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Cognitive Mechanisms Underlying the Associations between Inattention and Reading Abilities

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Abstract

This study aims to test cognitive skills underlying the association between inattention and reading in early primary school. Teachers rated inattention symptoms when children (N = 523-962) were 6-7 years old. Children were assessed at age 7-8 on phonological awareness, rapid automatized naming (RAN), rapid auditory and bimodal processing, vocabulary, and reading (decoding and comprehension). Phonological awareness, RAN of numbers, and vocabulary mediated the association between inattention and both decoding and comprehension. Rapid bimodal processing mediated the association between inattention and decoding, while RAN of colors mediated the association between inattention and comprehension. This study highlights mediators underlying inattention-reading associations.

Keywords: Inattention symptoms, decoding skills, reading comprehension, cognitive mediators, childhood.

Word count: 100

Cognitive Mechanisms Underlying the Association between Inattention and Reading Abilities

The association between ADHD dimensions and reading disabilities is well established. Approximately 15-40% of children with ADHD or dyslexia fit criteria for the other disorder (Willcutt & Pennington, 2000). Given that ADHD and reading disabilities represent the end-tail of a continuum, most studies investigating this association have used a dimensional approach covering the whole range of abilities/disabilities (Levy, Hay, McStephen, Wood, & Waldman, 1997; Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992). Population-based studies have shown that the associations between ADHD dimensions and reading abilities, such as decoding skills, fluency, and reading comprehension, are modest but consistent (rs = -.10 to -.55) (Greven, Harlaar, Dale, & Plomin, 2011; Paloyelis, Rijsdijk, Wood, Asherson, & Kuntsi, 2010; Plourde et al., 2015). Moreover, they have shown that inattention reported by teachers or parents (i.e. having difficulty paying attention to details and staying focused while ignoring distractors) is more associated with reading abilities than hyperactivity/impulsivity.

Thus, recent research has focused on explaining the mechanisms underlying the association between inattention and reading abilities. One model put forth to explain the co-occurrence of developmental disorders is the *Multiple Deficit Model* proposed by Pennington (2006). Applied to the association between inattention and reading, this model postulates that associated phenotypes possess specific as well as common multidimensional etiological factors. Their association therefore stems from common factors that may operate at multiple levels and interact together, i.e., genetic, environmental, neurological, and cognitive. Indeed, Germano et al. (2010) summarized potential genetic, neurofunctional, and neuropsychological underpinnings of the comorbidity between attention problems and reading difficulties.

In addition, some researchers have proposed a mediation model suggesting that inattention could interfere with the acquisition of specific cognitive skills, which in turn could affect reading abilities (Dally, 2006; Martinussen, Grimbos, & Ferrari, 2014; Sims & Lonigan, 2013). Although more mechanistic in nature, this hypothesis can actually be viewed as an extension of Pennington's model (2006), by linking factors at the cognitive level.

Cognitive skills associated with emergent literacy could underlie the association between inattention and reading. Among them, phonological awareness, the ability to perceive and manipulate phonemes, has been shown to be one of the strongest predictors of reading abilities (Johnston & Kirby, 2006; National Early Literacy Panel, 2008), and it has also been associated with inattention during preschool and the early school years (Dally, 2006; Dittman, 2013; Sims & Lonigan, 2013; Walcott, Scheemaker, & Bielski, 2010; Willcutt et al., 2007). Furthermore, rapid automatized naming (RAN), i.e., the ability to rapidly name letters, numbers, colors or objects, rapid processing, i.e., the low-level perception and rapid treatment of sensory signals, and vocabulary skills, i.e., the ability to understand and use new words, are documented predictors of reading abilities (Joshi & Aaron, 2000; Kirby, Desrochers, Roth, & Lai, 2008; Malenfant et al., 2012; Marshall, Snowling, & Bailey, 2001; Verhoeven & van Leeuwe, 2008) that have also been associated with inattention (Arnett et al., 2012; Dionne & Ouellet, 2011; Hurks & Hendriksen, 2010; Willcutt et al., 2007).

Some explanations about why these specific cognitive skills could be mediators of inattention-reading associations have been proposed. On one hand, being inattentive or showing inattention symptoms could interfere with children's receptivity to instructions (at home or school) related to phonological awareness and related to vocabulary skills, which could in return affect the acquisition of these skills and consequently impact the acquisition of reading abilities (Dally, 2006; Martinussen et al., 2014; Sims & Lonigan, 2013). On the other hand, rapid

automatized naming (Arnett et al., 2012; Norton & Wolf, 2012) and rapid temporal processing (Marshall, Snowling, & Bailey, 2001; Toplak, Dockstader, & Tannock, 2006) could be cognitive skills mediating the association between inattention symptoms and reading abilities because of some genetic (Cheung, Fazier-Wood, Asherson, Rijsdijk, & Kuntsi, 2014; Willcutt et al., 2010) and neurological (Moore, D'Mello, McGrath, & Stoodley, 2017; Norton, Beach & Gabrieli, 2015; Stoodley, 2014) factors shared with both phenotypes.

A few research groups have formally tested some of these cognitive skills as mediators of the association between inattention and word/pseudo-word reading. Stephenson, Parrila, Georgiou, and Kirby's (2008) findings have revealed that children's task-focused behavior rated by teachers in kindergarten predict word reading in first grade, and that this association is partially explained by letter knowledge and phonological awareness. Also, Dice and Schwanenflugel (2012) have shown that a latent factor composed of letter knowledge, phonological awareness, and vocabulary skills explained the association between preschool teacher-rated inattention, and decoding skills in kindergarten. More recently, Martinussen et al. (2014) have demonstrated in first graders that phonological awareness and RAN of numbers explained the association between teacher-rated inattention and pseudo-word reading, and partially explained the association between teacher-rated inattention and pseudo-word reading.

Notwithstanding the interest of these results, only a few cognitive skills have been investigated and reading comprehension was not considered in previous mediation studies. Given that reading comprehension draws more heavily on lexical/semantic as well as syntactical knowledge (Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006) compared to decoding skills, cognitive skills underlying its association with inattention could differ from those involved in decoding. Indeed, vocabulary skills have been shown to be more strongly associated with reading comprehension than decoding skills (Ricketts, Nation, Bishop, & Dorothy, 2007) while phonological awareness have been more strongly associated with decoding skills than reading comprehension (Johnston & Kirby, 2006). However, no known studies have investigated cognitive mediators involved in the inattention and reading comprehension's association. Thus, it remains unclear if cognitive mediators such as phonological awareness and vocabulary differentially underlie the association inattention – reading comprehension compared to inattention – decoding skills.

Therefore, the present study aims at testing cognitive factors as potential mechanisms involved in the association between inattention and reading abilities in early primary school, and seeing if there are differences between decoding skills and reading comprehension. The cognitive skills were measured between 7 and 8 years old and selected to cover phonological, RAN, rapid auditory/visual processing, and lexical/semantic skills. These measures were selected to include (1) cognitive skills previously identified as mediators of the association between inattention and reading (phonological awareness, RAN, and vocabulary) and (2) rapid processing tasks, who have been associated with both inattention (Hurks & Hendriksen, 2010) and reading abilities (Marshall, Snowling, & Bailey, 2001) but have not been tested as mediators of these associations.

More specifically, the objective was to examine the cognitive mechanisms underlying the association between inattention at 6 and 7 years old reported by teachers and reading abilities at 8 years old by testing two multiple mediation models, one for decoding skills and one for reading comprehension. Models were computed controlling for sex and nonverbal abilities. Based on the studies presented above, our first hypothesis is that all cognitive skills tested will be significant mediators of associations between inattention and both reading abilities. Our second hypothesis is that phonological awareness will be a more important mediator of the association between inattention and decoding whereas vocabulary will be a more important mediator of the association between inattention and reading comprehension.

Method

Participants

Participants were from the Quebec Newborn Twin Study (QNTS: Boivin et al., 2013). All parents living in the Greater Montreal area and having twin births occurring between April 1995 and December 1998 were contacted, by letter and by phone, and asked to enroll with their twins in the QNTS. More than 660 families were initially enrolled. Inclusion criteria at onset were the fluent use of French or English by the mother and no major medical complications at birth. The average household income (CAN \$54 000) was slightly higher than similar household incomes of the same geographical area (see Forget-Dubois et al., 2009 for more demographic information of the sample). Children were followed annually from birth on a range of individual, social, family, and school characteristics. Parents' consent was obtained before each data collection. Mean attrition between 5 months and 7 years was approximately 5% per year.

Data for this study were longitudinal and collected when children were between the ages of 5 and 8 years. Children were tested in their first language (French or English) and reading testing was only conducted in children with French as first language. As the analyses use a Full Information Maximum Likelihood (FIML) approach, the number of children varies across measures (see Table 1 for number of participants on each measure). Children were on average 5.30 years old (SD = .26) when nonverbal abilities were assessed before school entry (n = 929), 6 years old (SD = .27) and 7.09 years old (SD = .27) when teachers rated inattention (n = 962), and 7.09 years old (SD = .27) when vocabulary was assessed (n = 919). They were 8.37 years old (SD= .11) when a random sub-sample of French-speaking twins completed the other cognitive measures (n = 603-620) and the reading measures (n = 523-528). Because of the dimensional approach used in the present study, children were not excluded for high levels of inattention symptoms or low-level reading abilities. For descriptive purposes, 10% of participants included were having higher than 1.5 standard deviation inattention symptoms and a small percentage of participants included were having lower than 1.5 standard deviation decoding skills (11%) or reading comprehension (13%).

Measures and procedure

Predictor – Inattention dimension. Inattention was rated with a subscale of a questionnaire (Social Behavior Questionnaire – SBQ; Tremblay, Desmarais-Gervais, Gagnon, & Charlebois, 1987) well-validated and reliable for its use with school-age children (Leblanc et al., 2008; Mascheretti et al., 2017; Plourde et al., 2015; Salla et al., 2016). Teachers rated the level of inattention within the past six months, in kindergarten (Cronbach alphas = .89) and first grade (Cronbach alphas = .90), on a three-point Likert scale: (0) never or not true, (1) sometimes or a little true, (2) often or very true, with three items ("cannot concentrate, cannot pay attention for long"; "is easily distracted, has trouble sticking to any activity"; "is inattentive"). Correlation was moderate (r = .52) between kindergarten teacher inattention ratings and the first-grade teacher, indicating a good interrater agreement. Therefore, the two scores were averaged into one total score allowing for one missing score.

Mediators – Cognitive skills.

Phonological Awareness. A phoneme deletion task – French adaptation (Cormier et al., 1995) of the "Auditory Analysis Test" (Rosner & Simon, 1971) – was administered. Validity and reliability of this instrument with school-age children have been supported (Cormier et al., 1995). The child heard a word and was asked to repeat it aloud (e.g., "Repeat after me: fake"). Then, the assistant asked the child to remove a sound segment from the word and to say the remaining phoneme sequence (e.g., "Now say that word again but without the/k/"). Twenty-four items of the original scale were selected after a pilot study and ordered according to their difficulty levels (size of the sound segment to be removed, if the sound was a phoneme or a syllable, and the

position of the segment in the word). A score of 0 or 1 (correct and fluid deletion) was given for each item. Total score was the sum of correct items. The distribution showed a mild negative skewness and was transformed using the square root.

Rapid automatized naming (RAN). The subtests numbers and colors of the Rapid Automatized Naming task – RAN (Denckla & Rudel, 1974) were administered. Reliability and validity of this measures have been shown (see Howe, Arnell, Klein, Joanisse, & Tannock, 2006 for an example). This test consists in the rapid denomination of numbers and colors appearing on a 8"x11" board. First, the child was asked to name, without the assistant's help, the first five items on the top of the board. This first step was to ensure that the child knew the names of the colors and numbers. Second, the child was asked to rapidly name from left to right all the items on the boards (50 items for RAN colors and 50 items for RAN numbers). This part of the test was timed and the number of errors calculated. Time in seconds was retained for analyses. The scores for RAN numbers were winsorized at the 99-percentile. The distributions of both scores showed a positive skewness and were normalized using logarithmic transformations.

Rapid bimodal processing. The rapid bimodal processing task was inspired from the original auditory repetition task by Tallal and Piercy (1973). The child had to tell which signal, auditory or visual, came first. The child's answers were recorded on a computer. The visual signal was a light flash produced by a small circular light-emitting diode placed about 1 m from the child. The 1kHz auditory signal had duration of 5 ms, and was delivered by the computer in front of the child. Inter-stimuli intervals (ISIs) were determined on the basis of a pilot study with similar tasks (Grondin et al., 2007). ISIs of 60, 180, 300, and 420 ms, and the trial type (visual-auditory or auditory-visual) were equally and randomly distributed in 32 trials. A brief pause was introduced after the first 16-trial block. The total score was the sum of correct trials. The distribution showed a mild negative skewness and was transformed using the square root.

Rapid auditory processing. The rapid auditory processing task was inspired from the "Seashore Measures of Musical Talents" (Seashore, Lewis, & Saetveit, 1960). In this version, the child had to say which 1-kHz sound is longer: the first or the second sound heard. The two sounds were separated by an interval of 500 ms. The child's answers were recorded on the computer. This task implied two rapid auditory processing components; 1) stimuli duration comparison, and 2) determination of their order. For each trial, a sound of 800 ms, called the standard (S), was combined with another shorter sound of 700, 675, or 650 ms, called the comparator (C). Duration differences between S and C were of 100, 125 or 150 ms. The S-C order and duration differences were randomly distributed in two 15-trial blocks (total of 30 trials), separated by a brief pause. The total score is the percentage of correct trials.

Vocabulary skills. Expressive vocabulary was assessed with the subtest "Vocabulary" of the *Wechsler Intelligence Scale for Children* (WISC-III: Wechsler, 1991). The child was asked to define words and answers were coded according to the user manual: (0) point for an incorrect definition, (1) point for a partly correct definition, and (2) points for a correct and complete definition. The subtest ended after four consecutive incorrect definitions (0 point). The total raw score was the sum of points. This subtest is known for its validity and internal consistency (Wechsler, 1991). Raw scores (age regressed and Z-standardized) were used because the available French norms do not apply readily to this sample.

Outcomes – Reading measures. Two computerized subtests of the Reading Abilities Test (Pépin & Loranger, 1999) were administered. All scores were standardized based on the child's age.

Decoding. In the "Phonetic decoding subtest" of the THAL, a French phoneme was verbally identified in a stimulus-word shown on screen and verbal instructions were given to the child to identify if this phoneme appeared in a comparison-word (yes or no answer). The subtest

includes 50 items, each is rated as pass (1) or fail (0). The task was interrupted after the tenth item if the child failed five items or more. A time component bonus of 0 to 2 points per item was awarded when the response time was faster than the Z time scores of the normative sample. The test was standardized on a sample of 1418 French-speaking children and has good psychometric properties in school-age children (internal consistency coefficient is .93) (Guimond, 2003; Pépin & Loranger, 1999), and have been used in previous studies (for example, see Malenfant et al., 2012; Parent, Loranger, & Sirois, 2007). The norm raw mean for second graders is 37 (SD = 16) and 48 (SD = 12) for third graders.

Comprehension. In the "Reading comprehension subtest" of the THAL, the child had to silently read short texts with missing words and to choose the correct missing word from a twoor four-item forced-choice. The subtest includes two practice items followed by 40 items rated as pass (1) or fail (0) and was interrupted after three failed items or a response time larger than 30 seconds for two consecutive items. A time component bonus of 0 to 2 points per item was awarded when the response time was faster than the Z time scores of the norm sample. The test was standardized on a sample of 1418 French-speaking children and has good psychometric properties (internal consistency coefficient is .98; Pépin & Loranger, 1999). The norm raw mean for second graders is 31 (SD = 14) and 43 (SD = 12) for third graders.

Control variables – **Nonverbal abilities.** Nonverbal abilities were assessed with the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence – Revised (WPPSI-R: Wechsler, 1989). The child was asked to replicate 14 illustrated models with bicolor blocks. Points were given for accuracy and speed. The task ends after three consecutive failed items (0 point). Raw scores were converted to standard scores with a mean of 10 and a standard deviation of 3. This subtest is known for its good internal consistency, its' test-retest reliability, and its' strong correlation to the Performance IQ scale (Wechsler, 1989).

Statistical analyses

Analyses were performed with Mplus 7.3 (Muthén & Muthén, 2014). The FIML was the default estimator to allow the use of all available data, including participants with missing data to avoid biases due to missing data. All the analyses were conducted using transformed (phonological awareness, RAN, and rapid bimodal processing) or not-transformed scores as specified in the measures section. Measures were standardized (M = 0; SD = 1) before running mediation models. Sex and nonverbal abilities were included as covariates in the models.

Single-step multiple mediation models (Preacher & Hayes, 2008a) were performed (Figure 1). Models were computed by using clustered data by family and type=complex in Mplus, accounting for the non-independence of the twins. The standardized root mean square residual (SRMR) and the root mean square estimate of approximation (RMSEA) were used to quantify goodness of fit in mediation models.

Specific and total indirect effects were computed (see Preacher & Hayes, 2008b for a Mplus syntax of a multiple mediation model). A specific indirect effect of X on Y via a mediator "is the product of two unstandardized paths linking X to Y via that mediator" (a_ib_i in Figure 1) (Preacher & Hayes, 2008a, p. 28). In a single-step multiple mediation model, the specific indirect effect "is interpreted as the indirect effect of X on Y through a given mediator controlling for all other included mediators" (Preacher & Hayes, 2008a, p. 31). The total effect of X on Y (unstandardized path coefficient c in Figure 1) is equal to the direct effect of X on Y(c') plus the total indirect effect of X, which is the sum of specific indirect effects through each of the six mediators.

[FIGURE 1]

This method is prioritized because research has shown that it is more valid and powerful than other approaches (Preacher & Hayes, 2008a). Bootstrap (=500) was used to perform data

resampling and estimate the model in each resample, thus estimating indirect effects multiple times. Confidence intervals (95%) were obtained following bootstrap to test the significance of direct and indirect effects: paths were deemed not significant if 0 was included in the 95% confidence intervals.

Results

Descriptive Statistics

Means and standard deviations are displayed in Table 1. The means and standard deviations for reading and nonverbal abilities were comparable to population norms. There were significant mean differences between girls and boys in inattention, vocabulary, and nonverbal abilities (p < .05). Boys were rated as having more inattention symptoms and higher scores on vocabulary and nonverbal abilities than girls. There were also no significant differences between monozygotic and dizygotic twins on all measures.

Correlations between inattention, reading abilities, and cognitive skills

Table 1 also displays the correlations between the measures of interest. Reading abilities were moderately inter-correlated (r = .58). Inattention was moderately correlated with both reading abilities, with higher levels of inattention associated with lower reading scores. Cognitive skills were all significantly associated with inattention, decoding, and reading comprehension.

[TABLE 1]

What are the cognitive skills underlying the association between inattention and reading?

Results of the mediation models are reported in Table 2. Fits for both models were good (inattention-decoding: SRMR = .027, RMSEA = .059; inattention-reading comprehension: SRMR = .026, RMSEA = .060). The single-step multiple mediation model of the association between inattention and decoding showed significant indirect effects through phonological awareness, RAN of numbers, rapid bimodal processing, and vocabulary, respectively accounting

for 25%, 3.57%, 17.86%, and 10.71% of the total effect of inattention on decoding. Indirect effects for RAN of colors and rapid auditory processing were not significant. Moreover, a residual association between inattention and decoding remained significant (-.10). Thus, together, phonological awareness, RAN of numbers, rapid bimodal processing, and vocabulary skills were partial mediators of the association between inattention and lower decoding skills.

The single-step multiple mediation model of the association between inattention and reading comprehension showed significant indirect effects through phonological awareness, RAN of colors, RAN of numbers, and vocabulary, respectively accounting for 25%, 12.5%, 12.5%, and 12.5% of the total effect of inattention on reading comprehension. Indirect effects for rapid bimodal processing and rapid auditory processing were not significant. There was no residual association of inattention on reading comprehension (-.08): cognitive skills completely explained their association.

[TABLE 2]

In a second series of mediation models (results not reported), sex and nonverbal abilities were excluded as co-variables. Results were similar with the exception of a significant residual association of inattention with reading comprehension (-.10), indicating that these variables accounted for part of this association as well. Finally, a third series of mediation models were tested (results not reported) using reading scores without including the time component bonus and most results remained significant, with the exception of RAN numbers not being a significant mediator of inattention-decoding anymore [β (95% CI): -.01(-.02; .01)].

Discussion

The purpose of the study was to investigate cognitive mechanisms underlying the association between inattention and reading in the early school years, including both decoding skills and reading comprehension. Briefly, results do not fully support the first hypothesis, which

was that all cognitive skills would be mediators of both associations. Results rather suggest similarities and differences between the cognitive skills involved in the association between inattention and reading abilities. Phonological awareness, RAN of numbers, and vocabulary were cognitive skills underlying the association between inattention and both decoding and comprehension. Rapid bimodal processing was independently mediating the association between inattention and decoding only, while RAN of colors accounted for the association between inattention and reading comprehension only. These cognitive skills completely accounted for the association between inattention and comprehension, whereas there was a residual association between inattention and decoding. This suggests that other cognitive skills account for the residual association, or alternatively, that inattention may affect decoding skills directly.

Cognitive skills underlying the association between inattention and reading

Contrary to our second hypothesis, phonological awareness and vocabulary were mediators of similar strength for associations between inattention and both reading abilities. These results could partly be explained by the nature of the reading tasks used in the present study or by the age of the participants tested. As discussed previously (Plourde et al., 2015), reading comprehension measures including cloze-test formats have been showing higher correlations to decoding skills than other measures such as reading comprehension of longer text passages, especially in early primary school age children (Keenan, Betjemann, & Olson, 2008). Therefore, this could explain why phonological awareness and vocabulary were similarly significant in these two mediation models.

Previous studies have shown that inattention is a predictor of phonological awareness (Dally, 2006) and, as already suggested, "phonemically structured phonological representations" construct the foundation to the development of reading abilities (Melby-Lervag, Lyster, & Hulme, 2012). Moreover, phonological awareness has been shown to explain part of the association between inattention and decoding skills (Dice & Schwanenflugel, 2012; Martinussen et al., 2014). The present study replicates these previous results and propose that phonological awareness could also underlies the association of inattention and reading comprehension in early primary school.

Vocabulary was also a significant mediator of the associations between inattention and both reading abilities. Indeed, vocabulary growth has been shown to be affected by inattention levels from ages 30 months to 7 years (Dionne & Ouellet, 2011) and to predict decoding and reading comprehension (National Early Literacy Panel, 2008; Verhoeven & van Leeuwe, 2008). It has been proposed that semantic knowledge contributes to reading, in addition to phonological and orthographic representations (Bishop & Snowling, 2004). Thus, semantic word knowledge could help children read more efficiently and facilitate their understanding of what they read.

In addition, as direct instructions seem to help in acquiring and improving phonological awareness and vocabulary skills (Foorman et al., 2003), inattention symptoms could interfere with these processes. For instance, having difficulties listening to and retaining instructions in classrooms or in out-of-class settings could affect the development of phonological awareness and vocabulary skills, which in turn could lead to difficulties in decoding skills and reading comprehension. Other researchers have suggested similar hypotheses (Dally, 2006; Martinussen et al., 2014; Sims & Lonigan, 2013).

RAN of numbers also mediated the associations between inattention and both reading abilities. Consistent with previous studies (Martinussen et al., 2014; Willcutt et al., 2010), this finding suggests that inattention could interfere with the execution of RAN of numbers in a quick and constant way (Arnett et al., 2012). Moreover, RAN reflects the ability to make quick connections between serial visual and linguistic information (Norton & Wolf, 2012), and this sequential processing is inherent to the processing of printed text. Interestingly, the RAN of colors mediated the association between inattention and reading comprehension only. Alphanumeric RAN (letters or numbers) has been shown to be more strongly associated to decoding than non-alphanumeric RAN (objects or colors), whereas both types of RAN have been similarly associated with reading comprehension (National Early Literacy Panel, 2008). Our results replicate these findings, lending support for the hypotheses that RAN of colors may require greater cognitive effort on a perceptual and semantic level than RAN of numbers (Tannock, Martinussen, & Frijters, 2000), and that higher-level cognitive skills may be more involved in reading comprehension than decoding (Keenan et al., 2006).

Finally, rapid bimodal processing emerged as only involved in the association between inattention and decoding. Rapid processing of visual/auditory sequential stimuli taps on lowerlevel perceptual skills and these skills may be more involved in decoding than comprehension. Indeed, Walker, Hall, Klein, and Phillips (2006) have shown that multisensory rapid processing tasks, such as temporal order and onset judgment tasks, predict phonological reading tasks.

The fact that the rapid auditory processing task did not underlie the association between inattention and both reading abilities may be due to the nature of the task. It involves comparing sequential acoustic signal durations, while the rapid bimodal processing task involves identifying the order of auditory and visual signals. Toplak, Dockstader, and Tannock (2006) summarized that executive functions, motivation, arousal, as well as energetic resources could be involved in the association between ADHD and rapid processing. Thus, a possible explanation of our results could be that the bimodal task solicited these processes more than the auditory task.

In sum, results of the present study are consistent with a mediation cognitive model, suggesting that inattention could interfere with the acquisition of the cognitive skills posited as mediators and in turn, these could affect reading abilities (Dally, 2006; Martinussen et al., 2014; Sims & Lonigan, 2013). Cognitive skills could also underlie the inattention-reading association partly because of a common genetic etiology with inattention and reading abilities. This would be consistent with the multiple cognitive deficit model proposed by Pennington (2006) and with the Generalist Genes Hypothesis (Plomin & Kovas, 2005), which proposes that the same genetic factors explain why phenotypes are associated. This hypothesis would also be in line with previous studies showing genetic correlations between inattention, decoding, and reading comprehension (Greven et al., 2011; Paloyelis et al., 2010; Plourde et al., 2015). Moreover, Willcutt et al. (2010) have demonstrated that the association between inattention and word reading was partly attributable to common genetic factors shared with RAN and processing speed. Additional studies are needed to disentangle these theoretical proposals and to clarify our understanding of how inattention and reading become associated.

Limitations and future studies

One limitation is the availability of tasks measuring cognitive skills. The list examined is not exhaustive. For instance, it does not include working memory explored in previous studies (McGrath et al., 2011; Willcutt et al., 2010) and who has been shown to partially mediate inattention and reading achievement during adolescence (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). Other cognitive skills not included as mediators have been associated with inattention (such as inhibition; Barkley, 1997) or with reading abilities (such as orthographic knowledge or morphological awareness; Berninger, Abbott, Nagy, & Carlisle, 2010). The present study does include non-linguistic processing speed tasks, but they were different from those used in previous studies, therefore limiting comparisons and conclusions. Moreover, only teacher reports of ADHD symptoms were used and reading abilities were measured with only one task for each construct. The task assessing decoding skills was also different than usual decoding (word or pseudo-word reading) tasks administered in previous studies, which may have influenced results of the present study.

As single measures of each construct were used, some results may be task-specific rather than construct-specific. There are however previous studies who showed similar results using different measures of the same constructs. For instance, associations between inattention and reading abilities have been shown using parent reports of symptoms (Paloyelis et al., 2010) or different reading measures of decoding and reading comprehension abilities (Greven et al., 2011). In addition, mediation models between inattention and reading have been shown using different measures of inattention, cognitive skills (phonological awareness and rapid naming), and reading abilities (Martinussen et al., 2014). Therefore, despite a need of future studies, these combined results suggest that inattention could influence reading and cognitive constructs themselves rather than only the performance on the tasks.

Second, we acknowledge that vocabulary was tested one year prior to other cognitive skills and reading abilities, which could have decreased to strength of this variable as a mediator in the mediation models tested. Third, results should be replicated in singletons and twin samples. However, despite the use of only twins in the study, similar results have been shown in twins and singletons when looking at the associations between inattention and reading abilities (Plourde et al., 2015). Lastly, the present results pertain to early reading development only. Processes may differ in older more competent readers and the inattention-reading association may change as children consolidate basic reading abilities. Future studies should test similar models during different developmental periods, and use a longitudinal approach to see if the cognitive skills involved change over time.

Another future research avenue will be to explore the developmental cascade from genetic markers to neurological activation and cognitive functioning in order to understand the association between inattention and reading in a multiple deficit and longitudinal model. More specifically, the processes linking etiological (genetic and environmental factors), neuronal

(cerebral changes), cognitive skills, and symptoms (inattention and reading) could be investigated combining neuropsychological, molecular genetics, and imaging approaches. For instance, associations have been identified between the activation of the ventral attention networks (ventral-frontal cortex and temporoparietal junction) and attention difficulties (ADHD), reading difficulties (Stoodley, 2014), and with the automatization of some of the cognitive skills identified as mediators of the associations between inattention and reading (i. e., phonological awareness, RAN, rapid processing) (Moore et al., 2017; Nicolson, Fawcett, & Dean, 2001; Norton, Beach & Gabrieli, 2015). Therefore, this brain network could be one neuronal mechanism involved in the associations between inattention, cognitive skills, and reading. Studies however are necessary to directly test this hypothesis.

Clinical implications

The present findings may have preliminary implications regarding assessment and intervention strategies. First, these results underline the importance to assess inattention symptoms when evaluating for reading difficulties. The teacher reports of inattention (even if they were short) provided useful information and therefore should be integrated as part of the assessment. Second, these assessments for reading difficulties or co-occurrence with attention problems should include cognitive measures to get a better sense of the etiology underlying difficulties. For instance, neuropsychological assessments could include testing of the cognitive mediators identified (such as phonological awareness, RAN, and vocabulary), which could help pinpoint cognitive skills affected and how they may relate to the co-occurrence between attention and reading difficulties. This could also help identify potential intervention targets in children with co-occurring ADHD and dyslexia and how to best combine treatments for both conditions.

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Means (standard deviations) and correlations between inattention, reading, and cognitive skills.

	M(SD)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
	Ν										
1. Inattention	.82(.62)	-									
	962										
2. Decoding	33.73(17.68)	33**	-								
	523										
3. Comprehension	28.71(14.44)	28**	.58**	-							
	528										
4. Phonological	17.13(5.40)	27**	.49**	.47**	-						
awareness ¹	603										
5. RAN colors ²	49.39(14.67)	.20**	26**	39**	26**	-					
	612										
6. RAN numbers ²	34.39(9.16)	.16**	28**	39**	32**	.41**	-				
	612										
7. Rapid bimodal	23.97(3.35)	26**	.40**	.31**	.33**	24**	18**	-			

processing ¹	618										
8. Rapid auditory	67.27(12.78)	21**	.27**	.23**	.30**	17**	20**	.34**	-		
processing	620										
9. Vocabulary	Z score	21**	.29**	.29**	.19**	09*	02	.21**	.18**	-	
	919										
10. Nonverbal	10.01(2.82)	26**	.29**	.30**	.23**	13**	12**	.22**	.14**	.29**	-
abilities	929										

Notes. ¹Square-root transformed scores. ²Logarithmic transformed scores. RAN = rapid automatized naming. *p < .05, **p < .01.

Table 2.

Indirect effects of mediators and direct effects (standardized betas β) of inattention on decoding and reading comprehension in single-

step multiple mediation models.

Mediators	Paths in	Inattention-decoding β	Inattention-comprehension β		
	Figure 1	(95% CI)	(95% CI)		
Phonological awareness ¹	aıbı	07(11;04)	06(10;03)		
RAN colors ²	a2b2	00(02; .01)	03(05;01)		
RAN numbers ²	a3b3	01(03;00)	03(06;01)		
Rapid bimodal processing ¹	<i>a4b4</i>	05(07;02)	02(04; .00)		
Rapid auditory processing	asbs	01(04; .00)	00(02; .01)		
Vocabulary	asbs	03(05;01)	03(05;01)		
Total indirect effect		17(22;12)	17(22;12)		
Direct effect of inattention (c')		10(19;01)	08(16; .03)		
Total effect of inattention (c)		28(37;19)	24(34;16)		

Notes. All measures were standardized (¹Square-root transformed scores; ²Logarithmic transformed scores). CI = Confidence intervals; significant values are in bold. RAN = rapid automatized naming. Significant effects are highlighted in bold. These analyses used data available for all measures included (N = 523-962).

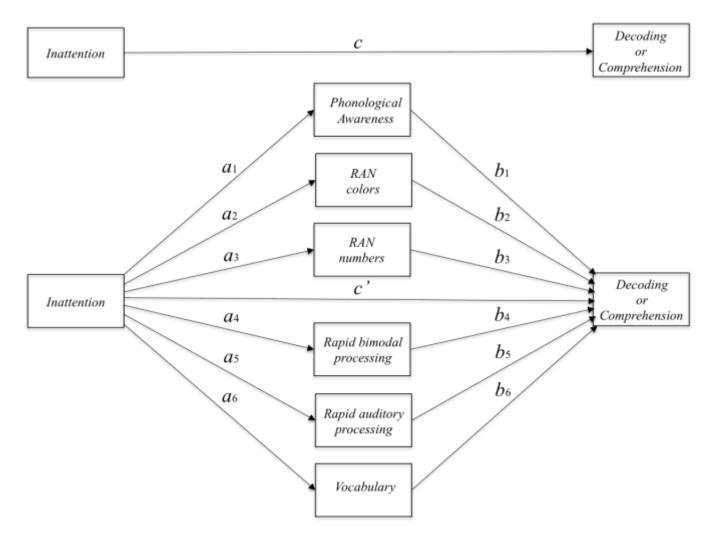


Figure 1. Single-step multiple mediation model.

Notes. *c* = total effet; *c*' = direct effect; a1b1 to a6b6 = indirect effects