal to 90, he has a probability of 0.71 of having ADHD of the combined type and ODD, a probability of 0.18 of having ADHD of the Hyperactive/Impulsive type with ODD, and a probability of 0.12 of having ADHD of the

Inattentive type with ODD. If you score below 90, you have a 0.14 chance of having ADHD of the combined type with ODD comorbidity, a 0.0 chance of having ADHD of the Hyperactive/Impulsive type comorbid with ODD, and a 0.86 chance of having ADHD of the Inattentive type with ODD.

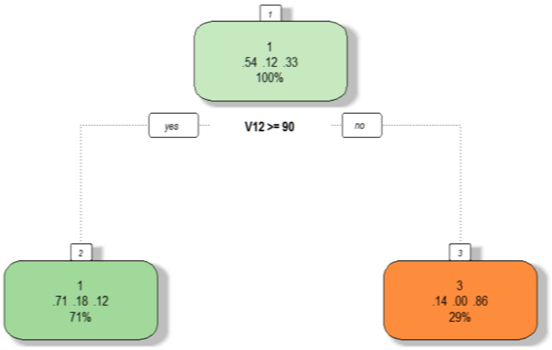

Figure 6. Decision Tree – Case 3

Figure 7 presents in order of importance the variables that have the greatest weight in the identification of the type of ADHD (combined, hyperactive/impulsive, inattentive) presented by children with ADHD with ASD comorbidity (G9, G10 and G11). The first three variables were Matrices, Digits and Perceptual Reasoning Index.

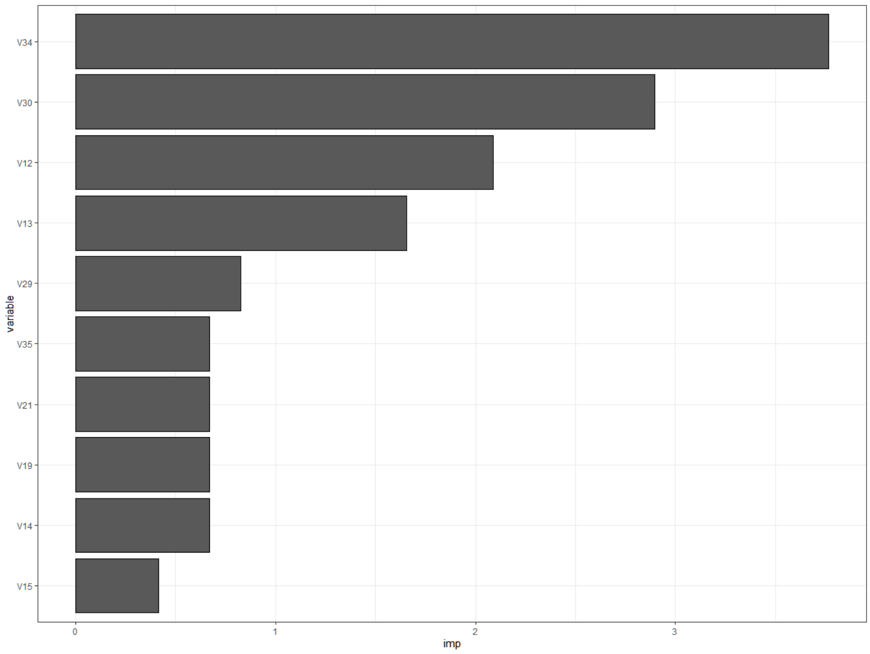

Figure 7. Importance order of predictor variables – Case 4

From the DTCM presented in Figure 8, the following results can be deduced: if the child obtains a score on the digit test greater than or equal to 9.5, he has a probability of 0.71 of having ADHD of the combined type and SLD, a probability of 0.29 of having ADHD of the

Hyperactive/Impulsive type comorbid with SLD, and a probability of 0.0 of having ADHD of the Inattentive type and SLD. If you score below 9.5 on the digit test, you have a 0.36 chance of having ADHD of combined type and SLD, a 0.08 chance of Hyperactive/Impulsive type with SLD, and a 0.56 chance of Inattentive type comorbid with SLD. If he obtains a score on the Matrices test lower than 6.5 he has a 0.70 probability of having ADHD of the combined type with SLD, a 0.10 probability of the Hyperactive/Impulsive type comorbid with SLD, and a 0.20 probability of the Inattentive type with SLD. Finally, if you score above 6.5 on the matrix test, you have a 0.24 probability of having ADHD of the combined type with SLD, a 0.07 probability of the Hyperactive/Impulsive type comorbid with SLD and a 0.69 probability of the Inattentive type with SLD.

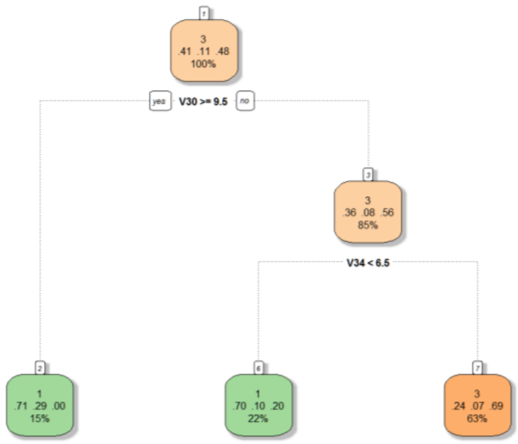

Figure 8. Decision Tree – Case 4

4. Discussion

Of the analyzed sample 29.63% of the children presented ADHD diagnosis without comorbidity, and 70.37% presented comorbidity with another neurodevelopmental disorder or NDD, this characteristic of the evaluated population is similar to the epidemiological data reported in various investigations (Mizuno et al., 2019; Morsanyi et al., 2018). In the present study, a family history of ADHD is reported in 75% of the analyzed cases, it has been estimated that there is a high heritability of ADHD (Boomsma et al., 2010). A longitudinal study with a population aged 3 to 12 years evaluated the heritability of ADHD with the same percentage indicated in this research in all ages evaluated (Rietveld et al., 2004), this figure is represented in several studies conducted with children (Derks et al., 2004; Vélez-van-Meerbeke et al., 2017).

The 43% of the children evaluated in this research presented a neurological risk, which refers to the presence of obstetric history; 33% presented delays in the successive evolution of developmental areas, indicating a lack of acquisition of motor, auditory/language or personal/social skills at the age at which they normally occur due to deficiencies in brain maturation or inadequate environmental stimulation practices. Navalón et al. (2022), note that children born after preterm birth threats are more likely to have ADHD, this finding is obtained from comparative studies with 6-year-old infants with and without this neurological risk. Minatoya et al. (2019), report that prenatal tobacco exposure generates symptoms compatible with ADHD at preschool age. Fine motor delay predicts greater ADHD symptomatology at age 6 years (Arnett et al., 2013), this clinical condition generates signs of developmental deviance in the early years (Lemcke et al., 2016). Seventy-nine percent of the sample of this research were males, a considerably higher prevalence of ADHD in males than in females has been indicated (London et al., 2021). The majority of the population analyzed was right-handed, about 90% of people worldwide are right-handed, this condition explains the reasons why there is no strong evidence for an association of left laterality with ADHD (Nastou et al., 2022).

The first DTCM "Case 1", was constructed with clinical assessments and neuropsychological test scores provided to children with ADHD without comorbidities, of the three clinical presentations (combined, hyperactive/impulsive, inattentive). The results indicated that children with pure presentation ADHD regardless of predominance, exhibit deficits of the equal sign on the working memory index (V13), and present difficulties in the retention and storage, operationalization, transformation and generation of new information. This finding is consistent with another research conducted with 704 children with ADHD who were evaluated with the WISC-III and WISC-IV indicating that 100% of children with ADHD present deficits in the working memory index (Mayes & Calhoun, 2006). The second variable in order of importance indicates that children with pure ADHD performed poorly on the WISC-IV matrix test, have difficulties in executing tasks involving problem-solving, low observational and reasoning skills (Sperafico et al., 2021). Research indicates that perceptual ability for visual tracking with varying degrees of difficulty is limited in children with ADHD (Bellato et al., 2022; Zheng et al., 2022).

The third variable in order of importance was IQ, the children with pure ADHD who made up the sample were in a range of average intelligence [90-100] (Muñoz-Suazo et al., 2019). This finding is consistent with the research of Celeste et al. (2019), which indicates that the diagnosis of ADHD without comorbidities does not affect total IQ, a condition that facilitates adherence to behavioral interventions and neurocognitive stimulation, avoiding the detonation of antisocial structures (Hirsch & Christiansen, 2018; Retz et al., 2021).

The second DTCM "Case 2", was constructed with clinical assessments and neuropsychological test scores provided to children with ADHD (combined, inattentive) with ASD comorbidity.

The first variable indicated that there are relevant deficits in attention, children with ADHD and ASD present problems in focusing stimuli or performing several activities involving cognitive effort at the same time. Comparative studies with child populations diagnosed with ADHD and ASD have referred to the existence of problems in selective and divided attention that entail negative effects on executive functions (Boxhoorn et al., 2018; Nejati, 2021). The second deficiency found in children with ADHD and ASD was in the processing speed index, which assesses visual perceptual ability, time-dependent visual tracking, attention and time-dependent symbol analysis. There is scientific documentation evidencing that children with ADHD have problems in processing speed, a condition that is aggravated with the presence of ADHD and ASD; children with this double clinical condition present deficient skills in associative speed, learning, visual perception, visuo-manual coordination, attention, motivation, and endurance in the face of repetitive tasks (Hirsch & Christiansen, 2018; Sinzig et al., 2008). The third variable affected was the working memory index; alterations in executive functions in children with ADHD and ASD predict the existence of multiple working memory difficulties in this population, with greater deficits being found in visuospatial working memory (Wang et al., 2018).

The third DTCM "Case 3", was constructed with the clinical assessments and neuropsychological test scores provided to ADHD children with comorbidity of NDD, from the three clinical presentations (combined, hyperactive/impulsive, inattentive). The first three variables were the perceptual reasoning index, matrices and concepts. These variables indicate skill-level deficits in constructional praxis, nonverbal concept formation and classification, visual analysis, and simultaneous processing. Boles et al. (2009) found that children with ADHD and NDD have problems processing visual information and low visuospatial orientation. According to Barkley (2006), the clinical features of ADHD comorbid with NDD lead this group of children to rush to complete fluid reasoning and visual processing tasks, failing to execute them correctly and making repeated errors. Perceptual reasoning is worse in girls with ADHD than in boys, according to research by Muoz-Suazo et al. (2019).

The fourth DTCM "Case 4", was constructed with the clinical assessments and neuropsychological test scores provided to the ADHD children with ASD comorbidity, from the three clinical presentations (combined, hyperactive/impulsive, inattentive). The first three variables identified in the DTCM were matrices, digits and perceptual reasoning index. The arrays test assesses visual analogy reasoning skills and involves the integration of visual information, recognition and time-controlled perception. ADHD with ASD generates difficulties in abstract reasoning, nonverbal concept formation, organization, and visual perception (Toffalini et al., 2022). The digit test assesses working memory, short-term auditory skills, and the ability to follow a sequence and encode it. Several investigations have reported that ADHD presents deficits in working memory and other executive functions that are exacerbated when there is comorbidity with SLD, it has been proposed that this deficit is due to problems in automatic information processing (Martino et al., 2017). In this population group, it is suggested that there are deficits in the encoding and recall of immediate information, and they have poor performance in verbal working memory (Becker et al., 2021; Ramos et al., 2020; Fosco et al., 2020). Children with ADHD and problems in reading, writing, and arithmetic show lower scores on the perceptual reasoning and working memory index compared to children with pure ADHD (Downing & Caravolas, 2020).

5. Strengths and limitations

The main limitations of this research are that the sample was not homogeneous in terms of sex, with a greater number of boys. Children diagnosed with hyperactive/impulsive ADHD and ASD were not included in the sample. We did not discriminate ASD symptomatology in dyslexia, dysgraphia and dyscalculia from children reported with this clinical condition and ADHD. It is suggested that future research include ADHD with comorbidity with motor coordination disorder and explores the emotional implications associated with this clinical condition.

6. Conclusions

In conclusion, our study provides relevant data on the neurocognitive characteristics of children with ADHD and predicts the type of ADHD a child may have according to neurocognitive particularities. The information reported in this research generates theoretical and clinical contributions. The hierarchization of the sample evaluated indicates that children with pure ADHD present low performance in tasks that evaluate the index of working memory and perceptual reasoning that is not explained by deficits in IQ. Deficits in working memory are generalizable to all presentations and comorbidities of ADHD. One of the main advantages of DTCM over other Machine Learning predictive techniques is the possibility of differentiating the hierarchy of importance of the dependent variables, in this case, allowing the identification of the most important variables in four different populations of children diagnosed with ADHD.

Ethical approval

The University Research Ethics Committee of Luis Amigo Catholic University endorsed and accepted the study protocol, which has file number 65136.

Informed consent statement

All study participants gave informed consent.

Conflict of interest statement

This study does not present any conflict of interest.

Funding

This study is a product of the Computerized Working Memory Training Program in Patients with a Diagnosis of Attention Deficit/Hyperactivity Disorder project, funded by the Luis Amigo Catholic University cost center no. 05020299124, doesn´t present any type of conflict of interest.

Authors' contributions

All authors participated in the analysis of the medical records and in the construction of the database of the participants that composed the sample, in the search for scientific background, in the construction of the predictive models of DTCM and the interpretation of the results.

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DOI: 10.13129/2282-1619/mjcp-3606