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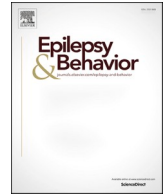
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Executive functions disorders in children with frontal and temporal epilepsy

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ABSTRACT

Introduction: Children with focal epilepsy often present with executive functions (EFs) deficits. EFs deficits can contribute to adaptive challenges and have a negative impact on academic achievement. The purpose of this study was to investigate the EFs profiles of children diagnosed with frontal lobe epilepsy or temporal lobe epilepsy. Also, we aimed to examine the impact of medical and sociodemographic features on executive functioning and to compare the results of performance-based tests and ratings measures.

Method: EFs were assessed using performance based-tests and rating scales. The Child Executive Functions Battery (CEF-B) and the Behavior Rating Inventory of Executive Function (BRIEF) for parents and teachers were used.

Results: Fifty children aged 6–16 years participated in the study, 28 diagnosed with frontal lobe epilepsy and 22 diagnosed with temporal lobe epilepsy. Results showed that approximately 30 % of both groups of epilepsy patients had significant deficits in EFs compared to normative data. Deficits were observed across various domains of EFs (inhibition, working memory, flexibility and planning). Most patients exhibited deficits in one or two of the 4 domains. Worse executive performances were significantly associated with older age at assessment time, longer duration of epilepsy, higher seizure frequency, earlier age at onset and higher number of anti-seizure medication. Additionally, correlation and congruence analyses showed significant discrepancies between the performance-based and rating measures of executive functioning.

Conclusion: Our findings provide substantial evidence of significant executive deficits in children with FLE and TLE and support the clinical validity of the CEF-B battery in this population. The low level of agreement between performance tests and daily life questionnaires suggests that the two methods are complementary for

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understanding children's executive functioning. Comprehensive assessment and targeted interventions to address EFs difficulties are recommended for this particular population.

1. Introduction

In children, epilepsy develops during cerebral maturation and contributes to the heightened susceptibility of the young brain to early lesions [1–3]. Children with focal epilepsy are at a higher risk of developing cognitive and learning disorders, compared to their neurotypical counterparts [4]. Prefrontal networks, known for their prolonged and late maturation and their anatomical support for executive functions (EFs), are particularly affected by atypical development [3]. Anderson et al. [5] showed severe EFs vulnerability among children with early brain injury, regardless of the location of the lesion. In fact, frontal lobes and their connections are indirectly impacted by posterior lesions or dysfunctions as temporal areas [6,7].

EFs encompass a set of high-level cognitive skills that are essential for goal-oriented behavior and the successful adaptation of children to their environment [8]. These skills are recruited when routines alone are insufficient to perform tasks [9,10]. EFs are commonly regarded as a multidimensional construct [11], with inhibition, working memory, and flexibility considered as fundamental and central components in various theoretical models [10,12–14]. These basic components are involved in the functioning of higher-level EFs, such as planning [10]. Although the components of EFs are usually considered as relatively independent constructs, they exhibit strong interrelationships, particularly during childhood [10,12,13].

In clinical practice, distinguishing between components of executive function (EFs) and applying a multidimensional assessment seems crucial for a better understanding of executive functioning across various clinical conditions. Studies report variability in executive symptoms, with some conditions showing selective deficits in specific EFs [15,16] and others exhibiting more diffuse impairments across the entire executive domain [17–19]. In focal epilepsies, numerous studies have identified significant executive impairments in children with temporal lobe epilepsy (TLE) and frontal lobe epilepsy (FLE) [4,20–23].

Regarding FLE, studies highlight severe and global executive impairments, including processing speed, problem-solving, working memory, sustained attention, shifting, and inhibition deficits [24–27]. These difficulties in cognitive control have been associated with behavioral disorders as measured by questionnaires [27]. In TLE, several EFs are also globally affected [28–30]. Some studies suggest that these impairments could be as significant as memory disorders, which are prominent cognitive features in TLE [31,32]. In fact, executive domains can be disturbed across varying degrees of severity [33], emphasizing the need for an exhaustive assessment of EFs. For instance, Rzezak et al. [33] demonstrated that the incidence of executive dysfunctions in children and adolescents with TLE increased from 77 % to 94 % when using a more extensive battery to evaluate EFs compared to a single executive measure. Furthermore, numerous studies [21,28,34] have highlighted the influence of medical and sociodemographic latent variables on EFs in both FLE and TLE. Among these variables, age at onset, duration of epilepsy, number of epileptic seizures, and number of anti-seizure medication (ASM) were considered.

Some studies have compared the executive profiles of children with FLE and TLE using multiple performance-based measures [28,34–41]. Overall, impairments are not specific to the localization of the seizure onset zone [16]. In addition, several studies have found no difference between these two groups in terms of executive performance [28,34–38,40,42]. However, some evidence suggests that children with FLE exhibit more severe dysfunctions than children with TLE in concept formation, planning, verbal fluency, sustained attention, working memory, and inhibitory control [40,41,43]. According to these authors, the pathological process linked to FLE may disrupt the maturation of the

frontal lobe, thereby affecting cognitive processes that are directly reliant on it, such as EFs. This disruption could account for the more pronounced executive deficits observed in patients with FLE, compared to other types of epilepsy [40,41,43].

Despite the recognition of executive deficits in children with FLE and TLE, the identification of a more detailed executive profile comes up against several methodological biases. Indeed, there are only few studies that assess exhaustively the three basic EFs (inhibition, working memory, and flexibility) and more complex EFs (e. g., planning, problem-solving) by performance-based tests [34,40]. By the way, according to Exner et al. [38] the commonly used neuropsychological tests are not sensitive enough to distinguish between FLE and TLE. Additionally, studies rarely incorporate different measures of the same EF component with different characteristics (e.g., verbal/nonverbal, motor/cognitive approach), to control for the influence of more basic cognitive processes on executive performance [42].

In addition to performance-based measures, studies utilizing rating measures, such as the Behavioral Rating Inventory of Executive Function (BRIEF), have compared the executive profiles of children with FLE and TLE in Spain, the United States, and France [34,44–46]. Overall, studies confirmed global executive deficits independent of seizure location. However, a French study [46] found that the monitoring domain appeared to be more impaired in FLE. In addition, studies employing the BRIEF questionnaire have found a significant association between executive impairments and higher number of ASM or earlier onset of epilepsy [34,44–46].

Due to the low correlation between rating measures and performance-based measures [47], additional studies are necessary to gain a comprehensive understanding of the executive functioning in children with FLE and TLE. To the best of our knowledge, no previous study has proposed a multifactorial assessment of different EFs components using performance-based tests and contrasting them to proxy ratings. In this regard, our study aimed to expand upon the work by Campliglia et al. [46], utilizing essentially the same cohort, with a focus on the assessment of EFs using the Child Executive Functions Battery (CEF-B) [48] and testing its clinical validity in this population. It is important to note that the CEF-B structure was specifically designed to address the methodological biases present in executive tasks. Evidence of its validity and reliability has been satisfactorily demonstrated in its French [19,48] and Brazilian [49,50] versions for children with typical development (1182 French children; 230 Brazilian children), but also in different clinical contexts (404 French children) such as Autism Spectrum Disorder (ASD), Dyslexia, Attention Deficit Hyperactivity Disorder (ADHD), Neurofibromatosis type 1, Hyperphenylalaninemia, Prematurity, Brain Tumors, Traumatic Brain Injury [19,48].

Therefore, the objectives of this study were (1) to identify executive profiles in children with FLE and TLE by exploring four executive processes, namely inhibition, flexibility, working memory, and planning [10]; (2) to examine the impact of medical and sociodemographic features of FLE and TLE on executive functioning; and (3) to compare the results of the CEF-B with parental and teacher ratings of the BRIEF. We expected to observe deficits in the four executive processes in both FLE and TLE [4,20–22]. We also expected that an earlier age of onset, older age at the time of assessment, longer duration of epilepsy, higher seizure frequency, greater number of ASM, and lower parental education levels would negatively impact executive functioning [21,28,34]. We expected to find limited correlations between the results of the performance tests (i.e. CEF-B) and the scores on the patients' daily life questionnaires (i.e. BRIEF) [51].

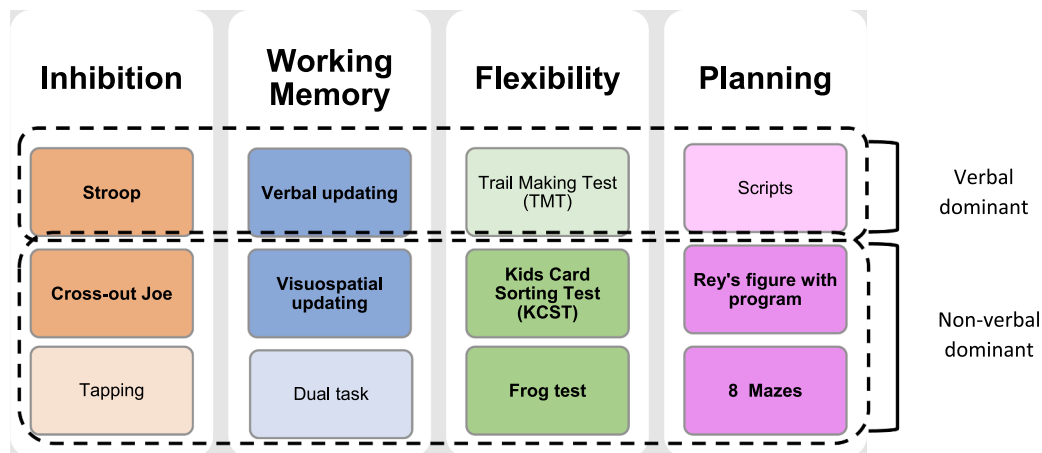


Fig. 1. Overview of the Child Executive Function-Battery Note. The main subtests per domain are highlighted in bold, and in darker colors, while complementary subtests are represented in light colors. This division was based on the factorial structure and differential analyses described in Roy et al., 2021.

2. Material and methods

2.1. Participants

The current study is an extension of the analysis carried out by Campiglia et al. [46]. The identical sample of children with FLE and TLE previously selected in the study of Campiglia et al. [46] was used in the present study. Inclusion criteria were: (1) FLE or TLE of unknown or structural cause (i.e., with a confirmed or suspected cerebral lesion such as focal cortical dysplasia or tumor); (2) age between 7 and 16 years at the time of the assessment; (3) ability to understand and read French; and (4) informed consent form signed by parents or legal guardians. Exclusion criteria were: (1) epilepsy due to another cause; (2) a history of other developmental, neurological or psychiatric disorders, (3) uncorrected sensory disorder (visual or hearing); and (4) ongoing psychoactive treatment.

Epilepsy type was characterized according to the criteria of the International League Against Epilepsy (ILAE) [15], in three French university hospital units. The initial clinical group included 58 children, among which 8 were excluded: 3 patients had focal epilepsy involving regions other than the temporal or frontal lobes, 2 patients had genetic epilepsy, 1 patient had Rasmussen's syndrome, 1 patient had episodes of migraine without epilepsy, and 1 patient had suspected psychiatric disorder. Therefore, the final group included 50 children (27 boys and 23 girls), 22 with TLE and 28 with FLE.

2.2. Material

2.2.1. Efs measures: Performance-based tests

Efs were assessed using the CEF-B (Fig. 1). This battery was created based on a child-centered theoretical model [10] to assess inhibition, working memory, flexibility and planning abilities. It comprises a set of 12 performance-based tests (3 per component) designed to evaluate children and adolescents between 6 and 16 years old [48]. Evidence of validity and reliability of the French version has been published in studies involving children with typical development [48], and with different clinical conditions, such as ASD, Dyslexia, ADHD, Neurofibromatosis type 1, Hyperphenylalaninemia, Prematurity, Brain Tumors, Traumatic Brain Injury [19,48]. These data indicate a good sensitivity of the battery for assessing Efs in pediatric populations.

CEF-B includes new experimental tasks and tests that already exist in the international literature but have been modified or expanded to better fit with a pediatric population (See [19,49] for a description of the tasks). Given the high number of tasks and variables, the authors of the battery created impairment indices for each component of the battery to allow a comprehensive overview (see [45] for a description). In this

paper, component scores and percentiles were used to evaluate Efs in a more comprehensive way. The percentile greater than or equal to 90 was established as the deficit threshold, according to the parameters set out in the normative data. In addition, deficits were classified as mild for scores between 90–94, moderate for scores between 95–98 and severe for scores in the 99th percentile.

2.2.2. Efs measures: Rating scales

Concerning rating scales, the parent and teacher reports of the BRIEF [French version; [51,52] were used. The BRIEF consists of 86 items, rated using a 3-point Likert scale, based on the child's behavior occurrence: "never" (1 point), "sometimes" (2 points), or "often" (3 points). Seventy-two of the 86 items are distributed across 8 clinically and theoretically driven individual scales measuring different aspects of Efs and yielding 2 composite indices derived from factorial analyses: behavioral regulation index (BRI: inhibition, shifting, and emotional control), metacognitive index (MI: initiation, working memory, plan/organize, organization of materials, and monitor). The global executive composite (GEC) index provides an overall measure of executive functioning. Raw scores for all scales were converted into T-scores and percentiles based on French normative data. The T-score was used to establish the pathological threshold in the BRIEF ($T \geq 65$) while the percentiles were used to homogeneously compare results with the performances in the CEF-B.

2.2.3. Measures of intellectual functioning and SES

Intellectual ability was assessed using age-appropriate Wechsler Intelligence Scales (WISC-IV) [53]. In this paper, The Verbal Comprehension Index (VCI), the Perceptual Reasoning Index (PRI), the Working Memory Index (WMI), the Processing Speed Index (PSI), and the Full-Scale Intellectual Quotient (FSIQ) were considered ($M = 100$; $SD = 15$). Regarding SES, we used the number of years of education of the 2 parents or legal guardians.

2.3. Procedure

The research was carried out in accordance with the ethics requirements of the local ethics committee Université de Savoie Mont-Blanc. Patients were included as in- or out-patients between 2010 and 2013. During a 24-hour hospitalization, all patients underwent awake and sleep electroencephalography (EEG) and a thorough and comprehensive neuropsychological evaluation for 4 to 5 h using paper-and-pencil tests assessing intellectual efficiency and Efs. The CEF-B was used to assess the executive functioning during a neuropsychological assessment planned for clinical or research purposes. The full 12 tests of the CEF-B were administered in 1.5 h per child. All children were

Table 1
Sociodemographic and medical data regarding the FLE and TLE groups.

	Frontal group	Temporal group	Test value
N	28	22	
Age at onset – months			
<i>M (SD)</i>	81.3 (54.4)	83.3 (52.2)	F(1) = 0.068
<i>Range</i>	0.5–179	7–183	p = 0.823
Age at assessment – years			
<i>M (SD)</i>	11.9 (2.7)	11.2 (2.6)	F(1) = 1.21
<i>Range</i>	7–16	7–16	p = 0.326
Epilepsy duration – months			
<i>M (SD)</i>	64.9 (48.8)	51.2 (43.1)	F(1) = 1.07
<i>Range</i>	7–187	2–160	p = 0.364
Number of current ASM			
<i>M (SD)</i>	1.4 (0.8)	1.5 (0.6)	F(1) = 0.235
<i>Range</i>	0–3	0–2	p = 0.277
Seizure Frequency – /month			
<i>M (SD)</i>	5.8 (10.6)	6.1 (12.8)	F(1) = 0.007
<i>Range</i>	0–30	0–45	p = 0.982
Sex (%)			
<i>Girls/boys</i>	14(50)/14 (50)	9 (41)/13 (59)	$\chi^2 = 0.52$
Maternal education – years			p = 0.447
<i>M (SD)</i>	12.6 (2.6)	11.6 (4.3)	F(1) = 0.913
<i>Range</i>	9–17	4–20	p = 0.323
Paternal education – years			
<i>M (SD)</i>	12 (2.7)	12 (4.3)	F(1) = 0.002
<i>Range</i>	9–18	6–23	p = 0.934
IQ measures			
<i>Verbal Comprehension Index – M (SD)</i>	101.6 (20.2)	96.3 (22.3)	F(1) = 0.678
<i>Perceptual Organization Index – M (SD)</i>	90 (16.3)	94.5 (17.4)	p = 0.230
<i>Working Memory Index – M (SD)</i>	85.8 (18)	86.2 (16.8)	F(1) = 0.007
<i>Processing Speed Index – M (SD)</i>	85.1 (16.9)	90.9 (18.1)	p = 0.853
<i>Full Scale IQ – M (SD)</i>	86.8 (20)	89.9 (20.1)	F(1) = 1.23
			p = 0.387
			F(1) = 0.262
			p = 0.757

Note. SD standard deviation, % percentages (frequencies), ASM = anti-seizure medication.

individually evaluated in a quiet room in their corresponding hospital units. All the performance-based tests were administered by trained neuropsychologists using standardized instructions.

2.4. Statistical analyses

Both groups of patients (TLE and FLE) were compared using univariate analyses of variance (ANOVA) for age, SES, and various medical variables related to epilepsy. Analysis with the chi-square test was performed to compare groups according to sex. In order to assess EFs on performance-based tests, component scores and percentiles of CEF-B were used. The percentile greater than or equal to 90 was established as the deficit threshold, according to the parameters set out in the normative data [48]. In addition, deficits were classified as mild for scores between 90–94, moderate for scores between 95–98 and severe for scores in the 99th percentile. Scores of FLE and TLE children on the 4 components of the CEF-B were compared with normative French data by using the one-sample-t-test [48]. This analysis was carried out for the entire sample of children with epilepsy and for each subgroup (FLE and TLE). In addition, we used Spearman’s rho correlation coefficient to analyze the associations between medical and sociodemographic variables (age at onset and at assessment, epilepsy duration, number of ASM, seizure frequency, SES and IQ tests) and executive scores. Spearman’s rho correlations were also performed to assess the degree of correlation between the 4 CEF-B components themselves. Furthermore, Spearman’s rho correlations were conducted to evaluate the extent of correlation between the components of the CEF-B and ratings provided by parents and teachers using the BRIEF. Additionally, for each participant, a dichotomous rating was assigned to assess the congruence and concordance between the CEF-B and parent/teacher ratings. This assessment aimed to ascertain the degree to which performance-based and questionnaire-based measurements were analogous in discerning executive deficits. The agreement rate was classified using Cohen’s kappa [54]. Statistical analyses were performed using SPSS v.20.0 [55]. For the majority of analyses, the significance level was set at 0.05. It was increased to 0.01 for correlations analyses involving numerous variables.

3. Results

3.1. Sample and executive performance on CEF-B

Descriptive statistics regarding demographic and medical data are summarized in Table 1. Both groups of patients were similar in sex, age and SES. No differences were found among the studied medical variables (age at onset and at assessment, duration of epilepsy, number of ASM and seizure frequency). In addition, no significant difference was observed in all IQ measures.

Table 2 summarizes the results of the comparison of epilepsy patients’ means on CEF-B components in the whole epilepsy sample, compared to normative data. The impairment indices were significantly increased when compared to neurotypical subjects, regardless of the EF component considered. Almost 30 % of the patients presented executive deficits. The percentage of deficits in both FLE and TLE was similarly high (Appendix A). In addition, most patients had deficits in 1 or 2 EFs domains (Fig. 2) and were in the 95th or 99th percentile ranges compared to normative data (Table 2). Correlation analyses between the 4 impairment scores showed that the planning component was significantly correlated with the other 3 components (Table 3).

No differences were found between the FLE and TLE groups for executive performance (Appendix A). However, when considering patients who obtained impaired components (.90th percentile or above), a tendency toward significance was shown regarding the amount of impaired EFs (p = 0.079), revealing more global difficulties for the FLE group. In fact, the number of children with deficits in 2 or less EFs components was identical in FLE and TLE groups (21 children – Fig. 2). Nevertheless,

Table 2
Group means and standard deviations on CEF-B measures for the whole epilepsy group regarding normative data.

	Epilepsy group*	Normative data*	Significance test	% of deficits per component ≥ 90 (total)			
				90–94	95–98	99	
Inhibition	1.2 $\sigma = 1.5$ (n = 49)	0.5 $\sigma = 0.8$ (n = 935)	t (48) = 3.423p < 0.001 d = 0.49 CI = [-0.09–1.1]	34.7	15.2	6.5	13
Working Memory	1.5 $\sigma = 1.8$ (n = 48)	0.5 $\sigma = 0.9$ (n = 814)	t (47) = 3.802p < 0.001 d = 0.55 CI = [-0.04–1.14]	35.6	6.7	15.6	13.3
Flexibility	1.0 $\sigma = 1.7$ (n = 48)	0.4 $\sigma = 0.8$ (n = 914)	t (47) = 2.391p = 0.01 d = 0.35 CI = [-0.24–0.93]	28.9	8.9	8.9	11.1
Planning	0.9 $\sigma = 1.2$ (n = 48)	0.4 $\sigma = 0.8$ (n = 920)	t (47) = 2.913p = 0.003 d = 0.42 CI = [-0.17–1.01]	24.6	2.2	17.8	4.4

Note. *The scores presented for the epilepsy group and the normative data are scaled scores. The percentage of deficits per component is presented in its total (≥ 90) but also according to the severity of the deficit. Deficits were categorized as mild for scores between 90–94, moderate for scores between 95–98, and severe for scores at the 99th percentile. d = Cohen’s effect size; CI = confidence interval for Cohen’s d.

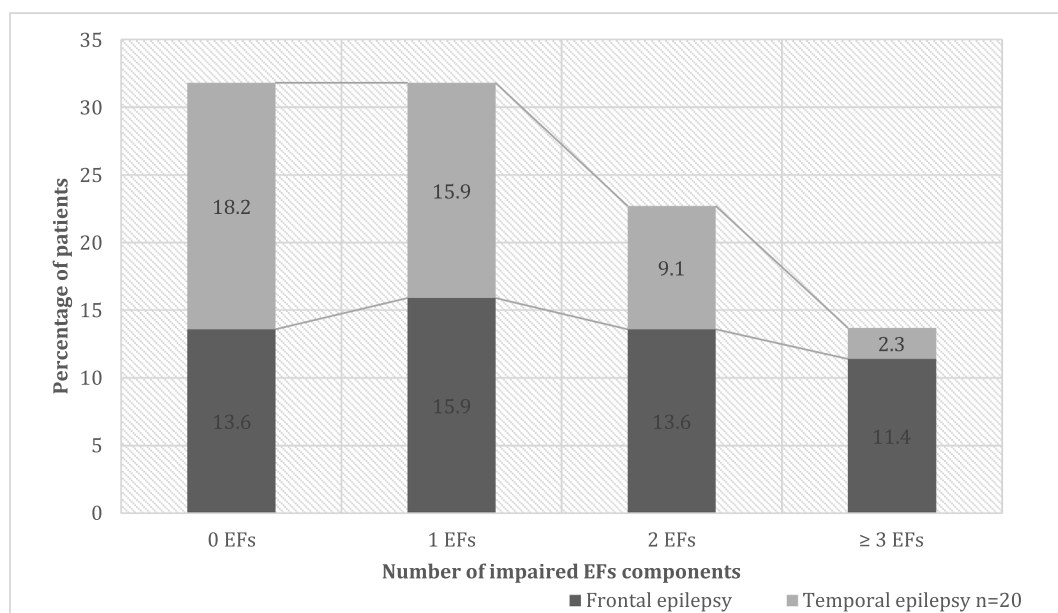


Fig. 2. Classification of epileptic patients according to the number of impaired EF components (n = 44).

Table 3
Spearman correlations between CEF-B components in the epilepsy group.

	Inhibition	WM	Flexibility	Planning
Inhibition	–			
WM	0.16	–		
Flexibility	0.29	0.18	–	
Planning	0.36*	0.31*	0.51**	–

Note *p < 0.05; **p < 0.01; WM = Working memory.

the number of children with FLE who presented deficits in more than 2 EFs (n = 5) was higher than that of children with TLE (n = 1). Overall, the results indicated that 68 % of the sample (30/44) exhibited executive difficulties with at least one of the components. For the two groups combined, we found 31.8 % of children with no impaired EFs, 31.8 % for 1 impaired EF, 22.7 % for 2 impaired EFs, 13.3 % for 3 or more impaired EFs. The rates are relatively high when compared to the population with typical development (no impaired EFs = 66.8 %; 1 impaired EF = 25.7 %; 2 impaired EFs = 6.1 %; ≥ 3 impaired EFs = 1.4 %), especially when the number of impaired EF is 2 or more. Concerning group differences between FLE and TLE in each executive component, children with FLE

presented significantly more deficits in flexibility than children with TLE (p = 0.043). For the other EFs, no significant differences were found (Fig. 3).

3.2. Associations between medical and sociodemographic variables and CEF-B scores

Table 4 describes exploratory correlation analyses performed between the scores obtained in the CEF-B components and factors known to influence EFs outcomes in the literature (age at onset and at assessment, duration of epilepsy, number of AMS, seizure frequency, SES and IQ tests). For these analyses, the significance level was set at p = 0.01. Significant correlations were found between the inhibition component and both the duration of epilepsy and the age at onset: inhibition deficits were more prevalent in patients with a longer duration of epilepsy and an earlier age at onset. Moreover, a significant correlation was found between age at follow-up and the flexibility component: children who were older at the time of assessment exhibited more flexibility deficits.

Regarding the number of current ASM, correlations were significant with the planning component: higher number of ASM was associated with worse performance in planning abilities. We found only a trend

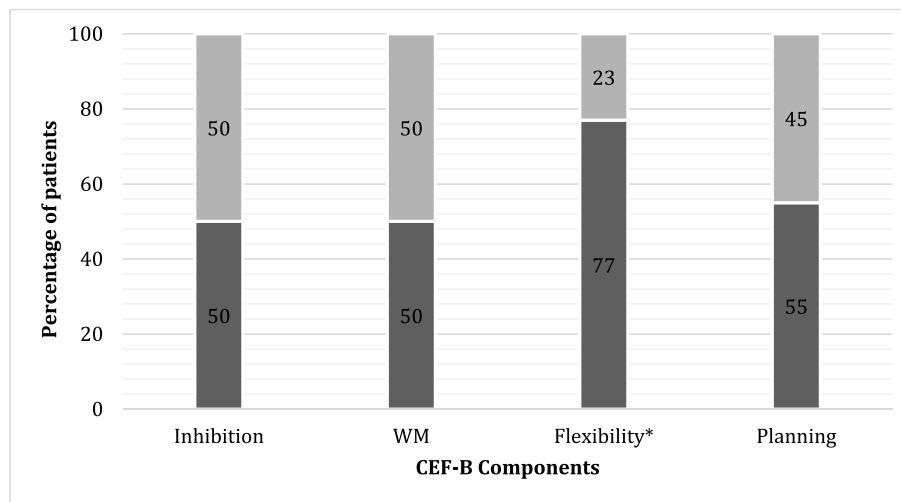


Fig. 3. Distribution of epileptic patients according to EF impaired components. Note. Dark gray = frontal epilepsy; light gray = temporal epilepsy; $\chi^2 = 4.087$; $p = 0.043$.

Table 4

Spearman correlations between epilepsy variables, IQ and level of parental education and CEF-B components.

	CEF-B components			
	Inhibition	WM	Flexibility	Planning
Epilepsy variables				
Age at onset	-0.47**	-0.27	-0.16	-0.26
Age at follow-up	0.07	-0.13	0.38**	0.03
Follow-up time since onset	0.51**	0.29	0.36	0.27
Number of current ASM	-0.04	0.12	0.33	0.56**
Seizure Frequency (month)	0.02	-0.11	0.33	0.30
IQ measures – WISC IV				
Verbal Comprehension Index	-0.54**	-0.21	-0.34	-0.34
Perceptual Organization Index	-0.49**	-0.42**	-0.57**	-0.52**
Working Memory Index	-0.43**	-0.44**	-0.19	-0.24
Processing Speed Index	-0.48**	-0.23	-0.38	-0.33
Full Scale IQ	-0.64**	-0.42**	-0.47**	-0.53**
Level of parental education				
Maternal education	-0.06	-0.13	-0.03	-0.04
Paternal education	-0.19	-0.14	-0.27	-0.24

Note. ** $p < 0.01$. IQ = intellectual quotient; WM = working memory; ASM = antiseizure medication.

towards a significant correlation between cognitive flexibility and seizure frequency ($r = 0.33$; $p = 0.05$). Flexibility deficits tended to be more prevalent in children with a higher frequency of seizures ($r = 0.33$; $p = 0.05$). Concerning IQ measures, the index scores were globally significantly correlated with all the EFs components, in particular with inhibition. In addition, full scale IQ correlated significantly with all executive components. For all these correlations, lower IQ scores were associated with increased executive deficits. In addition, a significant negative correlation ($r = -0.667$, $p = 0 < .001$) was found between the number of impaired EFs (Fig. 2) and the average IQ per group (no impaired EFs: $M = 103.79$, $SD = 14.33$; 1 impaired EF: $M = 97.17$, $SD = 18.47$; 2 impaired EFs: $M = 80.89$, $SD = 14.42$; ≥ 3 impaired EFs: $M = 64.40$, $SD = 6.87$). Finally, SES did not correlate with any components on the CEF-B.

3.3. Correlations/congruence between CEF-B components and BRIEF ratings

For these analyses, the significance level was set at $p = 0.01$. Correlations between parent/teacher ratings and CEF-B performances were

Table 5

Spearman correlations between similar CEF-B components and BRIEF clinical scales scores.

	Inhibition	WM	Flexibility	Planning
BRIEF – Parent (n = 47)				
Inhibition	0.19	-0.03	0.07	0.25
Shifting	0.32	0.12	0.32	0.28
Working memory	0.23	0.04	0.16	0.04
Planning	0.32	0.07	0.01	0.05
GEC	0.22	0.05	0.13	0.14
BRIEF – Teacher (n = 23)				
Inhibition	0.13	0.18	0.05	0.14
Shifting	0.28	0.39	0.20	-0.04
Working memory	0.37	0.31	0.28	0.15
Planning	0.37	0.24	0.31	0.15
GEC	0.28	0.25	0.18	0.15

Note: BRIEF: Behavior Rating Inventory of Executive Function; GEC: Global Executive Composite score; * $p < 0.01$.

non-significant for all clinical scales and composite scores (Table 5). However, closer examination of the rating congruence between the CEF-B and BRIEF parents and teacher forms (see Table 6) showed that 52 % to 65 % were similarly rated by parents and 55 % to 64 % by teacher as “normal” or “impaired”, on the basis of the GEC. Congruence level within BRIEF clinical scales was slight to fair for teachers (48 % – 73 %; $k = -0.08$ to 0.32), and parents (48 % – 72 %; $k = -0.22$ to 0.27). When divergent, EFs impairment was more frequently found in the CEF-B components than in the BRIEF parent or teacher rating.

4. Discussion

The primary aim of this study was to conduct a comprehensive assessment of EFs in children with FLE and TLE using a newly developed neuropsychological battery with performance-based tests (CEF-B), and testing its clinical validity in this population. Additionally, we sought to investigate the impact of demographic and epilepsy severity variables on executive functioning and to compare the executive performance on the CEF-B with parental and teacher ratings obtained through the BRIEF.

Consistent with our hypothesis, our findings demonstrate significant deficits in executive functioning in FLE and TLE, both in performance-based tests (CEF-B) and BRIEF ratings [45]. Specifically, impairment indices were significantly increased for all executive components compared to normative data. In fact, an important proportion of children demonstrated difficulties in EFs in performance-based assessments

Table 6
Rating congruence between CEF-B components and BRIEF (parent and teacher) ratings.

		CEF-B Components			WM				
		Inhibition							
		Congruent scores	Incongruent scores	Overall congruence	k	Congruent scores	Incongruent scores	Overall congruence	k
Parent									
Inhibition	29 (6)	17 (10)	29/46 (63 %)	0.15	27 (5)	18 (11)	27/45(60 %)	0.07	
Shifting	30 (5)	16 (11)	30/46 (65 %)	0.16	27 (4)	18 (12)	27/45(60 %)	0.05	
WM	28 (7)	18 (9)	28/46(61 %)	0.14	26 (6)	19 (10)	26/45(58 %)	0.08	
Planning	33 (8)	13 (8)	33/46(72 %)	0.28	25 (4)	20 (12)	25/45(55 %)	-0.02	
GEC	29 (6)	17 (10)	29/46(63 %)	0.15	25 (4)	20 (12)	25/45(55 %)	-0.02	
Teacher									
Inhibition	11 (2)	12 (8)	11/23(48 %)	-0.20	14 (3)	9 (6)	14/23(61 %)	0.12	
Shifting	14 (3)	9 (7)	14/23(61 %)	0.01	13 (2)	10 (7)	13/23(56 %)	0.01	
WM	16 (5)	7 (5)	16/23(69 %)	0.27	13 (3)	10 (6)	13/23(56 %)	0.05	
Planning	14 (4)	8 (6)	14/23(61 %)	0.24	13 (3)	9 (6)	13/23(56 %)	0.11	
GEC	12 (4)	10 (6)	12/23(52 %)	0.07	15 (5)	7 (4)	15/23(65 %)	0.33	
		Flexibility			Planning				
		Congruent scores	Incongruent scores	Overall congruence	k	Congruent scores	Incongruent scores	Overall congruence	k
Parent									
Inhibition	27 (3)	18 (9)	27/45(60 %)	-0.02	33 (6)	12 (5)	33/45(73 %)	0.32	
Shifting	28 (3)	17 (10)	28/45(62 %)	0.01	32 (4)	13 (7)	32/45(71 %)	0.19	
WM	24 (4)	21 (9)	24/45(53 %)	-0.06	26 (4)	19 (7)	26/45(58 %)	0.01	
Planning	25 (3)	20 (10)	25/45(55 %)	-0.08	27 (3)	18 (8)	27/45(60 %)	-0.02	
GEC	25 (3)	20 (10)	25/45(55 %)	-0.08	29 (4)	16 (7)	29/45(64 %)	0.05	
Teacher									
Inhibition	11 (1)	12 (7)	11/23(48 %)	-0.22	14 (1)	9 (4)	14/23(61 %)	-0.07	
Shifting	14 (2)	9 (6)	14/23(61 %)	0.05	15 (1)	8 (4)	15/23(65 %)	-0.02	
WM	14 (3)	9 (5)	14/23(61 %)	0.11	13 (1)	10 (4)	13/23(56 %)	-0.11	
Planning	14 (3)	8 (5)	14/22(63 %)	0.17	13 (1)	9 (4)	13/23(56 %)	-0.08	
GEC	12 (3)	10 (5)	12/22(54 %)	0.02	13 (2)	9 (3)	13/23(56 %)	0.03	

Note. Abbreviations: GEC, global executive composite; WM, Working memory. Congruent scores: sum of congruent normal percentiles (<90 for both CEF-B and BRIEF) and congruent deficits (percentiles ≥ 90 for both CEF-B and BRIEF). The number of congruent deficits is in brackets. Incongruent deficits: BRIEF percentile ≥ 90 and CEF-B percentile < 90 or BRIEF percentile < 90 and CEF-B percentile ≥ 90. The number of incongruent deficits for the CEF-B is in brackets.

(68 %).

Among the four components studied, working memory exhibited the highest impairment rate (35.6 %), followed by inhibition (34.7 %), flexibility (28.9 %), and planning (24.6 %), which is about 2 to 3 times more than the typical population. The percentage of deficits in both FLE and TLE was similarly high (Appendix A). Furthermore, the severity of impairments in the whole epilepsy sample was particularly pronounced, with most executive disorders falling within the 95th or 99th percentile range when compared to normative data. The importance of a detailed and comprehensive assessment of EF is highlighted, as the global EFs deficit is more pronounced than when evaluating a single function, as predicted by Rzezak et al. [33]. This is achievable by combining various measures that effectively control non-executive demands and are more sensitive to EFs deficits.

Our findings provide substantial evidence of significant executive deficits in children with FLE and TLE, corroborating previous reports [4,20–22], and support the clinical validity of the CEF-B battery in this population. It is important to note that the clinical validity of the CEF-B has also been proven in other populations as well. In acquired lesions (brain tumors and traumatic brain injury) the prevalence of executive deficits is high, reaching 7 times more than the typical population [19,48]. Conversely children with conditions such as ASD, dyslexia, ADHD, neurofibromatosis type 1, hyperphenylalaninemia and prematurity, show a similar prevalence of deficits compared to epilepsy, with between 2 and 5 times more deficits than their neurotypical peers [48].

Furthermore, our results revealed significant associations between the CEF-B components. The planning component was consistently correlated with the other three components, suggesting that impairments in inhibition, flexibility, and working memory may contribute to deficits in planning (Table 3). There is a consensus that developmental pathway varies according to executive processes. Thus, inhibition, working memory and flexibility, which are differentiated earlier in development, establish the foundations for the later emergence of more complex cognitive processes such as planning [10]. In this context, an

explanatory hypothesis could suggest that difficulties in more fundamental EFs may impact early-stage abilities, subsequently influencing the development of planning skills. It's important to note, however, that this explanation should be approached cautiously, especially since our study is cross-sectional. Further investigation would be necessary to determine whether this differentiation in skills occurs over time as hypothesized.

No significant differences were observed in executive performance between the FLE and TLE groups. In addition, the number of children with deficits in two or fewer EFs components was identical in both groups. Although FLE and TLE show differences in brain activity as measured by electroencephalogram, the vulnerability of prefrontal networks and their widespread connections involved in EFs leads to similar patterns of functional impairment in both conditions, regardless of the lesion's location [7]. Our findings, along with existing research, confirm that EF deficits in TLE are as pronounced as in FLE. Moreover, in TLE, these EFs impairments are comparable in severity to memory deficits, which are a hallmark of this type of epilepsy and are linked to the affected brain regions [31,32]. In this context, Exner et al.'s [38] claim that neuropsychological tests may lack the sensitivity to differentiate between FLE and TLE likely arises from the similar executive dysfunction profiles seen in both types of epilepsy, rather than from a flaw in the tests themselves.

However, a trend towards significance suggests that FLE patients tended to exhibit a higher incidence of deficits in more than three EFs components compared to TLE patients. This finding warrants further investigation, especially considering that our sample does not consist of an equal number of FLE and TLE patients. Additionally, children with FLE displayed more deficits in flexibility, which is consistent with other studies [35–37,56] and suggests that difficulties in adapting to changing situations could be a marker of executive disorders in FLE. Continued research in this area is crucial, as previous studies have indicated more severe executive disorders in FLE compared to TLE [35].

Our second hypothesis is partially validated. When examining the

Table A1
Comparisons of TLE and FLE groups to Normative data on the CEF-B.

	FLE group		t				% of deficits per component				TLE group		T				% of deficits per component				Group comparison		
				≥ 90 (total)	90-94	95-98	99				≥ 90 (total)	90-94	95-98	99				≥ 90 (total)	90-94	95-98	99	t	p
Inhibition	1.0	3.79		33	17	8	8	1.2	2.89		36	14	4	18				0.297	0.77				
	$\sigma = 1.2$ (n = 25)	p = 0.001						$\sigma = 1.2$ (n = 24)	p = 0.009														
Working memory	1.5	3.16		33	4	12	17	1.3	3.08		38	9.5	19	9.5				0.009	0.99				
	$\sigma = 1.9$ (n = 25)	p = 0.004						$\sigma = 1.7$ (n = 23)	p = 0.006														
Flexibility	1.7	3.37		42	8	17	17	0.9	2.18		14	9	0	5				0.646	0.52				
	$\sigma = 2.2$ (n = 25)	p = 0.002						$\sigma = 1.2$ (n = 24)	p = 0.040														
Planning	1.0	3.809		25	4	17	4	1.1	3.18		24	0	19	5				-0.651	0.52				
	$\sigma = 1.3$ (n = 25)	p = 0.001						$\sigma = 1.4$ (n = 24)	p = 0.005														

Note. The scores presented for the FLE and TLE group are scaled scores. The percentage of deficits per component is presented in its total (≥ 90) but also according to the severity of the deficit. Deficits were categorized as mild for scores between 90-94, moderate for scores between 95-98, and severe for scores at the 99th percentile.

influence of demographic and medical/epilepsy variables on CEF-B performance, correlation analyses yielded few significant associations. Our results indicate that patients with longer durations of epilepsy exhibit poorer executive performance in the inhibition and flexibility components in particular, depending on the early age of onset of epilepsy and the older age of assessment. These findings support the hypothesis of the early vulnerability of EFs in FLE and TLE. Children with early-onset epilepsy are thus more at risk of presenting increasing difficulties during their development, and all the more as the demand for autonomy increases with advancing age. We also observed that higher levels of ASM were associated with worse performance in planning. These results corroborate the findings of a previous study which found a link between the number of anti-seizure treatments and EFs in children with FLE and TLE [36] and in pediatric epilepsy more generally [56-59]. Different hypotheses may be advanced to explain this finding. A first hypothesis is that taking more treatments is a marker of a more severe epileptic disease, leading to more executive deficits. Alternatively, treatments could lead to executive side-effects, as suggested by other studies [60-63]. Regarding the impact of seizure frequency, the number of seizures per month tended to be associated with worse flexibility performance. Although partial, the results appear to align with previous studies that have highlighted a significant impact of more frequent seizures on executive functioning [61], and possibly on cognitive functioning more broadly in pediatric epilepsy. However, several studies have failed to show a link in FLE or TLE [24,46,64], necessitating further investigation.

Notably, lower IQ scores were consistently associated with increased executive deficits. This finding supports previous studies that have emphasized the influence of cognitive functioning on executive measures in children with FLE and TLE, following the example of the proposed rapprochement between these two concepts in certain models [10]. The correlation also appears significant when we analyze the amount of EFs impaired and IQ, suggesting that lower IQ is associated with a higher risk of generalized executive deficits. Regarding socio-demographic variables, our results did not reveal significant correlations with CEF-B scores. Although socioeconomic status has been reported as factors influencing EF outcomes in the literature [65], these effects are inconsistent and depend on the variables used. It should be noted that family functioning, parenting style, and other related factors were not specifically assessed in this study.

As expected in our third hypothesis, correlations between parent/teacher ratings and CEF-B performances were low and non-significant, which aligns with most studies that have examined correlations between direct testing and questionnaire-based reports using the BRIEF [47]. The use of tests and measures of daily life (if possible, in different contexts) should be considered as a complementary way to obtain a

global understanding of the child's functioning. It should be noted that the CEF-B appears to be particularly sensitive to the executive disorders that can occur in children with epilepsy, deficits in EFs being more often detected by the CEF-B components than by the BRIEF assessments.

The present study has some limitations. Primarily, a larger clinical population is needed to strengthen and extend our results. Furthermore, our sample was composed by convenience and this could also be a recruitment bias. Using the same population published by Campiglia et al. [46], we also listed the varied etiology of the epilepsies as a limitation of the study, given that some studies associate executive deficits with the etiology of epilepsy. Finally, with regard to socio-economic status, this indicator was only assessed by the level of education of the parents. Family functioning, parenting style and other related factors may be associated with executive development and were not examined in this study.

5. Conclusions

In summary, this study highlights the significant prevalence of EF deficits in childhood FLE and TLE. Although this is not a novel finding, the utilization of the newly developed CEF-B test battery, combined with daily life indicators, enabled a comprehensive assessment of deficits, focusing on domain-specific impairments. Given the importance of EFs disorders in epilepsy and their known impact on quality of life and academic achievement in other clinical contexts, a comprehensive exploration is warranted. The results showed impairment of all EFs components in both FLE and TLE groups. Poorer executive performances showed a noteworthy correlation with advanced age during the assessment period, an extended duration of epilepsy, increased seizure frequency, an earlier age at onset, and a higher number of ASM. Additional studies with greater sample size are needed to better understand the patterns of EFs deficits to these two focal epilepsies. Structured follow-up and systematic EFs evaluation are strongly recommended to detect and prevent EFs difficulties and prevent delayed impact as autonomy requirements increase with age.

CRedit authorship contribution statement

Amanda Guerra: Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Rafika Fliss:** Writing – original draft. **Mélodie Campiglia:** Writing – review & editing, Data curation. **Julie Remaud:** Writing – review & editing, Writing – original draft. **Olivier Cadeau:** Writing – review & editing. **Caroline Seegmuller:** Data curation. **Clotilde Boulay:** Validation, Data curation. **Lucas Gauer:** Validation, Data curation. **Patrick Van Bogaert:** Writing – review & editing, Writing – original draft, Validation. **Nathalie de**

Grissac-Moriez: Project administration, Conceptualization. **Maria Paola Valenti Hirsch:** Validation, Data curation. **Mathieu Kuchenbuch:** Validation, Data curation. **Jean-Luc Roulin:** Project administration, Formal analysis, Conceptualization. **Nathalie Fournet:** Project administration, Conceptualization. **Didier Le Gall:** Project administration, Conceptualization. **Arnaud Roy:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

See [Table A1](#).

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