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Motor impairment in dyslexia: The influence of attention disorders

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ABSTRACT

Developmental dyslexia is a heterogeneous syndrome with a phonological core deficit and frequent association with other developmental disorders. Controversies exist about the influence of motor difficulties frequently encountered in dyslexia. According to different theoretical approaches, these motor impairments would reflect either a frequent co-morbid entity or a cerebellar dysfunction that could constitute the causal factor of reading disabilities. The principal aim of this study was to determine the frequency of motor impairments in a population of children with phonological dyslexia and specify possible links with attention deficit. We analysed retrospectively motor and attention abilities of 58 children with phonological dyslexia. An important sub-group of children with dyslexia (40–57% depending on the severity of motor difficulties) presented a motor impairment affecting co-ordination, balance and manual dexterity suggesting a cerebellar dysfunction. There was a significant association between attention deficit and motor impairments, with a specific impact on balance and co-ordination deficits. The comparison of performance in four groups defined according to the presence versus absence of attention deficit and motor impairment, respectively, were not in favour of a unequivocal causal link between reading disabilities and motor or attention disorders.
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1. Introduction

Developmental dyslexia or 'Specific Reading Disability' has been defined as an unexpected, specific and persistent failure to acquire efficient reading skills despite conventional instruction, adequate intelligence and socio-cultural opportunity.[1] This disorder is remarkably common but with an uncertain prevalence rate, ranging from 5% to 17.5%.[2] A genetic origin with a neurological basis is admitted now for this developmental disorder, but the precise aetiology remains unknown.[3] At a behavioural level, dyslexia appears as a relative heterogeneous syndrome. The variability of the phenotype results from several factors: the severity of reading deficit, the sub-types of dyslexia depending on language impairment profile or the presence of co-morbidity. Several theories of dyslexia have been proposed.[3,4] As a 'top-down' conceptualization, the *phonological theory* emphasizes the central role of an impairment of phonological representations,[5]

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a core deficit linked to the unsteadiness of distinctive subunits of language. The absence of such a stable repertoire in long-term memory prevents efficient phoneme–grapheme links to be established during learning to read, thus accounting for persistent reading disorders. This mainstream theory has a variety of competitors that may be viewed as 'bottom-up' approaches to dyslexia since these challenger theories stress the relevance of impairment of diverse sensory-motor processes involved in such complex a skill as reading. For instance, cerebellar dysfunctions have been put forward to account for at least some frequently observed symptoms in dyslexia, either as consequences of the impairment of (visual and/or auditory) magnocellular pathways or as autonomous phenomena.[6,7]

Motor impairments in children with developmental dyslexia have been reported for a long time.[8] Nevertheless, their frequencies vary across studies. Nicolson et al. have reported motor impairment in about 80% of their cases; almost all dyslexic children they studied presented balance, muscle tone or co-ordination impairments that authors interpreted as consequences of cerebellar dysfunction.[7] Some neuroimaging studies using positron emission tomography,[9] spectroscopic[10] or structural magnetic resonance imaging[11] supported this hypothesis showing abnormalities of activation, metabolic or structural signals, respectively, in cerebellar regions in adult dyslexics compared to normal readers. Nicolson et al.'s conceptualization of dyslexia is two-fold. First and most importantly, dyslexia is viewed as one of the most obvious consequences of a general learning disorder that would result from a global impairment of the automatization of sensory-motor procedures, a mandatory prerequisite for effortless skills to emerge: in others words, fluent reading abilities rely on 'basic' associative functions which have been long acquired and have become automatic that link input language units (i.e. perceived speech sounds and visual-graphic prints) and output language units (pronounced speech and written spelling). Second, this primary deficit has a neurological basis consisting in a dysfunction of 'the cerebellum',[6] or more likely, a dysfunction of some parts of this massive and heterogeneous structure that are involved in the complex network supporting automatization of information processing in the human central nervous system. In this account, impairments of sensory-motor skills are conceived as consequences of the global impairment of automatization in the non-verbal domain, just as dyslexia reflects the impact of learning impairment in the written language domain. However, other authors have reported a less frequent rate of sensory-motor symptoms in dyslexia: Ramus et al. found only 33% and 59% of such symptoms in, respectively, adults and children with dyslexia.[4,12] In the framework of the phonological theory of dyslexia, these authors proposed a different neurological basis for this sensory-motor associated syndrome. Phonological deficits are thought to result from cortical abnormalities (ectopias or/and dysplasia) in the left perisylvian cortex while sensory-motor symptoms would be linked to cytoarchitectonic anomalies reported in thalamic nuclei in very few cases of dyslexia.[13] In this approach, motor signs are considered only co-morbid symptoms without a direct causal link to the reading impairment.

Kaplan et al. showed a high degree of co-morbidity for several developmental disorders.[14] For instance, the authors found a reading disability in 55% of the children who were diagnosed developmental co-ordination disorder (DCD) and conversely found motor impairment in 63% of the dyslexic children. They also found a frequent co-morbidity with attention deficit/hyperactivity disorder (ADHD) that may enhance motor symptoms. Accordingly, Wimmer et al. observed balance impairment only in dyslexic children with ADHD and underlined the possible confounding role of ADHD for symptoms of motor impairment.[15] Several attempts have been made to account for such co-morbidity with, for each hypothesis, strengths and limits.[16]

The first aim of the present retrospective study was to feature motor symptoms and their frequency in a population of children with phonological dyslexia. The second aim was to explore the influence of associated attention deficit on these symptoms.

2. Material and methods

The children included in this study have been referred to the Centre for Language and Learning Disabilities of the Children's University Hospital in Toulouse, between 1997 and 2004. For this study, we have included retrospectively all the children, among 950 in our database, who received a diagnosis of developmental dyslexia and underwent a complete assessment of motor skills.

Diagnosis of *developmental dyslexia* has been made on the basis of the WHO and ICD-10 criteria. These criteria included notably the association of a normal intelligence with $IQ > 80$ as measured with the Wechsler Intelligence Scale for Children[17] (WISC III) and a reading score below -2S.D. (reading age < 18 months to chronological age) on a standardized French reading test ("L'Alouette") evaluating reading speed and accuracy and yielding a reading age.[18] None of these children had any history of neurological or psychiatric diseases. Moreover, only children with deficits on phonological awareness tasks were included: phonological awareness tasks were those included in the standardized French BELEC battery.[19] Five children showing either no deficit on phonological awareness tasks or marginal reading deficits were excluded on these criteria. Children referred to our Centre with a history of persistent impairment of oral language were also excluded. Children presenting current symptoms, or history of symptoms, of ADHA as defined in the ICD-10[1] were not included in the study.

Each child completed evaluation over 2 half-days involving language assessment by a speech therapist, as well as neuropsychological and motor assessment by a neuropsychologist. A handedness score was established for each participant using the Edinburgh Questionnaire in which the child and parents were asked to indicate which hand he/she uses for 10 different activities.[20] Oral language abilities were assessed using Language Evaluation Battery-French (L2MA) from Chevrie-Muller, a standardized battery for children aged between 8 and 12 years.[21] Children scoring below -2S.D. in sub-tests of this battery other than the phonological sub-tests (for instance, syntactic or lexical sub-tests) were included in the study and diagnosed as dyslexia associated with specific language impairment (SLI) despite an apparently normal development of oral language. Sustained attention was evaluated by a cancellation test (d2 Test)[22]; selective attention and the ability to inhibit a non-relevant response was measured by a standardized French version of the colour Stroop Test.[23] Children were classified as presenting an attention deficit if they had an error score (F%) to the d2 Test (sustained attention) below to the 10th percentile or/and an error score to the fourth condition of the colour Stroop Test (selective attention) above 2S.D. Moreover, we used the third part of this test, colour naming, as a test for Rapid Automatized Naming (RAN). Planning ability was evaluated using the Tower of London Test which measures subject's ability to solve 12 problems within a certain time frame (less than 60 s), with a limited number of attempts (maximum of three) and a limited amount of moves allowed (varying from three to five depending on the problem).[24] Fine motor skills have been assessed with the Purdue Pegboard Test, this test has been normalized in a French population and yielded three scores of manual dexterity, one for the preferred hand, one for the non-preferred hand and one for the bimanual co-ordination (bimanual condition).[25] The diagnosis of dysgraphia has been made on the results of the two writing tests that are used in our Centre and were standardized for a population of French children.[26,27]

All the children included in this study underwent a *motor performance assessment* with the Lincoln-Orseretsky Motor Development Scale (LOMDS).[28] The LOMDS determines a total motor score: moreover, six factors have been isolated from a factorial analysis: F1, fine manual mobility; F2, general co-ordinations; F3, neuromotor co-ordinations; F4, wrists and fingers mobility; F5, balance; F8, global manual mobility. For each factor, the score is a percentage of accuracy. A total motor score for LOMDS below −2S.D. classified the child as presenting severe motor impairment and a score between −2 and −1S.D. as mild motor impairment.

2.1. *Statistical analysis*

The significance level for all statistical analyses was set at $p<0.05$. For the quantitative variables, mean comparisons between groups were carried out using ANOVAs. For the qualitative variables, comparisons between groups were carried out using χ^2-tests. For correlations analyses, Spearman test was used.

3. Results

3.1. *Descriptive analysis and neuropsychological assessment*

Fifty-eight children with complete assessments have been included in this study according to the inclusion and exclusion criteria. The mean age of the population was 138.8 months (S.D. = 25.0; range = 97–196) and the sex ratio was 2.6, with 42 boys and 16 girls. The handedness coefficient showed 76% of right-handers, 14% of left-handers and 10% of ambidextrous subjects.

Thirty-five children have been excluded from this study because of incomplete assessments of motor or attention functions. Nevertheless, statistical analyses showed no significant difference between this group (35 children) and the group included in the study (58 children) for chronological age ($F(1,91) = 0.23$, $p = 0.63$), mean reading delay ($F(1,91) = 0.02$, $p = 0.88$), verbal ($F(1,91) = 0.43$, $p = 0.51$) and non-verbal ($F(1,91) = 1.04$, $p = 0.31$) intelligence.

Moreover, a group of 42 children with phonological developmental dyslexia has been assessed for motor performance with the Movement Assessment Battery for Children (M-ABC) standardized in French children.[29,30] Because M-ABC and LODMS are two different motor evaluation tools and probably yield different information, these children have been excluded from this study and will be analysed in a future study.

In our group of 58 subjects, intelligence (IQ) was in the normal range (mean = 101.9; S.D. = 13.19; range = 79–136) with no significant difference between V IQ (mean = 99.4; S.D. = 12.88; range = 72–132) and P IQ (mean = 103.9; S.D. = 14.73; range = 73–131). The mean reading delay (comparing the reading age from the "L'Alouette" standardized reading test and the chronological age) was −44.9 months (S.D. = 20.2; range = −18; −101). An impairment (score <−2S.D.) in oral language abilities (independent of the scores on phonological sub-tests) was observed in 24% of the children. Dysgraphia was found in 36% of the children. On planning functions assessed with the Tower of London test: 4% of children scored below to −2S.D. and 8% between −2S.D. and −1S.D. (mean = 0.1; S.D. = 1.03; range = −2.8; 2.5). Rapid automatized naming (RAN) showed that 35% of children scored below −2S.D. and 30% between −2S.D. and −1S.D. (mean = −1.3; S.D. = 1.10; range = −3.3; 0.8). An attention deficit was found in 41% of the children. Both sustained attention ("d2" cancellation test) and selective attention were impaired in half of these subjects (46%). On isolation, sustained attention was more frequently impaired (38%) than selective attention (16%).

3.2. *Motor performances*

3.2.1. *Fine motor skills (Purdue Pegboard)*

Impairment was dependent on the hand involved: for the preferred hand (PP PH), impairment (<−2S.D.) was found in 18% of the children, in 26% for the non-preferred hand (PP NPH) and in 17% for bimanual condition (PP BM).

3.2.2. *General motor performances (LOMDS)*

The results for the total motor score showed that motor impairment was severe (<−2S.D.) in 23 children (40%), mild (−2S.D. to −1S.D.) in 10 children (17%) and absent (>−1S.D.) in 25 children (43%). The results for each factor of the motor scale showed predominant impairment for manual dexterity (F1 of LOMDS), co-ordination (F3 of LOMDS) and balance (F5 of LOMDS).

3.3. *Comparison between children with versus without motor impairment*

To rule out any overlap between normal and impaired children for motor tests we considered two separate groups.

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A group of children with normal motor function named motor-normal group, i.e., scoring within-normal normal range (>−1S.D.) for LOMDS ($n = 25$) and a group of children with impaired motor function named motor-impaired group, i.e., scoring below −2S.D. for LOMDS ($n = 23$). Analysis results are listed in Table 1 and showed significant differences between these two groups for either other tests linked to motor, or visual motor, functions or analyses referring to attention disorders.

Between-group differences for motor tests were somewhat expected as one might suppose correlation between LOMDS scores and other tests exploring the same domain. These differences concerned fine motor skills assessed by Purdue Pegboard test (PP PH ($F(1,35) = 8.15$, $p<0.01$); PP NPH ($F(1,35) = 6.38$, $p<0.05$); PP BM ($F(1,35) = 8.80$, $p<0.01$)); marginally significant differences were found for the block-design WISC-III sub-test ($F(1,40) = 3.98$, $p = 0.05$) and WISC-III Performance IQ ($F(1,46) = 3.53$, $p = 0.07$).

More important for the purpose of this study, between-group differences were also seen for tests linked to attention performance. Indeed, the number of children with attention deficit was higher in the group with motor deficit ($n = 34$, 61%) than in the unimpaired group ($n = 24$, 41%) ($\chi^2 = 6.70$, $p<0.01$); children was classified as with versus without attention deficit on the basis of scores on the "d2" and/or the Stroop test (see Section 2); further analysis revealed that by itself the percentage of errors (i.e., F%) on the "d2" test ($F(1,44) = 7.08$, $p<0.05$) also discriminated the two groups with versus without motor impairment.

Table 1 – Comparison between children with and without motor impairment

	Motor-normal group	Motor-impaired group	*p*
Children (number)	25	23	
	M (S.D.)	*M* (S.D.)	
Age (months)	131.0 (25.34)	142.6 (27.54)	0.13
Sex ratio[a]	2.6	2.3	0.85
SLI (%)[a]	20	30	0.40
Reading age (months)	90.2 (16.10)	95.0 (15.79)	0.31
Reading age discrepancy (months)	−40.8 (18.27)	−47.4 (22.2)	0.27
F IQ	103.3 (12.83)	98.7 (13.08)	0.23
V IQ	99.0 (11.92)	98.2 (12.77)	0.84
P IQ	107.1 (15.98)	98.9 (13.92)	0.07
Arithmetic	8.3 (2.17)	7.2 (2.93)	0.20
Block design	11.3 (2.54)	9.5 (3.30)	0.05
Digit span	5.3 (1.29)	5.0 (0.80)	0.52
RAN (S.D.)	−1.1 (1.06)	−1.6 (1.09)	0.19
Attention (%)[a]	24	61	<0.01
F%	6.0 (5.07)	11.5 (8.50)	<0.01
Planning (S.D.)	0.2 (1.23)	−0.1 (1.05)	0.49
Dysgraphia (%)[a]	29	45	0.25
PP PH (S.D.)	−0.3 (1.05)	−1.3 (1.09)	<0.01
PP NPH (S.D.)	−0.5 (0.98)	−1.4 (1.22)	<0.05
PP BM (S.D.)	−0.3 (1.12)	−1.3 (0.99)	<0.01

M: mean; S.D.: standard deviation; RAN: rapid automatized naming; PP PH: Purdue Pegboard Preferred Hand; PP NPH: Purdue Pegboard Non Preferred Hand; PP BM: Purdue Pegboard BiManual.
[a] χ^2-test.

3.4. *Comparison between children with versus without attention deficit*

Statistical analyses revealed significant differences between these two groups for digit span performance ($F(1,52) = 4.63$, $p<0.05$), performance planning ($F(1,48) = 5.92$, $p<0.05$). However, the main differences concerned motor tests (Table 2). The percentage of children with global motor impairment (<−1S.D.) was significantly higher in the group with attention deficit ($n = 18$, 75%) than in the unimpaired group ($n = 15$, 44%) ($\chi^2 = 6.72$, $p<0.05$).

While attention deficit had no influence on results on fine motor skills (Purdue Pegboard), we found a specific and significant influence of attention deficit on two factors of LOMDS. The two most impaired factors in the group with attention deficit were F3 or neuromotor co-ordination factor ($\chi^2 = 4.4$, $p<0.05$) and F5 or balance factor ($\chi^2 = 4.8$, $p<0.05$) for LOMDS. Fig. 1 shows the influence of attention deficit on each factor.

In addition, marginally significant differences between the two groups were also found for the block-design WISC-III sub-test ($F(1,50) = 3.79$, $p = 0.06$) and WISC-III Performance IQ ($F(1,56) = 3.55$, $p = 0.06$).

Table 2 – Comparison between children with and without attention deficit

	Attention-normal	Attention-impaired	*p*
Children (number)	34	24	
	M (S.D.)	*M* (S.D.)	
Age (months)	139.4 (28.65)	138.2 (27.83)	0.87
Sex ratio[a]	2.78	2.43	0.82
SLI (%)[a]	33	21	0.17
Reading age (months)	94.1 (16.37)	93.5 (16.83)	0.90
Reading age discrepancy (months)	−45.1 (20.41)	−44.8 (20.22)	0.96
Global motor impaired (%)[a]	44	75	<0.05
F IQ	104.1 (12.34)	98.6 (13.93)	0.12
V IQ	100.8 (12.0)	97.4 (14.06)	0.33
P IQ	106.9 (14.46)	99.7 (14.35)	0.06
Arithmetic	8.1 (2.47)	7.4 (2.82)	0.38
Block design	11.1 (2.65)	9.5 (3.12)	0.06
Digit span	5.5 (1.07)	4.9 (1.01)	<0.05
RAN (S.D.)	−1.3 (1.04)	−1.3 (1.20)	0.83
Planning (S.D.)	0.4 (1.11)	−0.2 (1.12)	<0.05
Dysgraphia (%)[a]	35	45	0.18
PP PH (S.D.)	−0.85 (1.22)	−0.89 (1.25)	0.90
PP NPH (S.D.)	−0.96 (1.24)	−1.08 (1.05)	0.72
PP BM (S.D.)	−0.91 (1.32)	−0.90 (1.17)	0.98

M: mean; S.D.: standard deviation; RAN: rapid automatized naming; PP PH: Purdue Pegboard Preferred Hand; PP NPH: Purdue Pegboard Non Preferred Hand; PP BM: Purdue Pegboard BiManual.
[a] χ^2-test.

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Finally, four groups were distinguished and compared (Table 3) to evaluate the respective influence of motor and attention impairments on reading scores and associated cognitive functions. These groups consisted of 19 children without any attention deficit (AD) or motor impairment (MI), 13 children with motor impairment but no attention deficit, 9 children with attention deficit but without motor impairment, and 17 children with both deficits. ANOVAs revealed no significant difference among the four groups on reading age discrepancy with chronological age and other neuropsychological variables excepted for WISC-III P IQ ($F(3,54) = 3.32$, $p<0.05$) and planning ($F(3,46) = 3.35$, $p<0.05$).

3.5. *Correlation analyses between language, motor and attention performances*

These analyses were performed on the whole group of subjects. No significant correlation was found between reading age discrepancy and (i) total motor scores of LOMDS ($r(58) = 0.09$, $p = 0.48$) or (ii) sustained attention score (F% from d2 cancellation test) ($r(56) = 0.23$, $p = 0.10$). By contrast, several significant negative correlations existed between sustained attention score and motor score. These correlations involved the F% score and respectively, the total motor score for LOMDS ($r(56) = -0.36$, $p<0.01$) as well as the neuromotor co-ordination factor (F3) ($r(50) = -0.46$, $p<0.01$) and the balance factor (F5) ($r(51) = -0.27$, $p = 0.05$). It means that motor impairment and especially co-ordination and balance impairments were more marked in those children with phonological dyslexia who presented a higher percentage of errors (F%) in the d2 cancellation test.

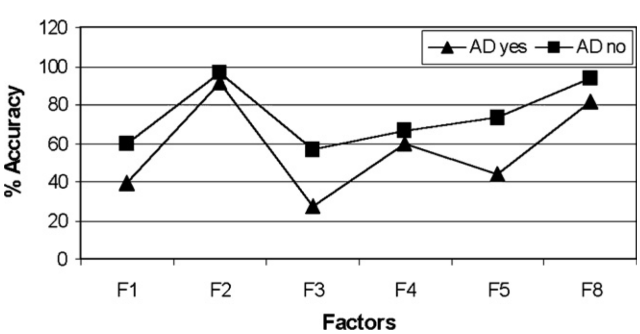

Fig. 1 – LOMDS (factors): role of attention deficit; AD = attention deficit.

4. Discussion

Two main results should be emphasized from the present retrospective study. First, our study shows that in this group of children, motor impairments were only co-morbid symptoms which are associated with developmental dyslexia but without direct causal link to the reading deficit. Second, the present results show the existence of a relationship between deficit of sustained attention and low scores on co-ordination and balance motor tests.

4.1. *Motor impairments are co-morbid symptoms*

The frequency of motor symptoms in groups of carefully selected dyslexic children is variable across studies. Ramus et al. reported motor impairment in 59% of cases in a group of 22 dyslexic children aged between 8 and 12 years.[12] Kaplan et al. found a DCD associated with dyslexia in 63% of their cases.[14] This variability might relate to the methods for assessing these disorders. In our study, the rate of children with motor symptoms ranged from 40% to 57% depending on the considered cut-off for severity, respectively, −2S.D. and −1S.D. On the other hand, the present study and others[12,14] concur to show that approximately 40% of children with developmental dyslexia exhibit no motor impairment. Therefore, motor deficits concern only a sub-group of children exhibiting dyslexia. Moreover, motor impairment appears independent to reading skills as we found no correlation between reading performance and motor scores. These results argue against the theory that suggest that cerebellar

Table 3 – Influence of attention deficit and motor impairment

	No AD nor MI	MI without AD	AD without MI	Both AD and MI	*p*
Children (number)	19	13	9	17	
Age (months)	132.1 (26.43)	145.8 (22.53)	141.8 (32.12)	139.5 (28.24)	0.54
Sex ratio[a]	2.8	2.3	3.5	2.4	0.97
SLI (%)[a]	26	9	11	41	0.14
Reading age (months)	92.2 (18.28)	96.6 (14.93)	92.0 (10.80)	94.5 (18.62)	0.88
Reading age discrepancy (months)	−40.1 (17.10)	−48.5 (19.82)	−49.8 (25.85)	−45.2 (20.92)	0.58
F IQ	102.8 (11.58)	105.4 (12.97)	107.3 (16.98)	95.3 (11.18)	0.08
V IQ	99.2 (10.65)	101.5 (12.12)	103.4 (18.58)	95.7 (12.36)	0.46
P IQ	106.1 (16.65)	108.2 (13.97)	109.7 (13.48)	95.2 (11.84)	<0.05
Arithmetic	8.3 (2.08)	7.6 (2.84)	7.7 (2.86)	7.4 (2.98)	0.82
Block design	11.0 (2.32)	11.6 (3.15)	10.5 (2.07)	9.0 (3.4)	0.12
Digit span	5.5 (1.25)	5.4 (0.87)	5.3 (1.32)	4.7 (0.73)	0.20
RAN (S.D.)	−1.4 (1.01)	−1.3 (1.01)	−1.5 (1.15)	−1.1 (1.26)	0.79
Planning (S.D.)	0.7 (0.91)	0.1 (0.67)	−0.2 (0.84)	−0.3 (1.23)	<0.05
Dysgraphia (%)[a]	21	50	55	56	0.33

AD: attention deficit; MI: motor impairment; S.D.: standard deviation; RAN: rapid automatized naming.
[a] χ^2-test.

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dysfunction could be the causal factor of reading impairment.[7,31] Nevertheless, analyses of motor symptoms showed that motor impairment was not a global deficit but rather concerned some specific domains of motor skills, i.e., manual dexterity, co-ordination and balance, and, disturbances of these three motor domains might be linked to cerebellar dysfunction. Estil et al. found similar deficiencies in motor skills in a group of children with SLI, a finding that suggests, according to these authors, a common mechanism that would mediate motor deficiencies in both dyslexia and SLI.[32] However, in our study, the presence of sequels of oral language deficit seems unrelated to motor performance as neither the proportion of children with these symptoms nor V IQ differed between the motor-normal and motor-impaired groups (Table 1). Finally, our results are not in favour of a simple maturational problem which would account for motor deficits in some children. Indeed, children with motor impairment tended to be older than unimpaired children in the present sample although the difference did not reach significance level. It is worth of note that motor deficits may persist with age and have been found even in adult population.[33]

4.2. *Relationship between attention deficit and motor impairment*

Although we did document motor impairments in some dyslexic children without attention deficit ($n = 13$ out of 34, 44%), the rate of motor deficiencies was higher in the group with attention deficit (75%) (Table 2). Reciprocally, the incidence of attention deficit, concerning predominantly sustained attention (Table 1), was significantly higher in the motor-impaired group relative to the motor-normal group (61% versus 24%). Moreover, correlations analyses showed negative correlations between sustained attention and motor scores. In accordance with previous studies,[8,12,34] these results are in favour of a confounding role of attention deficit in the assessment of motor disorders in dyslexic children. As previously proposed by Scandinavian authors, the concept of "DAMP" for "deficits in attention, motor control and perception"[35] could reflect this frequent overlap between ADHD and DCD. More specifically, our study suggests that this relationship between attention and motor impairment concerns two motor domains, balance and fine co-ordination.

The comparison of neuropsychological profiles of children with and without attention deficit revealed that digit span was significantly reduced in the group with attention deficit; this result was reported in several studies.[36,37] Recently, Reiter et al. studied executive functions in children with and without dyslexia. The authors reported impairments in dyslexic children for certain aspects of executive functions such as working memory or verbal and figural fluency. However, the authors found no difference between control and dyslexic subjects for concept formation; results were more inconsistent for problem solving or inhibition of inappropriate reactions.[38] In our study, planning, assessed with the Test of Tower of London, showed impairment for this ability in 4–8% of dyslexic children among whom children with attention deficit performed worse. Overall, both present results and those from other authors featured relationships between impairment of attention, planning functions and motor deficits in a sub-group of dyslexic children. It might be that these subjects suffer from a dysfunction of the cerebello-thalamo-prefrontal circuits involved in motor control and executive functions.

On the opposite, reading performance and other language performance seemed in our sample to be related to neither attention nor motor performance. No correlation was found between attention score and reading age discrepancy. The comparison of four groups (Table 3) defined by disjoint attention deficit and motor deficiencies binary factors (isolated attention deficit, isolated motor deficiencies, both disorders, none of them) did not suggest any specific effect of such factors on reading age discrepancy or other language-related performance.

4.3. *The possible aetiology of motor impairments*

Some authors like Kaplan et al. think that developmental disorders such as dyslexia, DCD or ADHD are different facets of a unitary syndrome which they termed Atypical Brain Development (ABD).[14] Recently, Ramus put forward a model for aetiology of developmental dyslexia that could generalize to all neuro-developmental disorders. Language symptoms (e.g. phonological deficit in dyslexia) are secondary to abnormalities of neural migration localized especially in the left perisylvian cortex, while motor impairments and perceptual deficits may be viewed as an associated sensory-motor syndrome which would be caused by abnormal cytoarchitectonic structure in sub-cortical areas.[13] For the same author, the presence of the latter abnormalities depends on environmental factors as hormonal influence and his model predicts that the sex ratio in the sub-group of dyslexics with motor impairment should be higher.[13] In our study, comparison of the sex ratio in the two groups has not revealed any significant difference (2.3 in the motor-impaired group versus 2.4 in the motor-normal group). As a co-morbid entity, motor dysfunction observed in a sub-type of developmental dyslexia might have a genetic origin. In a study of motor skills and reading ability, Francks et al. have reported that the genetic effects they observed were largely distinct; for instance, they did not observe linkage of hand motor skills to any chromosomal regions implicated in developmental dyslexia.[39]

4.4. *Limitations of the present study*

This study was retrospective and the results have to be confirmed by prospective studies. In addition, the frequency of motor disorders in dyslexia remains an issue as its appraisal depends on the method used to detect these disorders. The rate of impaired children is likely to be underestimated based only on dedicated scales in a clinical context, compared to experimental methods involving sophisticated measurements of, e.g., balance and motor performance.[40] On the other hand, small disturbances identified using the latter methods might lack clinical significance.

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5. Conclusion

Our retrospective study features two main points; a significant association exists between attention deficit and motor involvement in dyslexia, and second these two symptoms have little influence on reading skills. These results suggest that different pathophysiological mechanisms come into play for reading and motor/attention disorders, respectively and that cytoarchitectonic abnormalities may concern different regions of the central nervous system.

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