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Development and psychometric properties of the Difficulties in Executive Functions, Regulation and Delay Aversion Inventory – Version for children and adolescents

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ABSTRACT

The study reports the development and investigation of the psychometric properties of the Difficulties in Executive Functions, Regulation and Delay Aversion Inventory - Version for children and adolescents (IFERA-I). Items were developed to assess working memory, flexibility, inhibition, delay aversion and state regulation. All of these are constructs related to the complex cognitive heterogeneity of the Attention deficit and hyperactivity disorder. Evidence of content validity was gathered through verification by experts, and items with 100% agreement among evaluators were considered adequate. Parents (N=211) and teachers (N=189) of children (6 to 14 years of age) responded to the IFERA-I, Childhood Executive Functioning Inventory (CHEXI) and Swanson, Nolan and Pelham Questionnaire (SNAP-IV). Convergence patterns between the CHEXI and SNAP-IV were observed. Confirmatory Factor Analysis revealed an acceptable five-factor model for parental responses, with good levels of reliability. No model was corroborated for the teachers' responses. The results provide some evidence that the IFERA-I is a reliable and valid measure of different cognitive dimensions. They also suggest directions for future research and improvement of the measure.
Keywords: psychometrics; neuropsychological assessment; ADHD; cognition.

RESUMO – Desenvolvimento e propriedades psicométricas do Inventário de Dificuldades em Funções Executivas, Regulação e Aversão ao Adiamento – versão para crianças e adolescentes

O estudo relata o desenvolvimento e investigação das propriedades psicométricas do Inventário de Dificuldades em Funções Executivas, Regulação e Aversão ao Adiamento - Versão para crianças e adolescentes (IFERA-I). Foram desenvolvidos itens para avaliação de memória de trabalho, flexibilidade, inibição, aversão ao adiamento e regulação do estado, construtos relacionados à complexa heterogeneidade cognitiva observada no Transtorno de Déficit de Atenção e Hiperatividade/impulsividade. Evidências de validade de conteúdo foram reunidas através da verificação por especialistas, sendo considerados adequados itens com 100% de concordância entre avaliadores. Pais (N=211) e professores (N=189) de crianças (6 a 14 anos) responderam ao IFERA-I, Inventário de Funcionamento Executivo Infantil (CHEXI) e Swanson, Nolan e Pelham *Questionnaire* (SNAP-IV). Padrões de convergência com CHEXI e SNAP-IV foram observados. Análise fatorial confirmatória revelou um modelo aceitável de cinco fatores para respostas dos pais, com bons índices de confiabilidade. Nenhum modelo foi corroborado para respostas dos professores. Os resultados fornecem algumas evidências de que o IFERA-I é uma medida confiável e válida de diferentes dimensões cognitivas. Ao mesmo tempo, também sugerem direções para futuras pesquisas e aprimoramento da medida.
Palavras-chave: psicometria; avaliação neuropsicológica; TDAH; cognição.

RESUMEN – Desarrollo y propiedades psicométricas del Inventario de Dificultades en las Funciones Ejecutivas, Regulación y Aversión al Aplazamiento - versión para niños y adolescentes

El estudio relata el desarrollo e investigación de las propiedades psicométricas del Inventario de Dificultades en las Funciones Ejecutivas, Regulación y Aversión al Aplazamiento - Versión para niños y adolescentes (IFERA-I). Se desarrollaron ítems para evaluar memoria de trabajo, flexibilidad, inhibición, aversión al aplazamiento y regulación del estado, constructos relacionados con la compleja heterogeneidad cognitiva observada en el Trastorno por Déficit de Atención con Hiperactividad/Impulsividad. Evidencias de validez de contenido se recopilaron mediante la verificación por parte de expertos, y los ítems se consideraron adecuados con un 100% de acuerdo entre los evaluadores. Padres (N=211) y maestros (N=189) de niños (6 a 14 años) respondieron a IFERA-I, Inventario de Funcionamiento Ejecutivo de la Infancia (CHEXI) y Swanson, Nolan y Pelham *Questionnaire* (SNAP-IV). Se observaron patrones de convergencia con CHEXI y SNAP-IV. Análisis factorial confirmatorio reveló un modelo aceptable de cinco factores para las respuestas de los padres, con buenos niveles de confiabilidad. No se corroboró ningún modelo para las respuestas de los profesores. Los resultados proporcionan algunas evidencias de que el IFERA-I es una medida confiable y válida de diferentes dimensiones cognitivas. Al mismo tiempo, también sugieren direcciones para la investigación futura y la mejora de la medida.
Palabras clave: psicometría; evaluación neuropsicológica; TDAH cognición.

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Attention Deficit and Hyperactivity Disorder (ADHD) is characterized by symptoms of inattention and/or hyperactivity/impulsivity, with greater frequency and severity than expected for the general population (APA, 2014). Affected individuals present impairments in the academic, social and family areas and greater chances of comorbidities, as Specific Learning Disorder, Conduct Disorder and Oppositional Defiant Disorder (DuPaul & Langberg, 2015; Rodríguez et al., 2015; Seymour & Miller, 2017). With prevalence among children and adolescents ranging from 5.29% to 7.2% (Thomas, Sanders, Doust, Beller, & Glasziou, 2015), the estimated annual cost of untreated ADHD in Brazil is approximately R$ 1.594 billion, and, for the same period, approximately R$ 1 billion could be saved with treatment (Maia, 2014).

Until the 1990s, it was hypothesized that ADHD would be, at least in part, a reflection of executive function (EF) deficits (Nigg, 2005). Executive functions refer to dynamic cognitive processes that allow an individual to adapt to new situations and solve problems in order to achieve future goals. They are top-down processes that facilitate decision making, with a model widely accepted in the literature that delimits three basic EF skills, relatively independent of each other: inhibition (the ability to deliberately inhibit a predominant, automatic or familiar response or a stimulus), working memory (a temporary system that selects, maintains integrates and manipulates mental representations) and flexibility (the ability to switch cognitive processes and adapt to context) (Diamond, 2013; Miyake et al., 2000; Miyake & Friedman, 2012).

In fact, ADHD is consistently associated with deficits in EF (Silverstein, Faraone, Leon, Biederman, Spencer, & Adler, 2018). However, only moderate effect sizes of deficits in EF have been found in ADHD (e.g., Cohen's d between 0.3 and 0.6), which makes it difficult to consider this feature as a diagnostic criterion for the disorder (Miyake & Friedman, 2012). Furthermore, recent evidence claims that ADHD is characterized by neurocognitive heterogeneity with different profiles of EF deficits (Kofler, Irwin, Soto, Groves, Harmon, & Sarver, 2019; Wagner, Rohde, & Trentini, 2016).

Thus, although relevant for the understanding of the neurophychology of ADHD, EF skills are not enough to explain the entire heterogeneity of the clinical condition (Kofler et al., 2019; Wagner et al., 2016; Willcutt et al., 2005). This led to the investigation of other neuropsychological processes involved in the condition and that could be on the basis of its phenomenology. Among the suggested and investigated models, some evidence supports the role of delay aversion (Sonuga-Barke, 2002, 2003; Wagner et al., 2016) and of state regulation (Lijffijt, Kenemans, Verbaten, & Van Engeland, 2005; Sergeant, 2000, 2005; Wagner et al., 2016) in neuropsychological functioning of ADHD.

Sonuga-Barke (2002), for example, sought to understand the impairments of ADHD as a two-way street. The first includes executive deficits. The second addresses an affective-motivational pathway in which, due to dysregulation of the reward system, the person would tend to choose immediate rewards rather than rewards in the medium- or long-term (delay aversion). Many studies have linked ADHD with delay aversion and dissociate this phenomenon from deficits in EF (Sonuga-Barke, 2003; Sonuga-Barke, Sergeant, Nigg & Willcutt, 2008; Wagner et al., 2016). However, not all people with ADHD present delay aversion (Karalunas & Huang-Pollock, 2011; Solanto et al., 2007).

A third hypothesis to explain part of the ADHD phenomenology was developed by Sergeant (2005), after noting that individuals with ADHD present high response time variability (Castellanos et al., 2005) in neuropsychological tests. This variability can be explained by the difficulty in mobilizing energy to change the state of the body toward a task or situation (Sergeant, 2005). This difficulty is called state regulation. The state regulation hypothesis is part of the Cognitive-Energetic Model – CEM (Sergeant, 2000, 2005), which comprises three levels of functioning: cognitive processes, state factors or energetic pools, and EF. The model suggests that ADHD symptoms reflect deficits in EF. However, this model does not comprehend that a deficit in specific EF skills (e.g., inhibitory control) is primary or responsible for the cognitive impairments of ADHD, but proposes an impoverished regulation of the internal state (motivational) or difficulties in the activation and regulation of effort that, in turn, compromise the executive control. In fact, recent evidence supports the idea of greater difficulty in individuals with ADHD in regulating their responses in line with the speed of the stimulus presentation, leading to increased failure in inhibition at higher stimulus presentation rates (Huang-Pollock, Ratcliff, McKoon, Shapiro, Weigard, & Galloway-Long, 2017).

There is also evidence of an impairment in the perception of time in ADHD, in which these individuals would have an accelerated internal clock (Walg et al., 2015). This is in the basis of the Deficits in Temporal Processing model. However, the specific nature of these deficits still seems to be uncertain. The review by Wagner et al. (2016), for example, mentions both that temporal processing requires skills such as attention or working memory, and that variability in response times could be explained by the state factors of the Cognitive-Energy Model. The Deficits in Temporal Processing model is not even mentioned in a recent review about heterogeneity of ADHD (Luo et al., 2019).

Considering variables of the most consistent models, studies have consistently shown the heterogeneity of ADHD, and the independence among state regulation, EF and even delay aversion in the didorder (Lambek et al., 2010; Sjöwall, Roth, Lindqvist, & Thorell, 2013).

Beside this, there is no consensus on which measures are most often impaired in individuals with ADHD (for a review, see Nigg, Karalunas, Feczko, & Fair, 2020).

In summary, the evidence suggests that the heterogeneity of the cognitive functioning of ADHD includes deficits in EF (not necessarily all of them), delay aversion, state regulation, as well as a group of patients with no change in these aspects (Coghill, Toplak, Rhodes, & Adamo, 2018; Wagner et al., 2016). In general lines, these constructs have been associated with ADHD, although their heterogeneity within ADHD is not fully understood. In this sense, a measure that evaluates such constructs together is of potential utility to clinical researchers, once it could help in the identification of the cognitive profile for establishment of a more comprehensive treatment plan that considers the specific needs of the ADHD patient, as discussed by Sonuga-Barke et al. (2008).

In fact, using theory to guide assessment and decision making is a necessary step that could reach a better comprehension about the neuropsychological heterogeneity of ADHD (Nigg et al., 2020). In this sense, rating scales are widely used in assessment process, usually based on teachers' or parents' reports of daily functioning of children (Zan et al., 2018). Although the correlations between results in rating scales and performance tasks are low, both are important and necessary for a broader assessment process, since tests evaluate, more specifically, skills in a structured situation, while scales measure the performance related to daily life (Zan et al., 2018).

However, the most used scales for children and adolescents with ADHD are based on evaluation of symptoms, such as Swanson, Nolan e Pelham Questionnaire – SNAP-IV (Brazilian version by Mattos, Pinheiro, Rohde, & Pinto, 2006), or on the evaluation of specific neuropsychological functions, such as the Behavior Rating Inventory of Executive Function – BRIEF (Gioia, Isquith, Guy, & Kenworthy, 2000), that evaluates primarily executive functions, with behavioral regulation (including Inhibit, Shift, and Emotional Control) and metacognition (Initiation, Working Memory, Planning/Organization, Organization of Materials, and Monitor) domains. New instruments are needed to integrate the characteristics highlighted as possibly altered in the ADHD, according to the models previously described.

Faced with this need, the present study aimed to develop and investigate the psychometric properties of a functional instrument for Brazilian children and adolescents that more adequately covers the heterogeneity of cognitive functioning of ADHD, including deficits in EF, delay aversion and state regulation. Study 1 aimed to develop items for each cognitive dimension related to ADHD, based on the theoretical models, and to find (1) evidence of content validity. Study 2, in a non-clinical sample, sought for (2) evidence of convergent validity; also investigating (3) the factorial structure and (4) internal consistency of the new scale.

The *state of the art* in the area do not allow for a specific hypothesis about the structure configuration of such measure. In this sense, different models were tested. Considering the complex neuropsychology of ADHD (Coghill et al., 2018; Luo et al., 2019; Wagner et al., 2016), it was hypothesized that a more general factor, *"ADHD Cognition"*, unique (Model 3) or of third order, with the variables delay aversion, state regulation, and EF (as a second order factor covering Working Memory, Cognitive Flexibility, Inhibitory Control) as factors (Model 1) could be corroborated. On the other hand, considering some evidence about the relative independence of these constructs (Lambek et al., 2010; Sjöwall et al., 2013), a correlated multifactorial model (Model 2) and a bifactorial model (with five specific factors and one general '*ADHD Cognition*' factor) were also tested. In addition, the relationships between factors were considered to guide the testing of other configurations (as in Model 4). There was no hypothesis, a priori, of differential structure depending on the respondent (who is providing the information), parents or teachers. An instrument covering the heterogeneity of deficits in the disorder could be greatly useful for the comprehension of the symptoms and for the direction of the intervention.

Study 1 – Development and study of the evidence of content validity of the new scale

The project was approved by the Ethics Committee of the institution.

Method

The elaboration of the items related to EF was based on the review of the literature referring to the theoretical, empirical and factorial model of Miyake et al. (2000) reviewed by Miyake and Friedman (2012), and also Diamond's (2013) proposal. So, we considered three independent executive mechanisms included in these models, despite the covariance among them: (1) working memory (WM), (2) cognitive flexibility (CF), and (3) inhibitory control (IC).

The items related to state regulation were designed based on the model of Sergeant (2000, 2005). According with this model, arousal and activation is a need condition for an effective cognitive functioning and, in this sense, EF deficits in ADHD are related to a primary disfunction at energy level or state regulation (Luo et al., 2019). For this reason, this specific dimension was selected to integrate the inventory. Additionally, there were items for delay aversion, from the theory of Sonuga-Barke (2003, 2005). Thus, the instrument included the evaluation of two more constructs, in addition to the EF components: (4) Delay aversion (DA), and (5) State Regulation (StR).

A total of 28 items were developed, representing the five dimensions described above, with a Likert-type scale of five levels (Never to Always). The items depict examples of day-to-day behaviors/situations that require the different skills contemplated by the IFERA-I, from 4- to 17-year-old children/adolescents. The items reflect general situations of daily life, in order to: 1. allow only one version of the scale for teachers and for parents; 2.be related to different contents, such as verbal and non-verbal situations; and 3. include this broad age group. Examples: WM – *"When in the middle of an activity, he/she often forgets what he/she was doing"*; IC – *"He/she does things without thinking about what might happen after"*; CF - *"When he/she gets used to doing things one way, he/she does not like or finds it difficult to do it in another way"*; DA - *"He/she prefers to gain a simpler thing immediately rather than wait for something more interesting later"*; and StR - *"He/she has difficulty in organizing him/herself in time, sometimes being too fast and other times too slow"*.

Two protocols, one with a brief definition of the constructs and instructions (including the information that the same version of the inventory would be answered by teachers and parents) and the other containing the items developed, were available for the three judges, who were specialists in neuropsychology and cognitive psychology, all with a Ph.D, and with clinical and research experience. Each judge had to indicate the construct represented in each item and judge whether the item was necessary or unnecessary, whether it was clearly worded, and suggest modifications if pertinent. Given the participation of three judges, full concordance was considered adequate. Items that did not achieve 100% concordance were redrafted and resubmitted for further examination by the same judges, repeating the procedure.

Data analysis

Verification of the content validity was carried out from the analysis of the judge's concordance (i.e. the proportion of judges who agree with an expected answer), adopting 100% as the adequate concordance index.

Results

The initial stage of development of the IFERA led to the pilot version of the instrument, which was sent for the judges' analysis. Most of items were judged as necessary and clearly worded. Of the 28 items initially produced, four did not present the desired level of concordance considering the construct represented in the item (neither were judged as necessary and clearly worded). These four items were reworded, considering comments and suggestions of the judges, and resubmitted for further examination. After the suggested changes, all items achieved 100% concordance among the judges in aspects such as the content of the item in both school and family contexts, and the clarity of the instructions, as well as the general presentation of the instrument. From the observations of the judges, it was concluded that the items were adequate and capable of being used. This study led to the final version of IFERA-I used in Study 2.

Study 2: Investigation of the psychometric properties of the IFERA-I

The project was approved by the Ethics Committee of the institution.

Method

Participants

Initially, our sample was composed by parents/guardians and teachers of 222 children and adolescents, among 6 and 14 years of age, and enrolled in Elementary school. As not all respondents returned the protocols (the study instruments), the final sample was composed by 211 (referring to 95.04% return of the protocols filled out by the parents). Of these, 28 children were enrolled in the 1st-year, 28 in the 2nd-year, 32 in 3rd-year, 30 in the 4th-year, 42 in the 5th-year, 13 in the 6th-year, 15 in the 7th-year, 17 in the 8th-year, and 6 in the 9th-year of two private schools in São Paulo (53.6% boys).

From the 211 participants, there was a response for 189 (89.6%) of the protocols by the teachers (so, the complete information, provided by both respondents, was available for these 189 participants). The children belonged to a nonclinical sample, selected by convenience. When the child had more than one teacher (as is the case for 6th to 9th years of Elementary school), the one that spent more time with the student was chosen to respond to the instruments. No exclusion criteria were adopted for this study.

Instruments

Difficulties in Executive Functions, Regulation and Delay Aversion Inventory – Version for children and adolescents (IFERA-I). The IFERA-I version that originated from the previous study was used. The instrument consists of 28 items divided into five subscales: Working memory – WM (5 items), Inhibitory Control – IC (6 items), Cognitive Flexibility – CF (5 items) Delay Aversion – DA (5 items) and State Regulation – StR (7 items). Each item is rated on a Likert-type scale of 5 points. The instrument can be answered by parents and teachers and provides a functional measure regarding the executive skills, state regulation and delay aversion of the child. Response time is approximately 5 to 10 minutes. In all the subscales, as well as in the total score (which represents a general difficulty index), higher scores reflect greater problems/complaints in each respective area.

Childhood Executive Functioning Inventory (CHEXI). The CHEXI was originally developed by Thorell and Nyberg (2008) in order to evaluate EF in children with ADHD. This study used the Brazilian version of the instrument adapted and validated by Trevisan et al. (2017). The instrument has 26 items, each of which is scored on a Likert-type scale of five levels (definitely false, false, partially true, true, definitely true). The items are grouped into 4 subscales: working memory (WM; 11 items), planning (PLAN; 4 items), Inhibitory control (IC; 6 items), and self-regulation[2] (SR; 5 items). It is also possible to provide a total score. CHEXI can be answered by parents and teachers. Reliability indices (Cronbach's Alpha) for total scale in this sample were .97 and .96, for parents and teachers respectively.

SNAP-IV. The SNAP-IV (Mattos, Pinheiro, Rohde, & Pinto, 2006) is a public domain questionnaire, formulated from the DSM-IV criteria, aiming to evaluate symptoms of ADHD. It consists of the description of 18 symptoms, 9 of inattention and 9 of hyperactivity/impulsivity. Each item is scored on a scale of four severity levels (not at all, just a little, quite a bit, very much), and can be answered by parents and teachers. The Brazilian version was adapted by Mattos et al. (2006). In our sample, Cronbach's Alpha for inattention scale were .91 for parents and .94 for teachers. For hyperactivity/impulsivity, Cronbach's Alpha were .88 for parents and .94 for teachers.

Procedure

After signing the consent form, parents and teachers of the participating children were asked to complete the study protocol, composed by IFERA-I, CHEXI and SNAP-IV. The completion occurred in the absence of the researchers. As mentioned at 'Participants', there was 211 protocols filled out by the parents and 189 by the teachers (for the latter cases the protocols of both respondents were available). In the analyses we used all available information: the 211 parent's responses and the 189 teacher's responses.

Data analysis

Normal distribution of data (scores on IFERA-I, SNAP-IV, and CHEXI, answered by parents and teachers) was tested by Kolmogorov-Smirnov test. For convergent validity, subscores (WM, IC) and the total score of the IFERA-I were correlated with the respective scores (WM, IC) of the CHEXI. Also, convergent patterns were investigated from the correlations with related constructs, as StR of the IFERA-I and SR of the CHEXI. The relationship between the SNAP-IV and the IFERA-I were also investigated. Pearson's analysis was used and, as normality was not observed for all variables, we opted to use bootstrapping (1000 re-amostragens; 95% IC BCa) procedures, as a way to correct deviations from the normality of the sample distribution (Haukoos & Lewis, 2005). A correlation magnitude greater than or equal to .45 was considered as suggestive of convergent validity (DeVon et al., 2007).

To identify the factorial structure the free *software R*, in its R Studio interface (version 3.4.1; Development Core Team, 2017) was used. The packages adopted were: lavaan, semPlot, clusterGeneration and knitr. Initially, the analyzes of measurement models, through SEM and the CFA, were done in order to assess the contribution of each item to the factors (Hair et al., 2009). Then, it was verified the invariance evaluation of the chosen model through Multigroup Confirmatory Factor Analysis (MGCFA) to verify the factorial equivalence between groups of parents and teachers (Damasio, 2013; Hair et al., 2009). The estimation was made using the method *Diagonal Weighted Least Squares* (DWLS) suitable for categorical measures seeking to investigate five or more factors in samples without normal distribution, as in this case. In order to evaluate the fit quality of the built models, the following values were used (Hair et al, 2009; Hu & Bentler., 1998): chi-square value ($\chi 2$): $p>0,05$; Comparative Fit Index (CFI)>0.95, Tucker-Lewis Index (TLI)>0.95; Root Mean Square Error of Approximation (RMSEA)<0.06; Confidence Interval (CI) in 90%; and Standardized Root Mean Square Residual (SRMR)<0.08. Accepted model is highlighted in bold in tables.

To verify the model invariance, through MGCFA, in the first stage groups were estimated separately, and then investigations of the following invariabilities were sought: Configural, metric, scalar, structural and residual (Damasio, 2013). The same quality indices adopted for the SEM and the CFA were used. The interpretation parameters of the correlations were: 0 to 0.3 as weak; 0.3 to 0.7 as moderate; and >0.7 as strong (Cronk, 2017). The cut of factor loadings was fixed at 0.40 (Damasio, 2012). For internal consistency was used McDonald Hierarchical Omega (ωh) for the accepted model, for both total test and for each factor, independently. The value of >0.7 was adopted as indicative of good consistency (Cronk, 2017). The psych and user friendly science packages were adopted.

Results

Descriptive statistics, comparisons and correlations between respondents in the instruments can be requested from the authors. For good use of space, only the analyzes relevant to the objectives set are presented here.

Convergent validity study

To study the convergent validity, the IFERA-I scores were compared to those of the CHEXI and SNAP-IV,

[2] Thorell e Nyberg (2008) understand SR as one of core components of EF. In their study, SR items do not differentiate from IC items, grouping in the same factor. An example of SR item from CHEXI is *'Seldom seems to be able to motivate him-/ herself to do something that he/she doesn't want to do'*. Although SR is a different construct from State regulation, they are related constructs. Both includes components of activation or regulation of the internal state.

completed by the parents and teachers. The matrix of the relationship found is shown in Table 1. All correlational indices were significant. Considering the relationships with the CHEXI, virtually all presented magnitudes greater than .45, except for four measures answered by parents. The total score of the IFERA-I was related with high and very high magnitude to the total score of the CHEXI, considering the responses of the parents and teachers, respectively. In summary, the DA subscale of the IFERA-I presented the greatest discrepancy with the subscales of the CHEXI. In view of the responses of the teachers, there was convergence between all measures of the IFERA-I and the CHEXI. In addition, it should be noted that, considering each respondent, the largest relationships were found among the scales that assess the same construct in both instruments.

Taking into account the contents of the SNAP-IV, there were moderate or strong positive correlations with inattention. Only the WM subscale of the IFERA-I, answered by parents and teachers, and the CF, answered by parents, did not present correlations above .45 with hyperactivity of the SNAP. The total score of the IFERA-I presented a satisfactory level for convergence with both indices of the SNAP, answered by parents and teachers.

Table 1
Pearson Correlation Coefficients (with bootstrapping procedure) among the Scores in the Subscales of the IFERA-I with the CHEXI and SNAP-IV, for both Respondents

IFERA-I		CHEXI					SNAP-IV	
		WM	Plan	SR	IC	Total	Inattention	Hyperactivity/ impulsivity
WM	Parents	**0,74***	0,69*	0,63*	0,42*	0,69*	0,80*	0,37*
	Teachers	**0,89***	0,88*	0,69*	0,62*	0,86*	0,73*	0,37*
IC	Parents	0,53*	0,54*	0,61*	**0,62***	0,62*	0,77*	0,77*
	Teachers	0,64*	0,61*	0,74*	**0,76***	0,76*	0,74*	0,79*
CF	Parents	0,62*	0,57*	0,59*	0,38*	0,59*	0,65*	0,32*
	Teachers	0,83*	0,81*	0,81*	0,66*	0,86*	0,75*	0,54*
StR	Parents	0,66*	0,63*	0,70*	0,54*	0,68*	0,80*	0,57*
	Teachers	0,79*	0,75*	0,87*	0,71*	0,86*	0,82*	0,63*
DA	Parents	0,34*	0,33*	0,44*	0,48*	0,42*	0,49*	0,51*
	Teachers	0,54*	0,49*	0,67*	0,69*	0,66*	0,62*	0,62*
TOTAL	Parents	0,69*	0,66*	0,71*	0,58*	**0,72***	0,85*	0,62*
	Teachers	0,82*	0,79*	0,84*	0,77*	**0,89***	0,83*	0,66*

Note. *p<.001

Factorial structure and internal consistency

Initially, five models were tested for the general sample (with both, the teachers and parents´ data; Table 2). In the first model (MOD-1) the aim was to understand whether the WM, CF, and IC configured themselves as three factors of the first order to a factor of the second order of EF. Along with this last factor, in the same hierarchy, it was also stipulated two more factors, one called Delay Aversion and the other, State Regulation. Finally, a factor of the third order, called 'ADHD Cognition' was included.

According to the parameters adopted for model quality indices, only the significance of the χ^2 did not agree with the expected (p=.037). Thus, it was decided to construct a new model (MOD-2). Five related factors were developed, called WM, CF, IC, DA and StR. This time, the only quality score that was not adequate was the SRMR (.163). It has built up a third unifactorial model (MOD-3), called 'ADHD Cognition', as high correlations were observed among the factors previously established, in order to improve this index. However, there was only a subtle decrease in SRMR (.152) and also the maintenance of the significant value of χ^2 (p=.002).

A fourth model (MOD-4) was built and only two factors have been established, also based on the high correlations found among the factors of the second model. They were denominated (a) Executive Functions and Delay Aversion and (b) State Regulation. However, SRMR value remained similar to the previous model and it was also observed the significant value of χ^2 (p=.001). Finally, it was carried out a two-factor model (MOD-5), with a primary factor, called again 'ADHD Cognition', with five secondary factors, also called WM, CF, IC, DA, and StR. There was a further improvement in the amount of SRMR (.139) but still considered subtle and yet worse than expected.

Table 2
Factor Models Produced for the General Sample and Multigroup Analysis for Parents and Teachers' Samples

Produced models from the total sample of parents and teachers								
MOD-1	**3rd Order Hierarchic:** ADHD Cognition, Three Factors (Executive Functions, Delay Aversion and State Regulation) and Three subfactors for the Executive Functions Factor (Working Memory, Cognitive Flexibility, Inhibitory Control).							
MOD-2	**Five related Factors:** Working Memory, Cognitive Flexibility, Inhibitory Control, Delay Aversion and State Regulation.							
MOD-3	**Unifactor:** ADHD Cognition.							
MOD-4	**Two Factors:** (a) Executive Functions and Delay Aversion and (b) State Regulation.							
MOD-5	**Bifactor:** Primary Dimension: ADHD Cognition; Secondary Dimensions: Working Memory, Cognitive Flexibility, Inhibitory Control, Delay Aversion and State Regulation.							
Models	RMSEA	IC90%	CFI	TLI	χ^2	*p*	*df*	SRMR
MOD-1	0.027	0.007-0.039	0.995	0.994	392.223	0.037	344	0.074
MOD-2	0.000	0.000-0.000	1.000	1.015	247.568	1.000	340	0.163
MOD-3	0.026	0.017-0.033	0.988	0.987	433.079	0.002	350	0.152
MOD-4	0.026	0.017-0.034	0.988	0.986	433.079	0.001	349	0.152
MOD-5	0.000	0.000-0.000	1.000	1.011	256.030	0.997	322	0.139
Multigroup Analysis								
MOD-2/P	0.000	0.000– 0.000	1.000	1.015	247.568	1.000	340	0.163
MOD-2/T	0.000	0.000– 0.000	1.000	1.015	247.568	1.000	340	0.163
CI	0.126	0.121– 0.131	0.802	0.780	2608.306	<0.001	680	0.96

Note. RMSEA=Root Mean Square Error of Approximation; CI=Confidence Interval; CFI=Comparative Fit Index; TLI=Tucker-Lewis Index; χ^2=chi-square; *p*=significance; *df* = degrees of freedom; SRMR=Standardized Root Mean Square Residual; P=Parents; T=Teachers; CI=Configural Invariance

In any case, the models that showed better quality scores were the second and fifth (MOD-2 and MOD-5). The latter presented subtle best value in SRMR. However, when analyzing the solution of its latent variables other indicators that would not ensure its theoretical proposition were checked, with some items' factor loadings indicating Heywood cases (Kolenikov & Bollen, 2012), and others very low, less than .40. Furthermore, the factor loadings mostly showed no significant values (p > .05). Thus, the model chosen for multigroup analysis was the second (MOD-2).

The quality indices of invariance fit of the model for separately groups were mostly adequate, but again only SRMR presented values above expected (.163). Then, it was tested the configural invariance, but the quality indices were mostly bad. This may mean that the items load on different factors in different groups or that the groups produce different numbers of factors or even the two hypotheses. Damasio (2013) states that, in such situations, subsequent tests of invariance measurement should not be conducted anymore, not even groups comparison studies should be considered, as the factor structure of the instrument can not be considered equivalent for all groups. Consequently, the MGCFA analysis was concluded and disregarded for the total sample studied.

However, it was chosen to reproduce the built factor models in order to verify whether they would present appropriate quality indices and could be accepted separately for the samples of parents and teachers. In Table 3, those data can be observed. When analyzed, there are problems regarding the fit's indices related to the significance of χ^2 for the models one, three and four for the parents' sample and SRMR values for all models in the teachers' sample. Thus, it was decided to disregard all models produced for teachers and the non-significant ones for parents. Then, for this latter group, the two and five models were analyzed in order to determine which would be accepted.

As concerns the model 5, it showed discreet better SRMR, however, the same problems seen in the total sample were observed relating to the factor loadings of the items, with Heywood cases (Kolenikov & Bollen, 2012), and others also very low, lower than .40. Moreover, its factor loadings also presented mostly no significant values (p>.05). Thus, the second model (MOD-2) was accepted (Figure 1).

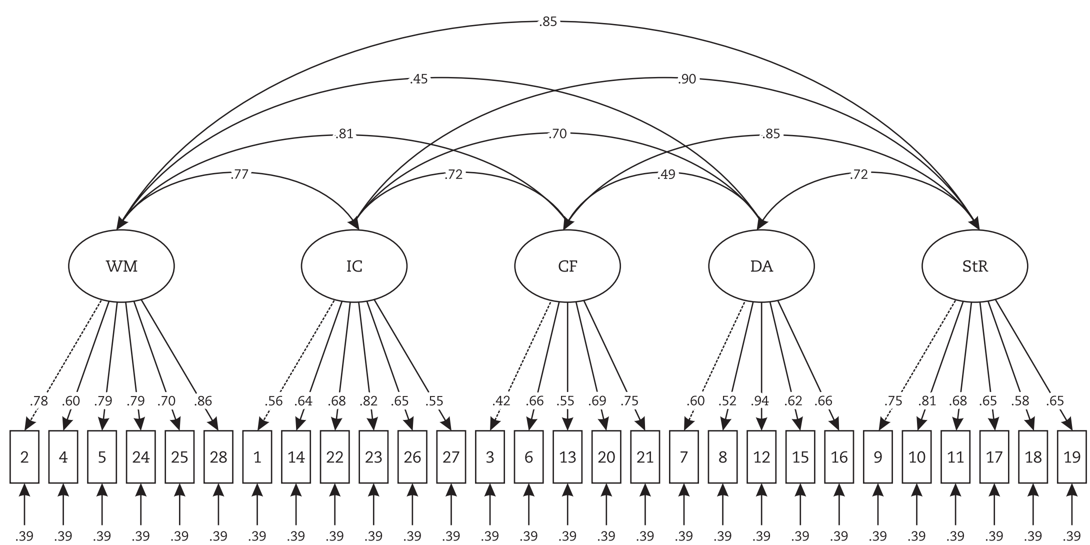
With regard to precision, considering the accepted model (with parents as respondents), the total consistency of the test was ωh=.93 (Confidence Interval (CI) .93 to .96). The internal consistency separately for each factor were also obtained: for WM: ωh=.90 (CI .88 to .92); CI: .83 (CI .80 to .87); CF: .77 (CI .73 to .83); DA: .85 (CI .82 to .89); and StR: .86 (CI .84 to .89).

Table 3
Factorial Models produced for the Independent Samples of Parents and Teachers

Produced Models for the independent samples of parents and teachers									
Models		RMSEA	IC90%	CFI	TLI	χ^2	*p*	*df*	SRMR
MOD-1	P	0.027	0.007-0.039	0.995	0.994	392.223	0.037	344	0.074
	T	0.000	0.000-0.000	1.000	1.037	227.263	1.000	344	0.242
MOD-2	P	**0.013**	**0.000-0.030**	**0.999**	**0.999**	**351.721**	**0.319**	**340**	**0.069**
	T	0.000	0.000-0.000	1.000	1.047	194.987	1.000	340	0.245
MOD-3	P	0.059	0.051-0.067	0.974	0.972	583.242	<0.001	350	0.089
	T	0.000	0.000-0.000	1.000	1.028	260.591	1.000	350	0.228
MOD-4	P	0.059	0.051-0.067	0.974	0.972	582.044	<0.001	349	0.089
	T	0.000	0.000-0.000	1.000	1.028	260.472	1.000	349	0.229
MOD-5	P	0.000	0.000-0.000	1.000	1.008	263.746	0.992	322	0.062
	T	0.000	0.000-0.000	1.000	1.043	195.801	1.000	322	0.212

Note. RMSEA=Root Mean Square Error of Approximation; CI=Confidence Interval; CFI=Comparative Fit Index; TLI=Tucker-Lewis Index; χ^2=chi-square; *p*=significance; *df*=degrees of freedom; SRMR=Standardized Root Mean Square Residual; P=Parents; T=Teachers

Figure 1
Model Representation accepted (MOD-2) for the sample of Parents with standardized data (Bidirectional arrows among factors represent correlations; the directional among the factors and the items represent the factor loadings, all significant, and those that come out independently of the items themselves represent the errors associated with each measure).



Discussion

This study reported the development of the IFERA-I, which incorporates the main cognitive components of the neuropsychology of ADHD and investigated its psychometric properties. Initially, in Study 1, the development of the items was carried out based on theoretical models of EF (Diamond, 2013; Miyake & Friedman, 2012; Miyake et al., 2000), Delay Aversion (Sonuga-Barke, 2003, 2005) and State Regulation (Lijffijt et al., 2005; Sergeant, 2000, 2005), aligned with increasing evidence of the heterogeneity of ADHD (Coghill et al., 2018; Kofler et al., 2019; Luo et al., 2019; Nig et al., 2020; Silverstein et al., 2018). Analysis by the judges revealed concordance of the experts regarding the constructs represented in each item, the clarity of the instructions for teachers and parents, and the general presentation of the instrument, deriving evidence of content validity for the IFERA-I. This step produced the current version of the IFERA-I.

Study 2 investigated evidence of convergent validity, internal structure and consistency in a non-clinical sample. The correlation indices between the IFERA-I and the CHEXI indicated, in general, the convergence necessary to establish this validity evidence, mostly with moderate to high magnitudes, when considering both the responses of the parents and the teachers. Relations between the same domains assessed by different instruments (for the WM and IC of the IFERA-I and CHEXI) were all high and tended to be stronger than those between distinct domains. Hight correlations were also found between the related constructs of StR (IFERA-II) and SR (CHEXI). As in this case, even the between-domain relationships were significant, ranging from low (especially for the DA of the IFERA-I, which established more modest relations with EF domains of the CHEXI) to high. Although understood as relatively independent dimensions (Lambek et al., 2010; Sjöwall et al., 2013; Sonuga-Barke, 2002), there is, in fact, overlapping between the constructs, which can explain the relationships observed. For example, in the model of Sergeant (2000, 2005), state regulation would be based on activation and executive functioning. In turn, delay aversion also requires some executive control (Sonuga-Barke, 2002).

The convergence among the subscales answered by the teachers was slightly higher than among the subscales answered by the parents. These results can suggest that the teachers responded more uniformly and less specific to the different items and scales. This hypothesis needs to be further investigated in future studies, but we believe that this finding could explain also the results of the CFA when considered the answers of the teachers.

In turn, the correlation indices between the Total score of the IFERA-I and the SNAP-IV indicated, in general, a strong pattern of convergence. Inattention symptoms measured by the SNAP-IV presented convergence with all the IFERA-I subscales. Only WM (parents and teachers) and CF (parents) of the IFERA-I showed no consistent relationship with hyperactivity indicators. These findings are consistent with previous studies and theoretical models that show changes in EF (Willcutt et al., 2005; Silverstein et al., 2018; Thorell & Nyberg, 2008), DA (Pauli-Pott & Becker, 2011; Sonuga-Barke, 2002, 2003, 2005) and StR (Huang-Pollock et al., 2017; Sergeant, 2005) associated with ADHD symptoms. However, it should be noted that in the present study these relationships were even observed in a non-clinical sample. Although it is complex to identify patterns, StR and WM had a stronger association with inattentiveness indicators, while inhibition was more strongly associated with hyperactivity indicators.

From the CFA, the suitability of the model was observed when considering only the responses of parents. In this case, a model with five independents, but related, factors could be accepted, confirming the interdependence of the constructs under analysis. The generated model from the parents' responses also presented good internal consistency for both total scale and for each subscale. Thus, interpretations regarding the results are relatively free of bias that could be determined by the specificity of the items.

Our analyses were unable to confirm a model when considering the responses of teachers (and hence the general sample with both respondents) and several can be the variables that contributed to this, including the number of responses obtained from these respondents and their own characteristics. For example, stronger relationships were observed between the data when considering the teachers compared to the parents. This high consistency of response may have led to CFA outcomes.

It is also possible that context (home x school) could be a variable we need to consider in more detail in our proposal for a functional measure. In this sense, it would demand items developed specifically for school contexts. That is, although the judges considered the items suitable for teachers and parents, it is possible that some of them may be more appropriate for one of the contexts, or it is possible that the behaviors included in the items can be more or better observable at home, for example. Future studies need to deep comprehension on how the instrument and items work especially for teachers as respondents. It includes larger samples (we had lower rate of responses from teachers) and reflection, as well as empirical verification, on the ability of teachers at different school grades to provide information about their students. For example, it is important to consider how appropriate the items and the instrument are to be answered by teachers from the 6th year onwards. This is because after that school level, children start to have teachers per discipline and no longer one conductor per class. This impacts the time the teacher spends with the child and can impact their ability to provide accurate information about the functioning and difficulties of each child. Not having considered this specificity of the school levels is a limitation of the study.

Aspects as those mentioned above may have impacted our findings and would explain the difficulty in corroborating a model using the teacher answers. Future studies should attempt to broaden the sample of teachers to better investigate the instrument structure. If the same results are found, it may need to develop different versions of the instrument for teachers and parents, which better specify the construct in each item context, or even to review both, items and subjacent theoretical structure. Also, considering that in clinical samples the dissociations between the constructs may be more evident, it is essential that further studies could be conducted with ADHD groups.

In summary, the results of this first investigation with the IFERA-I suggest that the instrument has evidence of content validity and shows patterns of convergence with instruments that assess same and related skills (CHEXI and SNAP-IV). However, internal structure and reliability deserve more attention. With respect to its internal structure, the theoretical model of five related but independent constructs was corroborated from the responses of the parents, but not the teachers. For the accepted model, thus considering only responses of the parents, IFERA-I shows satisfactory reliability. In this sense, such evidence strengthens the indication of IFERA's use to collect information from parents, but its reliability and internal structure from teacher's responses could not be confirmed.

The limited number of participants and the absence of some controls in Study 2, including intelligence and socioeconomic status, should be also mentioned as limitation. Since we do not apply exclusion criteria for our sample, it is possible that some variability in functioning in the assessed constructs could be due to some eventual participant with intellectual disability (Hronis et al., 2017). Also, our sample was derived from private schools. In Brazil, the type of school is associated with socioeconomic status (Engel de Abreu et al., 2015), a variable associated with some of our constructs, as EF, and neuropsychological development in general (Farah, 2018). It is possible that extend sample to include public school's children could impact variability of data and, as consequence, covariances between them.

Nevertheless, this study is the first one performed with IFERA-I, presenting a new measure with potential clinical utility in the sense that can be a useful tool to identify characteristics associated with the ADHD phenotype that can be specifically targeted for interventions or even assist in diagnostic purposes. It is important, however, to highlight that the IFERA-I does not contemplate and did not intend to contemplate all the heterogeneity of explanatory models of ADHD, such as the deficit in temporal processing. Despite that, from our actual knowledge, IFERA-I is the unique tool that integrates distinct theoretical models in the understanding of ADHD's cognition, considering elements of its heterogeneity (Nig et al., 2020; Wagner et al., 2016). A functional measure that can help to identify patters of functioning and guide treatment decisions would be quite useful, regardless if these impairments are specific or not to ADHD. At this point, although the development of IFERA has been based on ADHD cognitive models, it is reasonable to consider that the final version of the scale could be useful to evaluate children without a diagnosis of ADHD, in a context of neuropsychological assessment of the constructs addressed by the scale. For that, further studies are needed to analyze psychometric parameters in this case.

Future studies should deepen psychometric and utility data of the measure. In this sense, investigations should look for convergent validity of its subscales with performance tests of each construct, to give more support for IFERA-I's ability to measure the specific constructs of EF, StR and DA. Also, it is important to understand the relationships with similar or other measures in clinical samples, what will provide us more clarity about the utility of the measure to provide useful information to guide or select treatment above and beyond current measures. Lastly, it is desirable an investigation of IFERA-I's construct validity and theoretical structure in ADHD. These are the next steps for investigation. From this paper, the originality of a functional instrument, focused on capture aspects of daily functioning of children (Zan et al., 2018), that integrates theoretical models in order to better address the complexity of ADHD neuropsychology can be highlighted.

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Authors' contributions

We declare that all authors participated in the preparation of the manuscript. Specifically, the authors Bruna T. Trevisan and Alessandra G. Seabra participated in the initial writing of the study (conceptualization, investigation and visualization); the author) Arthur A. Berberian, Natália M. Dias and Rauni José Roama-Alves participated in the data analysis; and the authors Natália M. Dias and Alessandra G. Seabra participated in the final writing of the paper (review and editing).

Availability of data and materials

All data and syntax generated and analyzed during this research will be treated with complete confidentiality due to the Ethics Committee for Research in Human Beings requirements. However, the dataset and syntax that support the conclusions of this article are available upon reasonable request to the principal author of the study.

Competing interests

The authors declare that there are no conflicts of interest.

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