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Cortical morphology, epileptiform discharges and neuropsychological performance in BECTS

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Abstract

Objectives—The aim of this study was to understand the relationship between cortical morphology, CTS, and neuropsychological functioning in children with BECTS compared to their typically developing peers.

Materials and methods—To examine whole-brain differences in cortical thickness between groups, a general linear model approach was applied to T1-weighted structural MRI in children with BECTS and typically-developing children. Further region-of-interest (ROI) analyses were performed to examine the effects of frequency and lateralization of CTS. In addition, the relationship between Processing Speed Index (PSI) and cortical thickness was investigated.

Results—Twenty-three patients with BECTS and thirty-two controls were included. There was no statistically significant difference in global cortical thickness between groups. With ROI analyses, we found significantly thinner cortex within right pars opercularis when comparing children with right predominant CTS, and with very frequent right CTS (>10/min) to the control group ($p=0.028$ and $p=0.026$ respectively). A statistically significant interaction of group (controls vs. BECTS) and PSI was seen in bilateral frontal and right superior parietal cortices, indicating a positive relationship between cortical thickness and PSI in healthy controls but not BECTS.

Conclusion—A region of cortex where right CTS may originate was thinner in BECTS compared to children without BECTS. Typically-developing children with faster processing speed had thicker cortices in regions supporting visuo-motor integration, motor and executive function, but this relationship was not observed in BECTS. These results suggest that BECTS is associated with atypical cortical morphology that may underlie poorer neuropsychological performance.

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Keywords

Benign Epilepsy with Centrottemporal Spikes; cortical morphology; neuropsychological performance; processing speed

Introduction

Benign epilepsy with centrottemporal spikes (BECTS) is the most common idiopathic focal epilepsy syndrome of childhood.¹ Although BECTS generally has a good prognosis and patients may have only a few seizures, a subset of children with BECTS exhibit cognitive and behavioral problems.^{2–11} For example our studies have shown that children with BECTS have poorer processing speed and fine motor skills¹¹, and other studies found poorer performance in language domains compared to typically developing peers^{4,8} - therefore, BECTS is not truly a ‘benign’ epilepsy. The age-dependent onset and remission, very frequent epileptic spikes, and cognitive problems suggest that there may be an association between altered brain development, interictal spikes, and cognitive outcome, even though BECTS has previously not been thought to have a structural etiology. In order to understand this relationship, recently developed advanced Magnetic Resonance Imaging (MRI) analysis methods have been utilized to characterize the differences in cortical morphology in children with BECTS compared to typically developing healthy children.^{10,12–15} However, the findings among these reports are inconsistent. This might be due to heterogeneous patient populations. For example, most studies included participants with variable durations of epilepsy, and some of the participants were already taking antiepileptic drugs at the time of enrollment.^{10,12–15} Moreover, in some studies, the authors did not take into consideration centrottemporal spike (CTS) lateralization. Therefore, the relationship between CTS, structural brain development, and cognitive outcomes has yet to be determined. The aim of this prospective study was to investigate whether there are differences in cortical thickness in children with BECTS compared to age and gender matched typically developing children. In addition, we consider that the lateralization and/or frequency of CTS may affect the morphology of central and the temporal neocortex. We also investigated whether there is an association between cortical thickness and neuropsychological function. Based on previous reports, we hypothesized that children with BECTS will exhibit atypical relationships between cortical thickness and neuropsychological function. Finally, we hypothesized that regional cortical thickness would vary with centrottemporal spike frequency.

Methods

All study procedures were approved by the institutional review board at Cincinnati Children’s Hospital Medical Center.

Participants

Fifty-one patients (age: 5–13 yrs, mean $\pm$ SD: 7.9 $\pm$ 2.0 yrs, F/M=26/25) were consecutively recruited from New Onset Seizure and general Neurology Clinics in the Division of Neurology at Cincinnati Children’s Hospital Medical Center; diagnoses were rendered according to ILAE criteria¹⁶. Specifically, the mandatory seizure semiology was including

“fronto-parietal opercular features with hemifacial (lip, mouth and tongue) clonic movements, laryngeal symptoms, articulation difficulty, swallowing or chewing movements and hyper-salivation”. Seizures were all self-reported or reported by parents. Additional criteria were 1) less than one year from BECTS diagnosis 2) no history of AED use. We also recruited fifty six typically-developing children (age: 5–13 yrs, mean $\pm$ SD: 8.1 $\pm$ 2.2 yrs, F/M=27/29). All participants in both groups were native speakers of English with no history of neuropsychological or learning disorders. Informed consent was obtained from a parent/guardian for all participants, including written assent from participants age 11 and up. Assent was obtained verbally from participants whose age was 10 years or younger at the time of recruitment, written assent was obtained only from children age 11 and older, to assure that the children had a sufficient reading level to comprehend the written consent form. The data was collected as part of a prospective NIH funded study for children with BECTS (NIH R01NS065840).

Structural MRI

Three-dimensional isotropic T1-weighted MR images with 1mm slice thickness, 8.0 msec repetition time and 3.7 msec echo time were obtained using a 3-Tesla Philips Achieva MRI scanner using a 32-channel head coil (Amsterdam, The Netherlands) for all participants.

Neuropsychological testing

All participants underwent assessment with the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI -II).¹⁷ This test yields verbal and performance composites, and Full Scale IQ scores. Language skills were assessed using the core subtests of the Clinical Evaluation of Language Fundamentals (CELF), Fourth Edition.¹⁸ Non-language testing was included to assess visuo-spatial skill and general speed of processing: the Developmental Test of Visuomotor Integration, Sixth Edition, and Symbol Search and Coding subtests from the Wechsler Preschool and Primary Scale of Intelligence, Third Edition (WPPSI-III) or the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV)¹⁹ to yield the Processing Speed Index (PSI).

Centrotemporal spike evaluations on Electroencephalography (EEG)

Centrotemporal spikes were evaluated based on an ambulatory EEG recording done for 24 hours the day before or after neuroimaging data collection with international 10–20 electrode placement. Spikes were identified visually by a pediatric epileptologist (JRT) and location of each CTS was noted as left, right or bilateral. The definition of CTS were based on ILAE criteria (<https://www.epilepsydiagnosis.org>). This describes CTS as “High amplitude centrotemporal spikes or sharp-and-slow wave complexes that activate in drowsiness and sleep”. These may be unilateral or bilateral and are usually frequent. There may be focal spikes seen outside the centrotemporal region (midline, parietal, frontal, occipital). The centrotemporal spike has a typical morphology with maximum negativity in centrotemporal electrodes (C3/C4 and T3/T4) and maximum positivity frontally. It is mandatory that there must be marked increase in frequency of epileptiform activity in drowsiness and sleep, when spikes or spike-and-slow waves often also have a wider field and may be bilaterally synchronous.” The patients with CTS plus spikes in other locations were excluded from our study. Spikes were counted during the first 2 hours of sleep, starting

with the first sleep spindle. Our previous work found an excellent correlation between the centrottemporal spike rate during the entire duration of sleep and the first 2 hours of sleep,²⁰ and the lateralization criteria have been previously published.²⁰ Briefly, lateralization index [LI = (left-sided spike rate – right sided spike rate)/(left-sided spike rate + right-sided spike rate)] was utilized to quantify the predominance of CTS. This formula results in value such that LI = 1 is completely left-sided spikes, LI = –1 is completely right-sided spikes, and LI = 0 is equal left and right spike rates. Based on LI, we created 2 groups based on CTS predominance L-CTS (0.1 < LI < 1.0) and R-CTS (–1.0 < LI < –0.1). LI reflects the lateralization, but the frequency of CTS, so we also examined sub-groups of BECTS with frequent CTS (greater than 10/min during sleep) on either the right or left side, including children with BECTS who had a bilateral distribution of CTS.

Structural MRI Data Analysis

Cortical thickness analysis was performed using Freesurfer image analysis suite (version 5.3) (<http://surfer.nmr.mgh.harvard.edu/>). Cortical reconstruction and volumetric segmentation detail was as follows: motion correction and averaging,²¹ removal of non-brain tissue,²² segmentation of the subcortical white matter and deep gray matter volumetric structures,²³ intensity normalization, tessellation of the gray matter white matter boundary, automated topology correction,²³ and surface deformation following intensity gradients to obtain the boundaries between brain tissue (CSF, WM, and GM).^{24,25} This surface was then refined to follow the intensity gradients between the WM and GM (white surface). The white surface was nudged to follow the intensity gradients between the GM and CSF (pial surface). The thickness of cortex was then measured as the distance between the white and the pial surfaces at the paired vertices for each column. The cortex was parcellated into units with respect to gyral and sulcal structure.^{26,27} The results of preprocessing were reviewed to make certain that the segmentation was done without errors.

GLM analysis was then carried out with whole brain cluster-wise correction for multiple comparisons.²⁸ The cluster-forming threshold set at uncorrected $p < 0.001$ and cluster-wise p-value (cwp) at corrected $p < 0.05$. We compared BECTS and control groups and included age, gender and total brain volume (TBV) as covariates. We then examined the voxel-wise correlation of cortical thickness with processing speed scores and its interaction with group.

ROI Analyses—Anatomical ROIs were selected using the Desikan-Killiany Cortical Atlas²⁷ implemented in FreeSurfer. Each parcellated ROI was normalized with TBV scaling by division.

- a. Group differences related to CTS: For this analysis, we chose to examine ROIs limited to centrottemporal regions (pre- and post-central gyri, superior temporal gyrus, and frontal operculum including pars opercularis and pars triangularis on the corresponding side for each CTS lateralization subgroup). Student's 2-sample t-test was utilized to evaluate the significance of cortical thickness differences between groups for each ROI.
- b. Relationships between cortical thickness and PSI: we chose to limit our analyses of neuropsychological outcomes to processing speed because scores differed

between groups (see Results). We selected *a priori* ROIs hypothesized to support processing speed based on the existing literature, including bilateral primary motor and visuo-motor association cortices, and executive function regions in lateral/medial prefrontal and frontal areas.^{29–31} In these regions, we used a GLM approach to examine the relationship of processing speed with cortical thickness and its interaction with group (BECTS vs. controls).

- c. The interaction between frequency of CTS and PSI in cortical thickness was investigated within chosen ROIs for both CTS and PSI investigation. Univariate GLM was utilized to evaluate the interaction with the mean cortical thickness values for each ROI as an independent variable and frequency of CTS and PSI as dependent variables.

For these planned analyses, we report group differences and GLM results from each ROI at a threshold of $p < 0.05$.

Post-processing quality control procedure—Because of the higher sensitivity of automated cortical thickness measurements to small movements, resulting in underestimation of cortical thickness,^{32,33} a three step quality control process was carried out. First, all T1-weighted images were visually inspected before running through the pipeline of automated structural imaging processes for cortical thickness analyses. Images with severe motion artifacts and artifacts from the in-scanner EEG cap were eliminated from the study. This study was part of a larger fMRI study where an EEG cap was used. The EEG cap was not a part of the current study but it created imaging artifacts. Second, extensive visual inspection for quality of each subject's extracted white and gray matter surfaces was carried out. If the segmented images had severe distorted cortical definition, i.e., inclusion of WM within GM, capture of GM in the WM, or severe localized inhomogeneity of GM/WM, the participants with those issues were excluded. Third, if the distortion and localized inhomogeneity were moderate, the manual WM intensity and surface correction was performed. If the manual correction brought the reasonably corrected white and pial surfaces and GM and WM segmentation, the participants were included in this study.

Results

Demographics

A total of 26 of 107 enrolled participants were withdrawn from the study due to 1) clinical MRI abnormalities (BECTS=2, controls=2), 2) Full Scale IQ < 80 (BECTS=1, controls=2), 3) inability to comply with study protocol (BECTS=8, controls=3), 4) dental work with braces or permanent retainer (received during the period between at the time of enrollment and the MRI scan visit controls=2), 5) EEG results not consistent with BECTS (BECTS=5), or 6) abnormal EEG (controls=1). The remaining participants had structural MRI (BECTS=35, controls=46). The time since BECTS diagnosis ranged from 1 – 7 months (median: 2 months). History of recognized lifetime seizures ranged from 1 – 9 at time of participation. Groups did not differ significantly in age. All participants were right-handed, except 4 (BECTS=3, controls=1). After the visual quality controls of raw and segmented GM and WM images and manual correction of white and pial surface corrections,

participants were excluded due to 1) motion artifacts (BECTS=9, control=4) or 2) severe artifacts from the in-scanner EEG cap (BECTS=1, control=9). These artifacts were not able to be corrected manually. A total of 23 children with BECTS and 32 typically developing children were included for cortical thickness analyses (Table 1). For the analysis examining cortical thickness and PSI, one participant from each group was excluded because they did not complete the Wechsler assessment yielding a PSI score.

Subgroups of BECTS based on EEG CTS characteristics—Based on the LI, there were thirteen children with predominant R-CTS and six with predominant L-CTS. Since LI does not reflect the frequency of spikes, we further categorized 14 patients whose EEG exhibited right CTS more frequent than 10/min and 11 patients with left CTS more frequent than 10/min, regardless of overall lateralization pattern (Table 2).

Cortical thickness: group differences

Group difference between BECTS and Controls—There were no statistically significant differences in cortical thickness between BECTS patients and controls based on the global cortical thickness measure.

Group differences between lateralization subgroups of BECTS vs. Controls—We investigated the GM volume and cortical thickness differences between each of the four subgroups of BECTS (L-CTS predominant, R-CTS predominant, L frequency >10/min, R frequency >10/min) and the control group. There were no differences for all four comparisons in GM volume and cortical thickness using whole brain analyses. However, based on ROI analysis, we observed that the R-CTS predominant group, as well as the R frequency >10/min group had thinner cortex compared to the control group within the right pars opercularis ($t_{42}=2.276$, $p=0.028$ and $t_{42}=2.303$, $p=0.026$ respectively) (Figure 1.)

Neuropsychological performance and relationship with cortical thickness

Neuropsychological performance—The summary of neuropsychological testing scores for each group are shown in Table 3. One participant from each group had missing PSI scores. PSI was significantly different between BECTS and typically-developing children ($t_{50}=2.536$, $p=0.014$). The children with BECTS had significantly slower processing speed than typically-developing children. PSI did not relate to CTS lateralization or CTS frequency.

ROI Analysis: Interaction of Processing Speed Index and Group—We focused on the relationship between cortical thickness with processing speed because Wechsler PSI was significantly lower in the BECTS group compared to controls. There were five regions that exhibited a significant interaction between group and PSI in cortical thickness, including precentral ($F_{1,50}=5.914$, $p=0.0188$), superior parietal ($F_{1,50}=6.179$, $p=0.0165$), caudal middle frontal ($F_{1,50}=4.953$, $p=0.0308$), rostral middle frontal ($F_{1,50}=5.418$, $p=0.0242$), and pars opercularis ($F_{1,50}=4.060$, $p=0.0495$) within right hemisphere; and two regions, caudal middle frontal ($F_{1,50}=4.171$, $p=0.0466$) and precentral ($F_{1,50}=4.261$, $p=0.0444$) in the left hemisphere (Figure 3). Post-hoc tests in each group revealed that in these regions, there was

a significant positive correlation between cortical thickness and PSI in typically-developing children that was absent in BECTS. Details of these findings are included in Table 4.

ROI Analysis: Interaction of Processing Speed Index and frequency of CTS—

There were no statistically significant interactions between cortical thickness, PSI, and frequency of CTS for any of ROIs.

Discussion

Understanding the relationship between cortical development, epileptic spikes, and neuropsychological functioning is important for understanding the mechanism underlying the link between brain development, epilepsy, and neuropsychological comorbidities. Previous studies regarding cortical thickness in children with BECTS reported contradictory results for the differences in cortical thickness between the children with BECTS (Table S1) compared to controls.^{10,12–15} Overvliet et al. suggested that children with BECTS exhibit earlier onset of age-related cortical thinning and Garcia-Ramos et al. also reported that children with BECTS exhibited small regions thinner of cortex compared to controls at or near the diagnosis of BECTS. They also examined 2-year longitudinal follow-up data and found that children with BECTS exhibited a small region of age-related cortical thinning and another region of greater thickness over time.¹² In contrast, Kim et al., found that children with BECTS showed significantly thicker cortex in the several regions. These contradictory results may be due to several confounders related to heterogeneous participant demographics including: 1) antiepileptic drug naïve vs. mix of AED prescriptions, 2) older age of participants (8–14 years of age) or wide range (5–25 years). 3) Preselection of BECTS patients with normal-range IQ. Our findings of a lack of a widespread group difference in cortical thickness in a homogeneous population, while null results, may overcome the limitations of previous studies with a variety of patient variables that were more heterogeneous. We did not find any difference in cortical morphology between children with BECTS and typically developing peers. This null finding is discordant with any other previous structural imaging studies examining both cortical thickness and voxel-based morphometry noted above. Again unlike our very homogeneous population, others included relatively inhomogeneous population. Moreover, some of typically-developing children the studies did not have EEG reports at the time of MRI scan, and therefore it is difficult to confirm whether patients were still under the BECTS diagnosis with presence of centrotemporal spikes. This could potentially lead to false positive results with significant differences between patient and control groups, yet conflicting findings in different directions among studies.

When we investigated whether CTS affect any structural features in BECTS, we found that right pars opercularis (BA44) was significantly thinner, compared to the control group, in children with BECTS who had R-predominant CTS and in children that had frequent CTS, more than 10 spikes/min in the right hemisphere, regardless of overall lateralization. This suggests that CTS are associated with cortical thinning in BECTS compared to controls. On the other hand, we did not find any regions that showed correlation between cortical thickness and frequency of CTS and on the left hemisphere ROIs. This may due to very small samples (L-CTS, L>10/min: n=6, n= 11 respectively).

In terms of neuropsychological function, children with BECTS exhibited statistically significantly poorer PSI scores compared to typically-developing children, although both groups scored in the average range. Interestingly, there were several regions where we found a statistically significant interaction between group (BECTS vs. typically-developing children) and PSI in cortical thickness. Moreover, there was a trend of positive correlation between PSI and cortical thickness in typically developing children, whereas children with BECTS rather had either no correlation or even a negative correlation with PSI. The PSI assesses children's abilities to focus attention and quickly scan, discriminate between, and sequentially order visual information, meaning that they are required attending to visual material, visual perception and organization, visual scanning, hand-eye coordination and motor output. It requires persistence and planning ability, attention and focused concentration, and often visuospatial skills, supported by a complex network of brain regions.³⁴ Taken together, our finding suggests that children with BECTS have atypical functional cortical morphology compared to typically developing peers. In addition, those regions were relatively close to the location of the CTS source in BECTS. It remains undetermined whether atypical cortical morphology, CTS, and poorer processing speed have a common underlying cause, or whether frequent CTS are the cause of changes in cortical morphology. Interestingly, a recent study by Whelan et al, 2018 suggests that regional cortical thinning may be detected across patients with any type of epilepsy³⁵ if a very large sample is studied, raising the question of whether our results are specific to BECTS. Previous reports suggested that children with BECTS have poorer language function compared to typically developing peers. However, we did not find differences in language function within our small sample cohort. A larger sample size with high quality imaging data will be needed in order to investigate a wider range of extensive cognitive performance and their correlation with cortical development.

Our study was limited by the reduction in sample size after the post-processing quality controls from the initial enrollment. Second, we did not analyze white matter integrity since diffusion tensor images (DTI) were not obtained in this study, though we speculate that there may also be white matter changes in BECTS.³⁶ Third, multiple comparison corrections for ROI analyses were not performed for two reasons, 1) we conducted a planned analysis to look only at the predetermined ROIs 2) because the small sample size did not allow us to correct for the number of relevant ROIs. We tried to optimize the impact of our findings by using a homogenous sample and stringent quality control – both of which were lacking in other previously reported studies regarding structural findings in BECTS^{10,12–15} with conflicting results. To our knowledge, this is the first study that investigated the direct association between cortical thickness and neuropsychological performance in BECTS. Therefore, the findings should be validated either through replication in a separate larger cohort or specifically looking at only processing speed and pars opercularis.

Taken together, our findings suggest that there is not a direct relationship between CTS frequency and morphological changes; specifically, more frequent CTS are not correlated with greater deficits in processing speed, and do not modulate the relationship between processing speed and cortical thickness in a linear manner. However, we also found that children with R-CTS reaching a certain level of frequency had thinner cortex in the R pars opercularis (one of the regions that showed an interaction of group and processing speed).

This pattern of results suggests that the presence of CTS and changes in cortical morphology co-occur. However, we feel that it is difficult to strongly suggest causality in this relationship - it is unclear whether morphology cause the appearance of CTS and poorer neuropsychological function; or that CTS cause changes in morphology. Unfortunately, we cannot identify patients with BECTS to evaluate their cortical development before a seizure occurs.

In summary, our findings indicate that children with BECTS have atypical cortical features which may underlie poorer processing speed. Additional longitudinal data will be needed to elucidate the relationship between brain structural maturation, CTS, and cognitive function in BECTS. It is our hope that these findings will drive further research concerning the relationship between brain structure, interictal spikes, and neuropsychological function in children with epilepsy.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Cortical thickness ROI showed statistically significant differences between children with BECTS with predominant R-CTS, or frequent R-CTS and controls: right pars opercularis (BA44) was thinner in BECTS compared to controls (2-sample t-test: $p=0.028$ and $p=0.026$ respectively).

Figure 2. ROIs that exhibited a significant interaction between group Processing Speed Index and groups (orange) in cortical thickness (LH: left hemisphere RH: right hemisphere).

Table 1

Participants' demographics.

	BECTS (n=23)	Controls (n=32)
Age (mean $\pm$ SD in years)	8.61 $\pm$ 2.01	8.31 $\pm$ 2.26
(range in years)	5–12	5–12
Gender (M/F)	13/10	15/17
Handedness (R/L)	21/2	32/0
Age at diagnosis (mean $\pm$ SD in years)	9.02 $\pm$ 1.96	N/A
# of seizures at the time of the study (median)	2	N/A
(range)	1–9	N/A
Months since the first seizure (median)	2	N/A

Table 2

Frequency and lateralization of CTS, Neuropsychological scores in Children with BECTS

Participant	CTS lateralization and frequency (CTS/min)			Inclusion in subgroup analyses	LI	Number of seizures before enrollment	Full scale IQ	Processing Speed	CELF	Visuo-Motor Integration
	Left	Right	BL							
BECTS_1	20.60	0.00	0.00	L-CTS, L>10/min	1.00	2	109	80	97	79
BECTS_2	38.87	0.02	0.00	L-CTS, L>10/min	1.00	1	109	97	98	117
BECTS_3	15.23	0.00	0.00	L-CTS, L>10/min	1.00	2	119	103	85	111
BECTS_4	27.97	0.00	0.00	L-CTS, L>10/min	1.00	3	107	106	104	98
BECTS_5	30.42	11.15	0.44	L-CTS, L>10/min, R>10/min	0.46	1	125	100	99	102
BECTS_6	36.8	26.8	0.00	L-CTS, L>10/min, R>10/min	0.16	3	114	80	94	72
BECTS_7	15.34	21.53	0.28	R-CTS, L>10/min, R>10/min	-0.17	9	108	97	102	89
BECTS_8	0.02	22.43	0.01	R-CTS, R>10/min	-1.00	2	120	100	121	112
BECTS_9	0.00	26.87	0.01	R-CTS, R>10/min	-1.00	2	109	131	120	100
BECTS_10	0.03	0.18	0.00	R-CTS	-0.75	6	107	80	102	101
BECTS_11	0.01	1.70	0.00	R-CTS	-0.99	5	91	103	108	83
BECTS_12	0.00	25.56	0.03	R-CTS, R>10/min	-1.00	1	77	97	78	66
BECTS_13	0.00	40.30	0.00	R-CTS, R>10/min	-1.00	2	109	97	112	97
BECTS_14	12.28	15.21	0.72	R-CTS, L>10/min, R>10/min	-0.11	1	85	91	82	93
BECTS_15	3.35	11.99	0.07	R-CTS, R>10/min	-0.56	3	108	106	97	108
BECTS_16	0.00	39.79	0.00	R-CTS, R>10/min	-1.00	3	100	94	82	98
BECTS_17	0.00	38.63	0.00	R-CTS, R>10/min	-1.00	3	132	88	99	99
BECTS_18	0.00	21.89	0.00	R-CTS, R>10/min	-1.00	1	100	78	100	89
BECTS_19	0.00	5.5	0.00	R-CTS	-1.00	2	109	112	91	93
BECTS_20	15.62	16.13	0.31	L>10/min, R>10/min	-0.02	2	102	88	100	97
BECTS_21	11.08	11.47	0.57	L>10/min, R>10/min	-0.02	1	90	88	70	88

LI = Lateralization Index, CELF = Clinical Evaluation of Language Fundamentals. All neuropsychological scores are standard scores with mean of 100 and ± 15 standard deviation.

Table 3

Neuropsychological testing scores for each group.

	BECTS (n=23)	Controls (n=32)	p-value (t-test)
Full scale IQ	109.43 ± 13.65	108.94 ± 12.92	0.891
Processing Speed Index	96.22 ± 12.02 (n=21)	104.00 ± 10.47 (n=31)	0.014 *
CELF (core)	98.70 ± 13.25	102.16 ± 15.01	0.380
Visuomotor Integration	94.86 ± 12.53 (n=21)	97.04 ± 11.68 (n=27)	0.534

*
p < 0.05

ROIs that exhibited a significant ($p < 0.05$) interaction between group and PSI in cortical thickness.

Table 4

ROI	Interaction		Correlation significance (p)		Correlation coefficient (r)	
<i>Left Hemisphere</i>		<i>F</i>	<i>p</i>	<i>BECTS (n=21)</i>	<i>Controls (n=32)</i>	<i>Controls</i>
Caudal middle frontal		4.171	0.047 *	0.4195	0.0488 *	-0.1860
Precentral		4.261	0.044 *	0.6631	0.0203 *	-0.1016
<i>Right Hemisphere</i>						
Rostral middle frontal		5.418	0.024 *	0.9034	0.0021 *	0.9034
Caudal middle frontal		4.953	0.031 *	0.6948	0.0092 *	-0.0914
Precentral		5.915	0.019 *	0.5164	0.0089 *	-0.1515
Pars opercularis		4.06	0.046 *	0.6885	0.0197 *	-0.0939
Superior parietal		6.179	0.016 *	0.1199	0.0628	-0.3502

* $p < 0.05$