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Visual and auditory socio-cognitive perception in unilateral temporal lobe epilepsy in children and adolescents: a prospective controlled study

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ABSTRACT – *Aim*. A high rate of abnormal social behavioural traits or perceptual deficits is observed in children with unilateral temporal lobe epilepsy. In the present study, perception of auditory and visual social signals, carried by faces and voices, was evaluated in children or adolescents with temporal lobe epilepsy.
Methods. We prospectively investigated a sample of 62 children with focal non-idiopathic epilepsy early in the course of the disorder. The present analysis included 39 children with a confirmed diagnosis of temporal lobe epilepsy. Control participants (72), distributed across 10 age groups, served as a control group. Our socio-perceptual evaluation protocol comprised three socio-visual tasks (face identity, facial emotion and gaze direction recognition), two socio-auditory tasks (voice identity and emotional prosody recognition), and three control tasks (lip reading, geometrical pattern and linguistic intonation recognition). All 39 patients also benefited from a neuropsychological examination.
Results. As a group, children with temporal lobe epilepsy performed at a significantly lower level compared to the control group with regards to recognition of facial identity, direction of eye gaze, and emotional facial expressions. We found no relationship between the type of visual deficit

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and age at first seizure, duration of epilepsy, or the epilepsy-affected cerebral hemisphere. Deficits in socio-perceptual tasks could be found independently of the presence of deficits in visual or auditory episodic memory, visual non-facial pattern processing (control tasks), or speech perception. A normal FSIQ did not exempt some of the patients from an underlying deficit in some of the socio-perceptual tasks.
Conclusion. Temporal lobe epilepsy not only impairs development of emotion recognition, but can also impair development of perception of other socio-perceptual signals in children with or without intellectual deficiency. Prospective studies need to be designed to evaluate the results of appropriate re-education programs in children presenting with deficits in social cue processing.

Key words: social cognition, temporal lobe epilepsy, children, face identity, facial emotion, gaze direction recognition, perceptual deficit

Patients with childhood-onset temporal lobe epilepsy (TLE) exhibit widespread compromised neuropsychological performance and a substantial reduction in brain tissue volumes, extending to extratemporal regions, compared with healthy controls and late-onset TLE patients (Hermann *et al*., 2002). The Full Scale Intelligence Quotient (FSIQ) was found to be associated with white matter loss in TLE, within and outside the affected temporal lobe (Hermann *et al*., 2002), attesting to the clinical significance of the volumetric abnormalities. Additionally, early seizure onset in patients with TLE can be associated not only with impairment of memory, language, and problem solving (Hermann *et al*., 2002), but also impairment in other specific competences, such as perception of emotions. Deficits in negative facial emotional recognition (Golouboff *et al*., 2008), as well as emotional prosody recognition, have also been documented (Cohen *et al*., 1990).

The fact that specific deficits in face identity recognition or abnormal brain response to faces have been documented in both childhood-onset (Hermann *et al*., 2002; Taylor *et al*., 2008; Mabbott and Smith, 2003; Laurent *et al*., 2005) and late-onset TLE (Crane and Milner, 2002; Seidenberg *et al*., 2002) raises the question of whether the deficit in recognition of emotions is part of a deficit in emotional competences or/and part of a deficit in the domain of social cognition. Studies on functional anatomy of social competences in adults suggest that TLE is likely to be associated with deficits in the visual and auditory aspects of the face and voice that carry social information. Studies of brain-damaged patients and/or functional brain imaging in healthy adults also indicate involvement of partially distinct functional pathways, preferentially implicating the superior, lateral, ventral temporal and para-hippocampal cortex, and/or amygdala in face and voice identity recognition, facial and vocal emotion perception, and gaze direction detection (Allison *et al*., 2000; Zilbovicius *et al*., 2000; Belin *et al*., 2004; Pihan, 2006; Fusar-Poli *et al*., 2009; Gainotti, 2011).

Social perception develops during the first two years of life and includes individual face recognition (Bushnell *et al*., 1989; Pascalis *et al*., 1995, 1998; Sangrigoli and de Schonen, 2004), discrimination of facial emotions (Leppänen and Nelson, 2006), preference for direct over averted gaze (Farroni *et al*., 2004), ability to relate gaze or emotional expression to intentional action (Phillips *et al*., 2002), voice recognition (Mehler *et al*., 1978; de Casper and Fifer, 1980; Kahana-Kalman and Walkers-Andrews, 2001; Kisilevsky *et al*., 2003), and discrimination and categorization of prosodic intonations (Fernald, 1993; Cooper and Aslin, 1994; Kujala *et al*., 2004; Grossmann *et al*., 2005). Brain imaging studies in infancy and early childhood indicate that neural bases for social perception are similar to those described in adulthood (de Schonen and Mathivet, 1990; Deruelle and de Schonen, 1998; Allison *et al*., 2000; Dehaene-Lambertz *et al*., 2002; Tzourio-Mazoyer *et al*., 2002; Halit *et al*., 2004; Leppänen and Nelson, 2006; Lloyd-Fox *et al*., 2009; Grossmann *et al*., 2010; Nakato *et al*., 2011). Despite the very early development of social perception skills, age at which the adult level of social perception is reached differs according to the different competences.

Consequently, children with non-idiopathic unilateral TLE (MRI negative or with a structural lesion) may show a deficit in perception of social cues, in accordance with the damage of functional specialization of the temporal cortex and associated connections due to epileptic seizures during the development of the competencies mentioned above or in relation to the underlying pathological substrate at the origin of the epilepsy. To our knowledge, only one study dealing with facial and vocal emotion in adults is available (Bonora *et al*., 2011).

Our study is the first to investigate perception of several social cues, using different tasks, in a defined population of children and adolescents with TLE.

Intellectual disability of TLE patients was taken into account in order to investigate whether socio-perceptual deficits are always associated with intellectual deficiency or can be present independently. Children with an FSIQ of <80 or <70 (Mabbott and Smith, 2003; Golouboff *et al.*, 2008) are usually excluded from TLE studies based on facial identity and emotion deficits. As a consequence, it is not currently known to what extent perception of social cues is preserved in children with TLE and a low FSIQ.

Some studies in adults and children with intellectual disability, but without epilepsy, have shown a relationship between the severity (mild or moderate) of disability and the severity of facial identity and emotion deficits (Rojahn *et al.*, 1995; Simon *et al.*, 1996; Hetzroni and Oren, 2002), whereas this was not the case for others (Weisman and Brosgole, 1994). This is not really surprising given the heterogeneity of aetiology of intellectual deficits in children; in some cases, basic socio-perceptual skills are preserved, while in others, highly specific or all socio-perceptual skills are impaired.

In patients with TLE, intellectual disability might be associated with the specific aetiology of epilepsy. Social deficits might not be the mere consequence of limited general attention or computational resources or of slow processing, but a consequence of the underlying neurological aetiology. Although competences in socio-perceptual skills might show a correlation with intellectual level, our hypothesis is that a low intellectual level may not be the unique cause of socio-perceptual deficits found in TLE patients. This would be the case if a proportion of individuals with TLE and a low intellectual level presented with preservation of some socio-perceptual skills while others, with a good intellectual level, showed deficits in some perceptual skills. Thus, the present study investigated socio-perceptual skills (facial emotion, face identity, gaze direction, voice identity, and emotional prosody recognition) in a prospectively identified group of children or adolescents with unilateral TLE.

Methods

Participants

For all participants, both controls ans TLE patients, French was the native langage.

Control groups

Seventy-eight healthy control participants, children aged 5 to 14 years and young adults, were distributed across ten age groups (with eight participants/group, except in the 5-year-old group that included six individuals). The mean ages and SD for each group were: 5.6 years (SD: 4 months), 6.6 years (SD: 4 months), 7.7 years (SD: 3 months), 8.5 years (SD: 4 months), 9.6 years (SD: 4 months), 10.7 years (SD: 3 months), 11.5 years (SD: 2 months), 12.10 years (SD: 7 months), 14.6 years (SD: 3 months), and a young adult group of 23.3 years (SD: 35 months). All children were from middle and lower-middle-class families and were recruited during summer in a rural day care centre. All children within the control group attended regular school facilities and had average performance. An FSIQ score not inferior to 80 is typically required for attendance at standard schools. None of the control group children suffered from a neurological disorder.

Patients

With an aim to include children with epilepsy early in the course of their disorder, we initially prospectively included in the study all 62 patients who presented with focal non-idiopathic epilepsy (with or without an MRI-negative structural lesion), between November 2003 and January 2007 (Arzimanoglou, 2005). We deliberately decided not to wait for a confirmed TLE diagnosis before inclusion, thus allowing us to evaluate these children as early as possible with reference to onset of their epilepsy.

Only the 39 children with confirmed TLE were then selected for analysis. Syndromic diagnosis was based on usual electro-clinical criteria (Arzimanoglou *et al.*, 2004). They were all assessed for neuropsychology and socio-perceptual deficits by the same neuropsychologist (AL) at the Epilepsy Unit of the University Hospital Robert Debré, and the diagnosis was validated for all children by the same child neurologist (AA) following analysis of clinical description, available interictal and/or ictal 24-hour video-EEG, and MRI (1.5 Tesla in all cases). The neuroradiologist and child neurologist were blind to the patients' scores in the experimental tasks before confirmation of TLE diagnosis. Only one child was suspected to have an autism spectrum disorder and was clinically evaluated by a child psychiatrist who rejected the diagnosis.

Epilepsy and related neurological characteristics of the final sample with confirmed TLE (39 patients: 18 females/21 males; 14 right-sided TLE), aged 5-19 years, are summarized in *table 1*. The results related to side of epilepsy and its eventual effect on socio-perceptual performances should be interpreted with caution given the lack of data on functional hemispheric dominance (*f*MRI was not performed) and the difference in right- versus left-sided TLE samples (R/14-L/25).

All children presented with normal or corrected vision and normal hearing. Neuropsychological assessments at inclusion (including full IQ, auditory and visual memory tasks) are presented in *table 1*. With the

Table 1. Age, neuropsychological and neurological profiles of the Right-sided (RTLE) and the Left-sided (LTLE) TLE patients.

Variables	TLE (n=39)		LTLE (n=25)		RTLE (n=14)		Statistical tests Left- *versus* right-sided		
	Mean (M)	Standard deviation (SD)	M	SD	M	SD	F anova	df	p
Age at evaluation (yrs;mths)	10;6	3;11	9;8	3;4	11;11	4;7	3,2	(1,37)	ns
NEUROPSYCHOLOGY DATA									
Full IQ	86.2	23.8	78.7	20.9	98.6	23.8	7.2	(1,35)	p=.011
Verbal IQ	87.1	23.3	79.5	20.9	99.6	22.3	7.6	(1,35)	p=.009
Performance IQ	88	22.4	81.5	19.2	98.8	23.8	5.9	(1,35)	p=.020
Auditive memory									
immediate recall	-0.6	1.3	-0.9	1.2	-0.1	1.3	3.8	(1,37)	ns
delayed recall	-1.1	1.3	-1.4	1.4	-0.6	1,0	2.9	(1,34)	ns
Visual memory									
immediate recall	-0.5	1.5	-0.5	1.6	-0.5	1.3	0,0	(1,37)	ns
delayed recall	-0.2	1.5	-0.4	1.6	0.3	1.3	1.8	(1,34)	ns
NEUROLOGICAL DATA									
First seizure onset	5;5	3;8	4;7	2;8	6;10	4;10	3,6	(1,37)	ns
Disease duration	5;1	3;1	5;1	2;11	5;1	3;6	0,0	(1,37)	ns
	%	n	%	n	%	n	Chi^2	df	p
Focus localisation							3.4	(1,3)	ns
Fr-Temp	21%	8	28%	7	7%	1			
Temp	56%	22	52%	13	64%	9			
Temp-Occ	15%	6	16%	4	14%	2			
Temp-Par-Occ	8%	3	4%	1	14%	2			
Febrile convulsion							0.1	(1,1)	ns
No	67%	26	68%	17	64%	9			
Yes	33%	13	32%	8	36%	5			
Seizure frequency							0.9	(1,3)	ns
1	28%	11	24%	6	36%	5			
2	36%	14	36%	9	36%	5			
3	21%	8	24%	6	14%	2			
4	15%	6	16%	4	14%	2			
Anti-epileptic drugs							0,0	(1,1)	ns
2 AEDS	41%	16	40%	10	43%	6			
Monotherapy	59%	23	60%	15	57%	8			
MRI abnormality *							2.6	4	ns
None	23%	9	16%	4	36%	5			
Mesial	54%	21	60%	15	43%	6			
Lateral Temporal	8%	3	8%	2	7%	1			
Temp+Extra-Temp (bilateral)	3%	1	4%	1	0%	0			
Temp Junction+Extra-Temp	13%	5	12%	3	14%	2			

* Among the 21 patients with mesial abnormalities, 8 showed hippocampal sclerosis, 5 a dysplastic lesion, one a dysembryoplastic neuroepithelial tumour (DNET), one a benign astrocytoma, and 5 a non-specific hypersignal.
Among the 3 patients with lateral temporal abnormalities, one showed a dysplastic lesion, one a DNET, and one an abnormal vertical gyrus.
Among the 5 patients with MRI abnormalities implicating the temporal junction and the extra-temporal cortex, 3 presented with a dysplastic lesion which also extended to the parietal (one patient) or frontal (2 patients) regions, one other patient presented a non-specific signal abnormality of the frontal horn of the lateral ventricle with hypertrophy of a frontal cortical band and one had a haemorrhagic sequellae within the thalamus and a moderate ventricular dilatation. The patient presenting with bilateral MRI abnormalities showed poor differentiation of white/grey matter of the left temporal pole, associated with abnormalities of the cortical parietal gyrus on the left and a nodular temporal heterotopia on the right.

exception of FSIQ, VIQ, and PIQ, found to be significantly lower in the Left TLE group, no other variables listed in *table 1* were identified as significantly different between left and right-sided TLE patients. Given the relatively small size of the sample, such a result could be related to the ratio of left (*n*=25) versus right-sided (*n*=14) patients included. Thirty-three patients followed a regular, age-matched, academic cursus (FSIQ range: 48 to 136); the remaining six were schooled in specialized centres (FSIQ: 47, 49, 50 60, 60, and 65).

Stimuli, tasks and procedures

Intellectual efficiency (FSIQ) and memory were assessed in all patients using the WISC-III (Wechsler, 1992) or WPPSI-R (Wechsler, 1989) (with respect to the age of the child) and the Signoret Memory Efficiency Battery (BEM) (Signoret, 1991), respectively. Two subtests of the BEM were used: immediate and delayed (10 minutes) recall of a 12-word list orally presented and a list of 12-non significant signs presented visually, in succession, for 10 seconds each. Recall for the word list was made orally. Recall of signs was graphical. For the 5-year-olds, two memory subtests of the McCarthy Scales for children abilities (French version: MSCA; McCarthy, 1972) were used with the subtest recall of a list of words presented orally. FSIQ was not assessed for the age-matched control group.

The experimental protocol comprised eight computerized tasks (of which three were control tasks): three socio-visual tasks (face identity, facial emotion and gaze direction recognition), two socio-auditory tasks (voice identity and emotional prosody recognition) and three control tasks (lip reading, geometrical pattern and linguistic intonation recognition).

The rational for the choice of the five perceptual competences was based on the following:

– they have previously been shown to develop in infancy (Mehler *et al.*, 1978; de Casper and Fifer, 1980; Bushnell *et al.*, 1989; Fernald, 1993; Cooper and Aslin, 1994; Pascalis *et al.*, 1995, 1998; Kahana-Kalman and Walkers-Andrews, 2001; Phillips *et al.*, 2002; Kisilevsky *et al.*, 2003; Farroni *et al.*, 2004; Kujala *et al.*, 2004; Sangrigoli and de Schonen, 2004; Grossmann *et al.*, 2005; Leppänen and Nelson, 2006);

– they are good candidates for the screening of socio-perceptual competences, as they are considered to involve underlying neural networks of the temporal regions both in adults and children (de Schonen and Mathivet, 1990; Deruelle and de Schonen, 1998; Allison *et al.*, 2000; Dehaene-Lambertz *et al.*, 2002; Tzourio-Mazoyer *et al.*, 2002; Halit *et al.*, 2004; Leppänen and Nelson, 2006; Lloyd-Fox *et al.*, 2009; Grossmann *et al.*, 2010; Nakato *et al.*, 2011);

– they have been used to investigate abnormal social behaviours and abnormal function of the temporal regions in children with autism (Ohnishi *et al.*, 2000; Zilbovicius *et al.*, 2000; Boddaert *et al.*, 2004; Zilbovicius *et al.*, 2006; Saitovitch *et al.*, 2012).

Furthermore, the tasks were built so as to avoid implication of lexical, semantic, and syntactic skills, and to overcome the frequent naming deficit observed in TLE patients. The structure of the specifically designed tasks was based on studies of social perception in childhood (for example: Sangrigoli *et al.*, 2005; Mondloch *et al.*, 2006; Gao and Maurer, 2011).

For all tasks, the participants were presented with a target stimulus and subsequently asked to recognize the target using a two-choice display. Each task started with a familiarization period with all stimuli used in the task (pictures or speech segments) and training trials. Several breaks were allowed between tasks. The order of presentation of the eight computerized tasks was the same for all participants. The group of 5-year-olds (five patients and six controls) was assessed with a shorter version of the tasks (the number of trials was reduced to almost half) and the control linguistic intonation task was not presented.

For all tasks, the same scoring rule was applied: each trial was scored 1 (failure) or 0 (success). The error score of a child in a given task (or condition) was the calculated percentage of one over the number of executed trials.

Visual perception tasks

For all visual tasks, a cross was presented in the centre of the computer screen. When the child visually fixed on the cross, a target was presented in the upper central part of the screen for 250 m. Thereafter, a grey screen was presented for 500 m, followed by the presentation of a two-choice display in the lower part of the screen. The correct choice stimulus was pseudo-randomly situated on the right or left side of the screen. Choice stimuli remained on the screen until the child pointed out his/her choice. Each face stimulus was presented at an angle of 6° relative to the horizontal line of the cross intersection. Figures were selected from a large pool of photographs of faces that included emotional expressions, judged by eight independent experts to be unambiguous regarding positive *versus* negative valence. Photos expressing fear were not used.

Face identity recognition. Participants had to decide which of two unknown faces corresponded to the target face previously presented (36 trials). The tasks were presented in three different ways, in the following fixed order:

– the target and correct choice stimulus were identical (same photograph; 14 trials);

– the target and correct choice differed according to orientation (profile, three-quarter image, or full frontal view; 11 trials);

– the target and correct choice differed according to expression (positive or neutral; 11 trials).

Gaze direction recognition. Participants had to decide which of two faces was gazing in the same direction as the previously presented target face (36 trials). The target (a female face) was presented in such a way as to induce perception of eye pseudo-motion (rapid succession of three snapshots: 70 m, 70 m, and 250 m). For the two-choice display, gaze was static, directed either towards the participant or averted. The identity of the face for the target stimulus and the two-choice display were different. The gaze of the target was directed towards the participant (18 trials) or averted (18 other trials).

Facial emotion recognition. Participants had to recognize which of two faces displayed the same emotional expression as the target previously presented (52 trials). Facial expressions were either positive (happiness or surprise; 26 trials) or negative (sadness or anger; 26 trials), and the face identity of the emotional target was variable in the consecutive trials. In the first block of tests, the initial target stimulus was presented in the central visual field. In the second block, the target was presented in the right or left hemi-field in a pseudo-random order. For the hemi-field presentation, a face appeared for 250 m on the right or left, at an angle of 1-6° from the cross. Seventeen trials were performed in each position. Within each block, the four emotional expressions were pseudo-randomly presented in the same order for all participants.

Two additional control tasks were constructed and used.

Lip reading recognition (control task). Participants were shown photographs of faces (full frontal view) of people who were pronouncing one of three different phonemes: [a], [o] or [i] (producing three different lip positions). The children were asked to visually identify, from a choice of two people, the person pronouncing the same phoneme as the one previously visualized. The three different phonemes (lip positions) were pseudo-randomly presented in 36 trials (12 trials for each of the three phonemes). The faces presenting the stimuli (phonemes of the target and two-choice display) were of different people.

Lip gesture for pronunciation of phonemes and facial emotion are both facial gestures. Phoneme pronunciation is more closely related to speech competences than facial emotion. Preserved performances in this "control" task, combined with poor performances in facial emotion recognition tasks, excluded deficit(s) in general facial gesture processing.

Geometric pattern recognition task (control task). Participants had to recognize which of two patterns was identical to the target previously presented. The non-target pattern differed from the target pattern either by a configural or a local modification (position of components or component shape, respectively; for more details refer to de Schonen *et al.* (2005)). The order of presentation for the two conditions was pseudo-random. The target was presented for 500 m. This time frame was deliberately longer for the three social tasks in order to compensate the estimated difficulty of the task.

A preserved performance in this geometric pattern recognition task excluded any basic deficit(s) related to visual configural or local processing, both involved in face processing.

Auditory perception tasks

The stimuli consisted of audio recordings. The time interval between the target presentation and the two-choice display was 500 m. The correct choice stimulus was pseudo-randomly presented either first or second. The duration of the target and the two stimuli of the two-choice display were slightly different. However, each stimulus of a two-choice display included the same number of syllables. The overall duration of the presentation was therefore the combined duration of the three stimuli within a trial plus the 500 m interval.

Voice identity recognition task. Participants had to decide which of two voices was the target voice previously presented (36 trials). Voices were of a male or a female. The stimuli consisted of a short utterance (nine syllables). In the first 14 trials, intonation and content of the utterances were identical to the initial target presentation. In the subsequent 11 trials, only the content of the sentence differed, and in the last 11 trials, only the intonation differed.

Emotional prosody recognition task. Participants had to recognize the target emotional prosody of a voice from a choice of two voices (24 trials). The voices displayed either positive (happiness or surprise; 12 trials) or negative (sadness or anger; 12 trials) emotional prosodic intonations. The initial target sentence (two to six syllables) was made of words (the semantic content of which was not related to the emotional prosody), while the target and non-target sentences (four syllables) in the choice presentation were made of pseudo words. Only female voices were used. In each trial, the identities of the voices in the choice display and the target stimulus were different. Presentation order of the four emotions was pseudo-random.

Linguistic intonation recognition task (control task). Participants had to recognize a linguistic intonation (24 trials). Utterances were of sentences corresponding to questions (eight trials), commands (eight trials) or declarations (eight trials). The initial target sentence was made of words (a sentence of four syllables), which did not include any word related to the intonation (*e.g.* the question utterances did not include any question words). The sentences of the two-choice display were made of pseudo words (four syllables) and provided by

actors; the target presentation was provided by different actors. Only female voices were used. Presentation order of the three intonation conditions was pseudo-random.
Linguistic intonation and emotional prosody are both slow modulations. However, linguistic intonation, rather than emotional prosody, is more directly related to speech. We considered that if performances in the linguistic intonation task, but not in emotional intonation task, were preserved, general deficits in prosody processing could be excluded.

Data analysis

Performances in socio-perceptual and control tasks were measured by the number of trials with incorrect responses, in each condition and for each task. For each participant, this error number was transformed into a percentage of the number of trials for each task or each task condition.
A second type of approach was also used with an aim to control the dissimilar age distribution when analyzing the effect of neurological factors (side of epilepsy, brain abnormality, age-at-onset, duration of epilepsy) and the intellectual efficiency factor. Calibrated scores for socio-perceptual and control tasks were used. Each patient error percentage in a task, or task-condition, was calibrated with relevance to the error percentages of a group of eight age-matched children of the control group (16-19-year-old patients were paired to a group of 8-14-year-old control children; 19-year-old patients were paired to a group of eight young control adults). Patients calibrated error scores (*CalEr*) were computed as follows: CalEr=($\underline{x_p}$-$\underline{m_c}$/$\underline{SD_c}$); where $\underline{x_p}$ is the patient's percent error in a given task or condition task, $\underline{m_c}$ is the mean percent error of the matched control group in the same task or condition task, and $\underline{SD_c}$ is the standard deviation of the control group for the same task or condition task. The higher the positive *CalEr*, the greater was the impairment.
A *CalEr* score $\geq$+2 in a given task was considered as an atypical performance in this task. In accordance, and in order to assess the eventual relationship between socio-perceptual performances versus side of epilepsy and presence or absence of MRI-detectable brain damage, the patient performances were categorized as "typical" or "atypical".
In the BEM memory test and the subscale of the French version of the McCarthy Scales for children abilities, individual test scores were converted into calibrated scores (based on age-appropriate means and standard deviations from test norms). A score of <-2 was considered to correspond to a deficit.
Statistical analyses were performed with Statistica 10 (Statsoft). Continuously and normally distributed variables were compared using ANOVA or MANOVA (General Linear Model) with repeated measures with Greenhousse-Geisser correction for non-sphericity of measures repeated more than twice (the corrected p values are provided), and the Student's t-test, and the Chi^2 test was used for categorical variables. The Bravais-Pearson correlation was used to explore the eventual links between FSIQ and socio-perceptual performances. Spearman ρ was used to explore the eventual links between socio-perceptual performance and age at first seizure or duration of epilepsy. *P* values <0.05 were considered as statistically significant. When the group effect was significant, a two-by-two post-hoc comparison of the means was performed using Duncan's test.

Results

Group analysis

Each patient was matched with a control participant according to age. Mean percent error for the control and TLE groups for each task are presented in *table 2*. Patients scored significantly less than controls in three socio-visual tasks: *face identity recognition, emotional expression recognition, and gaze direction recognition*. No patient/control difference was found in the socio-auditory or the control-auditory tasks (see *table 2* for detailed results).
In the *face identity task*, all children (patients and controls) performed better in the "identical condition", compared to the "orientation condition" (planned comparisons: F[1,66]=51.8; *p*<0.000001), and also better in the "orientation condition" compared to the "expression condition" (F[1,66], F=6.5; *p*<0.02) (identical vs expression: F[1,66], F=67.3; *p*<0.000001).
The only condition which demonstrated a performance difference between TLE patients and the age-matched controls was the "orientation condition" (Duncan test; *p*<0.02, which was not significant for both identical and expression conditions; *p*=0.08 and *p*=0.53, respectively).
We concluded that a face recognition deficit in TLE patients, when present, is not related to the facial changes resulting from emotional expression, but rather to the changes resulting from modification of spatial orientation.

In the *facial emotion task*, TLE patients performed poorly compared to controls (*table 2*).
For all children, both TLE patients and controls, performances were globally worse for negative versus positive emotions, but not significantly worse in TLE patients, compared to controls.
Performances were better for positive compared to negative valences in the left (LVF) and the right hemi-

Table 2. Mean error percentage in each perceptual task for the control and TLE groups.

Recognition tasks	Participant n*	Mean error percent Control group	TLE group	Statistics	p
SOCIAL TASKS					
Face identity				**ANOVA** : 2 GroupX3 Condition	
Group	34	15.7	21.2	*Group effect* : F(1,66)=4.1	0.049
Face recognition conditions				*Face recognition condition effect* : F(2,132)=41.8	<.00001
Identical	34	8,0	13,9		
Orientation	34	16,8	25,4	Group X Condition : F(2,132)=1.9	>.10
Expression	34	24,3	26,5		
Gaze				**ANOVA** : 2 GroupX2 Gaze direction	
Group	33	11	18.9	*Group effect* : F(1,64)=7.2	.009
Gaze direction conditions				*Gaze direction effect* : F(1,64)=4.4	.04
Direct	33	9	16,0		
Averted	33	13	21,9	Group X Gaze direction : F(1,64)=0.4	>.10
Facial emotion				**ANOVA** : 2 GroupX2 ValenceX3 Position	
Group	33	10.6	15.2	*Group effect* : F(1,64)=4.20	.044
Position - Valence conditions				*Valence effect* : F(1,64)=32.2	<.00001
Central position - positive	33	11.1	16.8	*Position effect* : F(2,128)=0.4	>.10
Central position - negative	33	14.4	14.4		
L visual hemifield - positive	33	4.2	12.1	Group X Valence : F(1,64)=0.4	>.10
L visual hemifield - negative	33	17.5	21.5	Group X Position : F(2,128)=1	>.10
R visual hemifield - positive	33	4.4	8.1	Valence X Position : F(2,128)=16.6	<.00001
R visual hemifield - negative	33	15.9	23.8	Group X Valence X Position : F(2,128)=2,4	>.05
Voice identity				**ANOVA** : 2 GroupX3 Condition	
Group	28	10.4	14.4	*Group effect* : F(1,54)=2.5	>.10
Voice recognition conditions				*Condition effect* : F(2,108)=51.9	<.00001
Identical	28	1,5	5,1		
Different sentence	28	13,0	13,6	Group X Condition : F(2,108)=1.7	>.10
Different intonation	28	19,2	26,9		
Emotional prosody				**ANOVA** : 2 GroupX2 Valence	
Group	32	11	14,3	*Group effect : F(1,62)=2,5*	>.10
Valence conditions				*Valence effect :* F(1,62)=16.6	.00013
positive	32	13	18,5		
negative	32	8,1	10,2	Group X Valence : F(1,62)=1.1	>.10

field (RVF) (valence in LVF: F[1,64]=27.919, $p<0.00001$; in RVF: F[1,64]=39.790, $p<0.000001$). Performances did not differ for the central visual field (CVF). Performances for stimuli with a positive valence were better in the CVF than in the LVF and RVF (F[1,64]=11.732, $p<0.005$; F[1,64]=25.209, $p<0.00001$, respectively). No significant differences were recorded between the two visual fields. Similarly, performances for negative valences were better in the CVF than in the LVF and RVF (F[1,64]=6.882, $p=0.011$; F[1,64]=9.104, $p=0.004$, respectively) with no significant differences found between the two visual fields.

In the *gaze task*, patients performed significantly worse compared to controls (*table 2*). Errors were significantly more frequent in all children in the averted gaze than in the direct gaze conditions (*table 2*).

In the *voice identity* and the *emotional prosody* tasks, performances between TLE patients and control groups did not differ significantly for any of the conditions (*table 2*). In the emotional prosody task, contrary

Table 2. Mean error percentage in each perceptual task for the control and TLE groups. (*Continued*)

Recognition tasks	Participant n*	Mean error percent Control group	TLE group	Statistics	p
CONTROL TASKS					
Lip reading				Student *t* test	
Group	29	6	10.1	Group : t(1,56)=-1,7	>.05
Geometrical pattern				**ANOVA** : 2 GroupX2 Modification	
Group	32	13.6	14.8	*Group effect* : F(1,62)=0.3	>.10
Modification conditions				*Modification effect : F(1,62)=3.2*	>.05
configural	32	12.9	12.5		
local	32	14.2	17.2	Group X Modification : F(1,62)=1	>.10
Linguistic intonation				**Student *t* test** : 2 Group	
Group	27	10.2	15.7	Group : t(1,52)=-1,9	>.05

* The number of participants in each task is smaller than 39 because the 5 youngest patients and their matched control were not included in the comparison given they were presented with a shorter version of the tests. Additionaly, a few other patients were not included if they refused to complete a specific task.

to what was recorded in facial emotion tasks, errors were significantly higher for positive than for negative stimuli (*table 2*).

No significant difference was observed between the control and TLE patient groups in visual or auditory control tasks (*table 2*). Participants aged 5 years who presented with a shorter version of the tasks were not included in the group analysis, but were included in the calibrated error scores analysis.

Epilepsy and neurological substrate-related factors (analysis with calibrated scores)

No significant differences emerged between right and left-sided TLE patients in any of the eight tasks (five socio-perceptual and three control tasks) (*table 3*).

Considering a *CalEr* error score of ≥+2 as indicative of an atypical performance in at least one social task, a comparison between the LTLE and RTLE patients did not reveal a significant increase in one of the two categories. Atypical performance in at least one of the five social tasks was observed in 14/25 LTLE patients and 5/14 RTLE patients (Chi^2=1.48, df=1; $p>0.20$). Only three left-sided and none of the right-sided patients showed atypical performances in all five socio-perceptual tasks.

We found no significant correlation between the presence of MRI-detectable anatomical brain damage and a deficit in social perception. Of nine MRI-negative cases, six showed a *CalEr* score of <2 in all social tasks. Of the 30 patients with an abnormal MRI, 14 showed a *CalEr* score of <2 in all social tasks (Chi^2 Yates correction=0.45, df=1; p=0.5).

Table 3. Mean calibrated error score (*CalEr*) of right- and left-sided TLE in each perceptual task

	Mean CalEr Left-sided TLE	**Right-sided TLE**	**Student *t* test**	**ddl**	***p***
SOCIAL TASKS					
Face identity	1.4	0.5	1,1	37	>.10
Gaze	1.6	0.5	1,3	36	>.10
Face emotion expression	2.7	1.1	1,5	31	>.10
Voice identity	0.5	0.4	0,3	30	>.10
Emotional prosody	0.6	0.2	0,7	34	>.10
CONTROL TASKS					
Lip reading	0.9	0.8	0,2	32	>.10
Geometrical pattern	0.6	0,00	1,1	35	>.10
Phrastic prosody	1.3	0.4	1,1	25	>.10

Contrary to what could be expected, age at first seizure (range: from 1 month to 14 years; *table 1*) or duration of epilepsy (range: 2 months to 12 years; *table 1*) were not correlated to *CalEr* for any social task (Spearman rank correlation-first seizure: $-0.13<\rho<0.33$, all $p>0.10$; epilepsy duration: $0.06<\rho<0.32$, all $p>0.05$).

Intellectual disability and social-perceptional performances (assessed by FSIQ)

All five correlations computed between FSIQ and *CalEr* for each social task separately were found to be significant ($-0.40>R>-0.068$; $0.0000<p<0.03$): the lower the FSIQ, the worse the child's performance in a perceptual social task.

Twenty-four patients had an FSIQ score of >80 (13 LTLE), six had a score within the 70-79 range (four LTLE), and nine a score within the 47-69 range (eight LTLE). The number of low FSIQ scores (<80) in the LTLE group was not significantly greater than that of the RTLE group (FSIQ limit at 80: $Chi^2=2.7$, df=1, $p>0.10$).

The 20 patients without atypical score in any of the social tasks showed on average a higher FSIQ (mean FSIQ: 102; SD: 17; range: 55-136) when compared to the group of 19 patients with an atypical score in at least one social task (mean FSIQ: 68.5; SD: 15; range: 47-97), (t[36]=6.356, $p<0.0001$). In the group of patients with an FSIQ of ≤80, all patients with either LTLE (except for one) or RTLE obtained an atypical score in at least one social task. In the group of patients with an FSIQ ≥80, four of 13 patients with LTLE and two of the 11 RTLE patients obtained an atypical score in at least one social task.

Six of the 23 patients with a typical FSIQ, of between 84 and 136, showed a *CalEr* score ≥+2 in one or more social tasks. Among these six patients, four (FSIQ: 88, 92, 98, and 127) showed a deficit in only one of the five social tasks (two in face identity, one in voice identity and one in emotional prosody), one (FSIQ: 90) showed a severe deficit in two social tasks (face identity, facial emotion), and one (FSIQ: 84) a severe deficit in all three socio-visual tasks. These six patients showed good to average scores in several other social tasks (range of *CalEr*: -2.4 to +1.3) and/or corresponding control tasks (range of *CalEr*: -1.4 to +1.6) (see *figure 1a*).

Among the six patients with an FSIQ situated within a range of 70 to 75, one patient did not perform the auditory tasks but scored typically in all three socio-visual tasks. Three other patients had a deficit in only one of the five social tasks (one in gaze and two in emotional prosody) and two patients presented with a deficit in two of the five social tasks (one in facial emotion and voice identity and one in facial emotion and gaze). All six patients had a *CalEr* score of <2 in

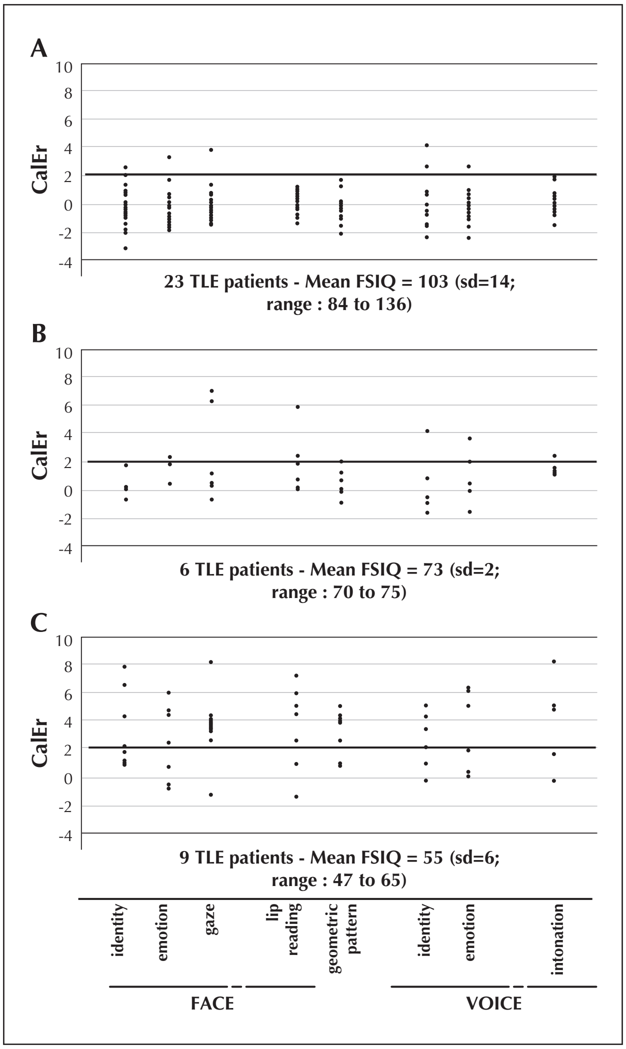

Figure 1. Distribution of the patients' Calibrated Error score around M = 0 (mean error score of each control group = 0) for each perceptual task according to the 3 FSIQ range. A *CalEr* score ≥+2 (horizontal line in Bold) in a given task was considered as an atypical performance in this task.
(A) 23 TLE patients with typical intellectual efficiency.
(B) 6 TLE patients with mild mental retardation.
(C) 9 TLE patients with moderate mental retardation.

at least one other social task in the same modality as their atypical performance. All six also scored typically in the control tasks corresponding to their atypical performance. The average *CalEr* for the preserved social tasks for these six patients was 0.17 (range: -1.6 to 1.8) and for the control tasks was 0.86 (range: -0.2 to 1.9). *Figure 1b* shows that in a number of cases, scores were generally closer to the control mean (*M*=0) than to the deficiency *CalEr* limit.

Among the nine patients with an FSIQ of between 47 and 65, only one patient performed within the typical range in all five social tasks, while three obtained poor scores in all five social tasks. From the remaining five patients, typical results were obtained by: one patient in four of five tasks (one atypical score gaze), one patient in two of five tasks (atypical score in the three socio-visual tasks), one patient in two of four tasks (the voice identity task was not performed), one patient in two of three tasks (auditory tasks were not performed), and one patient in one of five tasks (typical score in emotional prosody).

Two of the three TLE patients who failed all tasks also had poor scores in all control tasks. In the third patient, performances in the two visual control tasks, but not in the auditory control task, were preserved. The average *CalEr* for the preserved social tasks for the six patients was 0.43 (range: -1.3 to 1.9) and for the control tasks was 0.5 (range: -1.4 to 1.2). *Figure 1c* demonstrates that in many tasks, scores were mostly within the range corresponding to a good performance, suggesting a preserved domain in six of the nine patients with an intellectual deficit.

Memory skills and socio-perceptual performances

Among the 30 patients with typical or >70 FSIQ, we found only three children with a deficient memory score; two (typical FSIQ) in immediate visual memory and one (>70 FSIQ) in immediate auditory memory. None of them showed a deficient *CalEr* in any of the socio-perceptual tasks.

Among the nine patients with <70 FSIQ, two patients did not show a deficiency in the four memory tasks but both obtained a deficiency score in all socio-perceptual tasks. Among the remaining seven TLE patients, two failed in all four memory tasks, one failed in all five socio-perceptual tasks and one failed in only one task (gaze) with good scores in the other tasks. In one child, only the auditory immediate memory task was preserved, while only the facial emotion task was severely deficient despite good scores in the other tasks. For each of the four other patients, some memory and some socio-perceptual tasks were preserved.

Relationship between performances in socio-perceptual tasks (*CalEr*)

CalEr scores in identity or emotion tasks did not differ according to perceptual modality (identity tasks: face vs voice: t[27]: 0.849, $p>0.10$; emotion tasks: face vs voice: t[31]: 0.006, $p>0.10$).

Atypical *CalEr* scores in socio-auditory tasks were obtained less frequently than those in socio-visual tasks (identity: face vs voice: $chi^2=0.67$, df=1, $p>0.10$; emotion: face vs voice: $chi^2=1.01$, df=1, $p>0.10$). These differences were not significant.

Only three patients showed a deficient *CalEr* in all socio-perceptual tasks.

Discussion

We investigated socio-perceptual skills in a prospectively identified group of children or adolescents with unilateral TLE, assessed early in the course of the disorder.

Social perception performances: patients versus controls

In response to our tasks, patients with TLE, as a group, when compared to the control group, showed significantly lower performances in recognition of facial identity, direction of eye gaze, and emotional facial expressions, but not in auditory social perception.

In agreement with other studies (Mabbott and Smith, 2003; Taylor *et al.*, 2008), facial identity recognition proved to be largely impaired. We also demonstrated a clear deficit in face identity recognition under the "orientation condition", which precludes using a general non-specific strategy for matching two visual patterns and requires configural face processing. Our findings also exclude the assumption that a face recognition deficit results only from a deficit in facial emotion recognition.

It is possible that perception of different facial emotions does not follow the same timetable during development and might be differently affected in TLE during childhood (Todd *et al.*, 2011). However, a deficit in recognition of negative emotions (specifically fear), but not positive emotions, is frequently observed in TLE children (Golouboff *et al.*, 2008) and adults (Meletti *et al.*, 2003; Reynders *et al.*, 2005; Batut *et al.*, 2006; McClelland *et al.*, 2006). The emotional face stimuli used in our study were not the same as in other studies (fearful expressions were not included in our study). In addition, the tasks we applied did not use labelling, but non-verbal recognition. The deficits in emotion recognition in our patients were independent of emotional valence.

A deficit in gaze direction perception was also found to be impaired. This skill is known to be impaired in ASD children (Zilbovicius *et al.*, 2006), but not yet documented in TLE patients.

Performance preservation of lip reading and geometric pattern recognition control tasks, together with a deficit in facial emotion perception and other socio-visual perceptual skills, as shown by our *CalEr* analysis, supports the assumption that in some children with TLE the deficit is neither restricted to emotion perception, nor part of a general visuo-perceptual impairment. It rather affects, more specifically, basic perceptual social skills.

As a group, TLE patients did not differ significantly from control children in socio-auditory perceptual tasks.

Nevertheless, we also found no difference in patients' *CalEr* scores for auditory and visual identity or for auditory and visual emotion tasks. This lack of difference can be interpreted in various ways, however, the number of patients who presented with auditory tasks was smaller than that for visual tasks.

Social perception, intellectual disability, and memory deficit

The issue of an eventual link between a deficit in intellectual resources and a deficit in socioperceptual skills is crucial, as it is often assumed that poor performances in socio-perceptual tasks are a mere consequence of poor intellectual resources.

To discuss such an issue, it is also necessary to disentangle the effect of poor intellectual efficiency in development of social cue perception from the possible difficultly in coping with the structure of our perceptual tasks encountered by children with intellectual deficiency.

Our results confirm that FSIQ significantly correlates with *CalEr* scores in each social task, showing that the lower the FSIQ value, the greater the probability of a poor performance in a social task. However, our results clearly show that some patients may have a low FSIQ and no socio-perceptual deficit while, in other cases, a socio-perceptual deficit may be present despite a high FSIQ.

Furthermore, the majority of those with both a low FSIQ and the presence of a social deficit did not fail in all social tasks, demonstrating that while some socio-perceptual competences are affected, others may be preserved. If a deficit was due to a difficulty in coping with the task structure itself rather than a lack of socio-perceptual expertise, most probably this would have resulted in failure of more than one task. Based on our results, we conclude that despite an existing relationship between FSIQ and the presence or absence of perceptual social deficits, a low FSIQ is neither a prerequisite nor *per se* sufficient for the development of impaired social perception in TLE.

From the immediate and delayed recall tasks for spoken words or visual signs, our results also demonstrate that, in patients with TLE, there is no systematic correlation between episodic memory and socio-perceptual atypical performance. As for FSIQ, the effect of memory and attentional concentration deficit cannot be considered as the unique source of atypical scores in socio-perceptual tasks.

The preservation of lip reading skills and geometric pattern recognition in more than half of our patients with a facial socio-perceptual deficit indicates that disturbances in social perception cannot be explained by a deficit in more general visual pattern processing. Similarly, the preservation of linguistic intonation processing in most patients with socio-vocal processing atypical performance indicates that the presence of a socio-vocal deficit does not result from a general vocal or linguistic deficit.

In summary, it was found that:

– not all children with an intellectual deficit show impaired performances;

– children with intellectual deficit may show a deficit in only some of the social tasks;

– children with typical intellectual level may show a deficit in only part of the social tasks presented.

We support that socio-perceptual deficits should be seen as dissociable elements of cognitive impairment. In other words, the probability of socio-perceptual deficit might be the same for all TLE patients, whether they have a high or low FSIQ. However, children with a low FSIQ, compared to children with a high FSIQ, would have more difficulty in building an efficient compensatory strategy to cope with perceptual social cues.

Epilepsy-related factors

We found no significant correlation between age at onset or duration of epilepsy and atypical performance (*CalEr*), regarding the different social perceptual tasks. Such a result is rather surprising given that some relationship between severity of deficit and age at onset is documented in three studies with children (Hermann *et al.*, 2002; Mabbott and Smith, 2003; Golouboff *et al.*, 2008). We were unable to provide an evidence-based explanation for such a difference. The fact that in these three studies a relationship with age at onset was not observed for all tasks or conditions evaluated could eventually provide, if not an explanation, a basis for further discussion and research.

No significant correlation was found between atypical performance in perceptual social tasks and lateralization of focus or presence of MRI-detectable brain damage.

According to our findings, it appears that the pattern of socio-perceptual deficit is relatively variable across children and adolescents with TLE.

First, we showed that a socio-visual competence can be impaired without the auditory counterpart being affected, and *vice-versa*. This finding is not in agreement with results from adults with mesial TLE (Bonora *et al.*, 2011). However, in the study of Bonora *et al.* (2011), the mean age at onset of epilepsy for patients with both face and voice emotional recognition deficits was 10 years, whereas in our sample it was 3 years.

Second, deficits may affect the processing of emotional facial expression or prosody, face or voice identity, and gaze direction, independently. Dissociation between deficits in different emotion labelling tasks (fear, disgust, and happiness) has already been documented in the literature. Different sites of TLE focus (right *vs* left, anterior *vs* temporo-mesial) are related to a deficit in recognition or labelling of different emotions (Meletti *et al.*, 2003, Batut *et al.*, 2006; Golouboff *et al.*, 2008).

Our results support the possibility of dissociation between auditory and visual modality for perception of the same emotional expression, as well as dissociation between several socio-perceptual recognition skills within the same perceptual modality.

Conclusions

Our results confirm the presence of deficits in facial emotion and identity recognition in children with TLE, and demonstrate the existence of a deficit in gaze direction recognition. Impairment can affect different socio-perceptual skills independently. Socio-perceptual deficits should be seen as a genuine feature of TLE, and not as a simple consequence of an intellectual deficit, when present. In particular, a low FSIQ does not preclude typical social perceptual development.

Furthermore, our results support recently published guidelines suggesting that further investigation of the correlates of specific cognitive deficits and their structural, functional and connectivity-related patterns of underlying neurobiological abnormality, as well as development over time, would help us understand the mechanisms of these disorders (Hermann *et al.*, 2012).

From a clinical care perspective, it should be underscored that deficits in the social perceptual domain persist despite many years of relevant stimulation by the environment. Attempts for early recognition in everyday clinical practice unfortunately remain the exception. As a result, no attempt is made to rescue these deficits and re-education programs aimed at treating children with deficits in social cue processing are also rarely undertaken.

Behavioural interventions on perception of social cues might help children with TLE to develop social competences thus limiting associated disability. Atypical perceptual recognition of social cues might result in atypical social behaviour. It would be unwise to consider atypical perceptual learning of social cues as the only causal factor of abnormal social functioning in TLE.

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