Background: The dopamine D4 receptor gene (DRD4) has been linked to attention deficit hyperactivity disorder (ADHD) and reading disorders. In this study, we examined whether diminished anticipatory dopamine cell firing – typical of the long variant of the DRD4 allele – is related to emergent and advanced alphabetic skills, and whether executive attention is a mediator between this allele and alphabetic skills. Method: We tested alphabetic skills in a normative sample of 159 children in both kindergarten and Grade 1, and executive attention 1 year earlier. Cheek cells were collected and genomic DNA was isolated from the samples using the Chemagic buccal swab kit on a chemagen Module I workstation. Results: Thirty-seven percent of the children were carriers of at least one DRD4 7-repeat allele. Carriers of the long variant scored lower on alphabetic skills, and executive attention appeared to be a mediator of the relation between characteristics of DRD4 and alphabetic skills in kindergarten and first grade. Conclusion: This study shows how a genetic factor which has been shown to relate to variation in attention and regulatory behavior can explain delays in alphabetic skills. A practical implication is that in many cases early interventions should not only target reading skills, but also support children's engagement in tasks. Keywords: K-1 students, dopamine D4 receptor gene, executive attention, alphabetic skills, mediation.

Introduction

A substantial number of children experience reading problems. It is especially translating print into sounds that can be a serious bottleneck for learning to read (e.g., Hulme, Bowyer-Crane, Carroll, Duff, & Snowling, 2012). Cognitive deficits as explanation for early delays in reading have overshadowed the fact that attention problems may also play a role. Learning to combine an understanding of what words look like with knowledge of how they sound strongly depends on sustained practice, which makes the learning process vulnerable for uncontrolled regulatory behavior (e.g., Cartwright, 2012; Shaywitz & Shaywitz, 2008). In support of this hypothesis, an increasing number of studies now show that engagement in self-regulated behavior is a predictor of learning alphabetic skills in preschool age (e.g., Blair & Razza, 2007; Kegel & Bus, 2012; Kegel, Van der Kooy- Hofland, & Bus, 2009; McClelland et al., 2007). There is also evidence that children's failure to regulate their learning behavior interferes with practicing alphabetic knowledge when formal reading instruction has begun in Grade 1 (e.g., Deater-Deckard, Mullineaux, Petrill, & Thompson, 2009; Rabiner & Coie, 2000).

Consistent with findings from twin studies that the basis for reading problems is at least partly genetic (Olson, Wise, Conners, Rack, & Fulker, 1989), one hypothesis may be that, in addition to genetically driven variations in cognitive functioning, genetically driven regulatory skills may bias the acquisition of alphabetic skills that are a vital element of learning to read (Kane & Engle, 2002; Posner & Rothbart, 2007; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Recently, there has been considerable interest in several dopamine genes related to executive functions (Faraone, Doyle, Mick, & Biederman, 2001), specifically the dopamine D4 receptor gene (DRD4). DRD4 affects dopamine production in the prefrontal cortex, which regulates attentional behavior (Posner & Rothbart, 2007). The long variant (7-repeat allele) of DRD4 has been linked to a lower dopamine reception efficiency, which may result in lower levels of attention (Tripp & Wickens, 2008).

Knowing that insufficient dopamine production makes carriers of the long variant more at risk for attention deficit hyperactivity disorder (ADHD, Faraone et al., 2001; Froehlich et al., 2007; Maher, Marazita, Ferrell, & Vanyukov, 2002; Schmidt, Fox, Perez-Edgar, Hu, & Hamer, 2001) and that ADHD and dyslexia often co-occur (Willcutt & Pennington, 2000), we hypothesized that children with a delay in the development of basic skills for reading may be carriers of this specific gene (Ebejer et al., 2010; Willcutt et al., 2007). So far the exact significance of DRD4 remains undetermined, because research establishing a link between the D4 receptor gene and reading (or basic skills for learning to read) has been scarce and the results inconsistent. A study by Hsiung, Kaplan, Petryshen, Lu, and Field (2004) showed a marginally significant link (p = .06) between the 7-repeat allele and dyslexia, but others failed to demonstrate such a link (e.g., Marino et al., 2003).
Similarly, we hypothesized that executive attention is the main mechanism by which the DRD4 gene might be related to alphabetic skills. As children need sustained practice in how letters relate to their sounds (Both-de Vries & Bus, 2010), carriers of the long variant of DRD4 may have an increased chance in developing delays in emergent and advanced alphabetic skills. These pupils are typically less able to regulate their learning, and their reading development may lag behind due to their inability to stay focused during practice and instruction at home and in school. Consequently, we expected a causal model in which DRD4 explains the ability to stay attentive, and attention explains whether or not children benefit from practice and instruction and learn to translate print into speech during kindergarten and in first grade. Alternatively, DRD4 may be a candidate gene to explain delays in learning to read independently of executive attention; there is ample evidence that neurotransmitters are involved in early brain development, which then would explain delays in cognitive skills basic to reading development (Levitt, Harvey, Friedman, Simansky, & Murphy, 1997).

This study

In as far as the links between dopamine genes, executive attention, and reading development have been investigated, studies have focused on ADHD or dyslexia. However, there are very few studies in which the influence of dopamine genes on executive attention and reading skills has been tested for the full range of behavioral and cognitive skills rather than for categorical diagnoses (Ebejer et al., 2010). In our study, we sought to determine to what extent diminished anticipatory dopamine cell firing – as is typical of the long variant of the DRD4 allele – is related not only to executive functions and in particular to executive attention (essential for executive functions, such as inhibition and working memory; Robbins & Everitt, 1999), but also to alphabetic skills. Moreover, we examined whether the link between dopamine genes and alphabetic skills is the result of children’s executive attention. If this applies, we should find that executive attention mediates the link between DRD4 and alphabetic skills. Alternatively, if DRD4 relates to reading development independently of executive functions, executive attention would be at most a partial mediator between DRD4 and alphabetic knowledge at kindergarten age and in first grade.

Especially when there is no formalized instruction, as is typical of Dutch kindergartens, children may suffer particularly from their inability to attend to tasks and this may hinder the development of alphabetic skills. After the start of formal instruction in first grade, there might be more support in focusing attention on tasks and children might experience less trouble from their attention problems.

In other words, in this study, we tested three hypotheses: (a) DRD4 is linked with alphabetic skills as well as executive attention in a normative sample of children from kindergarten and first grade, (b) executive attention is a mediator between DRD4 and emergent and advanced alphabetic skills, and (c) the relations are more pronounced for emergent alphabetic skills in kindergarten than for advanced alphabetic skills in first grade.

Method

Participants

Participants were recruited from a longitudinal study on 15 Dutch schools. A total of 182 parents in the initial sample of 312 children gave informed written consent to have their children contribute buccal swab samples for the genetic part of the study. The children were 60–75 months old (Mean = 65.8, SD = 3.2) at the beginning of the senior kindergarten year. There was some attrition in Grade 1 (n = 23) due to removal or repeating a class resulting in our final sample of 159 children. The subsample participating in the genetic part of the study did not significantly differ from the total sample in age, gender, educational level of the mother, verbal skills, and alphabetic skills.

Study design

At the end of the junior kindergarten year (Time 1: T1), we tested children’s verbal skills (with the Peabody picture vocabulary test [PPVT]) and their executive functions as endophenotype of executive attention (Doyle et al., 2005). We assessed these skills prior to alphabetic skills to prevent the violation of causal precedence. After 3 months in the senior kindergarten year (Time 2: T2), we assessed children’s emergent alphabetic skills, and after 3 months in Grade 1 (Time 3: T3), we measured advanced alphabetic skills. Part of the children in this study was exposed to a literacy intervention in the junior kindergarten year (Kegel & Bus, 2012), which may affect links between executive attention, alphabetic skills, and DRD4. For this reason, we included a dummy-coded variable (non-exposed/exposed) in the analyses.

Procedure

Data were collected in sessions of approximately 20 min in a quiet room in the school. The testing was carried out by trained Bachelor and Master Students who were blind for genetic results, intervention, and previous tests. Assessment of executive functions, in counterbalanced order, was videotaped and scored afterward by coders blind for other test results.

Measures

Genotyping. Cheek cells were collected and incubated in lysis buffer. The amplification primers of the exon 3 fragment were 5’-GCGACTACGTGGTCTACTCG-3’ (5’ labeled with FAM) and 5’-AGGACCCCTATGGCCCTTG-3’. The fragment was amplified by an
were in Hardy–Weinberg equilibrium, Marino et al., 2003). These main DRD4 genotypes (7-repeat allele (e.g., Luijk et al., 2011; Marino et al., 2003). These main DRD4 genotypes were in Hardy–Weinberg equilibrium, with 0, 1, or 2 risk alleles is less useful because 2 risk alleles are rare. We applied, therefore, a widely used risk model based on the presence (7+) or absence (7–) of the 7-repeat allele (e.g., Luijk et al., 2011; Marino et al., 2003). These main DRD4 genotypes were in Hardy–Weinberg equilibrium, $\chi^2 (df = 1, N = 174) = .77, p = .38$. Thirty-seven percent of the children were carriers of at least one DRD4 7-repeat allele.

**Verbal skills.** We used a Dutch version of the PPVT (Schlichting, 2005) as indicator of verbal skills.

**Alphabetic skills**

In kindergarten, we assessed emergent skills to translate print into speech (Both-de Vries & Bus, 2010) and in first grade similar skills, but at a more advanced level and timed (Verhoeven & Van Leeuwe, 2008).

**Kindergarten**

**Spelling.** Children wrote five dictated words (i.e., *been [leg]*) that afterward were assigned (0) drawing-like scribble; (1) writing-like scribbles; (2) non-phonetic conventional symbols; (3) one phonetic letter; (4) two or more phonetic letters; (5) invented spelling (readable but not spelled correctly) or (6) conventional spelling (Levin & Bus, 2003). All words were double-coded (Kappa’s ranging from .88 to .97) and disagreements were settled in discussion. Scores were averaged resulting in a 0–6 scale ($\alpha = .92$).

**Letter knowledge.** Children were asked to name (either letter or sound) all letters of the alphabet, except c, q, x, and y. The total number of correct responses (max. 22) was the score for letter knowledge ($\alpha = .92$).

**Word recognition.** Children identified the target word among three distractors. The distractors for target words (e.g., *boot [boat]*) differed in 1 (beet), 2 (bok), or all phonemes (*viet*) from the target word. Responses were scored on a scale from 3 (*boot*) to 0 (*viet*). The total score was the average score on the 10 items ($\alpha = .74$).

**Emergent alphabetic skills.** A Principal Component Analysis (PCA) of spelling, letter knowledge, and word recognition revealed one component explaining 74% of the variance, with high loadings ranging from .83 for word recognition to .87 for spelling.

**Grade 1**

**Spelling.** Children were asked to write five dictated words (i.e., *steen [stone]*) that afterward were assigned to the same codes as spelling in kindergarten (see above). Scores on the five words were averaged resulting in a 0–6 scale ($\alpha = .79$).

**Letter knowledge.** Children had to name all 26 letters of the alphabet ($\alpha = .72$). Letter name or sound were both awarded one point.

**Phoneme deletion.** The phoneme deletion test consisted of three trials and 12 test items (Van den Bos, Lutje Spelberg, & De Groot, 2010). The child had to delete a sound of the stimulus word (‘how does “iglo” sound without i/l/?’). The items were one-syllable words of which the child had to delete the initial (six times), final (four times), or a middle (two times) sound ($\alpha = .71$). We measured the accuracy of the 12 test items.

**Rapid automatized naming.** Rapid naming was assessed through the administration of a Rapid Automatized Naming (RAN) test for letters (Van den Bos, Lutje Spelberg, Scheepstra, & de Vries, 2004). The child named high frequency lower-case letters (e, p, s, r, m, i, and v) randomly distributed over five rows of 10 symbols. The critical measure was the response rate to the complete set indicated by the number of items per second.

**Word-reading fluency.** Card 1c of the ‘Drie Minuten Test’ (Three Minutes Test) was administered to test fluency of word reading (Verhoeven, 1995). The child had to correctly read as many one-syllable CV, VC, and CVC words from a 150-item-list in 1 min ($\alpha = .96$). The score was the number of correct items read in 1 min.

**Advanced alphabetic skills.** A PCA of spelling, letter knowledge, phoneme deletion, rapid automatized naming speed, and word-reading fluency revealed one component ($R^2 = .54$), with high loadings ranging from .61 for rapid automatized naming speed to .80 for word-reading fluency.

**Executive functions**

**Stroop-like task (dogs).** Following the Stroop paradigm, children had to switch rules by responding with an opposite, that is, saying ‘blue’ to a red dog and ‘red’ to a blue dog (based on Beveridge, Jarrold, & Pettit, 2002). The task consisted of 96 trials distributed over four conditions, in which demands on working memory (remembering the name of one or two dogs) and inhibitory control of the most obvious response varied. Incorrect naming or no response was considered as an error resulting in a maximum number of correct items of 96. Internal consistency of the scale ($\alpha = .80$) was satisfactory.

**Forward span (words).** The forward span (Leidse Diagnostische Test; Schroots & Van Alphen de Veer, 1976) started with two practice trials. Wordlists of test-trials increased from two to a maximum of five 1-syllable concrete nouns (e.g., *boom [tree], vis [fish]*), and ended when a child failed to succeed three series in succession (max. score is 12).

**Backward span (digits).** The test (WISC-III; Wechsler, 1992) started with two digits and the number of digits gradually increased. The total score was the total
number of correct responses in the practice and test-trials (max. 14).

Intraclass correlation coefficients between two independent coders were high for all three tasks ($r$'s $> .97$).

**Executive attention.** A PCA applied to executive functioning tasks revealed one component with medium-to-high loadings (.69–.77) and explaining 55% of the variance. As attention is foundational to all executive function tasks, the communality in score is considered to be a good indicator of executive attention (Blair, 2006).

**Data analyses**

As participants were recruited from different schools ($N = 15$), we used Huber–White estimates of standard errors for clustering of scores within the same schools (cf. Hatcher et al., 2006). We included the corrected standard errors in the Complex Sample General Linear Model (CSGLM, IBM SPSS 17). Having at least one risk variant of DRD4 ($7+$) was coded 0 and having no risk variants ($7–$) was coded 1; see Table 1 for descriptives.

Executive attention mediates between DRD4 and alphabetic skills in kindergarten end first grade if (Baron & Kenny, 1986): (a) the independent variable (DRD4) relates to the dependent variable (emergent or advanced alphabetic skills); (b) the independent variable (DRD4) relates to the mediator (executive attention); (c) the mediator (executive attention) relates to the dependent variable (alphabetic skills); (d) when the mediator is held constant, the independent variable does not have an effect on the dependent variable (full mediation) or the relation becomes significantly smaller (partial mediation); and (e) the indirect effect of the independent variable on the dependent variable, using the Sobel test, should be significant. In all regressions, we controlled for gender, age, children’s PPVT scores, and exposure to an earlier intervention (dummy coded). Analyses were carried out for alphabetic skills after 3 months in kindergarten and after 3 months in first grade.

**Results**

**Correlations**

Table 2 displays correlations between included variables in analyses. Alphabetic skills in kindergarten (T2) and in Grade 1 (T3) correlated highly with each other ($r = .71$) and both moderately with executive attention ($r$'s equaled .50 and .45, respectively). Correlations of DRD4 with alphabetic skills in kindergarten ($r = .17$) and grade 1 ($r = .17$) and with executive attention ($r = .20$) were significant as well.

In all regressions required for testing mediation, age and exposition to an intervention were nonsignificant covariates ($p$'s $> .05$). PPVT was a significant covariate ($p$'s $< .05$) in step 1 and 2 of both mediation models. Gender was a significant covariate in step 1, 3, and 4 of the mediation models in kindergarten and first grade ($p$'s $< .05$). However, excluding all covariates from analyses did not change any of the regression effects (Simmons, Nelson, & Simonsohn, 2011).

We first regressed the effect of DRD4 on the aggregate measures of alphabetic skills after 3 months in the senior kindergarten year (T2) and after 3 months in first grade (T3). DRD4 was a

<table>
<thead>
<tr>
<th>DRD4 7– ($n = 100$)</th>
<th>DRD4 7+ ($n = 59$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age in months (T2)</strong></td>
<td>65.97</td>
</tr>
<tr>
<td><strong>PPVT (raw scores, T1)</strong></td>
<td>71.68</td>
</tr>
<tr>
<td><strong>Emergent alphabetic skills (T2)</strong></td>
<td>3.14</td>
</tr>
<tr>
<td>Spelling (max. = 6)</td>
<td>9.95</td>
</tr>
<tr>
<td>Letter knowledge (max. = 22)</td>
<td>18.78</td>
</tr>
<tr>
<td>Word recognition (max. = 30)</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Advanced alphabetic skills (T3)</strong></td>
<td>5.02</td>
</tr>
<tr>
<td>Spelling (max. = 6)</td>
<td>21.84</td>
</tr>
<tr>
<td>Letter knowledge (max. = 26)</td>
<td>0.48</td>
</tr>
<tr>
<td>Phoneeme deletion (max. = 1)</td>
<td>1.13</td>
</tr>
<tr>
<td>Rapid automatic naming</td>
<td>14.05</td>
</tr>
<tr>
<td>Reading fluency (max. = 150)</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>Executive functions (T1)</strong></td>
<td>86.36</td>
</tr>
<tr>
<td>Stroop-like task</td>
<td>5.62</td>
</tr>
<tr>
<td>Digit span (words; max. = 12)</td>
<td>2.36</td>
</tr>
<tr>
<td>Backward digit span (max. = 14)</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Executive attention</strong></td>
<td>10.14</td>
</tr>
<tr>
<td>PPVT = Peabody picture vocabulary test.</td>
<td></td>
</tr>
<tr>
<td>*PCA of spelling, letter knowledge, and word recognition.</td>
<td></td>
</tr>
<tr>
<td>1*PCA of spelling, letter knowledge, phoneeme deletion, RAN, and reading fluency.</td>
<td></td>
</tr>
<tr>
<td>2*PCA applied to the executive functioning tasks.</td>
<td></td>
</tr>
</tbody>
</table>
significant covariate in kindergarten ($b = .32$ [95% CI .06, .59]; $t(14) = 2.61$, $p = .02$) and first grade ($b = .33$ [95% CI .12, .54]; $t(14) = 3.36$, $p = .005$); see Table 3.

A second set of analyses demonstrated that DRD4 was a significant predictor of executive attention ($b = .40$ [95% CI .20, .61]; $t(14) = 4.15$, $p = .001$).

As a third step, the mean effect of executive attention on emergent and advanced alphabetic skills was analyzed. Executive attention was a significant covariate in kindergarten ($b = .44$ [95% CI .31, .58]; $t(14) = 7.06$, $p < .001$) and first grade ($b = .44$ [95% CI .26, .62]; $t(14) = 5.25$, $p < .001$).

The next series of analyses aimed at testing the models in which DRD4 and executive attention were entered simultaneously. DRD4 was no longer a significant predictor of alphabetic skills in kindergarten ($b = .12$ [95% CI −.14, .38]; $t(14) = 1.00$, $p = .33$) and in first grade ($b = .13$ [95% CI −.05, .32]; $t(14) = 1.53$, $p = .15$), but executive attention remained a significant predictor (T2: $b = .43$ [95% CI .29, .57]; $t(14) = 6.60$, $p < .001$; T3: $b = .42$ [95% CI .24, .60]; $t(14) = 4.99$, $p < .001$). The models had an explained variance of 32% in kindergarten and of 26% in Grade 1.

Finally, Sobel tests of the indirect relation between DRD4 and alphabetic skills were significant (kindergarten: $t(159) = 3.59$, $p < .001$; Grade 1: $t(159) = 3.26$, $p = .001$). The model suggests executive attention to be an almost complete mediator of the relation between DRD4 and alphabetic skills in kindergarten and first grade (see Figure 1).

### Discussion
In a normal sample of Dutch children, we found that the dopamine D4 gene explained about 10% of the differences in alphabetic skills after 3 months of education in kindergarten and Grade 1. This result confirms the presence of genetic influences on reading problems, and specifies the mode of inheritance. So far the relatively recent interest in dopamine

<table>
<thead>
<tr>
<th>Table 2 Correlations between all included variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gender (0 = boy, 1 = girl) &amp; 1.00</td>
</tr>
<tr>
<td>2. Age &amp; −.15</td>
</tr>
<tr>
<td>3. PPVT (raw scores) &amp; −.11*</td>
</tr>
<tr>
<td>4. DRD4 (0 = 7+, 1 = 7−) &amp; .02</td>
</tr>
<tr>
<td>5. Emergent alphabetic skills (T2) &amp; .21**</td>
</tr>
<tr>
<td>6. Advanced alphabetic skills (T3) &amp; .13</td>
</tr>
<tr>
<td>7. Executive attention (T1) &amp; −.04</td>
</tr>
</tbody>
</table>

$N = 159$.
PPVT = Peabody picture vocabulary test.
*Correlation is significant at the .05 level (two-tailed).
**Correlation is significant at the .01 level (two-tailed).

<table>
<thead>
<tr>
<th>Table 3 Testing executive attention as mediator between DRD4 and alphabetic skills, in kindergarten (T2) and in grade 1 (T3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing steps in mediation model</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Step 1</td>
</tr>
<tr>
<td>Outcome: Alphabetic skills</td>
</tr>
<tr>
<td>Step 2</td>
</tr>
<tr>
<td>Outcome: Executive attention</td>
</tr>
<tr>
<td>Step 3</td>
</tr>
<tr>
<td>Outcome: Alphabetic skills</td>
</tr>
<tr>
<td>Step 4</td>
</tr>
<tr>
<td>Outcome: Alphabetic skills</td>
</tr>
<tr>
<td>Predictor: executive attention</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Step 5*</td>
</tr>
<tr>
<td>Outcome: Alphabetic skills</td>
</tr>
</tbody>
</table>

T2 = November 2009; T3 = November 2010.
*Step 5 is a hand calculation of the Sobel test ($z$-value = $a \times b$/SQR($(b^2 \times s_a^2 + a^2 \times s_b^2)$), so only $t$- and $p$-values are available. The Sobel test shows that the indirect effect of the independent variable (DRD4) on the dependent variable (alphabetic skills) through the mediator variable (executive attention) is significant.
Immediate supportive feedback may be particularly useful for remedial strategies. There is evidence that children who are not able to focus on instruction and tasks may prevent children from developing core elements of reading. Likewise, our findings have implications for the early stages of learning to read. Given that children’s ability to stay attentive may improve with age, the link between the DRD4 gene and reading may weaken in later years.

**Limitations**

As in any study, some limitations of our study should be noted. First, it would be naive to suppose that only one neurotransmitter system (and its related polymorphisms) will influence individual differences in a straightforward fashion. Single genes cannot be the exclusive cause of protein and neurotransmitter production leading to learning behavior and development. We consider DRD4 an important index to the dopamine system-related genetic pathway, a pathway comprising several genes working together to regulate dopamine levels in the brain. However, we should expand the neurophysiological evidence to multiple neurotransmitter systems.

Second, the data were collected from children in the early stages of learning to read. Given that children’s ability to stay attentive may improve with age, the link between the DRD4 gene and reading may weaken in later years.

**Conclusions and practical implications**

In sum, our study clearly indicates that the dopamine system, regulated in the prefrontal cortex, can cause problems in the learning-to-read process via poorly developed executive attention, which may then explain comorbidity of reading and attentional problems. To consolidate reading proficiency, intervention programs meant to remediate and prevent early delays in alphabetic skills need to target not only components of reading, but also self-regulated behavior, in contrast with what has become common practice in intervention programs. Most full-scale programs for emergent reading skills, intended to prevent reading failure, are exclusively designed to train elements of literacy without assisting children in how to carry out assignments. An exception to this rule is the full-scale *Tools of the Mind* program for preschool and kindergarten children, with built-in instructions and tools to ensure that young children stay attentive while learning (Bodrova & Leong, 2007; Diamond, Barnett, Thomas, & Munro, 2007).

Furthermore, well-structured learning experiences as offered by some computer programs appear to be highly beneficial for preschool and kindergarten children with the DRD4 7-repeat allele (Kegel et al., 2011). Our findings are similar for kindergarten and first grade, which indicates that the fairly structured instruction as offered in Grade 1 cannot prevent the negative consequences of attentional problems. In first grade, too, we need additional programs that help children to control their learning behavior during reading instruction.
Acknowledgements
The present study was supported by a grant from the Dutch organization Kennisnet/ICT op School to Adriana G. Bus.

Correspondence to
Adriana G. Bus, Department of Education and Child Studies, Leiden University, P.O. Box 9555, 2300 RB Leiden, The Netherlands; Tel: +3171 527 3392; Fax: +3171 527 3619; Email: bus@fsw.leidenuniv.nl

Key points
- Genetic variations in efficiency of dopamine production are associated with variations in self-regulated behavior and reading disorders.
- Little is known about the mechanisms that explain how the dopamine D4 receptor gene relates to reading skills.
- Our study demonstrates that the dopamine D4 receptor gene can cause problems in the learn-to-read process via poorly developed executive attention.
- The results suggest that in many cases early interventions need to target not only reading skills, but also support children's ability to engage in tasks as well.

References


Received for publication 3 July 2012