Patrícia Silva Lúcio

TDAH, LEITURA E ESCRITA: MODELOS NEUROPSICOLÓGICOS E INVARIÂNCIAS

Tese apresentada à Universidade Federal de São Paulo – Escola Paulista de Medicina, para obtenção do título de Doutor em Ciências.

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Lista de Abreviaturas

2C-RT	*Two-Choice Reaction Time task*
a	*boundary sepparation* (Parâmetro de cautela)
β	Coeficiente padronizado
ABEP	Associação Brasileira de Empresas de Pesquisas
ADHD	Attention-deficit/hyperactivity disorder
ANOVA	Analysis of Variance
APA	American Psychiatric Association
BIP	Processamento básico de informação
Boot	Bootstrapping
CAPA	*Child and Adolescent Psychiatric Assessment*
CI	Confidence Interval
CID	Classificação Internacional de Doenças
CFA	Análise fatorial confirmatória
CFI	*Comparative fit index*
CNPq	Conselho Nacional para o Desenvolvimento da Pesquisa
DIF	*Differential item Functioning*
DAWBA	*Development and Well-Being Assessment*
DISC	*Diagnostic Interview Schedule for Children*
DSM	Manual Diagmóstico Estatístico dos Transtornos Mentais
FAPESP	Fundação de Amparo à Pesquisa do Estado de São paulo
FHS	*Family History Survey*
ICC	Intraclass Correlation Coefficient
IQ	*Intelligence Quotient*
LLCI	*lower confidence bound*

MGCFA	Análise fatorial confirmatória para múltiplos grupos
MIMIC	*Multiple indicators, multiple causes*
s.d.	Standard Deviation
SES	Nível socioeconômico
RAN	*Rapid Automatized Naming*
RMSEA	*Root mean square error of approximation*
TDAH	Transtorno de déficit de atenção/hiperatividade
TDE	Teste de Desempenho Escolar
T_{er}	*Non-decision time* (Parâmetro de codificação e resposta motora)
TLI	*Tucker-Lewis Index*
v	*Drift rate* (parâmetro de qualidade da evidência a partir do estímulo)
WM	*Working Memory*
VSWM	*Visuospatial working memory*
VWM	*Verbal working memory*
WISC-III	*Wechsler Intelligence Scale for Children 3rd edition*
WLSMV	*Means and Variance Adjusted Weighted Least Squares Estimation*
WRMR	*Weighted root mean residual*
χ^2	*Chi-squared*
ULCI	*Upper confidence bound*

Resumo

Uma importante questão de pesquisa centra-se no estudo das comorbidades entre transtornos mentais. Diversos tipos de modelos têm sido desenvolvidos para esclarecer esta interrelação. Além disso, os achados de estudos que determinam a prevalência de transtornos em diferentes populações geralmente fazem uso de comparações diretas entre os indivíduos que compõem essas populações. O presente estudo utiliza um modelo neuropsicológico para demonstrar uma relação preditiva entre os sintomas de TDAH e as dificuldades da aprendizagem da leitura. Também atesta para a validade das comparações entre sujeitos com e sem TDAH a partir da análise de invariância entre medidas. Sendo assim, esta tese é composta por dois estudos distintos, ambos realizados a partir de uma amostra comunitária de crianças e adolescentes com QI estimado normal (≥70) pertencentes a 66 escolas públicas de São Paulo e Porto Alegre. Os participantes (n = 1857; 6-15 anos; 47% meninas) foram avaliados quanto à leitura, escrita, memória de trabalho (visoespacial e verbal) e uma tarefa de escolha forçada de BIP (2C-RT). Os sintomas de TDAH foram avaliados por meio do DAWBA. O Estudo 1 teve por objetivo investigar o feito mediador de uma medida de discriminação do estímulo (*mean drift*) nas relações entre os sintomas de TDAH e as habilidade de leitura. O sexo, o nível socioeconômico e a memória (verbal e visoespacial) foram covariáveis e a idade foi moderadora da relação. Em um modelo de moderação moderada, a capacidade de discriminação do estímulo mediou o efeito dos sintomas de TDAH na leitura e esse efeito indireto foi moderado pela idade (o efeito foi maior entre as crianças menores). Os achados dão suporte à hipótese de que o TDAH e a habilidade de leitura estão ligados, nas crianças jovens, por um déficit neuropsicológico relacionado à capacidade de discriminação do estímulo. O Estudo 2 objetivou avaliar a invariância de medidas de leitura e de escrita entre subpopulações de crianças com TDAH e com desenvolvimento típico. Participaram do estudo 1.935 crianças com e sem diagnóstico de TDAH (47% meninas; 11% TDAH). A invariância da mensuração foi investigada por meio de análises fatoriais confirmatórias para múltiplos grupos (MGCFA) e por funcionamento diferencial de itens (DIF) por meio de modelos MIMIC. Por meio de ambos os métodos, a invariância das medidas de leitura e de escrita foi atestada, demonstrando a comparabilidade de grupos de crianças com e sem TDAH nessas tarefas. As repercussões dos estudos para investigações futuras sobre as relações entre as habilidades de leitura e de escrita e os sintomas de TDAH são discutidas.

Palavras-chave: TDAH; leitura; escrita; processamento básico de informação; mediação moderada; invariância de mensuração.

Abstract

An important research question focuses on the study of comorbidity among mental disorders. Different models have been developed to clarify this interrelation. Furthermore, the findings of studies that determine the prevalence of disorders in different populations generally use direct comparisons between the individuals that compose these populations. This study uses a neuropsychological model to demonstrate a predictive relationship between ADHD symptoms and difficulties of learning to read. In addition, it attests to the validity of the comparisons between subjects with and without ADHD through measurement invariance analysis. Thus, this dissertation is composed of two separate studies, both performed from a community sample of children and adolescents with normal estimated IQ (≥70) belonging to 66 public schools of São Paulo and Porto Alegre. Participants (n = 1857; 6-15 years; 47% female) were evaluated in reading, spelling, working memory (visuospatial and verbal), and a forced choice task BIP (2C-RT). ADHD symptoms were evaluated by the DAWBA. Study 1 aimed to investigate the mediation effect of a measure of stimulus discriminability (mean drift) in the relationship between the symptoms of ADHD and reading skills. Sex, socioeconomic status, and memory (verbal and visuospatial) were covariates, and age was the moderator. In a moderated-mediation model, the stimulus discriminability mediated the effect of ADHD symptoms on reading and this indirect effect was moderated by age (the effect was greater among younger children). The findings support the hypothesis that ADHD and reading skills are linked, in young children, for a neuropsychological deficit related to stimulus discrimination capacity. Study 2 aimed to evaluate the invariance of reading and spelling measures between subpopulations of ADHD and typically developing children. The study included 1,935 children with and without ADHD diagnosis (47% girls; 11% ADHD). The invariance of the measurement was investigated by factor analysis for multiple groups (MGCFA) and differential item functioning (DIF) via MIMIC models. Through both methods, the invariance of the reading and spelling measures was certified, demonstrating the comparability of groups of children with and without ADHD in these tasks. The impact of this study for future research on the relationship between reading and spelling skills and the symptoms of ADHD is discussed.

Keywords: ADHD; reading; spelling; basic processing information; moderated-mediation; measurement invariance.

1. INTRODUÇÃO

O Transtorno de déficit de atenção/hiperatividade (TDAH) é uma desordem neurodesenvolvimental caracterizada por um padrão persistente de desatenção, hiperatividade e/ou impulsividade que pode afetar crianças, adolescentes e adultos (American Psychiatric Association [APA], 2013). Trata-se de um dos transtornos mais comuns na infância e sua prevalência tem crescido nos últimos anos (Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014). A prevalência estimada do TDAH entre a população de crianças é de 3-7%, sendo que os meninos são mais afetados do que as meninas, em uma proporção de 2:1 (Barkley, 2014).

Há uma extensa literatura concernente às dificuldades de aprendizagem associadas aos sintomas de TDAH (p. ex., Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2015; Birchwood & Daley, 2012; Weyandt et al., 2013; Wu & Gau, 2013). Em uma meta-análise utilizando 72 estudos publicados a partir de 1990, Frazier, Youngstrom, Glutting e Matkins (2007) mostraram que indivíduos com TDAH apresentam um desempenho acadêmico menor do que controles, sendo que este efeito, apesar de alto em geral (d = 0,71), é maior para amostras de crianças (d = 0,74) do que de adultos (d = 0,57). O domínio de habilidade investigado também produz diferenças, sendo maior para a leitura (d = 0,73) do que para a aritmética (d = 0,67) ou a escrita (d = 0,55).

Os consistentes resultados ligando o TDAH a problemas de aprendizagem geraram algumas hipóteses a respeito da relação entre as duas condições. Alguns autores (p. ex., Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005; Willcutt et al., 2010) argumentam que tanto o TDAH quanto as habilidades de leitura e de escrita compartilham alguns déficits genéticos, cognitivos e neuropsicológicos. Este constitui um dos temas da presente tese, que pretende investigar alguns fatores neuropsicológicos subjacentes aos sintomas de TDAH e as habilidades de leitura.

Algumas medidas neuropsicológicas apresentam déficits tanto em crianças com TDAH quando em sujeitos com dificuldades de leitura. Por exemplo, as crianças com TDAH apresentam dificuldades em múltiplos componentes na memória de trabalho (espacial, verbal e executivo central) em relação a controles (Holmes et al., 2014; Martinussen, Hayden, Hogg-Johnson, Tannock, 2005), da mesma forma que crianças com dificuldades de leitura (de Jong, 1998; Siegel & Ryan, 1989; Swanson & Ashbaker, 2000). Problemas na velocidade de processamento também têm sido apontados como uma característica cognitiva tanto do TDAH quanto na dificuldade de leitura (Willcutt et al., 2005; 2010). Ademais, alguns estudos encontraram que as dificuldades de leitura se concentram mais entre as crianças com TDAH predominantemente desatentas (e.g., Cain & Bignell, 2014; Czamara et al., 2013).

O foco do primeiro artigo que compõe esta tese, aqui chamado de Estudo 1, constitui a investigação da relação entre o TDAH e as habilidades de leitura, por meio da mediação de medidas de processamento básico de informação (BIP). Estudos recentes (p. ex., Metin et al., 2013; Salum et al., 2014) têm demonstrado que as crianças com TDAH são mais lentas e menos acuradas em tarefas de escolha forçada de BIP, quando comparadas a controles. Além disso, análises por modelos de difusão (White, Ratcliff, Vasey, & McKoon, 2010) demonstraram que tal desempenho é devido à ineficácia no processamento de informações perceptuais (i.e., uma baixa habilidade de coletar informações a partir do estímulo ou a capacidade de acumular informações).

Utilizando análises por modelo de difusão e tarefas de decisão lexical, alguns estudos investigaram o papel da eficiência no acúmulo de informações em amostras de indivíduos com dificuldades de leitura. Tais estudos demonstraram que problemas na aquisição da leitura estão associados com uma menor eficiência de processamento em tarefas de decisão lexical (Ratcliff, Perea, Colangelo, & Buchanan, 2004; Zeguers et al., 2011).

Apesar de estudos na leitura terem focado em tarefas de decisão lexical, a hipótese do Estudo 1 é que uma baixa eficiência em processar as informações do estímulo em tarefas de BIP (conhecido como o parâmetro *mean drift*) funciona como um mediador entre os sintomas de TDAH e as habilidade de leitura. Para atingir este objetivo, utilizou-se uma nova estatística denominada PROCESS ANALYSIS (Hayes, 2013). Esta estatística é baseada em regressões que se aplicam a modelos que simultaneamente combinam mediação e moderação (também chamada de interação). Desta forma, a hipótese é que o parâmetro *mean drift* deverá funcionar como mediador da relação entre os sintomas de TDAH e a habilidade de leitura, sendo que esta relação indireta seria adicionalmente moderada pela idade. O modelo foi testado com as variáveis de controle QI, sexo, nível socioeconômico e memória de trabalho (verbal e visuoespacial). O efeito indireto moderado pela idade mostrou-se significativo para além dos efeitos das variáveis de controle supracitadas, confirmando a primeira hipótese do estudo.

A segunda questão de pesquisa desta tese recai sobre a extensão em que podemos confiar nos resultados das pesquisas que fazem uso de comparações entre grupos de indivíduos com e sem TDAH em tarefas de leitura e de escrita. Este tema será explorado no Estudo 2. A questão da comparabilidade entre subpopulações de indivíduos tem recebido recentemente a atenção de pesquisadores de diversas áreas e relaciona-se à invariância da mensuração. A invariância da medida refere-se ao grau em que podemos confiar que o mesmo construto está sendo medido em dois ou mais grupos de interesse, por exemplo, nas comparações realizadas entre indivíduos de diferentes sexos, idades, culturas ou condições clínicas (Chen, 2008). Para Milfont e Fischer (2015), é infundada a pressuposição de que grupos de comparação, mesmo submetidos a uma mesma medida (p. ex., teste, escala), apresentam a mesma representação do construto avaliado, sendo que é necessário investigar esse pressuposto por meio de demonstrações empíricas.

Segundo Brown (2015), a invariância de mensuração tem sido investigada por meio de duas técnicas principais. A primeira constitui a análise fatorial confirmatória para múltiplos grupos (MGCFA) que é usada para dados escalares e investiga em que medida que um dado modelo teórico corresponde à estrutura observada em duas ou mais amostras determinadas. A segunda constitui os modelos MIMIC, acrônimo do inglês "*multiple indicators, multiple causes*", em que as medidas indicadoras são regredidas às covariáveis que representam o grupo de subpopulações, por esta razão também conhecida como análise fatorial confirmatória (CFA) com covariáveis; uma de suas vantagens frente ao MGCFA, é que o MIMIC permite acomodar covariáveis de natureza para além de serem categóricas, por exemplo, contínuas. Para o seguinte estudo, nosso interesse é investigar não apenas o status dicotômico das crianças em serem classificadas como TDAH ou controle, mas sim, considerar o TDAH como um espectro contínuo.

No Estudo 2 desta tese, ambos os tipos de invariância foram investigados. A questão que se colocou é se crianças em idade escolar com e sem TDAH representam, da mesma maneira, os construtos das habilidades de leitura e de escrita, avaliados pelos respectivos subtestes do Teste de Desempenho Escolar (TDE; Stein, 1994). Para os modelos de CFA, utilizou-se como estratégia a investigação de três tipos de invariância: configural, escalar e escalar versus estrutural (Muthén & Muthén, 2012). No primeiro caso, investigou-se se os construtos ou habilidades de leitura e escrita eram representados de forma unidimensional para ambos os grupos de criança, com e sem TDAH. Partiu-se do pressuposto da unidimensionalidade tanto das habilidades de leitura quanto da escrita, haja vista que um estudo recente atentou para a unidimensionalidade de ambos subtestes avaliados (Knijnik, Giacomoni, Zanon, & Stein, 2014). A invariância escalar investiga se a dificuldade e a discriminação dos itens são as mesmas para as subpopulações, enquanto que o terceiro tipo de invariância investiga se os índices de ajuste do modelo mais estrito (escalar) piora ou não em relação ao modelo menos estrito (configural).

Os resultados dos modelos de CFA apontaram para a invariância das medidas entre os grupos de crianças com e sem TDAH e comparações entre as médias dos traços latentes apontaram para uma diferença significativamente menor nas habilidades de leitura e de escrita do grupo de crianças com TDAH. Os modelos MIMIC considerando o TDAH como medida contínua confirmaram os resultados da CFA, demonstrando que não houve funcionamento diferencial dos itens das tarefas de leitura e de escrita em função da classificação diagnóstica da criança (ou seja, pode-se confiar que as crianças com diferentes quantidades de sintomatologia de TDAH apresentam significativamente menor habilidade de leitura e de escrita do que as crianças típicas e que as diferenças oriundas das comparações realizadas entre os grupos não são devidas a um artefato estatístico por características do instrumento de medida).

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3. ESTUDO 1 – EFEITO MEDIADOR DE MEDIDAS DE PROCESSAMENTO BÁSICO DE INFORMAÇÃO NAS RELAÇÕES ENTRE SINTOMAS DE TDAH E HABILIDADES DE LEITURA

O artigo tem como título original “Poor stimulus discriminability as a common neuropsychological deficit between ADHD and reading ability in young children: a moderated mediation model”. Foi recentemente aceito pela revista *Psychological Medicine* e apresenta os seguintes autores: Lúcio, P. S., Salum, G. A., Rohde, L. A., Swardfager, W., Gadelha, A., Vandekerckhoveh, J.; Pan, P. M., Polanczyk, G. V., Rosario, M. C., Jackowski, A. P., Mari, J. J., Cogo-Moreira, H.

3.1. Poor Stimulus Discriminability as a Common Neuropsychological Deficit between ADHD and Reading Ability in Young Children: A Moderated Mediation Model

Abstract

Attention-deficit/hyperactivity disorder (ADHD) is frequently associated with poorer reading ability (RA); however, the specific neuropsychological domains linking this co-occurrence remain unclear. This study evaluates information-processing characteristics as possible neuropsychological links between ADHD symptoms and RA in a community-based sample of children and early adolescents with normal IQ (≥ 70). The participants (n = 1857; aged 6 to 15; 47% female) were evaluated for reading ability (reading single words aloud) and information processing (stimulus discriminability in the two-choice reaction time task [2C-RT] estimated using diffusion models). ADHD symptoms were ascertained through informant (parent) report using the Development and Well-Being Assessment (DAWBA). Verbal working memory (VWM; digit span backwards), visuospatial working memory (VSWM; Corsi Bloks Backwards), sex, socioeconomic status, and IQ were included as covariates. In a moderated mediation model, stimulus discriminability mediated the effect of ADHD on reading ability. This indirect effect was moderated by age such that a larger effect was seen among younger children. The findings support the hypothesis that ADHD and reading ability are linked among young children via a neuropsychological deficit related to stimulus discriminability. Early interventions targeting stimulus discriminability might improve symptoms of inattention/hyperactivity and reading ability.

Keywords: ADHD, reading ability, moderated-mediation, diffusion model.

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is characterized by a persistent pattern of inattention, hyperactivity, and/or impulsivity symptoms (APA, 2013). Most patients with ADHD present with co-morbid psychiatric disorders in youth, including oppositional defiant, conduct, anxiety, and/or learning disorders (Angold et al., 1999; Biederman, Newcorn, & Sprich, 1991; Murphy, & Barkley, 1996; Pliszka, 1998).

The impairments associated with ADHD are particularly relevant to school-aged children due the potential impact on future occupational and social achievements (Sciberras, Roos, & Efron, 2009). In this context, a better comprehension of comorbid learning disorders in ADHD patients is especially relevant to develop more appropriate interventions (Stanford, & Tannock, 2012). Studies have presented comorbidity rates between ADHD and learning disorders that range from 10% to 90%, depending on the methodology, which differ in sample selection procedures and diagnostic criteria for both disorders (Biederman et al., 1991; DuPaul, Gormley, & Laracy, 2013; Fortes et al., 2015).

Some authors (e.g., Willcutt, Pennington, Olson, Chhabildas, & Hulslande, 2005; McGrath et al., 2011) argue that the frequent comorbidity reported between ADHD and reading disability may be attributed to shared cognitive deficits. Competing models have tried to explain such comorbidity (e.g., Neale & Kendler, 1995) and, to this end, the present study takes a neuropsychological approach (e.g., Willcutt et al., 2005; Rucklidge & Tannock, 2002). Specifically, this study aims to investigate the relationship between ADHD symptoms and reading ability through a moderated mediation model, which considers stimulus discriminability as a link accounting for this relationship, which is conditional upon age. For this purpose, ADHD symptoms and reading ability were both measured as a continuous trait (raw scores in their respective scales) and stimulus discriminability was assessed through diffusion model parameters derived from a basic processing efficiency task. First, we briefly describe the parameters of the diffusion model (e.g., Ratcliff, 1978). Second, we synthesize the research findings about how diffusion model parameters (stimulus discriminability in particular) are related to ADHD and reading disability. Finally, we present the research problem of the study and our main hypothesis.

The Diffusion Model: Overview

There is a wide range of competing models that describe the process of making simple, binary decisions (e.g., Brown, & Heathcote, 2008; Usher, & McClelland, 2001; Wagenmakers, Van Der Maas, & Grasman, 2007). We focus on the well-validated diffusion model of Ratcliff and colleagues (e.g., Ratcliff, 1978; Ratcliff, & McKoon, 2008; White, Ratcliff, Vasey, & McKoon, 2010). Diffusion models have been used to interpret behavioral and neuropsychological data taking into account both accuracy and speed for correct and incorrect answers (Ratcliff & McKoon, 2008). For that reason, the models provide advantages over the classical cognitive analysis of RT by decomposing the stages of processing used by the subject to make simple choices. They are applicable broadly to tasks that illicit decisions of the binary type (White et al., 2010). The binary response involves three different processes, namely, encoding the stimulus, decision-making and execution of the response.

The diffusion model focuses on the decision process. The model supposes that the binary decision occurs after a certain accumulation of information that results from noisy evidence. It encompasses different cognitive parameters that represent the three stages of processing: first, the encoding/motor response parameter (T_{er}) that is not part of the decision process; second, the boundary separation parameter (*a* or *0*) that represents one of the poles of decision (yes/no, go/no-go, etc.) starting from the origin *z*; and finally, the drift rate parameter (*v*) that represents the quality of evidence of the stimulus.

The parameter *a* indexes the response style (greater values indicate a cautious answer style and lower values, an impulsive pattern of response). As T_{er} encompasses two different processes (i.e., encoding and motor response) its interpretation is not straightforward. With respect to the drift rate parameter, *v*, larger drift rate values indicate an easier classification of the stimulus proposed by the specific test (because drift rate assess the quality of evidence from the stimulus, the higher its value, faster and more accurate are the responses). For a complete explanation of the model, see Ratcliff and McKoon (2008) and White et al. (2010).

ADHD and the Diffusion Model Parameters

Children with ADHD and comparison subjects consistently differ in their capacity for basic processing, as measured for instance by simple two-choice reaction time tasks (Metin et al., 2013; Salum et al., 2014a, 2014b). Results for the parameters a and T_{er}, however, have been less consistent. Metin et al. (2013) and Salum et al. (2014a, 2014b) found that children with ADHD have poorer drift rates and faster non-decision times in two-choice RT tasks compared with controls. In both studies, no differences were found in boundary separation. Similarly, Karalunas, and Huang-Pollock (2013) found the same pattern of results using working memory and executive function tasks. In a meta-analysis, Huang-Pollock et al. (2012) estimated the EZ-diffusion model parameters from 12 studies and showed that drift rate values are smaller for ADHD than controls in sustained attention on the Continuous Performance Task but the groups did not differ in boundary separation or non-decision time.

Reading Disability and the Diffusion Model Parameters

Although reported yet in a small number of studies, diffusion models have been used to compare cognitive results from normal and impaired readers with interesting results (Ratcliff, Perea, Colangelo, & Buchanan, 2004; Zeguers et al., 2011). Those studies suggested that while encoding representations with a poor quality of evidence from stimuli is associated with problems in reading acquisition, more time spent in non-decision processes is linked with acquired dyslexia. In addition, a more cautious pattern of response (> *a*) may be a common deficit in both acquired and developmental dyslexia.

Another source of evidence about the developmental role of drift rates in normal development comes from studies of aging. Ratcliff, Love, and Thomson (2012) suggest that the U-shaped lifespan curve of RT development in which children and older adults present slower response times has a different explanation in the diffusion model. While slower RT in children is due to lower drift rates compared with young adults, in older adults it is due to cautious answers or greater values for the *a* parameter (Ratcliff, Spieler, & Mckoon, 2000; Thapar, Ratcliff, & McKoon, 2003) and also slower encoding/motor responses (McKoon & Ratcliff, 2016). From the results of these studies, we may speculate that in normal development, the drift rate rises from childhood toward a plateau in adulthood, whereas slower ascent towards, or a lower maximal value of this plateau may be attained in abnormal development (e.g., dyslexia).

ADHD, Reading Disability, and Diffusion Model Parameters: The Research Problem

As discussed in the previous sections, research findings from lexical decision tasks tend to suggest a lower drift rate in reading disability, and lower drift rates in basic information processing (BIP) tasks are seen in ADHD. Although lexical decision making and BIP tasks measure different cognitive processes, both rely on a common ability to encode visual information (either orthographic or perceptual). Therefore, it is reasonable to postulate that diffusion model parameters may provide interesting data on the reading skills of children with ADHD. Here, we hypothesize that low drift rate values may function as a shared deficit between ADHD symptoms and poorer reading performance.

The main goal of the present study is to test a mediation effect of drift rate in the relationship between ADHD symptoms and reading performance. It has been established that drift rate is influenced by age in lexical decision tasks (e.g., Ratcliff et al., 2012); therefore, age may function as a moderator of the relationship between drift rate on reading ability. Our hypothetical model therefore links ADHD symptoms to reading skills via an indirect path that includes drift rate (a mediator), which will differ as a function of age (moderator), resulting in a conditional indirect effect. Figure 1 depicts the second stage moderated mediation model to be tested (Hayes, 2013). Traditional confounding variables of relevance (i.e. sex, IQ, socioeconomic status (SES), will be considered as general covariates. Additionally, we considered verbal and visuospatial working memory as covariates because verbal working memory is a predictor of reading ability (Swanson, Zheng, & Jerman, 2009) and recent studies have suggested that the role of visuospatial WM in reading might be more important than previously thought (Pham & Hasson, 2014).

<Insert Figure 1>

For testing the discriminant validity of the moderated mediation model, models for the a and T_{er} parameters were also assessed. The association between ADHD symptoms, reading ability, and the a and T_{er} parameters are less clear than the relationship with drift rate. A cautious pattern is associated with responses of people with dyslexia, aphasia, and children with normal development in reading tasks (Ratcliff et al., 2004, 2012; Zeguers et al., 2011), whereas no study has shown an association between *a* and ADHD symptoms (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Karalunas & Huang-Pollock, 2013; Metin et al., 2013; Salum et al., 2014a). For this reason, caution may not function as a link between ADHD and reading ability. For the non-decision time parameter, contradictory results have been found both for ADHD and reading studies. Metin et al. (2013) and Salum et al. (2014a; 2014b) reported faster T_{er} values for ADHD samples, while Huang-Pollock et al. (2012) did not find any difference. On the other hand, lower non-decision times were found in childhood and aphasic samples compared to adults (Ratcliff et al., 2004; 2012), but dyslexic children and poor readers do not differ from controls (Zeguers et al., 2011). For this reason, the T_{er} parameter is less likely to explain the link between ADHD and reading ability.

As no *a priori* assumptions are made about the relationship between the *a* and T_{er} parameters and age (because results from the literature are less consistent for them), a simple mediation model will be tested (Figure 2). In contrast to drift rate, we hypothesize that the parameters T_{er} and *a* will not mediate the relationship between ADHD and reading ability.

<Insert Figure 2>

Methods

Participants

The Ethical Committee of the Federal University of Sao Paulo approved the study (protocol number 1.327.777/15). For this specific study, we used the baseline wave of a large longitudinal community school-based study from Brazil (Salum et al., 2015). Parents gave written consent for the children to participate, and children gave verbal assent.

Detailed information about the recruitment of the sample is available elsewhere (Salum et al., 2015). In summary, this sample of children attending second to ninth grades in 63 schools in the cities of São Paulo and Porto Alegre. From an original set of 8,802 parents who answered the Family History Survey (FHS; Weissman et al., 2000), we recruited 1524 children with high-risk for mental disorders and 958 randomly selected children for evaluation (N = 2,482). The final sample was composed of 1,857 participants (61.20% from the high-risk group) after excluding children with low IQ (< 70), those attending first grade, those who did not complete all tasks, and outliers at the diffusion model analysis. Therefore, 25.18% of the 2,482 children were excluded.

The age range was between 6 and 15 years old (mean = 9.81, s.d. = 1.86) and 47% of the children were female. Socioeconomic status (SES) was defined following the Associação Brasileira de Empresas de Pesquisas (ABEP; 2010). The ABEP system of socioeconomic classification is a scale ranging from zero to 46 points, which corresponds to a categorization of eight classes ranging from A1 to E. In our sample, mean ABEP scores were 20.15 (s.d. = 4.73, minimum = 04, maximum = 40).

Measures

ADHD symptoms. ADHD symptoms were estimated from the "Attention and Activity" section of the Development and Well-Being Assessment (DAWBA; Goodman, Ford, Richards, Gatward, & Meltzer, 2000), with no skipping rules. DAWBA is a structured informant interview designed to generate ICD-10 and DSM-IV psychiatric diagnoses for children and adolescents. It is a valid and reliable tool for psychiatric diagnose (e.g., Angold, Erkanli, Copeland, Goodman, Fisher, & Costello, 2012; Goodman, Heiervang, Collishaw, Goodman, 2011). For the present study, we used the validated Brazilian version of the instrument (Fleitlich-Bilyk & Goodman, 2004). Trained lay interviewers administered the instrument to biological parents (87.5% mothers). For the statistical analysis, dimensional inattention and hyperactivity-impulsivity scores (i.e., ADHD symptoms) were derived from DAWBA´s attention and activity section (mean = 8.64, s.d. = 8.67, minimum = 0, maximum = 36). In our database, 201 students met criteria for a full ADHD DSM-IV diagnoses (35.82% predominantly inattentive; 13.43% predominantly hyperactive/impulsive; 36.82% combined subtype; and 13.93 other type).

Basic information processing task. Basic information processing (BIP) was evaluated in a Two-Choice Reaction Time task (2C-RT), which measures the ability to perform very basic perceptual decisions by pressing a button to indicate the direction of an arrow (right or left). There were 100 presentations of the arrow, half on the right and half on the left side of the computer screen. The stimulus duration was 100 ms and the inter-trial interval was 1500 ms. Task instructions emphasized both speed and accuracy. Participants received no rewards or feedback. Diffusion model parameters were estimated for stimulus discriminability (drift rate, v), cautious answering (boundary separation, a) and non-decision time (T_{er}). Correlations between the diffusion model parameters and mean RT and standard deviation RT are within expectations (v: mean = 0.31, s.d. = 0.16, minimum = -0.39, maximum = 0.68; a: mean = 0.12, s.d.= 0.03, minimum = 0.03, maximum = 0.23; T_{er}: mean = 0.25, s.d. = 0.12, minimum = -0.18, maximum = 0.78; data are available upon request).

Reading ability. Reading ability was assessed using the reading subtest of the School Performance Test (Stein, 1994), which contains one card presenting 70 isolated words. The validity and reliability of the subtest and its items have been previously established (e.g., Cogo-Moreira et al., 2013; Lúcio & Pinheiro, 2014; Athayde, Giacomoni, Zanon, & Stein, 2014). Internal consistency (Cronbach's alpha coefficient) is fair (0.80). As with ADHD symptoms, we used the sum of the reading raw scores for data analysis (mean = 54.82, s.d. = 20.04, minimum = 0.0, maximum = 70).

Intelligence. Vocabulary and block design subtests of the Wechsler Intelligence Scale for Children (WISC-III) were used to estimate the Intelligence quotient (IQ), using the Tellegen & Briggs (1967) method. Residual associations with age were regressed out using Studentized residuals. The estimated mean IQ of the sample was 100.88 (s.d. = 15.34, minimum = 70.01, maximum = 154.95).

Verbal working memory. As a measure of verbal working memory (VWM), we used the raw score from the WISC-III digit span backward score (mean = 3.64, s.d. = 1.52, minimum = 0.0, maximum = 12).

Visuospatial working memory. To evaluate visuospatial working memory (VSWM), we used the raw score of the backward Corsi Block-Tapping Test (mean = 4.89, s.d. = 2.05, minimum = 0.0, maximum = 14).

Statistical Analysis

A conditional process analysis was used to evaluate the indirect effects of ADHD on reading scores. For the drift rate variable, the effect was tested in a second stage moderated mediation model and for the other two variables (i.e., a and T_{er}) by a mediation model. Bootstrapping bias corrected confidence intervals with 10,000 bootstrap samples were used to test the null hypothesis (i.e., the indirect effect of ADHD on reading ability is not significant). When confidence intervals contain zero, the null hypothesis is accepted. A macro implementation of PROCESS (version 2.16) for SPSS was used for data analysis (Hayes, 2016). The index of moderated mediation was used as a formal test for the mean drift model; its significance is evaluated via bootstrapping bias corrected intervals as well (Hayes, 2013).

Due to the multilevel structure of the data (i.e. children nested in schools), it was necessary to evaluate whether the observed variance within schools is less than the variance observed among schools. The extent of variance between versus within groups (also called homogeneity of variance) was described using an intraclass correlation coefficient (ICC). An ICC value less than 0.2-0.3, indicates that standard error estimates are unlikely to be biased (Stapleton & Thomas, 2008), i.e., there are similar variances within and between schools. The presence of one or more comorbidity (e.g., depression, obsessive-compulsive disorder, social phobia, etc.) was included as a covariate in models *post-hoc*.

Results

Model for Mean Drift

Inhomogeneity of variance was not detected (ICC=0.045); therefore, ordinary least squares regressions were used. For the moderated mediation model, outcome variables were mean drift rate (v) and reading skills and age was the moderator (Figure 1). Sex, IQ, socioeconomic status (SES), and verbal (VWM) and visuospatial working memory (VSWM) were control variables. Table 1 summarizes the overall model (regression coefficients, standard errors, t, and significance). Elevated ADHD symptoms (DAWBA raw scores) were associated with lower drift rate, independent of the covariates (b = -0.0017; $p < 0.0001$). Elevated ADHD symptoms were also associated with poorer reading ability (direct effect; b = -0.2151; $p < 0.0001$). The moderation component (age*v) was also significant (b = -8.5034; $p < 0.0001$). Nevertheless, such an interaction only estimates the effect of v on reading by age, and it does not quantify the relationship between the moderator and the indirect effect. Therefore, a formal test of the moderated mediation is required, which is given by the index of moderated mediation (Hayes, 2015).

<Insert Table 1>

The indirect effect proved significant, as the bootstrap CI of the index of moderated mediation does not contain zero (effect = 0.0144; SE 0.0044; CI = 0.0070 to 0.0246). Thus, the indirect effect of ADHD symptoms on reading ability through mean drift was dependent on age. The index of moderated mediation was positive, indicating that as age increases, the indirect effect becomes less negative. Table 2 presents the conditional indirect effect at three values of the moderator: the mean age (= 9.82); the mean age, less 1 s.d. (= 7.95); and the mean age plus 1 s.d. (= 11.68). The findings indicate that ADHD symptoms led to poorer reading scores as a result of lower mean drift values, but the magnitude of this effect depended on age: at age 7.95, a child with one additional ADHD symptom was estimated to achieve 0.0478 fewer words correct; at age 9.82, a child with one additional ADHD symptom was estimated to achieve 0.0210 fewer words correct; and by the age of 11.68, the effect lost significance.

<Insert Table 2>

To test the hypothesis that the loss of significance in older children was secondary to the fact that most subjects presented maximum scores (ceiling effect) we analyzed the frequency of observed scores for the ceiling and floor effects (scores 70.0 and 0.0, respectively). While most of the children with 0.0 points were 8 years-old or younger (88.30%), not only the oldest children achieved the maximum score (55.82% of the sample between 8 and 11-years-old reached the ceiling). Since the effect remained significant at the mean age (~ 9.82 years), a ceiling effect does not reasonably explain the results. Another possibility would be the reduced sample size at this range of age. Nevertheless, 21.90% of the sample was above 11 years old, while 27.41% was 8 years old or younger.

One or more comorbidities were present in 26.4% of the sample. Including the presence of one or more comorbidity as a covariate did not change the models, so the results are presented without this variable (data available upon request).

Models for boundary separation and non-decision time

For the mediation models including a and T_{er} as mediators, age was not included as a moderator, but as a covariate (Figure 2). The control variables were sex, IQ, SES, VWM, VSWM, and age. The model statistics are presented in Tables 3 and 4.

<Insert Tables 3 and 4>

The models present a lack of evidence for an indirect effect of ADHD symptoms on reading that is mediated through the boundary separation parameter because the confidence interval contains zero (effect = -0.0031; SE = 0.0042; 95% CI = -0.0021 to 0.0043). Similarly, no support for an indirect effect of ADHD symptoms on reading that is mediated by the T_{er} parameter was found (effect: -0.0009; SE = 0.0029; 95% CI = -0.0085 to 0.0036).

Discussion

The present study investigated the relationship between ADHD symptoms and the ability to read single words using a community based school-age sample. Specifically, we tested the hypothesis that the drift rate parameter in a stimulus discriminability task would link these two outcomes, based on previous investigations that showed reduced values of drift in both ADHD and in children with reading disabilities (e.g., Zeguers et al., 2011; Metin et al., 2013; Salum et al., 2013). The data provide support for poor stimulus discriminability on simple choice tasks as a common neuropsychological deficit that links symptoms of ADHD and reading ability among school-aged children.

The results indicated that the presence of ADHD symptoms was related to drift rate, which in turn influenced reading ability, and that this indirect effect was moderated by age. Specifically, the relationship between drift rate and reading ability was moderated by age, such that mean drift had less impact on reading scores at higher ages. The effect of age on the indirect effect lost significance around the age of 11, an effect unlikely to be due to ceiling effects or sample size. The results concur with a moderating effect of age on the relationship between ADHD and academic skills demonstrated in a meta-analysis by Frazier et al. (2007).

The idea of discriminability (or the quality of evidence from stimulus) as a link between ADHD and reading is in line with the hypothesis that the frequent associations between ADHD symptoms and reading disability do not occur by chance. Some authors have demonstrated that this co-occurrence is largely due to shared genetic influences (e.g., Cheung, Fazier-Wood, Asherson, Rijsdijk, & Kuntsi, 2014; Cheung et al., 2012; Greven, Rijsdijk, Asherson, & Plomin, 2012); although a role of environment has also been found (e.g., Zumberge, Baker, & Manis, 2007; Hart et al., 2010). Willcutt et al. (2005) argue that a useful approach would be to discover a neuropsychological deficit common to both disorders that may act as a "trait" to be investigated as a correlate of genetic variations. They found that a deficit in processing speed was a common feature, and they replicated this effect in a cross-validation sample (Willcutt et al., 2010). The results of the present study concur with those findings, as the diffusion model parameters derived from the two-choice reaction time may also reflect processing speed indirectly. Processing speed tasks usually have a cognitive and a motor component. We speculate that our results concerning the drift rate parameter are related to the cognitive aspect of the task. The motor component of processing speed is represented by the non-decision time (T_{er}) parameter (which encompasses both encoding process and response output). In our sample, T_{er} parameter did not function as a mediator of ADHD symptoms and reading ability, confirming our hypothesis (Zeguers et al., 2011; Karalunas & Huang-Pollock, 2013; Metin et al., 2013). The role of encoding remains unclear because it is a cognitive process closely associated with the T_{er} parameter. Therefore, of the parameters derived from the two-choice reaction time task, the drift rate parameter specifically might offer a useful phenotype to determine genetic variants that increase susceptibility to both ADHD and reading disorders.

Future research should include a direct measure of processing speed to test the stability of the model. At a first look, the results of McGath et al. (2011) might suggest that the relationships observed between variables in the present study might change. Using regression analysis in Structural Equation Modeling, the authors showed that only processing speed contributed independently to both ADHD symptoms and reading ability, whereas verbal working memory and naming speed were not significant. Nevertheless, in McGrath et al.'s model, reading and ADHD symptoms were correlated, i.e., there are no regression model linking these latent traits. Furthermore, in their model, both VWM and processing speed were direct predictors of the outcomes reading and ADHD symptoms. In the present work, two measures of WM (i.e., verbal and visuospatial) and we assumed that both measures are predictors of mean drift and reading ability. While the model may change with inclusion of a processing speed measure, the results of McGrath et al. do not provide evidence regarding the effects of verbal and visuospatial working memory as covariates.

The present study also confirmed the hypothesized lack of significance for the boundary separation parameter as a mediator of the relationship between ADHD and reading ability. Although a more cautious pattern was present in reading performance studies (Ratcliff et al., 2004; 2012; Zeguers et al., 2011), no studies found a relationship between this deficit (i.e. the *a* parameter of the diffusion model) and ADHD symptoms (Huang-Polloc et al., 2013; Metin et al., 2013; Salum et al., 2014a). Our data confirmed those findings, showing no influence of ADHD symptoms on boundary separation in the simple mediation model (b = 0.001, p = 0.4451; Table 3) although an effect of boundary separation (i.e. cautious answering) was demonstrated on reading scores regardless of ADHD symptoms (b = -49.4332, p = 0.0001; Table 3).

The demonstrated indirect relationship between ADHD and reading ability that was mediated by drift rate highlights the promise of using diffusion model parameters as continuous neuropsychological measures to improve our understanding of the complex co-occurrence of ADHD symptoms and reading ability. For this study, ADHD symptoms were derived from DAWBA item scores to test relationships between ADHD symptoms as a continuous measure and reading skills. Our results extend the findings of previous studies that linked ADHD, and particularly its inattentive subtype, to reading problems (e.g., Greven et al., 2012; Pham, 2016; Cain & Bignell, 2014). In other words, our data support an influence of ADHD symptoms independent of categorical classifications, consistent with a dimensional view of the ADHD phenotype (e.g., McGrath et al., 2011; Willcutt et al., 2012; Salum et al., 2014a; Wagner et al., 2016).

It is necessary point out some limitations of this study. Some variables previously linked to reading ability or ADHD symptoms, such as rapid automatized naming (RAN) tasks and measures of executive function were not assessed as potential confounders, although the observed effects were shown to be independent of sex, IQ, working memory (verbal and visuospatial) and SES. Although our results are highly significant, we did not assess their specificity. Executive tasks might also be included in a similar manner to determine the best mediators and to test the independence of the observed effect. In addition, ADHD symptoms were assessed only by a structured interview (i.e., DAWBA) administered to biological parents by trained interviewers as opposed to psychiatric assessments of the children directly or using data from teachers. In addition, data from this large community school-based sample may not generalize to predominantly clinical populations. Finally, the cross-sectional design does not permit conclusions about causality between the linked variables. As Winer et al. (2016) explain, despite the utility of mediational analysis to help establish causality, the "statistical result is not evidence for a causal chain in which a predictor variable leads to a mediator variable, which leads to an outcome variable" (p. 2). This work took mediation models as atemporal associations, because no *a priori* assumptions were made about how the relationship between ADHD symptoms and reading abilities might unfold over time. For this aim, a longitudinal design would be required. Therefore, the results should be interpreted as relationships between predictors and outcomes rather than as relationships between causes and consequences.

Conclusion

The present study establishes a specific neuropsychological factor related to both ADHD and reading ability. The results demonstrate a role of stimulus discriminability in basic information processing as a mediator of the relationship between ADHD and poorer reading. Moreover, the relationship between ADHD and reading ability mediated by mean drift was dependent on age, disappearing in older children. As a particular measure of stimulus discriminability, mean drift obtained from diffusion modeling represents a potential common neurobiological mechanism between these ADHD symptoms and reading ability. The findings may have implications for improving diagnostic accuracy, and for the development of treatments (Kendler & Neale, 2010). Interventions might aim to improve stimulus discriminability in patients with ADHD or reading disabilities, particularly as early interventions for children at risk for both disorders.

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Conflict of Interest

Patrícia Silva Lúcio, Giovanni Abrahão Salum, Walter Swardfager, Joachim Vandekerckhove, Andréa Parolin Jackowski, Jair de Jesus Mari, and Hugo Cogo-Moreira declare no potential conflicts of interest.

Luis A. Rohde has received Honoraria, has been on the speakers' bureau/advisory board and/or has acted as a consultant for Eli-Lilly, Janssen-Cilag, Novartis and Shire in the last three years. He receives authorship royalties from Oxford Press and ArtMed. He also received travel awards for taking part of 2014 APA and 2015 WFADHD meetings from Shire. The ADHD and Juvenile Bipolar Disorder Outpatient Programs chaired by him received unrestricted educational and research support from the following pharmaceutical companies in the last three years: Eli-Lilly, Janssen-Cilag, Novartis, and Shire.

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Maria Conceição do Rosário has received Honoraria, has been on the speakers' bureau/advisory board and/or has acted as a consultant for Novartis and Shire in the last three years.

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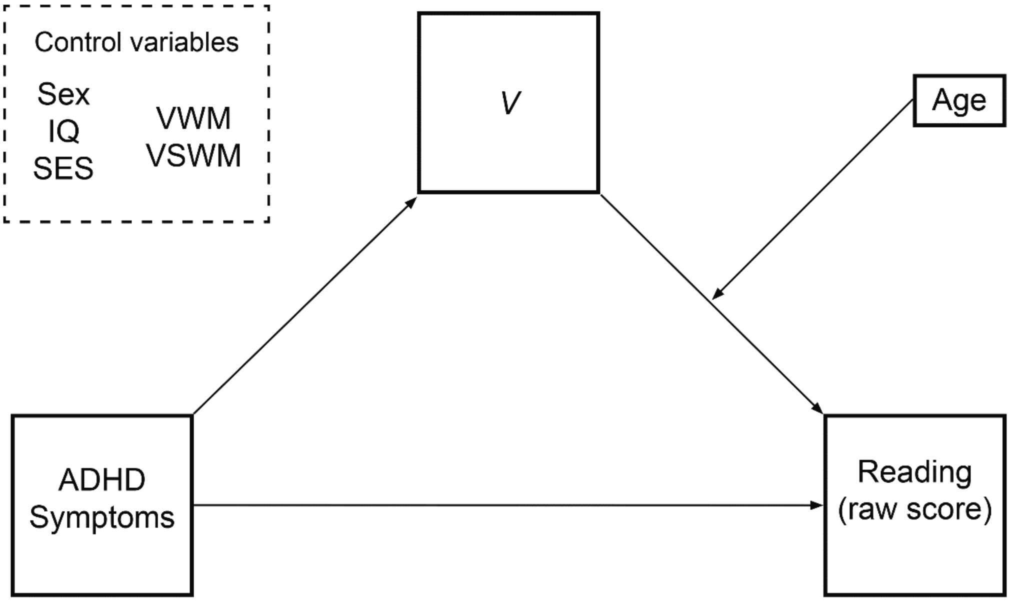

Figure 1. Conceptual model of the moderated-mediation model. Control variables are depicted in the dashed square. ADHD, attention-deficit/hyperactivity disorder; IQ, estimated intelligence quotient (WISC-IIII); SES, socioeconomic status; *v*, mean drift; VWM, verbal working memory (digit span backwards); VSWM, visuospatial working memory (Corsi Blocks backwards).

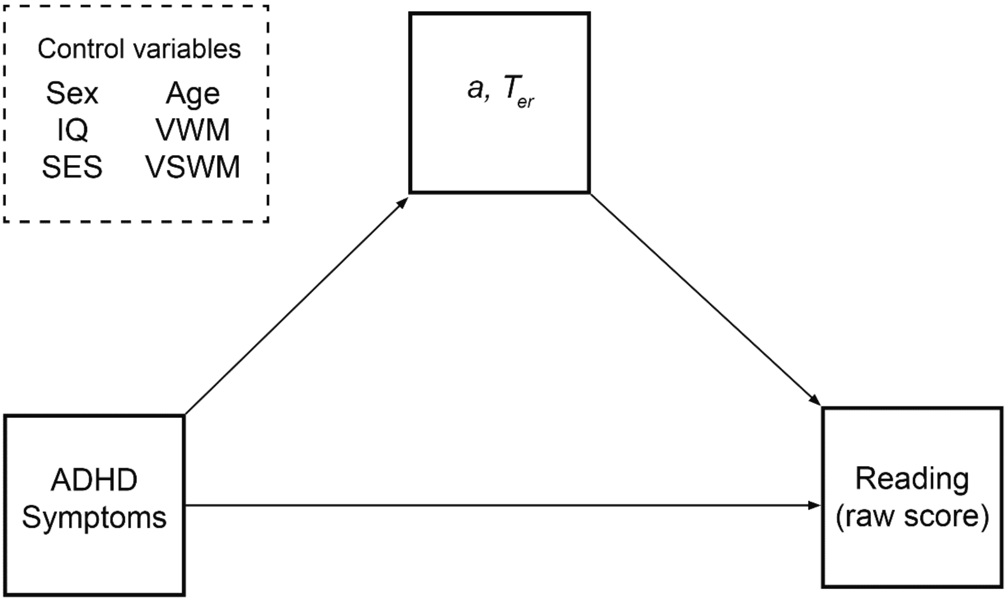

Figure 2. Conceptual model of the mediation models. Control variables are depicted in the dashed square. ADHD, attention-deficit/hyperactivity disorder; IQ, estimated intelligence quotient (WISC-IIII); SES, socioeconomic status; verbal working memory (digit span backwards); VSWM, visuospatial working memory (Corsi Blocks backwards); *a,* boundary separation; T_{er}, non-decision time.

Table 1

Statistics of the moderated mediation model: results of the outcomes mean drift and reading score

Variables' name	Outcome: mean drift			
	b	SE	*t*	*p*-value
Constant	0.1466	0.0268	5.4700	<0.0001
ADHD symptoms (predictor)	-0.0017	0.0004	-4.1785	<0.0001
IQ (covariate)	0.0005	0.0002	1.9759	0.0483
Sex (covariate)	0.0288	0.0070	4.0909	<0.0001
SES (covariate)	0.0016	0.0008	2.0720	0.0384
Corsi Blocks Bkw (covariate)	0.0064	0.0020	3.2374	0.0012
Digit span Bkw (covariate)	0.0128	0.0026	4.8952	<0.0001
F(6, 1850) = 23.1517, $p < 0.0001$, $R^2 = 0.0690$				
	Outcome: reading score			
Constant	-39.5312	5.2683	-7.5035	<0.0001
ADHD symptoms (predictor)	-0.2151	0.0434	-4.9551	<0.0001
v (predictor)	95.8027	13.1163	7.3041	<0.0001
Age (moderator)	6.4116	0.4609	13.9108	<0.0001
*v**age (Interaction)	-8.5034	1.2937	-6.5728	<0.0001
IQ (covariate)	0.1288	0.0269	4.7817	<0.0001
Sex (covariate)	1.2177	0.7517	1.6198	0.1054
SES (covariate)	0.1853	0.0810	2.2875	0.0223
Corsi Blocks Bkw (covariate)	0.8425	0.2209	3.8136	0.0001
Digit span Bkw (covariate)	2.7431	0.2859	9.5948	<0.0001
F(9, 1847) = 121.1430, $p < 0.0001$, $R^2 = 0.3712$				

Note. The first column presents the predictors, moderators, and covariates. ADHD, attention-deficit/hyperactivity disorder; IQ, estimated intelligence quotient (WISC-IIII); SES, socioeconomic status; *v*, mean drift; WM, Bkw (backwards); *b*, unstandardized beta weight; SE, standard error.

Table 2

Conditional indirect effects of ADHD on reading scores at values of the moderator age

Age (Range)	Effect	Boot SE	Boot LLCI	Boot ULCI	Result
7.9523	-0.0488	0.0145	-0.0803	-0.0236	Significant
9.8148	-0.0210	0.0070	-0.0375	-0.0097	Significant
11.6773	0.0059	0.0050	-0.024	0.0179	Nonsignificant

Note. ADHD, attention-deficit/hyperactivity disorder; Boot SE, bootstrap estimates; LLCI, lower confidence bounds; ULCI, upper confidence bounds.

Table 3

Statistics of the mediation model: results of the outcomes boundary separation and reading score

Variables' name	Outcome: boundary separation			
	b	SE	*t*	*p*-value
Constant	0.1645	0.0067	24.4876	<0.0001
ADHD symptoms (predictor)	0.0001	0.0001	0.7638	0.4451
Age (covariate)	-0.0030	0.0004	-7.2137	<0.0001
IQ (covariate)	-0.0001	0.0001	-1.6179	0.1058
Sex (covariate)	-0.0027	0.0014	-1.8938	0.0584
SES (covariate)	-0.0002	0.0002	-1.4437	0.1490
Corsi Blocks Bkw (covariate)	0.0001	0.0004	0.3173	0.7510
Digit span Bkw (covariate)	-0.0009	0.0005	-1.6261	0.1041
$F(7, 1849) = 13.0597$, $p < 0.0001$, $R^2 = 0.0471$				
	Outcome: reading score			
Constant	-6.2794	4.1246	-1.5224	0.1281
ADHD symptoms (predictor)	-0.2274	0.0437	5.1983	<0.0001
a (predictor)	-49.4332	12.4180	-3.9831	0.0001
Age (covariate)	3.8531	0.2272	16.9564	<0.0001
IQ (covariate)	0.1325	0.0272	4.8729	<0.0001
Sex (covariate)	1.2853	0.7589	1.6937	0.0905
SES (covariate)	0.1302	0.0809	1.6104	0.1075
Corsi Blocks Bkw (covariate)	0.8944	0.2235	4.0012	0.0001
Digit span Bkw (covariate)	2.7823	0.2890	9.6268	<0.0001
$F(8, 1848) = 127.3385$, $p < 0.0001$, $R^2 = 0.3554$				

Note. The first column presents the predictors, moderators, and covariates. ADHD, attention-deficit/hyperactivity disorder; IQ, estimated intelligence quotient (WISC-IIII); SES, socioeconomic status; *a*, boundary separation; WM, Bkw (backwards); b, unstandardized beta weight; SE, standard error.

Table 4

Statistics of the mediation model: results of the outcomes non-decision time and reading score

Variables' name	Outcome: non-decision time			
	b	SE	*t*	*p*-value
Constant	0.2890	0.0254	11.3685	<0.0001
ADHD symptoms (predictor)	-0.0007	0.0003	-2.2803	0.0227
Age (covariate)	-0.0073	0.0016	-4.6244	<0.0001
IQ (covariate)	0.0002	0.0002	1.1542	0.2486
Sex (covariate)	0.0531	0.0054	9.0675	<0.0001
SES (covariate)	0.0004	0.0006	0.7144	0.4751
Corsi Blocks Bkw (covariate)	-0.0028	0.0016	-1.7626	0.0781
Digit span Bkw (covariate)	-0.0023	0.0020	-1.1030	0.2702
$F(7, 1849) = 20.8292$, $p < 0.0001$, $R^2 = 0.0731$				
	Outcome: reading score			
Constant	-14.7961	3.7231	-3.9742	<0.0001
ADHD symptoms (predictor)	-0.2295	0.0440	-5.2187	<0.001
T_{er} (predictor)	1.3384	3.2930	0.4064	0.6845
Age (covariate)	4.0126	0.2263	17.7276	<0.0001
IQ (covariate)	0.1363	0.0273	4.9923	<0.0001
Sex (covariate)	1.3473	0.7812	1.7248	0.0847
SES (covariate)	0.1405	0.0812	1.7307	0.0837
Corsi Blocks Bkw (covariate)	0.8916	0.2247	3.9684	0.0001
Digit span Bkw (covariate)	2.8289	0.2901	9.7502	<0.0001
$F(8, 1848) = 124.3202$, $p < 0.0001$, $R^2 = 0.3499$				

Note. The first column presents the predictors, moderators, and covariates. ADHD, attention-deficit/hyperactivity disorder; IQ, estimated intelligence quotient (WISC-IIII); SES, socioeconomic status; *a*, boundary separation; WM, Bkw (backwards); b, unstandardized beta weight; SE, standard error.

4. ESTUDO 2 – INVARIÂNCIA DE MENSURAÇÃO PARA TAREFAS DE LEITURA E ESCRITA EM CRIANÇAS COM TDAH E CRIANÇAS COM DESENVOLVIMENTO TÍPICO

4.1 Measurement Invariance for Reading and Spelling Tasks: Are ADHD Children comparable to Typical Developing Children?

Abstract

Measurement invariance evaluates the extension in which a measured construct is equivalent in two or more groups. The literature is consistent in demonstrating that ADHD children perform significantly lower than typically developing children in reading and spelling tasks. Such studies rely in the assumption that those groups of children are comparable in these measures. Nevertheless, meaningful comparisons of statistics only should be made if the comparability across different groups were statistically attested. The main objective of this study is to investigate measurement invariance in reading and spelling abilities for subpopulations of children based on diagnostic status for ADHD. The participants (n = 1,935; 47% female; 11% ADHD) were recruited from a community-based sample of children and early adolescents aged 6 to 15 with normal IQ (≥ 70). They performed reading and spelling tasks (reading single words aloud and writing down single words under dictation). ADHD diagnostic status was obtained through informant (parent) report using the Development and Well-Being Assessment (DAWBA). Measurement invariance was investigated through Confirmatory Factor Analysis (CFA) from configural, scalar, and scalar against configural invariance; and through Multiple Indicators Multiple Causes (MIMIC) models. For both methods, invariance measurement was attested what demonstrate direct comparability of the groups of children based on diagnostic status for ADHD.

Keywords: measurement invariance; ADHD; reading; spelling.

Introduction

According to the Diagnostic and Statistical Manual (DSM-5; American Psychiatric Association, 2013), the attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental condition that encompasses a set of symptoms of inattention, hyperactivity, and impulsivity that intervene in the person's daily functioning. Its worldwide prevalence is around 5.3% (Polanczyk, Silva de Lima, Lessa Horta, Biederman, & Rohde, 2007) and there is evidence for stability of its prevalence estimates over the past three decades, even controlling for study methods (Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014).

There is a clear association between ADHD and learning disabilities, with comorbidity ranging from 31% to 45% of students (e.g., DuPaul, Gormley, & Seth, 2013). Moreover, ADHD children and adolescents often present lower achievement or test scores than typical developing peers in academic areas, such as word recognition, reading comprehension mathematical reasoning, and spelling/handwriting. (e.g., Johnels, Kopp, & Gillberg, 2014; Martinussen, & Mackenzie, 2015; Miller et al., 2013; Pham, 2016, Re, & Cornoldi, 2015). In their great majority, such studies are based on direct comparisons between groups of ADHD children and controls in standardized or cognitive tasks.

A problem with this approach (i.e., compare group of children with/without ADHD symptoms in some characteristic or ability) is the assumption that the used tasks are assessing the same constructs in each of these groups. When assessing groups, an important issue to be observed is if the instruments used to compare such groups (e.g., standard tests) are, in fact, measuring the same construct among them. In another words, it is necessary to empirically demonstrate if the observed scores in a measure represents the same latent trait for different subpopulations in which the test is used (e.g., subpopulations based on gender, race, etc.). This property can be statistically investigated by the measurement invariance (MI), and its demonstration is a prerequisite for valid comparisons among groups (Meredith, 1993) for example, simple *t*-test or ANOVA procedures (Vandenberg, & Lance, 2000)

In the recent years, the measurement invariance have aroused the interest of researchers studying ADHD samples. The Majority of those studies is concerned with explorations about the underlying structure of ADHD across groups, for example, based on gender, age, and raters (Caci, Morin, & Tran, 2016; Gomez, 2013; 2016; Makransky, & Bilenberg, 2014; Morin, Tran, & Caci, 2016; Narad et al., 2015; Zeeuw, van Beijsterveldt, Lubke, Glasner, & Boomsma, 2015).

For academic measures, the number of studies investigating measurement invariance is still small. For example, we found out only five studies of measurement invariance for reading measures (Cirino et al., 2013; Farrington, & Lonigan, 2015; Furnes & Samuelsson, 2011; Oliden, & Lizaso, 2013; Pae, Greenberg, & Morris, 2012). For spelling, this number is even reduced (Furnes & Samuelsson, 2011). In general, the studies are concerned with differential item functioning for subpopulations of children (based on gender, age, and ethnicity) or for samples of struggling and typical readers.

To our knowledge, any study considered measurement invariance for reading and spelling measures in subpopulations of typical developing children and ADHD samples. This question is essential for direct comparability of those subpopulations. Therefore, the main question raised in the present study is: do the items composing reading and spelling tasks measure the same construct (i.e., posit the same unidimensional factor structure for both abilities) and these construct exhibit similar relationships (i.e., similar factor loadings between items and latent variables) in the groups of typically developing and ADHD children? If so, both groups are directly comparable in such tasks.

Method

Participants

This study is part of the baseline wave of a large longitudinal community school-based study from Brazil (Salum et al., 2015), from which detailed methodological information is available. The sample came from 64 schools in grades 2nd-9th in the cities of Sao Paulo and Porto Alegre, Brazil. Firstly, 8,802 parents answered the Family History Survey (FHS; Weissman et al., 2000), from which we recruited 1,524 children with high-risk for mental disorders and 958 randomly selected children for evaluation (N = 2,482). From this sample, we excluded the children with low IQ (< 70), those that did not complete all tasks, and those attending first grade (because in Brazil, they are not supposed to be reading at this age group). The final sample was composed of 1,935 participants (22.04% of the 2,482 children; 61.30% from the high-risk group).

Procedures

The research procedures received approval of the Ethical Committee of the Federal University of Sao Paulo (protocol number 1.327.777/15). The participants provided informed consent prior to participation (parents gave written consent and children gave verbal assent). The children were individually tested in a room handed over by the school. Parents (87.7% mothers) responded to the DAWBA for psychiatric diagnose of the children. The instructions followed the standards recommendations in the manuals (see the section Measures). The children were tested in a quiet room at their school.

Measures

Estimated IQ. Intelligence quotient (IQ) was estimated from scores on Vocabulary and Block Design subtests of the Wechsler Intelligence Scale for Children (WISC-III), using Tellegen & Briggs (1967) method. Residual associations with age were regressed out using Studentized residuals.

Psychiatric diagnoses. Psychiatric diagnoses were derived from the ADHD section of the structured interview Development and Well-Being Assessment (DAWBA; Goodman et al., 2000) to assess inattention and hyperactivity/impulsivity in the sample. The DAWBA is composed of verbatim and structured questions about specific symptoms and related impairment. It presents fair agreement with Child and Adolescent Psychiatric Assessment (CAPA) and the Diagnostic Interview Schedule for Children (DISC) (respectively, 0.49 and 0.57, respectively, according to Angold et al., 2012). In the present research, no skipping rules were used. The scale is composed of 18 items that evaluate ADHD symptoms through a Likert scale of three points (0-2) representing, respectively, the strength of the symptomatology, i.e., ‘No more than other’, ‘A little more than others’ and ‘A lot more than others’. Based on the results, 212 children met full ADHD DSM-IV diagnose (77 predominantly inattentive; 28 predominantly hyperactive/impulsive; 79 combined type; and 28 other type).

Reading and spelling assessment. For evaluation of reading and spelling ability, we used the reading and spelling subtests of the School Performance Test (TDE; Stein, 1994). The TDE is a basic academic test for children for children and adolescents with good psychometric proprieties (e.g., Lúcio & Pinheiro, 2014; Athayde et al., 2014). In the reading subtest, the children should read aloud 70 isolated words presented in a card. In the spelling subtest, children should write down under dictation 34 isolated words presented in context of sentences. In both subtests, correct responses receive a score of 1 and wrong responses of 0.

Statistical Analysis

Descriptive statistics and statistical comparisons of sample characterization were performed with the Statistical Package for the Social Sciences (SPSS) version 20.3. Significant differences were set at $p < 0.05$. The measurement invariance was tested from two procedures: multi-group confirmatory factor analysis (MGCFA) and multiple indicators multiple causes (MIMIC) models. In both cases, the models were estimated with Mplus 7.0 (Muthén, & Muthén, 2012) using weight least square estimator (WLSMV).

For the CFA models, grouping was based on ADHD diagnostic status (ADHD vs controls). To avoid bias due to sample selection (which is not randomly assigned, but based on high-risk), weighs were created to counterbalance bias selection. Additionally, schools were clustered to avoid bias due multilevel structure of the data (i.e. children nested in schools).

Multi-group confirmatory factor analysis. After proving evidences regarding the unidimensionality's fit of the reading and spelling tasks (initial model), a sequential strategy for testing invariance measurement was performed, following Meredith's (1993) recommendations. Firstly, it was tested if factor structure was the same across the groups of ADHD and typical developing children (configural invariance). In sequence, it was tested the equivalency in items' thresholds and items' factor loadings (scalar invariance). In other words, the meaning of the construct (the factor loadings also called under item response theory the items' discrimination), and the difficulty are equal in both groups and consequently, groups can be compared on their scores on the latent variable. Finally, it was tested if the imposed restriction (scalar [more restricted model] against configural model [less restricted model]) did not worsen the model underlying decoding and spelling skills.

For model fit and adjustment index, we report the WLSMV chi-squared statistic (χ^2), the 90% CI of the root mean square error of approximation (RMSEA), the comparative fit index (CFI), the Tucker-Lewis Index (TLI), and the weighted root mean residual (WRMR). The interpretation of these indexes follows the recommendations of Hu and Bentler (1999) and Yu (2002). Therefore, for an adequate model fit the cutoffs are the followed: $p > 0.05$ for the χ^2; 0.06 or smaller for the RMSEA; 0.95 or greater for CFI and TLI; WRMR < 1.00. As the χ^2 is highly sensitive to sample size, an alternative interpretation has been used 1) ΔCFIs of the free and constrained models differ by less than 0.01 (Cheung & Rensvold, 2002) and change in RMSEA of less than 0.015 RMSEAs is smaller than 0.015 would indicate the added restrictions did not worsen the most constrained model, depicts evidences for invariance (Chen, 2007).

Multiple indicators multiple causes (MIMIC) models. Two different MIMICs were conducted: one using ADHD diagnostic (dichotomous variable status) and other using ADHD as a continuous variable as covariate. Because MIMIC models do not slit the sample (based on group comparisons), it does not requires large sample size when compared to multiple-groups CFA (Brown, 2006) and, therefore, it is less likely to occur problems during the parameters estimation as, for example, bivariate empty cells; it means that two items are not statistically distinguishable and both items should not be used in the analysis, being most common when variables have extreme, for example, 95% of children answered correctly of a give word against 5% who did not. However, differently from MGCFA, MIMIC only evaluates two potential sources of invariance: items' thresholds and factor means. A significant direct effect of the covariate (i.e., ADHD status or ADHD number symptoms) on reading or spelling items' was taken as evidence of measurement noninvariance (an index of differential item functioning –

DIF) and direct effect of the covariate on reading or spelling traits was taken as evidences of population heterogeneity (group differences on latent means).

Results

Multi-Group Confirmatory Factor Analysis (MGCFA)

Table 1 presents the descriptive statistics for the participants of the study (groups and total sample). The ADHD and control groups did not differ by age. Nevertheless, the ADHD group presented significantly lower IQ and more males, what is consistent with the literature (e.g., Gershon, & Gershon, 2002; Jepsen, Fagerlund, & Mortensen, 2009). Table 2 presents the descriptive statistics for the initial model for the reading and spelling tasks. Two items were excluded for testing the unidimensional model for reading due bivariate empty cells. The spelling model run with all items.

<Insert Tables 1 and 2>

For the initial model, both the reading and spelling models showed god fit indices for unidimensional solution. The fit indexes of the initial models are presented in the Table 3. For the reading initial model, mean item discrimination was 2.76 (s.d. = 1.40; minimum = 1.25; maximum = 7.38) and mean item difficult was -0.87 (s.d. = 0.35; minimum = -1.52; maximum = -0.02). For the spelling initial model, mean item discrimination was 1.47 (s.d. = 0.64; minimum = 0.54; maximum = 4.35) and mean item difficult was -0.15 (s.d. = 0.67; minimum = -1.46; maximum = 1.34).

<Insert Table 3>

As the initial models for both reading and spelling presented goodness of fits for the total sample, we investigated the measurement invariance for the ADHD and typical-developing children groups. As a first step to investigate measurement invariance of the tasks, we tested the configural invariance, i.e., if the basic model structure is invariant across the groups (ADHD vs controls). Table 4 presents model fit information for the configural model.

For the reading task, 30 out of the 68 original items were excluded due to bivariate empty cells. The model depicted in Table 4 contains, therefore, 38 items in the reading task. The fit indices showed configural invariance hold. For the spelling task, 5 items were excluded and the final model contains 29 items. For both tasks, configural invariance was attested what means that the constructs measured by the tasks are unidimensionally represented in both groups.

<Insert Table 4>

As the configural model was attested for both tasks, we investigated the scalar invariance holding items' factor loadings and thresholds (under item response theory called discrimination and difficulty parameter, respectively) equal between the groups. Table 5 presents the fit indices results for scalar invariance testing. For the reading and the spelling tasks, items proved to be invariant.

<Insert Table 5>

When the scalar invariance is achieved, the mean in the latent traits can be compared in both groups. Scalar against configural invariance was attested for both reading and spelling tasks (reading: $\chi^2(36) = 43.489$, p = 0.1827; spelling: $\chi^2(27) = 37.795$, p = 0.0812). The *d* index of Cohen was of moderated magnitude for the comparisons between ADHD and typical developing children in the reading task (0.511) and of low magnitude for the spelling task (0.326), being both statistical significant comparisons (respectively, $p < 0.0001$ and $p = 0.004$).

MIMIC Modeling

The MIMIC analysis showed absence of DIF for items of in both tasks regardless of the ADHD used as a diagnostic status (ADHD vs. non ADHD children) and the dimensional inattention and hyperactivity impulsivity score. Regarding the population heterogeneity, ADHD as continuous variable predicted negatively the reading trait (β=-0.195, p <0.001) and writing trait (β=-0.177, p <0.001). For ADHD as dichotomous, for reading (Cohen's d = -0.371) and writing (Cohen's d = -0.349, p=0.003).

Discussion

The present study investigated the measurement invariance of reading and spelling measures (reading aloud and spelling isolated words) for groups of ADHD and typical developing children of a community sample of school aged children. The analysis were preformed by two strategies: multi-group CFA and MIMIC modeling. In the first case, it was tested configural, scalar and scalar against structural invariance, following a sequential strategy (Meredith, 1993). In the second case, ADHD diagnostic status was used as covariate for the latent traits (i.e., reading and spelling abilities) for evaluating population heterogeneity. With both methods, the hypothesis of measurement invariance was not rejected, meaning that scores in the reading and spelling tasks are not affected by diagnostic status of the children.

Proofing measurement invariance between groups in a given measure is important to avoid bias that could invalidate comparisons between those groups. When equivalence is not attested, subjects with the same level of competence would obtain different scores in the measure, leaving to erroneous conclusions about means differences. In the present study, under MGCFA, ADHD children were 0.5 SD bellow typical developing children in the reading latent trait and 0.33 SD lower in the spelling latent trait. Based on the invariance measurement results, it is safe to conclude that it is a true difference between the groups, and not merely a task artifact. Therefore, the results of this study endorse the lower scores obtained by ADHD children in reading and spelling tasks in relation to controls (e.g., Greven, Rijsdijk, Asherson, & Plomin, 2012; Johnels et al., 2014; Miranda, Mercader, Fernández, & Colomer, 2013; Pham, 2016; Re, A. M., Mirandola, Esposito, & Capodieci, 2014; Willcutt et al., 2005).

DIF analysis (MIMIC modeling) was used to confirm the previously obtained results, determining the extent to which item properties were influenced by characteristics of the children. There was not DIF for the items of the reading and the spelling tasks and the results did not change considering both diagnostic status (i.e., ADHD versus controls) and dimensional inattention and hyperactivity-impulsivity scores. It means that for the same amount of latent trait, children with different levels of ADHD symptoms (or in different groups, i.e., ADHD and control) have equal probabilities to endorse correctly the items in the reading and spelling tasks.

To our knowledge, this was the first study to evaluate measurement invariance for reading and spelling latent traits considering as subpopulations the diagnostic status concerning ADHD, in a large community based sample. The results for both CFA and MIMIC models confirmed measurement invariance and, therefore, the direct comparability of the groups in such tasks. Nevertheless, some limitations of the study should be placed. First, diagnostic status for ADHD was assessed only by a structured interview (i.e., DAWBA) administered to biological parents, as opposed to psychiatric assessments of the children directly or using teachers evaluation. Second, despite weights were used to avoid sample bias selection of a high-risk study, the data from this sample may not generalize to predominantly clinical populations. Finally, the extent of the results are limited to reading and spelling single words and invariance of other related abilities, as reading comprehension and expressive writing, which are commonly related to be lower in ADHD sample, is still to be demonstrated (e.g., Re, Pedron, & Cornoldi, 2007; Martinussen, & Mackenzie, 2015).

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Table 1

Descriptive Statistics of the Sample Characterization

Group	Age	IQ	Female
Control	9.98 (1.89)	101.25 (15.34)	48%
ADHD	9.64 (1.74)	97.84 (14.92)	40%
Total	9.80 (1.87)	100.87 (15.33)	47%
	Statistical comparison		
t	1.385	3.061	$\chi^2 = 5.461$
df	1933	1933	1
p	0.166	0.002	0.019

Note. Standard deviations are in brackets. ADHD = Attention-deficit hyperactivity disorder; *df* = degrees of freedom; IQ = estimated IQ.

Table 2

Descriptive Statistics for the Baseline Models of Reading and Spelling

Group	N	Minimum	Maximum	Mean	s. d.	α
			Reading (raw score; 68 items)			
Control	1719	0.00	68.00	53.66	19.16	0.99
ADHD	212	0.00	68.00	47.26	22.41	0.99
Total	1931	0.00	68.00	52.96	19.64	0.99
			Spelling (raw score; 34 items)			
Control	1723	0.00	34.00	19.12	9.81	0.95
ADHD	212	0.00	33.00	15.79	9.83	0.95
Total	1935	0.00	34.00	18.76	9.87	0.95

Note. ADHD = Attention-deficit hyperactivity disorder; s.d. = standard deviation; α = Chronbach's alpha.

Table 3

Model fit Information for the Baseline Model for Reading and Spelling Tasks

Indexes	Reading	Spelling
χ^2 (model fit)	2446.068	659.056
df	2210	527
p-value	0.003	0.0001
RMSEA	0.007	0.011
90% C.I.	0.005-0.009	0.008-0.014
Prob. $\leq$ 0.005	1.000	1.000
CFI	0.998	0.995
TLI	0.998	0.994
χ^2 (baseline)	154859.113	24597.378
df	2278	561
p-value	0.0000	0.0000
WRMR	0.919	1.200

Note. χ^2 = Chi-squared; C.I. = confidence interval; CFI = comparative fit index; *df* = degrees of freedom; RMSEA = root mean square error of approximation; TLI = Tucker-Lewis Index; WRMR = weighted root mean residual.

Table 4

Model Fit Information for the Configural Model for Reading and Spelling Tasks

Indexes	Reading	Spelling
Free parameters	152	116
χ^2 (model fit)	1398.873	900.727
df	1330	754
p-value	0.0924	0.0002
RMSEA	0.007	0.014
90% C.I.	0.000-0.011	0.010-0.018
Prob. ≤ 0.005	1.000	1.000
CFI	0.999	0.993
TLI	0.999	0.993
χ^2 (baseline)	105628.520	23103.806
df	1406	812
p-value	0.000	0.000
WRMR	1.112	1.439

Note. χ^2 = Chi-squared; C.I. = confidence interval; CFI = comparative fit index; *df* = degrees of freedom; RMSEA = root mean square error of approximation; TLI = Tucker-Lewis Index; WRMR = weighted root mean residual.

Table 5

Model Fit Information for the Scalar Model for Reading and Spelling Tasks

Indexes	Reading	Spelling
Free parameters	116	89
χ^2 (model fit)	1435.399	928.157
df	1366	781
p-value	0.0937	0.0002
RMSEA	0.007	0.014
90% C.I.	0.000-0.011	0.010-0.017
Prob. ≤ 0.005	1.000	1.000
CFI	0.999	0.993
TLI	0.999	0.993
χ^2 (baseline)	105628.520	23103.806
df	1406	812
p-value	0.000	0.000
WRMR	1.123	1.463
ΔCFI	0.000	0.000

Note. χ^2 = Chi-squared; ΔCFI = CFI more restricted model – CFI less restricted model; C.I. = confidence interval; CFI = comparative fit index; *df* = degrees of freedom; RMSEA = root mean square error of approximation; TLI = Tucker-Lewis Index; WRMR = weighted root mean residual.

Table 6

Model Fit Information for the MIMIC Models for Reading and Spelling Latent Traits with ADHD Symptoms (Raw Scores on DAWBA) and ADHD Diagnostic Status as Covariates

	Reading		Spelling	
Indexes	ADHD symptoms	ADHD diagnostic status	ADHD symptoms	ADHD diagnostic status
Free parameters	137	137	69	69
χ^2 (model fit)	2519.378	2514.083	697.278	695.702
df	2277	2277	560	560
p-value	0.0002	0.0003	0.0001	0.0001
RMSEA	0.007	0.007	0.011	0.011
90% C.I.	0.005-0.009	0.005-0.009	0.008-0.014	0.008-0.014
Prob. ≤ 0.005	1.000	1.000	1.000	1.000
CFI	0.998	0.998	0.994	0.994
TLI	0.998	0.998	0.993	0.994
χ^2 (baseline)	151809.162	152545.813	22675.693	23797.727
df	2346	2346	595	595
p-value	0.0000	0.0000	0.0000	0.0000
WRMR	0.924	0.914	1.201	1.183

Note. χ^2 = Chi-squared; C.I. = confidence interval; CFI = comparative fit index; *df* = degrees of freedom; RMSEA = root mean square error of approximation; TLI = Tucker-Lewis Index; WRMR = weighted root mean residual.

5. CONSIDERAÇÕES FINAIS

A presente tese foi organizada em dois estudos principais que têm como temática comum o Transtorno de Déficit de Atenção/Hiperatividade (TDAH) e as habilidades acadêmicas, particularmente aquelas relacionadas às habilidades de leitura e escrita de itens isolados. A motivação do presente estudo deve-se à tentativa de esclarecimentos sobre a constate comorbidade relatada na literatura entre as dificuldades de aprendizagem e os sintomas relacionados ao TDAH, particularmente em crianças em idade escolar. Por se tratar dois problemas frequentemente enfrentados nesta faixa etária, sua relevância mostra-se evidente.

O primeiro estudo (Estudo 1) acrescenta o conhecimento da literatura a respeito das relações entre TDAH e leitura por uma série de razões. É a primeira vez que um estudo é conduzido ligando-se as habilidades de leitura e o TDAH a déficits de processamento básico de informação. Na literatura prévia, havia relatos de pesquisas ligando tais déficits a dificuldades de leitura (p. ex., Ratcliff et al., 2004; Zeguers et al., 2011) e a sintomas de TDAH (p. ex., Metin et al., 2013; Salum et al., 2014a; 2014b), mas nenhum outro modelo estabeleceu a relação entre as três medidas. O Estudo 1 fez uso de estatísticas recentemente disponibilizadas para demonstrar tal efeito mediador do processamento básico de informação nas relações entre TDAH e leitura (Hayes, 2013) em diferentes idades (mediação moderada). Por meio destas, foi possível demonstrar um efeito indireto entre as variáveis e, mais do que isso, comprovar que este efeito indireto não é o mesmo para as crianças de todas as faixas etárias. Isso implica que a idade é um moderador das relações observadas entre TDAH e leitura via *mean drift*, o que aponta que esta relação indireta se enfraquece com a idade, desaparecendo entre as crianças nas maiores faixas etárias.

Para além da contribuição deste novo achado, o Estudo 1 também acrescenta em questões teóricas importantes para as variáveis sob investigação. Em primeiro lugar, utilizou-se um modelo neuropsicológico para a explicação das comorbidades entre o TDAH e os problemas na leitura. Assim, o presente estudo segue a linha de outros autores (p. ex., Willcutt et al., 2005) que buscam traçar perfis neuropsicológicos na busca por déficits comuns entre transtornos que frequentemente concorrem. Em segundo lugar, utilizou-se uma medida contínua para a avaliação dos sintomas de TDAH, o que está de acordo com a visão atual sobre o caráter dimensional de transtornos mentais (Caspi et al., 2014). Estudos recentes têm apontado para uma maior estabilidade e confiabilidade de medidas contínuas de TDAH em detrimento de fatores específicos como inatenção e hiperatividade (p. ex., Willcutt et al., 2012; Wagner et al., 2016). Apesar de grande parte dos estudos relacionando TDAH e leitura apontarem que o fator de atenção é o que mais bem explica essas relações (p. ex., Cain & Bignell, 2014; Czamara et al., 2013), os resultados obtidos no Estudo 1 (que demonstraram o valor preditivo dos sintomas de TDAH na habilidade de leitura) reforçam a tendência para a compreensão do TDAH em sua dimensionalidade. Finalmente, ressalta-se que os resultados devem ser considerados em sua especificidade e alcance. A medida de processamento básico de informação utilizada (a saber, *mean drift*) mostrou-se significativa na explicação das relações entre sintomas de TDAH e habilidades de leitura a despeito do controle de variáveis tradicionalmente relacionadas tanto ao TDAH quanto à leitura (memória de trabalho verbal e visuoespacial) e de variáveis clássicas de controle (QI, nível socioeconômico e sexo). Além disso, modelos alternativos criados para outros parâmetros do modelo de difusão (a saber, a e T_{er}) apontaram para a validade discriminante do modelo criado. Sendo assim, os resultados do estudo apontam que é possível confiar que uma nova variável neuropsicológica pode ser relevante para futuras pesquisas que busquem compreender as relações entre TDAH e leitura. Além disso, apesar do caráter transversal da presente pesquisa, é possível se pensar na criação de modelos de intervenção devido à posição de mediador da variável de processamento básico de informação (Neale & Kendler, 2010). Futuras pesquisas deverão ser conduzidas de modo a confirmar esse ponto, sejam elas interventivas ou longitudinais.

O Estudo 2 reforça a extensão dos resultados obtidos no Estudo 1 ao demonstrar que a representação do construto de medidas de habilidade de leitura e de escrita ocorre da mesma forma em grupos de criança com TDAH e sem TDAH. A questão da invariância da medida é fundamental para a validade dos resultados de pesquisas que comparam grupos de subpopulações. Sem esta demonstração empírica, é impossível concluir se resultados de comparações (análises de variância, correlações, regressões, etc.) é devida a diferenças reais nos traços latentes das medidas sob consideração ou fruto de representações distintas do construto, ou mesmo porque os itens em uma determinada tarefa funcionam de forma diferente para certo grupo. A demonstração empírica no Estudo 2 da invariância escalar e configural (e a validação do modelo via invariância escalar versus configural) e da ausência de funcionamento diferencial dos itens (DIF) nas tarefas de leitura e escrita aponta para a confiabilidade dos constantes relatos de que crianças com TDAH apresentam pior desempenho acadêmico em relação a crianças típicas.

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