Deficits in executive functions and motor coordination in children with frontal lobe epilepsy

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Abstract

Frontal lobe dysfunction in adults has been associated with impairments of planning abilities, working memory, impulse control, attention and certain aspects of motor coordination. However, very few studies have attempted to assess these functions in children suffering from frontal lobe epilepsy. The aim of the present study was to determine whether some or all of the components of the frontal lobe syndrome are present in children with this disorder. For this purpose, a neuropsychological test battery was administered to 32 unresected epileptic children, aged 8–16 years: 16 with frontal lobe epilepsy (FLE), eight with temporal lobe epilepsy (TLE) and eight with generalized epilepsy whose principal manifestations were typical absences (GEA). The performances of the three epilepsy groups were further compared to normative data derived from 200 French-speaking, healthy children aged 7–16 years, except for standardized tests for which the norms provided in the manual were used. The three epilepsy groups did not differ with respect to conceptual shift and recency memory. However, the FLE children showed deficits in planning and impulse control. Furthermore, they had significantly more coordination problems and exhibited greater rigidity than the other epilepsy groups on the motor tests. These problems were more marked in younger FLE children (8–12 years). The latter were also more impaired on verbal fluency measures. No differences were observed with respect to gender, localization of the epileptic abnormality (unilateral versus bilateral) or medication (monotherapy versus polytherapy). The findings reveal similarities between the neuropsychological profiles of FLE children and adults with frontal lobe lesions. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Frontal functioning; Childhood epilepsy; Neuropsychological evaluation

1. Introduction

Experimental and clinical evidence points to the importance of the frontal lobes, especially the prefrontal areas, in the mediation of executive functions and motor coordination [8,27,65,67]. Executive functions represent a cognitive construct which refers to the ability to maintain an appropriate problem-solving set for the attainment of future goals [13,14,32,61,71]. They include planning, self-monitoring, organized search, concept formation, attention and impulse control [72] as well as working memory [7,52,53].

Data documenting the role of prefrontal cortex in the organization of executive functions have been derived from a variety of sources such as studies in adult patients with frontal lobe damage [2,4,8,34,61,65], lesion studies in non-human primates [11,13,19], single-cell recordings [16] and, more recently, neuro-radiological studies using regional cerebral blood flow [23], positron emission tomography (PET) [52,53], single photon emission computed tomography (SPECT) [57] and functional magnetic resonance imaging (fMRI)
in patients and healthy subjects [7,30,55]. The common finding is that the prefrontal areas are involved in various aspects of executive functions. Furthermore, cerebral imaging procedures have shown that the prefrontal cortex is functionally heterogeneous. For instance, there is evidence that the mid-dorsolateral frontal cortex is associated with working memory whereas the posterior dorsolateral region is crucial for visual associative learning [52,53]. With regard to motor functions, results of fMRI studies [27] in normal subjects point to the important role of the dorsolateral and medial premotor regions in the programming of trains of repetitive tapping movements.

Most of the research in patients with frontal lobe epilepsy has been carried out on adults who have undergone frontal lobectomy [22,39,41,43]. These patients display deficits on spatial, non-spatial and sensory delay tasks, sorting tests, tests requiring the monitoring of sequences of external events [15,29,41–43], concept formation and response inhibition tasks [40,63], associative learning tasks [51,54], as well as on a variety of attention and memory tasks [25,63,67]. In a recent neuropsychological study, Helmstaedter et al. [22] compared the performance of unresected temporal lobe epilepsy and frontal lobe epilepsy adults. The latter performed more poorly on Luria’s unimanual and bimanual motor sequencing tasks. They were also inferior to patients with temporal lobe epilepsy with regard to response maintenance and response inhibition on the Stroop Test. Furthermore, they were impaired on tests designed to assess visuo-perceptual speed (rapid discrimination of symbols) and interference (reverse reading of a letter sequence). Finally, they showed impairments with respect to concept formation, planning behaviour and response inhibition on the Wisconsin Card Sorting Test (WCST) and on a Maze test which were similar to those previously observed in patients with various types of frontal lobe lesions [32,33]. In contrast, the two epilepsy groups did not differ on the Verbal Fluency Test and on a letter cancellation test measuring sustained visual attention.

Studies in children have to take into account developmental aspects of frontal lobe functioning [10]. There is evidence that executive functions emerge in the first year of life, begin to mature between the ages of 4 and 7 years [47], undergo major changes between 8 and 12 years [5,47] and continue to develop in certain aspects at least until puberty (12–15 years and beyond) [18,72]. The maturational stages are demonstrable in the children’s increasing proficiency on various neuropsychological measures. This is exemplified in a study by Levin et al. [28]. These authors used the WCST, the Verbal Fluency and Graphic Fluency Test, the Tower of London, a Delayed Alternation task and a go–no-go task in healthy children who were divided into three groups along age lines. Children aged 7–8 and 9–12 years demonstrated increasing skills in concept formation and conceptual shift on the WCST and the go–no-go task, while the 13- to 14-year-old children showed important gains in the areas of response generation, planning ability and performance speed, as evidenced by an enhanced performance on the Graphic Fluency Test and the Tower of London.

A developmental trend was also observed by Chelune and Baer [5] who found that skills in concept formation, planning and problem-solving, measured on the WCST, developed progressively in children between 6 and 10 years. Around the age of 11 years most of the children were performing the task at adult level.

In another study, conducted by Welsh et al. [72] healthy children aged 3–12 years were submitted to a battery of ‘frontal’ tests in order to determine the point in development at which adult-level performance was achieved. Planning ability, assessed on a simple version of the Tower of Hanoi (TOH), was efficient at the age of 6 years. Children between 3 and 4 years of age showed significant steps towards achievement of this task. Conceptual shift was mastered around the age of 10 years, whereas the development of motor sequencing, verbal search and more complex planning skills (involving the manipulation of four or more disks on the TOH) appear to continue beyond the age of 12, since the 12-year-olds in the study were unable to attain adult level performance in these functions. Evidently, any insult at a given stage in development would be expected to interfere with the emergence of age-appropriate executive functions and motor skills.

Studies in pediatric patient populations have shown that impairments in executive functions can result from a variety of neurological conditions such as closed head injury [29,30,37], meningitis [68], brain hemorrhage [20] and exposure to environmental toxins [44], to name but a few. Some of these deficits can be directly related to frontal lobe dysfunction [29,30,37]. For instance, using fMRI in children with traumatic head injury, Levin et al. [30] observed that frontal lobe damage, but not extrafrontal damage, was associated with impaired performance on the Tower of London.

Distinct patterns of frontal lobe dysfunctions have also been described in four frontally-injured children, studied by Mateer and Williams [38]. The children showed cognitive and behavioural changes marked by impaired attention, academic deficits, irritability and social problems in the absence of apparent intellectual, linguistic or perceptual problems. Two children exhibited difficulties in planning and organization on the Mazes and the Block Design subtests of the revised Wechsler Intelligence Scale for Children (WISC-R). A reduction in verbal fluency (animal names) was observed in another case. Furthermore, all four children showed reduced speed on the interference part of the Stroop Test.
Similar impairments have been reported by Grattan and Esslinger [20] for a patient who suffered a subarachnoid hemorrhage in the left fronto temporal region at the age of 7 years. A 26-year follow-up of this patient further indicated important long-term deficits in psychosocial development and adaptive behaviour which could be attributed to poor auto-regulation. Deficits in self-regulatory and self-monitoring control also dominated the neurobehavioral tableau of a young boy, described by Marlowe [37] who sustained traumatic injury to the right prefrontal cortex. The patient was unable to elaborate and maintain efficient problem-solving strategies in spite of normally developed, even superior, verbal and non-verbal reasoning abilities.

Studies investigating executive functions in children with frontal lobe epilepsy are still scarce. Boone et al. [3], in a single case study, reported a frontal lobe syndrome in conjunction with a focus in the left frontal lobe in a 13-year-old girl. Neuropsychological testing revealed impaired performance on tasks measuring motor speed (Finger Tapping Test), attention and concentration (Digit Span of the WISC-R), alternation between two concepts (Trail Making Test, part B), planning ability (Mazes of the WISC-R) and response inhibition (Stroop Test). The motor performance on the Finger Tapping Test was depressed, particularly for the non-dominant left hand. No deficits were observed on tasks requiring categorization, abstract reasoning and concept formation (WCST). Similarly, Jambaque and Dulac [24] observed frontal lobe deficits in an 8-year-old boy of normal intelligence who presented with an epileptic focus in the right fronto-temporal region. The child showed marked behavioural and affective changes which abated when adequate seizure control was achieved. On neuropsychological tests, he manifested deficits in motor speed and planning ability on the WISC-R subtests Coding and Mazes. Manual dexterity was also affected as evidenced by a deterioration of his handwriting. Furthermore, he had difficulties reproducing a sequence of hand movements. His verbal fluency was reduced as was his attention span.

To our knowledge, no group studies have been conducted to date that have attempted to distinguish children with frontal lobe epilepsy (FLE) from children with other types of epilepsy. The purpose of the present study was to determine whether some or all characteristics of frontal lobe dysfunction are present in children with FLE as compared to children with temporal lobe epilepsy (TLE) or generalized epilepsy (GEA). Based on the few single case studies reviewed above, we expected that the FLE children would do more poorly on measures of motor coordination, mental flexibility, response initiation, impulse control and planning than the TLE and GEA children. We were also interested to know which of the tests employed to assess these functions would be most sensitive to frontal lobe dysfunction in children. The performance of the epileptic children was further compared to normative data derived from healthy children. Finally, the effects of the patients’ age and the localization of the epileptic abnormality (unilateral versus bilateral) were analyzed in order to assess maturation factors and possible effects of the extent of the pathology.

2. Methods

2.1. Subjects

Epileptic children. Thirty-two unresected epileptic children aged 8–16 years, participated in this study: 16 patients with frontal lobe epilepsy (12 boys and four girls) and 16 children (eight boys and eight girls) with other epilepsy types. The latter included eight patients with temporal lobe epilepsy (four boys and four girls) and eight with generalized epilepsy (four boys and four girls) whose main clinical manifestations were typical absence seizures. Eight of the FLE patients and all TLE and GEA patients were selected from the clinical population of the Hôpital Sainte-Justine in Montreal. The other eight FLE children were chosen from the patient pool of the Hôpital Saint Vincent de Paul in Paris. Demographic data of the patients are presented in Table 1. To assure uniformity of test procedures and scoring, all the test-givers in Montreal and Paris were trained by the same neuropsychologist (M.L.)

To be included in the study, the children had to have frontal, temporal or generalized (absences) epilepsy as

Table 1
Description of the sample (ranges, means and standard deviations)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Gender</th>
<th>Age at testing (years)</th>
<th>Age at seizures onset (years)</th>
<th>Duration of epilepsy (years)</th>
<th>Global IQ</th>
<th>Verbal IQ</th>
<th>Performance IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLE (n = 16)</td>
<td>12 boys</td>
<td>7.11–15.11</td>
<td>3.6–14.10</td>
<td>0.6–12.5</td>
<td>71–113</td>
<td>78–119</td>
<td>71–110</td>
</tr>
<tr>
<td></td>
<td>4 girls</td>
<td>11.34 (2.77)</td>
<td>7.77 (3.07)</td>
<td>3.82 (3.76)</td>
<td>91.75 (13.59)</td>
<td>95.19 (14.40)</td>
<td>90.00 (13.97)</td>
</tr>
<tr>
<td>TLE (n = 8)</td>
<td>4 boys</td>
<td>8.5–16.1</td>
<td>2.0–13.9</td>
<td>0.11–6.3</td>
<td>81–123</td>
<td>72–133</td>
<td>84–131</td>
</tr>
<tr>
<td></td>
<td>4 girls</td>
<td>12.44 (2.81)</td>
<td>9.06 (3.50)</td>
<td>3.64 (2.17)</td>
<td>97.00 (14.02)</td>
<td>95.50 (14.48)</td>
<td>99.00 (14.56)</td>
</tr>
<tr>
<td>GEA (n = 8)</td>
<td>4 boys</td>
<td>8.5–16.5</td>
<td>3.0–15.0</td>
<td>1.0–7.11</td>
<td>77–114</td>
<td>74–113</td>
<td>82–136</td>
</tr>
<tr>
<td></td>
<td>4 girls</td>
<td>11.15 (2.89)</td>
<td>8.21 (3.54)</td>
<td>2.84 (2.28)</td>
<td>94.00 (11.69)</td>
<td>92.00 (12.59)</td>
<td>97.63 (17.44)</td>
</tr>
</tbody>
</table>
the principal diagnosis according to clinical history and recent EEG recordings (within the last 2 months). Children with concomitant neurological problems (e.g. hemiplegia, tumors, head injury, diseases of the CNS), brain surgery and/or psychiatric problems were excluded. Information about the patient’s clinical, electroencephalographical, psychological, academic and social history was obtained from their hospital files and interviews with their parents. Informed consent was obtained from all patients or their parents.

All the children were unilingual francophone. FLE, TLE and GEA children were matched for age, IQ, age at seizure onset and duration of the epilepsy. The ranges, means and standard deviations of these variables are presented in Table 1. Similarly, the localization of the EEG abnormalities was comparable in the FLE and TLE groups: half of the cases had bilateral foci, the other half had unilateral foci, 25% in the right and 25% in the left hemisphere. Neuroimaging (MRI or CT scan) revealed a localized abnormality in three FLE children (left frontal dysplasia in two cases and right frontal dysplasia in one case) and two TLE patients (left temporal dysplasia, ventricular asymmetry). In the remaining patients no structural abnormalities were detected.

Partial complex seizures were the predominant seizure type in 15 of the 16 FLE children and all TLE children. This seizure type is difficult to control. Consequently, seizure frequency fluctuated considerably over the years in the FLE and TLE groups. Nine (56%) FLE children, four (50%) TLE and GEA children still present occasional seizures, especially in stress situations. However, at the time of testing, they had not experienced a seizure for the past 2 months. In fact, seven (44%) FLE children and four (50%) TLE and GEA children had not had a seizure for at least 1 year. All but two cases (one TLE and one GEA child) were on medication. In six (38%) FLE children, four (50%) TLE children and seven (88%) GEA children the seizures were controlled with a single anticonvulsant drug (Carbamazepine, Valproic acid, Vigabatrin, Trileptal or Stiripentol). Ten of the FLE children (62%) and three of the TLE children (38%) received more than one antiepileptic drug. In these cases, Clobazam, Lamotrigine and Vigabatrin were most frequently added to Carbamazepine, Valproic acid or Phenytoin.

**Healthy controls.** Because at the time of testing no normative data for children existed for most of the tasks employed, the following tests were administered to an unselected group of 200 healthy French-speaking children, aged 7–16 years (n = 20 for each age group) who all attended regular classes: Thurstone’s Uni- and Bimanual Performance Test, Self-ordered Pointing Task, Verbal Fluency Test and the Tower of London [35,36].

### 2.2. Preliminary tests

The children’s intellectual capacities were assessed on a French version of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) [70]. Separate statistical analyses were conducted comparing the three groups on verbal IQ, performance IQ and full scale IQ as well as on age at testing, age at seizure onset and duration of the epilepsy. An additional analysis was performed comparing FLE and TLE children on monotherapy and polytherapy.

### 2.3. Experimental tests

The evaluation was completed during the course of two sessions, lasting ~ 2 h each, during which a battery of ‘frontal tests’ designed to assess motor coordination and executive functions was administered to each child. The tests used in the assessment are displayed in Fig. 1.

1. **The Purdue Pegboard Test** [31]. This test evaluates manual dexterity and bimanual coordination. The child has to introduce as quickly as possible small metal pins into holes arranged in two vertical rows on a wooden board, starting on top of the row on the side of the preferred hand. The test is performed consecutively with the preferred hand and with the non-preferred hand. Finally, both hands are used to fill simultaneously the two rows. The total number of pins placed within 30 s was recorded for each trial.

2. **The Thurstone’s Uni- and Bimanual Performance Test** [31] is a more complex test of motor coordination that requires the maintenance of a sequence of movements and the bimanual performance of asymmetrical movements in rapid succession. Adult patients with frontal lobe lesions have been found to be impaired on this task [26]. In the present study, an adaptation by Leonard, Milner and Jones [36] was used. The apparatus consists of two circular copper plates (r = 7 cm) mounted on the left and the right side of a wooden board which is plugged into an electric outlet (see Fig. 1). Each plate is divided into four sectors which are numbered from 1 to 4. The numbers are positioned in such manner that the numbers 1 and 2 on the right circle correspond to the numbers 3 and 4 on the left circle and vice versa. Each plate is connected to a metal stylus which in turn is connected to a mechanical counter. The contact between the stylus and the copper plate closes an electrical circuit which activates the counter. The child is instructed to touch the quadrants with the metal stylus in the sequence 1–2–3–4 as quickly as possible. Each contact is registered on the counter. The task is performed alternately with the preferred hand, with the non-preferred hand and finally with both hands whereby the child has to touch simultaneously the same numbers situated in different locations on both circles. Two trials of 30 s each are given.
Fig. 1. Tests used in the present study.

1. Purdue Pegboard Test
   motor coordination, manual dexterity

2. Thurstone's Uni and Bimanual Performance Test
   complex motor coordination

3. Luria’s Motor Sequences
   motor coordination, sequencing, response inhibition, flexibility
   **Gestural sequences**
   a) palm-fist-side alternations
   b) alternate tapping
   c) reciprocal palm-fist alternation
   d) reciprocal alternation (3-2)
   **Graphic sequences**
   a) continuation of peek-and-valley pattern
   b) serial reproduction of "curl" model

4. Wisconsin Card Sorting Test (WCST)
   mental flexibility, conceptual shift

5. Self-ordered Pointing Task
   recency memory, self-regulatory behavior

6. Verbal Fluency Test
   verbal search, response initiation under time constraints

7. Tower of London
   planning ability

for each hand and in the bimanual condition. The number of errors (break of sequence) is monitored by the experimenter. The score is the number of contacts registered by the counter minus the number of errors.

3. **Luria’s Motor Sequences** [34]. This series of tests was chosen to assess motor programming, response inhibition and mental flexibility. The child has to perform a series of sequences of hand movements or to continue an alternating graphic pattern for 30 s. Four gestural sequences and two graphic sequences are administered according to the administration and scoring rules described in the ‘Programa Integrado de Evaluacion Neuropsicologica: Test-Barcelona’ [48].

The gestural sequences consisted of: (a) rapid repetitions of the sequence fist–palm-side; (b) alternate tapping where the child has to alternate between one hard tap and two soft taps on the table with the same hand. These two sequences are first performed with the preferred hand then with the non-preferred hand following a 30-s practice trial with each hand; (c) reciprocal palm–fist alternation requiring simultaneous but asynchronous, alternating movements with both hands (e.g. the right hand is closed to a fist when the left hand is extended palm facing down and vice versa); and (d) reciprocal alternation 3 versus 2 where the child is asked to alternate between three taps on the table.
with the right hand and two taps with the left hand (see Fig. 1).

The graphic sequences required: (a) continuation of an alternating pattern. In this task, the child has to continue a graphic model which alternates between two variations of a peak-and-valley pattern without lifting the pencil; (b) reproduction of a pattern requiring the repetitive copy of a ‘curl’ model.

The following scoring criteria were used for the gestural and graphic sequencing tasks: (a) score of 2 points was given for a series of sequences that was performed correctly, quickly and without error; 1 point was allotted for a correct but slow performance or for any hesitation or loss of rhythm. A score of 0 was given for interruption of the sequence, vague gestures, contaminations (mixing gestures of different tasks), perseverations, closing-in (with the graphic model) and/or absence of a response.

4. The Wisconsin Card Sorting Test (WCST) [21,31] was used to assess response inhibition and mental flexibility on the cognitive level. In this test, four target cards (one red triangle, two green stars, three yellow crosses and four blue circles) are placed in front of the child. The latter is given two packs of cards with the instruction to place the cards, one by one, under the stimulus cards where he/she thinks they go. During the course of the test, the child must try to guess the sorting principle used by the examiner on the basis of verbal feedback (‘right’ or ‘wrong’) which he/she receives on each response. The cards have to be sorted first according to color, then to form and finally to number. After 10 correct responses, the category is changed without prior warning. The test ends when the child has completed the three categories twice or when both packs of cards are used up. Three scores are obtained. These include: (a) the number of perseverative responses referring to persistence in responding to any one particular category throughout the test; (b) the number of perseverative errors referring to persistence, in spite of negative feedback, in a response that would have been correct at an earlier stage of the test but is later considered an error; and (c) the number of categories completed (0–6).

5. Self-ordered Pointing Task. This task was first used by Petrides and Milner [54] to examine recency memory and self-regulation of behaviour in adult patients with frontal lobe lesions. The subject is shown three series of six, eight and ten abstract designs. Each series is presented three times. The arrangement of the designs on the page differs from one trial to the other. The subject is instructed to point to one design on each page without pointing twice to the same one. After completing the test, a recognition task is given where the subject is asked to find among an array of abstract designs, some of which have not been shown before, the designs he/she has pointed to previously. The following scores are obtained on this test: (a) the number of errors for each of the three series; (b) the total number of errors; (c) the total number of stimuli recognized.

6. The Verbal Fluency Test [24,32] which assesses response initiation and verbal search was chosen because of its sensitivity to frontal lobe damage in adult patients [40,50]. In this two-part test, the child has to say as many different words as possible according to the test instructions within a limited time (1 min). In the phonemic condition, the child is asked to generate words starting with a given letter (P, F, L in the French version) to the exclusion of proper names and words with the same stem (i.e. peel-peeled). In the semantic condition, the subject has to produce words that belong to a specific category (first names, fruits/vegetables and animals). The final score is the total number of correct words generated in each of the two conditions.

7. The Tower of London [61] is a test that evaluates the subject’s ability to plan and to anticipate his actions. The child is presented with three colored spheres (blue, green and red) which can be placed on three sticks of different length. Always starting from the same configuration, the child is allowed a limited number of moves to match the model presented on a stimulus card (Fig. 1). Twelve models are presented that increase in difficulty with the easier models requiring two moves and the most difficult ones requiring five moves. The child is allowed six trials to reproduce each model. Five different measures are obtained: (a) the number of models completed on the first trial; (b) the total number of trials required to reproduce the 12 models; (c) the planning time referring to the time the child takes to remove the first sphere; (d) the total time defined as the time from the start to the completion of a model; and (e) the execution time which is obtained by subtracting the planning time from the total time. The time measures are calculated only for the models completed on the first trial.

3. Data analysis

3.1. Preliminary tests

The demographic variables of the three epilepsy groups (see Table 1) were submitted to separate analyses of variance (ANOVA) to determine whether the groups were adequately matched. Furthermore, a Chi-square analysis was performed comparing the number of FLE and TLE children on monotherapy with those on polytherapy.
3.2. Experimental tests

A multivariate analysis (MANOVA) with group as a factor and age in years as covariate were performed on the scores of six of the seven experimental tests (tests 1, 2, 4, 5, 6, 7) comparing the three epilepsy groups (FLE, TLE, GEA) among themselves. Post-hoc group differences were computed using the Tukey statistic. The scores of the epileptic children were further compared to normative data derived from 200 French-speaking controls aged 7–16.5 years [28,29], except for the Purdue Pegboard Test and the Wisconsin Card Sorting Test for which the age norms provided in the manual were used [17,24]. Since the data at different age levels are not normally distributed, a quadratic fit was performed on the means and standard deviations of these norms for each variable and each age level using the formula \( f(\text{age}) = a + b \times \text{age} + c \times \text{age}^2 \) (SPSS) where \( a \), \( b \), and \( c \) are the parameters for which an optimum fit is desired. These adjusted norms were then entered in a graph together with the raw scores of each of the epileptic children. In addition, two separate analyses of covariance (ANCOVA) with age in years as covariate were performed on polytherapy; and (2) boys versus girls collapsed across the three epilepsy groups.

For the discrete variables of Luria’s Motor Sequences, comparisons between the three epilepsy groups were carried out using Chi-square analyses. No norms for children are available for these tasks.

To analyze the effects of age and localization of the epileptic foci (unilateral vs. bilateral) the Mann-Whitney U test was employed. This nonparametric statistic was chosen because splitting the groups according to age or localization of the foci resulted in a relative small number of data in each cell. To test the effect of age, three separate analyses were performed comparing: (1) younger FLE children (8–12 years: \( n = 9 \)) with older FLE children (13–16 years: \( n = 7 \)); (2) younger TLE and GEA children combined (\( n = 10 \)) with older TLE and GEA children combined (\( n = 6 \)); and (3) younger FLE children (\( n = 9 \)) with younger TLE and GEA children combined (\( n = 10 \)). To assess the effect of the localization of the lesion(s), two analyses were carried out comparing: (1) FLE children with a unilateral focus (\( n = 8 \)) versus FLE children with bilateral foci (\( n = 8 \)); and (2) TLE children with a unilateral focus (\( n = 4 \)) versus TLE children with bilateral foci (\( n = 4 \)).

4. Results

4.1. Preliminary tests

Inspection of Table 1 reveals that there was a higher proportion of boys in the FLE group. The ANOVA revealed that the three epilepsy groups did not differ with respect to other demographic or clinical variables such as age at testing (\( F_{(2,29)} = 0.724, P > 0.05 \)), age at seizure onset (\( F_{(2,29)} = 0.412, P > 0.05 \)) and duration of the epilepsy (\( F_{(2,29)} = 0.270, P > 0.05 \)). Similarly, the Chi-square analysis comparing the number of FLE and TLE children on monotherapy and polytherapy was not significant (\( \chi^2 = 2.76, P > 0.05 \)). Furthermore, no significant differences were observed with respect to global IQ (\( F_{(2,29)} = 0.422, P > 0.05 \)), verbal IQ (\( F_{(2,29)} = 0.167, P > 0.05 \)) and performance IQ (\( F_{(2,29)} = 1.242, P > 0.05 \)). However, inspection of Table 1 shows that the Performance IQ of the FLE group was nine points lower than that of the TLE group (see Table 1). In order to determine whether this difference could be attributed to a reduced performance of the former on the Picture Arrangement subtest which has a strong executive component in that it requires sequencing, planning and organization, a Chi-square analysis was conducted to compare the performances of FLE and TLE children on this subtest. The analysis failed to yield a significant effect for this factor (\( \chi^2 = 10.72, P > 0.05 \)).

4.2. Experimental tests

The means and standard deviations of six of the seven experimental tests obtained from FLE, TLE, GEA children and normal controls are depicted in Table 2. The results of Luria’s Graphic and Gestual Sequences are presented in Table 3.

1. Purdue Pegboard Test. The manual of the Purdue Pegboard Test provides separate norms for boys and girls. For the purpose of the analysis, the scores obtained from the two gender were combined. The MANOVA Group (FLE, TLE, GEA) × Condition (preferred hand, non-preferred hand, bimanual) yielded a significant group effect for the bimanual condition (\( F_{(2,29)} = 3.2303, P < 0.05 \)), the performance of the FLE children being significantly inferior to that of the TLE and GEA children. The performance of the FLE children was characterized by slow, rigid or impulsive movements leading to the frequent dropping of pins. The three groups did not differ in the unimanual conditions.

Fig. 2 shows the individual scores of the three epilepsy groups in relation to the age norms. The solid lines represent the means for boys (Fig. 2(A)) and girls (Fig. 2(B)) obtained from the test manual. The broken lines denote one and two standard deviations (SD) above and below these means. Combining the scores of boys and girls, it can be seen that 14 (88%) FLE children (11 of the 12 boys and three of the four girls) and three (38%) TLE and GEA children obtained scores that fell 1 SD or more below the norms. In fact, seven (44%) of these FLE children, as opposed to two
Table 2
Test results (means and standard deviations) of the three epilepsy groups

<table>
<thead>
<tr>
<th>Test</th>
<th>FLE ($n = 16$)</th>
<th>TLE ($n = 8$)</th>
<th>GEA ($n = 8$)</th>
<th>Normative data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purdue Pegboard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A) Boys:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred hand:</td>
<td>11.42 (2.06)</td>
<td>12.50 (2.30)</td>
<td>12.50 (2.29)</td>
<td>15.00 (1.87)</td>
</tr>
<tr>
<td>Non-preferred hand:</td>
<td>10.00 (2.20)</td>
<td>11.50 (2.06)</td>
<td>12.75 (2.16)</td>
<td>13.92 (1.89)</td>
</tr>
<tr>
<td>Bimanual condition:</td>
<td>7.58* (1.23)</td>
<td>10.00 (2.44)</td>
<td>10.50 (2.69)</td>
<td>11.86 (1.68)</td>
</tr>
<tr>
<td>(B) Girls:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred hand:</td>
<td>13.75 (3.98)</td>
<td>12.00 (1.22)</td>
<td>13.25 (3.03)</td>
<td>15.54 (1.70)</td>
</tr>
<tr>
<td>Non-preferred hand:</td>
<td>13.00 (3.08)</td>
<td>11.25 (1.64)</td>
<td>13.75 (3.51)</td>
<td>14.01 (1.62)</td>
</tr>
<tr>
<td>Bimanual condition:</td>
<td>9.25 (1.30)</td>
<td>10.25 (1.30)</td>
<td>10.00 (2.12)</td>
<td>12.04 (1.52)</td>
</tr>
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<td><strong>Uni- and Bimanual Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred hand:</td>
<td>63.91 (18.15)</td>
<td>80.87 (20.78)</td>
<td>74.12 (17.19)</td>
<td>99.95 (14.71)</td>
</tr>
<tr>
<td>Non-preferred hand:</td>
<td>58.72* (15.45)</td>
<td>78.12 (20.90)</td>
<td>70.06 (18.98)</td>
<td>88.94 (14.46)</td>
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<tr>
<td><strong>Wisconsin Card Sorting Test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perseverative responses:</td>
<td>33.38 (12.38)</td>
<td>26.50 (12.31)</td>
<td>27.00 (16.94)</td>
<td>20.56 (15.80)</td>
</tr>
<tr>
<td>Perseverative errors:</td>
<td>26.06 (12.31)</td>
<td>23.13 (12.01)</td>
<td>23.00 (12.72)</td>
<td>18.12 (12.69)</td>
</tr>
<tr>
<td>Categories completed:</td>
<td>3.69 (0.51)</td>
<td>4.38 (0.56)</td>
<td>4.63 (0.42)</td>
<td>4.96 (1.47)</td>
</tr>
<tr>
<td><strong>Self-ordered Pointing Task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Errors-6 designs:</td>
<td>2.44 (2.16)</td>
<td>2.13 (1.46)</td>
<td>2.00 (1.20)</td>
<td>1.76 (1.34)</td>
</tr>
<tr>
<td>Errors-8 designs:</td>
<td>5.38 (2.39)</td>
<td>4.25 (3.15)</td>
<td>5.00 (2.07)</td>
<td>3.20 (1.60)</td>
</tr>
<tr>
<td>Errors-10 designs:</td>
<td>6.94 (2.86)</td>
<td>4.75 (2.92)</td>
<td>6.25 (2.60)</td>
<td>3.92 (1.86)</td>
</tr>
<tr>
<td>Total errors:</td>
<td>14.38 (5.38)</td>
<td>11.13 (6.75)</td>
<td>13.25 (4.89)</td>
<td>8.82 (3.75)</td>
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<tr>
<td>Stimuli recognized:</td>
<td>6.43 (1.02)</td>
<td>6.50 (1.51)</td>
<td>6.00 (1.71)</td>
<td>6.85 (1.07)</td>
</tr>
<tr>
<td><strong>Verbal Fluency Test</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonemic condition:</td>
<td>14.69* (6.37)</td>
<td>21.00 (6.85)</td>
<td>23.00 (4.87)</td>
<td>24.29 (6.92)</td>
</tr>
<tr>
<td>Semantic condition:</td>
<td>33.38* (11.06)</td>
<td>45.00 (11.01)</td>
<td>44.75 (14.10)</td>
<td>51.23 (9.60)</td>
</tr>
<tr>
<td><strong>Tower of London</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Models completed at first trial:</td>
<td>5.75 (1.73)</td>
<td>7.63 (1.60)</td>
<td>6.00 (2.07)</td>
<td>6.76 (1.64)</td>
</tr>
<tr>
<td>Total number of trials completed:</td>
<td>23.06 (5.52)</td>
<td>17.88 (3.94)</td>
<td>24.50 (6.61)</td>
<td>21.55 (4.31)</td>
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<td>Planning time (s):</td>
<td>4.16* (2.36)</td>
<td>7.18 (1.93)</td>
<td>6.15 (2.19)</td>
<td>4.66 (2.6)</td>
</tr>
<tr>
<td>Execution time (s):</td>
<td>9.25* (3.17)</td>
<td>6.10 (1.97)</td>
<td>6.19 (1.76)</td>
<td>4.95 (1.40)</td>
</tr>
<tr>
<td>Total time (s):</td>
<td>12.01 (3.81)</td>
<td>12.77 (2.40)</td>
<td>12.34 (3.09)</td>
<td>9.67 (2.99)</td>
</tr>
</tbody>
</table>

* $P < 0.05$. 
Table 3
Percentages of FLE, TLE and GEA children who obtained scores of 0, 1 and 2 on the seven conditions of Luria’s motor sequences

<table>
<thead>
<tr>
<th>Groups</th>
<th>Total points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 points</td>
</tr>
<tr>
<td>FLE (n = 16)</td>
<td>21&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TLE (n = 8)</td>
<td>0</td>
</tr>
<tr>
<td>GEA (n = 8)</td>
<td>0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Fist–palm-side: preferred hand and non-preferred hand; alternate tapping: preferred hand and non-preferred hand; reciprocal palm-fist alternation; reciprocal alternation 3–2; graphic sequences (a and b combined).

<sup>b</sup> P < 0.05.

(25%) TLE children and two (25%) GEA children performed 2 SD below the norms of their age mates whereas one TLE and one GEA child (13%) performed 2 SD above these norms.

2. Thurstone’s Uni- and Bimanual Performance Test. Significant group differences were obtained for the non-preferred hand (F<sub>12.28</sub> = 3.6526, P < 0.05) and in the bimanual condition (F<sub>12.28</sub> = 3.1901, P < 0.05). FLE children made significantly fewer correct contacts (taps) than the TLE group in both conditions. Furthermore, they had difficulties maintaining the sequence. The three epilepsy groups did not differ with respect to the preferred hand.

Fig. 3 illustrates the performance of the three groups of patients with the non-preferred hand (Fig. 3(A)) and in the bimanual condition (Fig. 3(B)) in comparison to the adjusted norms of the control group. In the unilateral condition, 14 (88%) of the FLE children and five (63%) of the TLE and GEA children obtained scores for the non-preferred hand that fell 1 SD or more below the norms of the age-matched sample. Six (38%) of these FLE children scored 2 SD below the mean of the controls as did one (13%) TLE child. In the bimanual condition, nine (56%) of the FLE subjects, but only one TLE (13%) child and two GEA (25%) children performed 1 SD below the age norms.

3. Luria’s Motor Sequences. Chi-square analyses revealed significant differences between the three epilepsy groups with respect to the frequency distribution of the total points received for their performance of the seven conditions (see Table 3). Thus, a significantly greater proportion of FLE patients obtained error scores (0-points) (21% FLE versus 0 TLE and GEA children: χ<sup>2</sup> = 24.00, P < 0.05) and fewer attained perfect performance (2-points) (44 FLE versus 66 and 82% TLE and GEA children, respectively: χ<sup>2</sup> = 9.406, P < 0.05). Furthermore, the FLE group exhibited several qualitative characteristics that are usually seen in patients with frontal lobe lesions [27], such as rigidity and slowness of hand movements, difficulties in maintaining a smooth flow of sequences (e.g., in the more complex fist–palm-side condition) and a tendency to use spatial strategies (changing the place of the hand for each movement of a sequence) and verbal strategies (verbalizing the individual movements) to direct their movements.
4. *Wisconsin Card Sorting Test*. No significant differences were found between the three epilepsy groups with respect to the number of perseverative responses, perseverative errors or categories completed. Qualitatively, however, FLE children tended to respond more impulsively (e.g. placing the cards quickly without paying attention to the examiner’s feedback) or had greater difficulties following test instructions, (e.g. taking any card of the stack in spite of being repeatedly instructed to always take the first card), behaviours that were not observed in the other two groups.

Examination of the results of the three epilepsy groups in relation to normative data obtained from the test manual (Table 2) reveals that FLE, TLE and GEA children completed as many categories as normal children but they seemed to produce more perseverative responses and to make more perseverative errors than the latter.

5. *Self-ordered Pointing Task*. The analysis of the error scores for the three series of designs and the recognition condition failed to yield any significant differences between the three epilepsy groups. A comparison with normative data (Table 2) suggests that the epileptic children had more difficulties on the pointing tasks, but not on the recognition task, than healthy children.

6. *Verbal Fluency Test*. The MANOVA performed on the data indicated that FLE children generated significantly fewer words beginning with a given letter than the GEA children in the phonemic condition ($F_{(2,28)} = 6.7830, P < 0.05$) and produced fewer words belonging to a specific category than the TLE children in the semantic condition ($F_{(2,28)} = 5.3292, P < 0.05$). The majority of FLE children had considerable difficulties generating words in the phonemic condition. They spent 20 s or more before producing the first word. They were somewhat more fluent in the semantic condition.

When the scores obtained in the phonemic condition were compared to the norms of the controls (Fig. 4(A)), 11 (67%) of the FLE patients and four (50%) TLE performed 1 SD below the mean. Two (13%) of these FLE patients and one (13%) TLE performed 2 SD below the mean. In the semantic condition (Fig. 4(B)), 13 (81%) FLE children versus three (38%) TLE and two (25%) GEA children performed 1 SD below the norms. The scores of six (38%) of these FLE and two (25%) of the TLE children fell 2 SD below the norms of the control group.

7. *Tower of London*. The analyses yielded significant differences in planning time ($F_{(2,28)} = 4.9131, P < 0.05$) and execution time ($F_{(2,28)} = 5.2906, P < 0.05$) between the three epilepsy groups. The FLE children took less time to plan their moves but required more time to execute the models than the TLE and GEA children. They either made their first move immediately after the model was placed before them or ignored the instructions of moving one sphere at a time. No significant differences among the three groups were observed with regard to the number of models completed on the first trial or the total number of trials required to successfully reproduce the models.
Compared to normal children, six (38%) FLE children but none of the TLE and GEA children obtained shorter planning times placing them 1SD or more below the mean (Fig. 5(A)). As for execution times, the majority of FLE children (13 or 81%) as opposed to three (38%) TLE and two (25%) GEA children required more time than the controls, their performance falling 1–2 SD above the time taken by the controls (Fig. 5(B)). In fact, nine (56%) FLE children obtained scores falling 2 SD above the average execution time of the controls.

4.3. Effect of polytherapy versus monotherapy on test performance

The ANCOVA exploring the effect of polytherapy versus monotherapy on test performance across the epilepsy groups was non significant, which indicates that the number of drugs taken by these children at the time of testing did not influence their performance in a significant way.

4.4. Effect of gender on test performance

No significant gender differences were found for any of the tests across the three epilepsy groups.

4.5. Effect of age on test performance

Mann Whitney U analysis comparing younger (8–12 years) versus older (13–16 years) epileptic children yielded a significant age effects for the FLE children for: (1) the Thurstone’s Uni- and Bimanual Performance Test for the non-preferred hand ($U = 6.5, P < 0.01$); (2) and in the bimanual condition ($U = 5.0, P < 0.01$), showing that the younger FLE children were less apt than the older FLE children on this motor task; (3) the alternate tapping task (Luria) for the preferred hand ($U = 17.5, P < 0.05$) where the younger FLE children had more difficulties than the older FLE children; and (4) the Verbal Fluency Test in the phonemic condition ($U = 11.5, P < 0.05$) and the semantic condition ($U = 7.0, P < 0.05$), indicating that the younger FLE children generated significantly fewer correct words in these conditions than the older FLE children. No significant differences emerged for younger TLE and GEA versus older TLE and GEA combined on these measures. Comparison between the young children of all epilepsy groups (FLE young versus TLE and GEA young combined) revealed that the younger FLE children also produced fewer words in both the phonetic condition ($U = 6.5, P < 0.05$) and the semantic condition ($U = 13.0, P < 0.05$) than the younger children of the other two groups. In contrast, no significant age differences were obtained on the remaining sequencing tasks, the Purdue Pegboard Test, the WCST, the Tower of London and the Self-ordered Pointing Task for any of the groups.

4.6. Effect of the localization of the epileptic abnormality on test performance

Within-group comparisons of FLE and TLE children with unilateral versus bilateral foci failed to produce significant effects with regard to the localization of the abnormality. That is to say, bilateral foci in the frontal...
or temporal lobe did not affect test performance more than unilateral foci in our small sample.

5. Discussion

The aim of the present study was to investigate whether children suffering from frontal lobe epilepsy would present some or all of the characteristics of frontal lobe dysfunction seen in adult patients with frontal lobe lesions. Furthermore, in addition to providing a neuropsychological profile of children with FLE, the results of the present study were also expected to provide information as to which of the tests used in the assessment of frontal functions would be most useful in discriminating between children with FLE and children with epileptic foci in other areas of the brain.

On the basis of the few single cases reported previously [3,24], we expected that the FLE children would manifest impairments on many tasks tapping executive functions and motor coordination. Our results confirmed this hypothesis: Compared to children with temporal lobe epilepsy and generalized seizures (absences), the children with frontal lobe foci showed deficits on tasks assessing motor coordination, verbal fluency, mental flexibility, impulse control and planning. The performance of the other epilepsy groups was also to some extent affected relative to healthy controls which suggests that epilepsy per se has a deleterious effect on ‘frontal’ functions, irrespective of the area(s) involved in the production of the seizures. Several authors have noted that any diffuse dysfunction interfering with normal brain activity, can disrupt executive functions [17,66]. Indeed, as mentioned before, impairments in executive functions have been described in a variety of childhood disorders [44,68]. Furthermore, it is well known that seizure activity originating in the frontal lobe rapidly spread to other regions owing to the rich connections of this lobe with neighboring cortical and subcortical areas [2,9,73,74]. Finally, the antiepileptic medication, that was taken by all but two of our subjects, may have adversely affected their test performance. For instance, Riva and Devoti [58] found that scores on tests assessing frontal lobe functions improved significantly after withdrawal of carbamazepine in children who had been treated with monotherapy at therapeutic levels. However, the performance of the FLE children in the present study was inferior to that of the TLE and GEA children on several measures of motor coordination and of executive functions, such as the Verbal Fluency Test and the Tower of London, that have been found to be selectively impaired in children and adults with frontal lobe damage [29,30,40,56,61].

It might be argued at this point that the strong gender bias in favor of boys in our FLE sample may have affected the results, due to different maturation levels of boys and girls. However, no significant gender differences were observed for any of the tests. Furthermore, it should be kept in mind that impairments similar to the ones reported herein have been observed in other mixed samples of children with frontal lobe lesions [29,30,38] as well as in the 13-year-old female patient with FLE studied by Boone et al. [3].

The finding that the FLE children had significantly more difficulties on motor coordination tasks than the TLE and the GEA children is indicative of a dysfunc-
tion in motor integration in this population similar to that found in unresected epileptic adults [22]. This was true especially for tasks requiring bimanual coordination. Unimanual performance was impaired only on the more complex motor test (Thurstone) when the task was performed with the non dominant hand. The performance of the preferred hand was not significantly more affected in FLE children than in TLE or GEA children, probably because this hand is more skilled and thus more apt to master novel motor tasks. Most new motor skills such as writing and drawing are acquired only with the preferred hand. The observation that bimanual performance was generally more impaired than unimanual performance in the FLE group indicates that frontal lobe epilepsy, like other lesions involving the frontal lobes [4,33,65] interferes mostly with more complex aspects of motor activity. Furthermore, the greater impairments of these functions in the younger FLE group, not seen in the younger TLE and GEA children, suggest that the pathological process associated with frontal lobe epilepsy may interfere with maturational time tables of frontal lobe development.

Like the adults studied by Luria [33] and Helms-taedter et al. [22], the FLE children in the present study manifested various difficulties on tasks requiring sequencing and alternation between different hand movements. They made significantly more errors and obtained fewer perfect scores on these tasks than TLE and GEA children. Typically, their movements were rigid and slow attesting to a lack of flexibility for which the children tried to compensate by using spatial and/or verbal strategies. The difficulties were particularly evident in tasks requiring reciprocal, asymmetrical gestures. Similar observations have been reported for the 8-year-old boy studied by Jambaque and Dulac [24]. These results suggest once more that the integrity of the frontal lobes is important for the smooth execution of complex motor programs, in particular those requiring intermanual, and thus bihemispheric, coordination.

The finding of impaired performance of the dominant hand on the alternate tapping task, observed in the younger FLE children, is more difficult to explain. This task is less complex than the other gestural sequences since it does not require the production of distinct hand movements. A possible explanation may be that the younger FLE children were more impulsive on the first trial and required more practice before their performance stabilized.

Results assessing mental flexibility at the cognitive level were more variable. Thus, the Wisconsin Card Sorting Test which has been found to be sensitive to frontal lobe functions and frontal lobe disorders in children and adults [6,12,39,45,60], failed to discriminate between the three epilepsy groups. FLE children did not differ from children with TLE or GEA with respect to mental flexibility and conceptual shift, although the FLE children tended to respond more impulsively. The results are comparable to those reported by Boone et al. [3] who observed normal performance on the WCST in their 13-year-old FLE patient. Similarly, the Self-ordered Pointing Task, which purports to evaluate self-regulation of behaviour, was not differentially affected in the three groups. However, all three epileptic groups appeared to be inferior to healthy children in several aspects of the WSCT and SOPT.

Several explanations can be advanced. To begin with, it is possible that differences are more subtle and that with larger sample size impairments in the expected direction may become significant. On the other hand, there is some evidence [49] that the WCST may not be sensitive enough to detect such subtle differences. In addition, these complex tests are multi-factorial and may tap functions that are not exclusively mediated by the frontal lobes. Furthermore, both the WCST and the Self-ordered Pointing Test (SOPT) involve working memory [59]. The subject has to remember the order of the three sets in the WCST or the designs of the SOPT he or she had previously pointed out. Working memory demands attention, which is most frequently compromised in any type of epilepsy [1]. It is thus possible that the three epilepsy groups did not differ with respect to attention and working memory or that working memory was not differentially affected in the FLE group.

Another explanation for the negative results maybe that there is fractionation within executive skills with some of the functions being more affected due to the underlying pathology or the localization of the epileptic lesion. In fact, several studies suggest [for review see 49] that the WCST does not discriminate patients with focal from patients with diffuse frontal lesions. This touches upon the broader issue, addressed by Stuss and Alexander [64], of whether patients with frontal lobe damage can be considered as a group, even those with a common etiology. Thus, it may be that very few of the 16 FLE children who participated in this study had the type of lesion that would result in impairments on these tasks. Furthermore, given that the epilepsy seemed to be well controlled in our sample at the time of testing, the extent of frontal dysfunction may not have been important enough to affect all executive functions. This argument is in line with the observation of Upton and Thompson [69] who found that frontal lesions were not associated with reduced performance on neuropsychological tests unless greater cortical involvement was suspected.

Finally, several authors [45,64] have raised the point that some of the variance may be attributable to differences in cognitive style and strategy. By providing minimal instructions, the WCST invites subjects to form their own hypothesis about the sorting principle. Clinical neuropsychologists can confirm that some bright subjects may elaborate a complicated, but irrele-
vant, hypothesis that will lead to fewer correct responses on this test. By the same token, individual differences in strategy could have masked possible group differences on the SOPT. Further research using tasks that measure the same construct may be needed to satisfactorily respond to the question of whether these functions are selectively impaired in children with frontal lobe epilepsy.

With regard to verbal fluency, deficits on tasks requiring systematic and spontaneous word search have been previously described in FLE adults [40,56]. Consistent with these observations, the FLE children in the present study scored significantly lower than the TLE and GEA children on the Verbal Fluency Test, both in the phonemic and the semantic conditions. However, this was to a great extent attributable to the poorer performance of the younger FLE children (8–12 years). The results are congruent with the study of Jambaque and Dulac [24], whose 8-year-old FLE child was impaired on the Verbal Fluency Test whereas the 13-year-old FLE patient described by Boone et al. [3] did not show any deficits on this task.

One might argue that younger children have not yet developed the necessary phonetic skills or semantic repertory to succeed at this test. Although a developmental trend has been reported for this test [72], it may be recalled that the performance of the young FLE children was also inferior to that of the younger children of the two other epilepsy groups. In contrast, the younger TLE and GEA children did not differ from the older ones. The poorer performance of the young FLE children can therefore not be entirely attributed to maturational factors. It is more likely that the young FLE children had greater difficulties mobilizing their resources to initiate the verbal search. One might deduce from these observations that the impact of FLE on some ‘frontal’ functions is greater at a time when the frontal lobes are still at an earlier stage of development.

The Tower of London was found to be the most sensitive measure of frontal lobe dysfunction of our battery, even though not all variables were statistically significant. Thus, the number of models completed at the first trial, which is considered to be an important variable reflecting planning abilities [61], did not differ between the groups. However, FLE children acted more impulsively and took less time to reflect before making a move. Furthermore, they required significantly more time to complete the task than TLE and GEA children or healthy controls. Similar results have been reported by Owen et al. [46]. These authors found that adults with frontal lobe lesions took less ‘thinking time’ before making their first move than matched controls but required significantly more time than the latter in trying to solve the problem. Similarly, Stuss and Benson [65] have shown that frontal lobe lesioned patients fail to analyze the steps necessary to solve complex arithmetical problems. In both cases, this behaviour has been termed ‘impulsive’. Impulse control is an important aspect of adaptive behaviour that has been linked to the intervention of a hypothetical frontal lobe system which is assumed to modulate behaviour by selectively activating or inhibiting lower-level activity [62]. Our results suggest that the poor planning abilities seen in our FLE children are primarily attributable to inadequate impulse control due to damage to or dysfunction of frontal lobe structures involved in this modulating activity.

Finally, the extent of the epileptogenic abnormalities had no measurable effect on the deficits. The FLE children with bilateral foci did not perform more poorly on any of the tests than did those with unilateral focal lesions. This may be attributable to interhemispheric propagation of seizure activity which may obscure possible laterality effects. As mentioned before, frontal lobe seizures are known to spread rapidly [2,73,74] owing to the complex connectivity of the frontal lobes with the limbic system and other brain regions [9].

6. Conclusion

A specific neuropsychological profile was obtained for FLE children that distinguished them from children with TLE and GEA on several measures that purport to assess frontal lobe functions. FLE children exhibited many characteristics that are commonly associated with frontal lobe dysfunction in adult patients. More specifically, they showed impairments in motor coordination, response generation, impulse control and planning ability. Motor deficits were more marked for tasks involving bimanual coordination and asymmetrical movements, thus confirming the crucial role of the frontal lobes in interhemispheric integration of complex motor programs. FLE children aged 8–12 years were less skilled in these activities than children aged 13 years and beyond. They were also inferior to younger TLE and GEA children on cognitive tasks requiring initiation of verbal search and response generation which points to an interaction between the epileptic process and the maturation of the frontal lobes in FLE children.

The measures found to be most sensitive in distinguishing FLE children from TLE and GEA children were the Purdue Pegboard, Thurstone’s Uni- and Bimanual Performance Tests, the Verbal Fluency Test, Luria’s Motor Sequences and the Tower of London.
In contrast to results reported in adults patients with frontal lobe lesions, the Wisconsin Card Sorting Test and the Self-ordered Pointing Task [42,54] failed to discriminate between FLE, TLE and GEA children in this study, possibly because of differences with regard to the extent and localization of the underlying pathology. In addition, individual differences in cognitive style and strategy may influence the performance on these tasks. Replication of the study in a larger sample may, however, yield significant results.

Finally, the observation that TLE and GEA children also performed slightly below the expected age norms on several of the ‘frontal’ tasks suggests that factors related to the epilepsy itself and its treatment, such as fluctuation of attention and/or decreased arousal may affect the test performance of these children to various degrees.

Acknowledgements

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