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CEREBELLAR FUNCTION, DYSLEXIA AND ARTICULATION SPEED

D. S. Kasselimis, M. Margarity, and F. Vlachos

The main aims of this study were a) to assess the cerebellar deficit hypothesis examining children’s performance in cerebellar and cognitive tasks associated with the dyslexic syndrome and b) to investigate if there is a differentiation in articulation speed in children with dyslexia. A battery consisted of five cerebellar tests, five cognitive tests, and an articulation speed test was administered to three age- and sex-matched groups of dyslexics, children with attention deficit/hyperactivity disorder (ADHD) and normal readers aged 8–12 years. The dyslexics showed significant impairment in one cerebellar test compared with the control group and in two cognitive tests compared with both the control and the ADHD group. Additionally, the dyslexic children performed significantly worse than the control group during the articulation speed test; such a difference was not observed between the control and the ADHD group. The present study provides clues to support the cerebellar deficit hypothesis and the possible relationship between reading impairment and speed of articulation. Further research is considered essential to clarify the relationship between cerebellar function, dyslexia, and oral language speed.

Keywords: Dyslexia; Cerebellum; Articulation.

INTRODUCTION

Dyslexia is defined as “a specific language-based disorder of constitutional origin, characterized by difficulties in single word decoding, usually reflecting insufficient phonological processing abilities” (Orton Society, 1995, pp. 16–17). However, a significant problem for the phonological deficit hypothesis is the existence of cases of developmental dyslexia that do not appear to have phonological processing impairments. Recent research has shown that there may be an alternative explanation concerning the underlying cause of developmental dyslexia, opposing to the two major theories of dyslexia: the phonological deficit hypothesis (Snowling, 2000) and the magnocellular theory of dyslexia (Stein, 2001). That is, namely, the cerebellar deficit hypothesis, as stated by Nicolson, Fawcett, and Dean (2001a).

The cerebellum has been traditionally considered to be a motor area (Eccles, Ito, & Szentagothai, 1967; Holmes, 1939). Nevertheless, over the past few years, it has been well established that the cerebellum contributes to higher cognitive functions, such as language...
Moving a step forward, Nicolson et al. (2001a) endorse the idea that a deficit involving cerebellar function is the underlying cause for the emergence of developmental dyslexia. Here the biological claim is that the dyslexic’s cerebellum is mildly dysfunctional and that a number of cognitive difficulties ensue. First, the cerebellum plays a role in motor control and therefore in speech articulation and it is postulated that retarded or dysfunctional articulation would lead to deficient phonological representations. Secondly, the cerebellum plays a role in the automatization of over-learned tasks, such as driving, typing, and reading (Nicolson et al., 2001a). Lately, there is great debate about this theory, with some researchers (e.g., Beaton, 2002) remaining sceptical in front of the contradicting data, and others (Ivry & Justus, 2001; Zeffiro & Eden, 2001) challenging the idea that a cerebellar lesion or dysfunction could be the main cause of developmental dyslexia, while offering possible explanations concerning other, mainly cerebral, brain areas (but see also Nicolson, Fawcett, & Dean, 2001b).

The universality of a hypothesized cerebellar impairment in dyslexic children has been questioned. Several studies (Ramus, Pidgeon, & Frith, 2003; Ramus, Rosen, et al., 2003) found only a small proportion of dyslexics having even mild motor problems. These results led the above authors to conclude that there is not a causative relationship between cerebellar dysfunction and the most prominent feature of dyslexia, the phonological deficit. Ramus, Pidgeon, and Frith (2003) corroborate the idea that the high incidence of motor problems in dyslexics found in previous studies (Fawcett & Nicolson, 1999; Fawcett, Nicolson, & Dean, 1996; Fawcett, Nicolson, & Maclagan, 2001) is an artifact due to comorbidity with other developmental disorders such as ADHD. In support of these arguments, an alternative model (Ramus, 2003, 2004, in press) postulates that dyslexia emerges directly from a phonological deficit due to congenital anomalies in specific left perisylvian areas. This model also predicts the incidence of a cerebellar deficit modulated by genetic-dependent hormonal factors.

Nevertheless, there is mounting evidence supporting the cerebellar deficit hypothesis. Several studies (Brookes & Stirling, 2005; Fawcett & Nicolson, 1999; Fawcett et al., 2001; Fawcett et al., 1996; Vlachos, Ioannou, & Mati-Zissi, 2004; Yap & Van der Leij, 1994) have found that dyslexic children show significant impairment during cerebellar tests. In addition, many neuroimaging studies indicate that there are significant alterations regarding the brain volume and neurological organization of the dyslexic readers (Brown et al., 2001; Eckert et al., 2003; Leonard et al., 2001; Rae et al., 2001), and, in many cases, these alterations were significantly correlated with literacy skills (Eckert; Rae).

The above findings provide strong evidence of cerebellar abnormalities in the panel of dyslexic children. The first aim of the present study was to assess the cerebellar deficit hypothesis examining children’s performance in cerebellar and cognitive tasks associated with the dyslexic syndrome. Given the discrepant findings and the concern about a confound between dyslexia and attention deficit/hyperactivity disorder (ADHD), we included a group of ADHD children in this study, in order to examine the claim of Ramus, Pidgeon, and Frith (2003) that motor problems observed in dyslexics are due to the coexistence of dyslexia and ADHD. Based on the aforementioned studies, we expect to find dyslexic children to be significantly impaired during cerebellar and cognitive tasks (Hypothesis 1).

The investigation of oral speech deficits in dyslexic children is prima facie paradoxical. By definition, dyslexia is strictly referred to reading and writing. Contrary to this definition, there have been studies showing impairment of dyslexic children in several
aspects of oral language (Davenport, Yingling, Fein, Galin, & Johnstone 1986; Plaza, Cohen, & Chevrie-Muller, 2002) or an overlap between dyslexia and language impairment (Bishop & Snowling, 2004; McArthur, Hogben, Edwards, Heath, & Mengler, 2000). There are also studies demonstrating that the majority of dyslexic children have some form of language deficit (Denckla, 1977), while others (Mattis, French, & Rapin, 1975) found that 48% of their dyslexic sample have problems with speech articulation, graphemic motor skills, and poor sound blending and described this subgroup as having “articulatory and graphomotor dysco-ordination” difficulties. Apart from the fact that the cerebellar deficit hypothesis per se predicts the emergence of articulation problems, recent studies have demonstrated the presence of such problems in dyslexic individuals. More specifically, children with developmental dyslexia exhibit slower speech rate compared with normal readers, when asked to articulate single articulatory gestures (Fawcett & Nicolson, 2002), single words (Fawcett et al., 2001), or whole phrases (Catts, 1989).

As previous studies have established that dyslexic children are deficient in several areas of language functioning, the second aim of our study was to compare the articulation speed of dyslexic children to those of normally developing and ADHD children. According to the findings mentioned above, we expect dyslexic children to have slower articulation speed compared with nonimpaired readers (Hypothesis 2).

**METHOD**

**Participants**

Thirty Greek elementary school pupils, aged 8–12 years old, participated in our study. The first group consisted of 10 dyslexic children (diagnosed by the Center of Diagnosis, Rehabilitation and Support at Magnesia, Greece) with a mean age of 9.92 years ($SD = 1.22$). The second group comprised 10 children with ADHD (diagnosed by the Center of Diagnosis, Rehabilitation and Support at Magnesia, Greece) with a mean age of 10.24 years ($SD = 1.27$). The control group consisted of 10 normal readers with a mean age of 10.01 years ($SD = 1.27$). The three groups were matched for age and sex. The participants were selected from the school population of Volos, Greece, after the permission of the Greek Ministry of Education. All the children were in regular school placement and had no history of medical or psychiatric illness according to the medical reports of their school. Each participant was assessed separately, after his/her parent’s consent, in a quiet room. Administration of the battery required approximately 35 minutes.

**Materials and Procedure**

**Cerebellar tests.** A range of clinical cerebellar tests taken from the Dow & Moruzzi (1958) battery was used. All of these tests are dependent on clinical judgment. The selection of the particular tests was based upon the criterion of maximal objectivity according to Fawcett, Nicolson, and Dean (1996). The tests included:

*Balance time:* The children were blindfolded and asked to stand up straight, with their feet together and their arms stretched forward. The score was the time required for the child to make his/her first swing.

*Weight time:* The children were again blindfolded and asked to stand up straight, with their feet together and their arms stretched forward, while holding the neck of two bottles
containing 1 liter of water each. They were asked to outfight the weight of the bottles, holding their arms outstretched for as long as possible. The task was timed and the score noted was the time until their arms fell by at least 20º.

**Hand declination:** The children were asked to sit down. The experimenter rolled up the subject’s sleeves and removed any object such as watch, bangle, etc. Then, he placed the child’s elbows on a desk so as his/her wrists were at the same level with his/her shoulders and asked the child to let his/her hands “flop,” “as if they were paralyzed.” The experimenter slightly shook both hands to make sure that they were really flabby. Finally, he used a protractor to measure the angle between the forearm and the top of the hand. The score given was the difference between the measures of the two hands.

**Kicking speed:** This test is based on the toe tap speed test (Dow & Moruzzi, 1958). Each child was asked to stand up straight with his/her feet together towards a firm vertical surface. Then he/she was asked to kick the surface as fast as possible, letting his/her sole touch the floor after each kick. After a short practice, the child performed 15 trials. The sounds were recorded digitally using a microphone and an Acer Travel mate 803 LCI Notebook (stereo, 16bit, 44.1 kHz) and the speed of kicking was assessed using Wavelab 3.0. The score was the time interval between the second and the twelfth kick.

**Past pointing:** A bulls-eye target printed onto A4 paper (80gr/m²) was affixed to a wall at the eye level of the child. Then, the child was shown how to point repeatedly to the bull’s eye using a marker and, after a short practice, the experimenter asked him/her to stand in a constant position opposite the target, with his/hers feet together and (being blindfolded this time) to perform 10 trials. A score was fixed for each annulus of the target, ranging from 0 for the trials that fell out of it to 10 for the bull’s-eye. Maximum score for this test was 100.

**Cognitive tests.** To compare children’s performance on the cerebellar tests with standard tests for dyslexia, we also administered to the three groups the tests described below. The constructs measured by the particular tests are well-established dyslexia indicators (Nicolson & Fawcett, 1994; Snowling, 2000).

**Word naming processing time speed (WNPTS):** This test is a part of the word reading test used by Porpodas (1981). The child is asked to read aloud as fast as possible single words (letter size: 0.5 cm) presented to him/her on an Acer Travel mate 803 LCI Notebook screen using Microsoft PowerPoint. The child’s voice was recorded digitally (stereo, 16 bit, 44.1 kHz) and the time interval between the stimulus and the complete articulation of the word was assessed using Wavelab 3.0. The child’s score was the mean time required for the child to read 12 words that were separately presented to him/her.

**Picture naming processing time speed (PNPTS):** This test has been used by Fawcett & Nicolson (1999). The child is asked to name as fast as possible single pictures presented to him/her on an Acer Travel mate 803 LCI Notebook screen using Microsoft PowerPoint. The depicted objects corresponded to the words used in the previous test. The child’s answers were recorded digitally (stereo, 16 bit, 44.1 kHz) and the time interval between the stimulus and the child’s response was assessed using Wavelab 3.0 as above. The child’s score was the mean time required for the child to name the 12 pictures.
Verbal short-term memory (VSTM) test: This test is based on the VSTM test created by Platsidou (1993). Each child was asked to repeat a sequence of words uttered by the experimenter with an approximate rate of 1 word/2 sec. The test was divided into six levels of difficulty according to the number of words the child had to recall. Each level had three conditions of complexity in terms of morphology. The test was discontinued after failure in all three conditions of a level. The child’s score was the number of conditions (word strings) that were correctly recalled. Maximum score for this test was 18.

Nonword repetition (NWR): This test was based on the Children’s Test of Nonword Repetition (Gathercole & Baddeley, 1996). The child was asked to repeat a single nonword spoken by the experimenter. There were 20 nonwords, divided into 4 subgroups: two-, three-, four-, and five-syllable nonwords, generated from real words by changing one or two consonants. The child’s score was calculated by summing the number of correctly repeated nonwords. Maximum score for this test was 20.

Nonword rhyme judgment (NWRJ): This test was based on a test used by Besner (1981). Each child was given 20 pairs of nonwords typed on a piece of paper (A4). The nonwords were created by following the procedure described above. Then, the child was given 90 sec to underline the paired nonwords that rhymed (a total of 10 pairs). The child’s score was the number of correctly underlined pairs. Maximum score for this test was 10.

Articulation speed test. In this test the child was asked to say out loud the days of the week, then the 12 months, and, finally, twice the Greek national anthem. These word strings were chosen because they are overlearned sequences that require minimum effort for recall. To further minimize the effect of mnemonic recall in time, we gave the child the word strings to read before the test. The child was instructed to say these word strings with his/her usual speech rate. The child’s voice was recorded digitally (stereo, 16 bit, 44.1 kHz) using a microphone and an Acer Travel mate 803 LCI Notebook and the time needed for him/her to articulate each of the aforementioned word sequences was assessed using Wavelab 3.0, after extracting pauses, word repetitions, and lasting phonemes (/el/ or /af/) made by the child in an effort to recall. Four scores were generated by this test: the time needed for the child to say the seven days of the week (Td), the 12 months of the year (Tm), twice the Greek national anthem (Tna), and the total time required for all three word strings (Ttotal).

RESULTS

Two types of nonparametric statistical analyses were performed because of the fairly small group sizes: a Kruskal-Wallis test and a Mann-Whitney test. The purpose of the Kruskal-Wallis test was to assess differences among the three groups of children. The nonparametric Mann-Whitney test was performed to examine whether two of the three groups exhibited significant group differences in their performance on the different tasks.

Table 1 presents the mean scores and standard deviations on the cerebellar tests for dyslexic, ADHD, and normal children. Although dyslexic children performed poorer in most tests compared to the ADHD and the control group, the nonparametric Kruskal-Wallis test showed no significant differences between the three groups. The Mann-Whitney test revealed statistically significant differences between dyslexics and the control group for the balance time test ($z = -2.117, p < .05$).
The means and standard deviations for the cognitive tests are presented in Table 2. Nonparametric Kruskal-Wallis test detected statistically significant differences between the three groups concerning word-naming processing-time speed \(z = 9.788, p < .01\) and nonword repetition \(z = 7.643, p < .05\). The Mann-Whitney test revealed that the dyslexic group performed significantly worse at the aforementioned tasks compared to the control (WNPTS: \(z = −3.099, p < .01\), NWR: \(z = −2.619, p < .01\)) and the ADHD groups (WNPTS: \(z = −2.042, p < .05\), NWR: \(z = −2.074, p < .05\)). The same test detected significant impairment of the ADHD group during the verbal short-term memory (VSTM) test compared with the controls \(z = −2.032, p < .05\).

The means and standard deviations for the articulation speed test are presented in Table 3. No significant differences between groups were shown using a nonparametric Kruskal-Wallis test. A posteriori Mann-Whitney test revealed statistically significant difference \(z = 1.965, p < 0.05\) between the dyslexic children and the control group regarding total articulation time. Such difference was not observed between the control and the ADHD group.

In an attempt to investigate possible relationships between children’s performance on cognitive and articulation speed tasks, correlation analysis was performed. Analysis using Pearson \(r\) revealed a different correlation pattern for the three groups between the articulation speed test and the cognitive tests. Significant negative correlations were found between Tna and VSTM score \(r = −.694, p < .05\), Tna and NWR score \(r = −.647, p < .05\), and Ttotal and NWR score \(r = −.653, p < .05\) in the dyslexic group.

### Table 1 Mean Scores and Standard Deviations of Dyslexic, ADHD, and Normal Children in the Cerebellar Tests

<table>
<thead>
<tr>
<th>Cerebellar tests</th>
<th>Control</th>
<th>Mean</th>
<th>SD</th>
<th>Dyslexic</th>
<th>Mean</th>
<th>SD</th>
<th>ADHD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kicking speed</td>
<td></td>
<td>8753.30</td>
<td>1958.83</td>
<td>9171.90</td>
<td>1557.57</td>
<td>8935.40</td>
<td>1503.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Past pointing</td>
<td>33.50</td>
<td>30.17</td>
<td>52.60</td>
<td>26.83</td>
<td>47.60</td>
<td>24.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight time</td>
<td>52.25</td>
<td>26.33</td>
<td>35.20</td>
<td>18.35</td>
<td>54.88</td>
<td>37.99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand declination</td>
<td>4.20</td>
<td>2.53</td>
<td>4.90</td>
<td>2.42</td>
<td>3.10</td>
<td>2.33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*\(p < .05\).

### Table 2 Mean Scores and Standard Deviations of Dyslexic, ADHD, and Normal Children in the Cognitive Tests

<table>
<thead>
<tr>
<th>Cognitive tests</th>
<th>Control</th>
<th>Mean</th>
<th>SD</th>
<th>Dyslexic</th>
<th>Mean</th>
<th>SD</th>
<th>ADHD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word-naming processing-time speed</td>
<td></td>
<td>873.33**</td>
<td>138.13</td>
<td>1808.77**</td>
<td>1015.92</td>
<td>1056.20**</td>
<td>405.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picture-naming processing-time speed</td>
<td></td>
<td>966.18</td>
<td>115.80</td>
<td>1000.38</td>
<td>138.74</td>
<td>970.43</td>
<td>125.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbal short-term memory</td>
<td>8.30*</td>
<td>1.89</td>
<td>6.90</td>
<td>1.79</td>
<td>6.60*</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonword repetition</td>
<td>18.20*</td>
<td>1.62</td>
<td>15.80*</td>
<td>1.81</td>
<td>17.80*</td>
<td>2.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonword rhyme judgment</td>
<td>7.80</td>
<td>1.69</td>
<td>7.50</td>
<td>2.59</td>
<td>8.20</td>
<td>2.86</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*\(p < .05\); **\(p < .01\).
DISCUSSION

The main objectives of this study were (a) to examine the cerebellar deficit hypothesis and (b) to explore if there is a differentiation in articulation speed in dyslexic children. It is a priori postulated that the core deficit of dyslexia refers to written language impairment rather than speech. Therefore it must be taken into consideration that if there are any differences in articulation speed, these are not easily perceivable and the use of specialized software for speech recording and waveform analysis is needed in order to be detected.

Our results indicate that dyslexic children performed significantly worse in word-naming processing-time speed and nonword repetition, compared with the ADHD and the control groups. These results are consistent with previous studies (Hulme & Snowling, 1997; Porpodas, 2001; Snowling, 1987). Nonetheless, in contrast to previous findings (Baddeley, 1986; Bradley & Bryant, 1983; Shankweiler et al., 1995; Thomson, 1996), our results did not show any significant differences in the remaining cognitive tests between the experimental groups.

Moreover, the dyslexic children showed significant impairment in comparison with the control group concerning only one of the cerebellar tests; namely, the balance time test. However, this observation contradicts previous studies showing that dyslexic children appeared to be impaired also in several cerebellar tasks (Fawcett & Nicolson, 1999; Fawcett et al., 1996). These discrepancies between our results and previous findings of dyslexics’ inferior performance in both cognitive well-established dyslexia indicators and cerebellar tasks could be attributed to our small sampling fraction. Nevertheless, our study confirms some of the findings of the aforementioned studies, suggesting, thus, a putative existence of a cerebellar deficit in a significant proportion of dyslexics as stated by Ramus et al. (2003). The case that cerebellar deficits of dyslexics are an artefact due to comorbidity with ADHD (Ramus, Pidgeon, & Frith, 2003) does not stand according to our results, given that the performance of the ADHD and the control groups was similar during cerebellar tests.

Our dyslexic group exhibited slower articulation speed compared with the control and the ADHD groups. This finding confirms our second hypothesis and the prediction of the cerebellar deficit hypothesis (Nicolson et al., 2001a). Our results are in accordance with some previous studies (Catts, 1989; Fawcett et al., 2001; Fawcett & Nicolson, 2002). Considering that no such difference was found between the ADHD and the control groups,

Table 3 Mean Scores and Standard Deviations of Dyslexic, ADHD, and Normal Children in the Articulation Speed Test

<table>
<thead>
<tr>
<th>Articulation time</th>
<th>Groups</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td></td>
<td></td>
<td>Dyslexic</td>
<td></td>
<td></td>
<td>ADHD</td>
</tr>
<tr>
<td>Time for days</td>
<td>4430.1</td>
<td>879.8</td>
<td>4102.6</td>
<td>832.0</td>
<td>3877.4</td>
<td>596.0</td>
<td></td>
</tr>
<tr>
<td>Time for months</td>
<td>8024.6</td>
<td>3700.3</td>
<td>11361.3</td>
<td>3117.5</td>
<td>9783.0</td>
<td>2651.9</td>
<td></td>
</tr>
<tr>
<td>Time for National Anthem</td>
<td>26045.0</td>
<td>4611.3</td>
<td>30830.9</td>
<td>7278.8</td>
<td>26112.6</td>
<td>7782.9</td>
<td></td>
</tr>
<tr>
<td>Total time</td>
<td>38499.7*</td>
<td>7534.5</td>
<td>46294.8*</td>
<td>8328.0</td>
<td>39773.0</td>
<td>10180.2</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05.
it is concluded that ADHD is not a factor that could induce slower articulation. Consequently, it could be suggested that the only cause for lower articulation speed in our case is the presence of dyslexia. Therefore, articulation speed could be used as an indicator for detecting dyslexia at a very early stage.

Correlation analysis also indicated that articulation speed is significantly correlated with verbal short-term memory and nonword repetition for the dyslexic group. More specifically, a negative correlation has been demonstrated between the time needed to articulate some of the word strings given and the scores of NWR and VSTM tests. Thus, it could be hypothesized that articulation speed is positively correlated with nonword repetition and verbal short-term memory. As long as the last two constructs are strong indicators of dyslexia (Nicolson & Fawcett, 1994; Snowling, 2000), these results confirm the aforementioned hypothesis that slow articulation speed might be a dyslexia precursor. However, extensive and longitudinal studies are required in order to firm this conclusion.

Overall, our results provide clues in support of the cerebellar deficit hypothesis and suggest that children with dyslexia need more time than normal readers to articulate single words or word strings. Nevertheless, there are some interesting questions raised. Firstly, the specific role of the cerebellum in language, reading, and, consequently, reading impairments has to be elucidated. The involvement of cerebellar areas in oral speech and reading has been well established (for a review see Justus and Ivry, 2001), but there is still a debate of whether the observed language deficits are due to a cerebellar abnormality or dysfunction or to a diaschisis between the cerebellum and prefrontal cortex (for a discussion see Vlachos, 2004). Secondly, as eloquently stated by Zeffiro and Eden (2001), “it seems strange that individuals with developmental dyslexia, if that disorder results from a primary cerebellar lesion, do not exhibit more florid manifestations of the classic cerebellar clinical syndrome” (p. 512). Although Nicolson et al. (2001b) encounter this argument, claiming that a child having a congenital developmental disorder will make adaptations, so as to minimize the difficulties suffered, this controversy is not fully explained. Finally, there is an issue concerning the proportion of dyslexics presenting cerebellar impairment. Some studies (Ramus, Pidgeon, & Frith, 2003; Ramus et al., 2003) failed to identify cerebellar deficits in a large proportion of their dyslexic sample, in contrast with others (Fawcett & Nicolson, 1999; Fawcett et al., 2001; Fawcett et al., 1996). Therefore, it has been claimed that the dyslexic sample of these studies was “contaminated” with ADHD, with the latter being a causative factor for the high incidence of cerebellar deficits (Ramus, Pidgeon, & Frith, 2003). However, according to our results, the comorbidity claim does not seem to be plausible.

Conclusively, our study provides partial support to the cerebellar deficit hypothesis. Moreover, we claim that dyslexic children might present slower articulation speed in comparison with normal readers or children with ADHD. Further research, mainly longitudinal studies, is considered essential to clarify the degree of incidence of a cerebellar deficit in the dyslexic population and the relationship between cerebellar dysfunction and developmental dyslexia. Through these longitudinal studies it will also be revealed whether the articulatory speed deficit found in our study does indeed occur in a large proportion of dyslexics. With such an establishment, articulation speed could be a candidate indicator for developmental dyslexia. Moreover, the aforementioned hypothesized adaptations made by the dyslexic children (Nicolson et al., 2001b) would be monitored through development. Further studies in this direction concerning not only opaque (like English) but also more transparent languages such as Greek or German are considered essential so as
the relationship between developmental dyslexia, articulation speed, and cerebellar function can be clarified.

REFERENCES


