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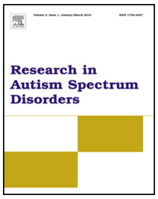

Recognizing syntactic errors in Chinese and English sentences: Brain electrical activity in Asperger's syndrome

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ABSTRACT

This study investigates electroencephalographic (EEG) oscillatory activity in the brain for bilingual participants with Asperger's syndrome (AS) and bilingual healthy control participants during visual recognition of syntactic errors in traditional Mandarin Chinese (native) and English (foreign) sentences. Reading performance is similar for the two groups in both languages. While reading Mandarin Chinese, the control group showed a left-hemispheric specialization within the 400–600 ms interval in delta synchronization. However, delta synchronizations were widely distributed in all scalp regions and lasted longer than 600 ms in the AS group. One possible interpretation of our data is the hypothesis that the AS group has more difficulty in brain organization of semantic and syntactic processes than the control group when reading their native language, because Chinese syntactic structure requires more work to be done by the perceiver. Nevertheless, other brain mechanisms (e.g., top-down regulation), can partially compensate for this difficulty, allowing AS subjects to attain the same level of response activity as the controls.

1. Introduction

Asperger's Syndrome (AS) was initially defined by Austrian psychiatrist Hans Asperger (cf. Asperger, 1994) to be an autism spectrum disorder in both behavioral and mental levels, with major difficulty in social communication. Examining the medical literature, there are numerous research paradigms focusing on the AS disorder, including physiological factors and possible treatments (American Psychiatric Association, 2000; Attwood, 2008; Fombonne, 2003; Klin, Volkmar, & Sparrow, 2000; Matson, Kozlowski, Hattier, Horovitz, & Sipes, 2012; Saracino, Noseworthy, Steiman, Reisinger, & Fombonne, 2010). The disorder appears in the first three years of life, and is more frequently observed in males than in females (Baron-Cohen et al., 2011). In clinical assessment, AS subjects demonstrate functional disorders in visual and phonological related perceptions (Jansson-Verkasalo et al., 2003; Saalasti, Tiippana, Katsyri, & Sams, 2011), and have problems of movement coordination and body position maintenance. When communicating verbally with others, they have essential difficulties in recognition of others' intentions and in expression of their own emotional states. According to Duverger, Da Fonseca, Bailly, and Deruelle (2007), AS children often experience failure to recognize emotional situations portrayed in pictures. On the

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other hand, their cognitive profiles show high verbal intelligence and normal linguistic ability with regard to syntax and semantics in speech recognition (Attwood, 2008; Klin et al., 2000). According to the ICD-10 criteria Asperger's syndrome differs from the non-specified autism spectrum disorder primarily in the fact that there is no general delay or retardation in language or in cognitive development.

It is possible to note that AS individuals can be worse in some mental abilities but better in others as compared with healthy controls (O'Connor & Kirk, 2008). Many AS adults are very successful in professional skills requiring a high intellectual ability, but involving relatively less inter-personal communication (Church, Alisanski, & Amanullah, 2000; Griswold, Barnhill, Myles, Hagiwara, & Simpson, 2002; Howlin & Yates, 1999). AS individuals who keep a normal level of cognitive development can partially compensate for syndrome-related behavioral disturbances through attention regulation. While AS children and adolescents occasionally exhibit aggressive behavior against peers and parents, for example, AS adults can use a mindfulness-based procedure to effectively control their aggressive tendencies to achieve a considerable amount of social success regardless of their perceptive and communicative deficits (Singh et al., 2011).

Neurophysiological studies on the disorder have primarily focused on its biological causes in the nervous system using modern neuroimaging techniques. For instance, structural and functional magnetic resonance imaging (fMRI) studies have shown that the disorder is accompanied by a decrease in volume size and hemodynamic responses in the amygdala, hippocampus (Dziobek, Fleck, Rogers, Wolf, & Convit, 2006; Murphy et al., 2012; Nacewicz et al., 2006; Schumann et al., 2004; Via, Radua, Cardoner, Happé, & Mataix-Cols, 2011; Williams et al., 2006) and thalamus (Baron-Cohen et al., 2006; Egawa et al., 2011; Hardan et al., 2006, 2008), and by a connectivity failure in the cortical-subcortical networks (Di Martino et al., 2011; Ecker et al., 2012; Langen et al., 2012; Williams, 2008). It is well known that AS children have difficulty recognizing vocal intonation, resulting in social communication problems (Kujala, Lepisto, Nieminen-von Wendt, Naatanen, & Naatanen, 2005). Functional MRI research indicates that AS deficits in perception in general and in identification of emotional faces in particular can be attributed to structural abnormality in the subcortical structure such as the amygdala and thalamus, which further deteriorate cortical-subcortical interactions (Aylward et al., 1999; Kleinhans et al., 2011; McAlonan et al., 2008; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Salmond, de Haan, Friston, Gadian, & Vargha-Khadem, 2003).

While fMRI offers excellent spatial resolution for localizing brain regions activated during experiments, execution of tasks may engage real-time functional processes, which cannot be easily identified without tools of sufficient temporal resolution. Recently, there has emerged a research interest in neural correlates of AS using electro/magneto-encephalography (EEG or MEG) techniques, which assist the investigation of temporary dynamics of cognitive processes with reasonable accuracy (Lewine et al., 1999; Yang, Savostyanov, Tsai, & Liou, 2011; Yasuhara, 2010). These studies have used various experimental paradigms, namely resting-state (Barttfeld et al., 2011; Murias, Webb, Greenson, & Dawson, 2007), visual stimulus recognition (Milne, Scope, Pascalis, Buckley, & Makeig, 2009), speech recognition (Pijnacker, Geurts, van Lambalgen, Buitelaar, & Hagoort, 2010), face recognition (O'Connor & Kirk, 2008; Yang et al., 2011) and different sleep states (Lazar et al., 2010). AS subjects in general show atypical EEG reactions in visual perception (Milne et al., 2009), and tend to engage greater amplitudes in event-related potentials (ERPs) than healthy controls under stressful situations (Tiinanen et al., 2011). Although AS has been well studied by use of EEG paradigms, the isolated research findings do not serve an integrated support for interpreting behavioral disorders in terms of atypical brain oscillations. There is also a lack of knowledge on the compensatory mechanisms that assist AS adults in achieving a high level of success in cognitive performance.

High-level cognitive control is a self-regulation ability modulated by attention to important details in the environment. Cognitive controls are typically associated with top-down activity from the prefrontal cortex to other cortical and subcortical regions (Forstmann, van den Wildenberg, & Ridderinkhof, 2008; Koechlin, Ody, & Kouneiher, 2003; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). In EEG studies, electrographic responses in the frontal and anterior temporal cortical regions reflect top-down brain activity associated with high-level cognitive controls, whereas responses in occipital-parietal regions are more related to sensory bottom-up processes (Näätänen, 1992). Top-down cognitive controls are also included in stimulus recognition during language processing (Yvert, Perrone-Bertolotti, Baciu, & David, 2012). The recognition of written speech includes both top-down and bottom-up processes, as indicated by different ERP peaks or fMRI blood oxygen level-dependent (BOLD) responses. It was shown that the left inferior prefrontal cortex (LIPC) is involved in top-down control in language comprehension, and its activation level is correlated with task difficulty in word and sentence recognition (Mishra, 2009; Hirschfeld & Zwitserlood, 2011; Whitney, Grossman, & Kircher, 2009). A fMRI study on brain transfer effects also suggested that language training may modulate brain activity in the fronto-parietal regions involved in the top-down regulation of auditory functions (Elmer, Meyer, Marrama, & Jäncke, 2011). Clinical studies have suggested that some neurological and psychiatric disorders in stimulus recognition can be compensated for by strengthening top-down controls (Clement & Belleville, 2010; Rabinovich, Afraimovich, Bick, & Varona, 2012; Woodard et al., 2009); that is, patients suffering disorders in bottom-up processes can demonstrate almost normal behaviors by strengthening top-down cognitive controls. For example, an age-related decline in sensory functions in elderly people can be compensated for by strengthening top-down activity in language comprehension (Wingfield & Grossman, 2006). It seems that the language organization in the AS brain differs in some aspects from that in the brains of healthy controls. As mentioned, AS children have gross violations in diction and phonological perception (Jansson-Verkasalo et al., 2003; Saalasti et al., 2011), but AS adults are able to improve their linguistic skills, using speech communication effectively. We hypothesize that AS adults with the compensated disorder (e.g., high response accuracy in language tasks) will demonstrate an increase in the brain electrical activity that reflects top-down control in language comprehension tasks.

Since the work by Broca and Wernicke in the 19th century, information processing in speech recognition has been studied in many experimental paradigms. These studies suggest that speech perception sequentially engages a variety of functional structures in an organized fashion in temporal sequence (Dick et al., 2005; Fischer, Bernstein, & Immordino-Yang, 2007; Stiles, Bates, Thal, Trauner, & Reilly, 2002; Tallal, 1980; Thal et al., 1991). During sentence reading, for example, the periods of phonologic (150–300 ms after stimulus onset), semantic (about 400 ms) and syntactic (600–800 ms) recognitions are distributed in successive time intervals, each specialized in different brain regions (Hagoort, 2003; Hagoort, Wassenaar, & Brown, 2003; Kuperberg, 2007; Bastiaansen & Hagoort, 2006). Some studies also distinguish the time periods as the early stage of syntactic and semantic recognition and late stage of syntactic recognition (Friederici, 2004). In this study, we compare EEG oscillatory activity along with ERPs between AS and control subjects in visual recognition of syntactic errors in Mandarin Chinese and English sentences. We hypothesize that a part of the brain function linked to speech recognition will be more pronounced in AS subjects than in healthy controls, suggesting a compensatory mechanism for functional disorders.

It is well known that perception of native and foreign languages can differ to a large degree even in healthy controls (Friedrich, Herold, & Friederici, 2009; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012; Rossi, Gugler, Friederici, & Hahne, 2006; Rüschemeyer, Zysset, & Friederici, 2006). In clinical assessment, functional disorders in the brain can affect linguistic ability in one language without disturbing proficiency in another language (Avila, González, Parcet, & Belloch, 2004; Heinemann & Assion, 1996; Vygotsky, 1993). The Chinese and English languages belong to different linguistic groups and have considerable discrepancies in syntactic structures. In EEG studies with healthy controls, it has been suggested that ERP peaks during recognition of Chinese words and sentences can essentially differ from those during recognition of European languages (Yang et al., 2011; Ye, Luo, Friederici, & Zhou, 2006). It is reasonably assumed that perception of the two languages would differ not only in AS subjects, but also in healthy controls. The language tasks considered in this study include native (Mandarin Chinese) and foreign (English) languages and participants are all native Mandarin Chinese speakers living continuously in Taiwan. The experimental design also permits evaluation of oscillatory activities for the healthy controls in both languages.

In summary, this study is intended to search for differences in EEG oscillatory activity along with ERPs in AS subjects and healthy controls during visual recognition of syntactic errors in Mandarin Chinese and English sentences. In the next section, we detail the experimental protocol, data processing and analysis methods employed. The results are presented by mainly comparing differences in the ERPs and oscillatory activity between Mandarin Chinese and English languages in healthy controls, and in visual recognition of syntactic errors between AS subjects and healthy controls. The oscillatory activity for AS individuals also suggests more top-down processes during reading than is found in control subjects. Finally, we discuss the implications of the experimental findings in this study and suggest a few directions for future research on AS.

2. Methods

2.1. Subjects

Twenty-one right-handed neurologically normal adults (age 24.6 ± 2.91; 11 male), and ten adults with Asperger's syndrome (age 19.2 ± 1.79; 8 males) participated in this study. Diagnosis of AS was carried out by psychiatrists on the basis of Gillberg (1991) and DSM-IV criteria (American Psychiatric Association, 2000) and was also confirmed by the ICD-10 criteria. The diagnostic scales included social inference, emotional communication, language and cognitive abilities and motor coordination skills. All AS subjects were recruited from the National Taiwan University Hospital and the Taipei City Hospital. One of the participants with AS was left-handed, and the others were right-handed. Four of the AS subjects reported to be hypersensitive to foods, sounds or touch. Eight of the AS subjects never used any pharmacological medicine for therapy of their syndromes before the experiment. The other two were under medication for at least 2 years before the experiment (one took Trazodone and Bupropion, and one had been taking MgO, Metoclopramide, Buspirone, Sibelium, Methylphenidate and vasoconstrictors). One of the medicated subjects was off medication for 6 months before the experiment. None of the participants had a history of speech and language disorders or the comorbid psychiatric disorder.

All participants were native speakers of Mandarin Chinese with basic knowledge of English; none of the participants was a professional linguist. The control and AS groups differ slightly in age and educational background. All participants gave informed written consent prior to the experiment that satisfied the requirements of the human subject research ethics committee/IRB (Institutional Review Board) at Academia Sinica, Taiwan.

2.2. Experimental task and procedure

More than 400 draft Chinese/English sentences were pretested on 50 participants (25 males, age 27.14 ± 2.91). None of those pretested subjects was a language professional, nor was later recruited in the EEG experiment. A cognitive interview protocol was included in the pretesting phase. Each of the 50 participants was interviewed regarding the semantic meanings of the draft sentences, after s/he responded to all draft sentences by indicating if there were syntactic errors in these sentences. The final sentences selected in the EEG experiments had clear semantic meanings, at least 80% response accuracy, and small variations in reaction times among the pretesting participants. In the EEG experiment, there were 60 out of 120 Mandarin Chinese sentences with syntactic errors, and 60 out of 120 English sentences with syntactic errors. A few examples of the experimental sentences in the language tasks are given as follows:

眾人的祝福給他力量的無限.. (incorrect)
這位老翁有著慈祥的笑容.. (correct)
The girl is not mine sister. (incorrect)
He does not know my name. (correct)

During the experiment, each subject was seated comfortably in a chair with eyes open in a sound insulated dimly lit chamber. The sentences were presented in black and white (15 cm × 15 cm) via a 24.4 cm × 18.3 cm monitor located 60 cm in front of the participant. After about 12 min of spontaneous EEG registration, they were instructed to verify whether a sentence presented contained a syntactic error. A fixation cross appeared at the center of the screen for 0.5 s before the task onset, followed by a stimulus presented for 4 s, and subjects were instructed to complete the evaluation as quickly as possible. Correct and incorrect sentences were presented randomly, and inter-stimulus-interval varied between 4 and 7 s.

2.3. *EEG record and data processing*

EEGs were recorded using 132-channels (122 EEG, VEOG, HEOG, EKG, EMG, and 6 face muscles channels) via Ag/AgCl electrodes. The EEG electrodes were placed on 122 head sites according to the extended International 10–10 system and referred to Cz with ground at FzA. The Quik-Cap128 NSL was used for electrode fixation. Electrode resistance was maintained below 5 kΩ. The signals were amplified using "Neuroscan (USA)" amplifiers, with 0.1–100 Hz analog bandpass filtering and digitized at 1000 Hz. To assess a difference in evoked potentials and spectral power in Mandarin Chinese and English sentences between groups, event-related potentials (ERPs) and event-related spectral perturbations (ERSPs) were computed using the EEGLAB toolbox (Delorme & Makeig, 2004).

The wavelet transformation using the Morlet wavelet was applied to time-frequency representation of EEG time series. On-going EEGs from −1.6 to +2.0 s before and after the stimulus onset were selected for data analysis. EEGs from −1.6 to −0.85 s before the stimulus onset were selected as the baseline EEGs for correcting ERPs and ERSP in statistical analysis. Artifacts resulting from eye movements, blinks, muscle noise, and line noise were estimated by independent component analysis (ICA) (Makeig, Bell, Jung, & Sejnowski, 1996). A separation of brain activity from artifacts was performed by an automatic approach based on the reference signals in the VEOG, HEOG, and EKG channels. A significantly high multiple correlation ($R^2 > 0.9$) between the ICA scores and these reference signals indicated that the particular ICA component was mainly contributed by artifacts and should be excluded from further analysis. For each subject, 10–15 components were identified as artifacts and removed from EEGs. After the ICA preprocessing, ERSP-indices were computed for each channel, subject and experimental task, respectively. The window size used was 512 samples (512 ms) for the lowest frequency. In all, 189 frequencies were displayed from 1.0 Hz to 44.9 Hz.

Before averaging ERPs and ERSPs across channels, we partitioned scalp channels into eleven regions: left- (10 channels), midline- (11), and right-frontal (10); left- (17) and right-temporal (17); left- (9), midline- (9) and right-central (9); left- (9), midline- (12) and right-occipital parietal (9). ERPs and ERSPs were averaged across channels within each region for each individual participant. For each time-frequency interval, repeated measures MANOVA was applied to testing the main effects of the language (Chinese vs. English), region (eleven scalp regions), and group (AS vs. control) as well as the interaction effects among language, region, and group. In the statistical analysis, we also considered gender (male vs. female) as a covariate, and all the main and interaction effects were already controlled for gender differences. In the MANOVA layout, participants had repeated ERSP measures on the two languages across the eleven regions. The ERSP measures at the eleven regions were nested within the two languages. MANOVA assumes multivariate normality and an equal covariance matrix (among the eleven regions) across the AS and control groups. In general, the test is robust to departure from multivariate normality especially in larger sample sizes and balanced cases (equal sample sizes in different groups). Deviation from normality could make the test more conservative (i.e., less likely to see significant differences between groups). The ERSPs in our analysis were those averaged across channels and time intervals, the normality assumption would be retained by the central limit theorem. However, the homogeneity of covariance matrices could easily be violated because the AS group had larger variances in general. In MANOVA, the Pillai's trace criterion is known to be more robust to violation of the homogeneity of covariance matrices assumption as compared with the Wilks' lambda. But the sampling distributions of these criteria are not well understood, and commonly converted to approximate F-ratio statistic (Tabachnick & Fidell, 1996). Wilks' and Pillai's criteria produce identical F tests when there are only two groups (i.e., AS vs. control groups).

3. Results

3.1. *Behavioral data*

The average reaction times of the Chinese task are, respectively, 2159.62 ± 499.23 ms in the control group and 2669.40 ± 1034.36 ms in the AS group. The average reaction times of the English task are, respectively, 2656.67 ± 852.19 ms in the control group and 3655.10 ± 1724.50 ms in the AS group. There is a significant difference between the two groups on the English task ($p < 0.038$), but not on the Chinese task. Participants spent more time on the English task than on the Chinese task. The average response accuracy of the Chinese task is 0.93 ± 0.15 in the control group, and 0.96 ± 0.04 in the AS group. The average response accuracy of the English task is 0.92 ± 0.15 in the control group, and is 0.85 ± 0.12 in the AS group. Response accuracy for the two language tasks does not differ significantly between the two groups.

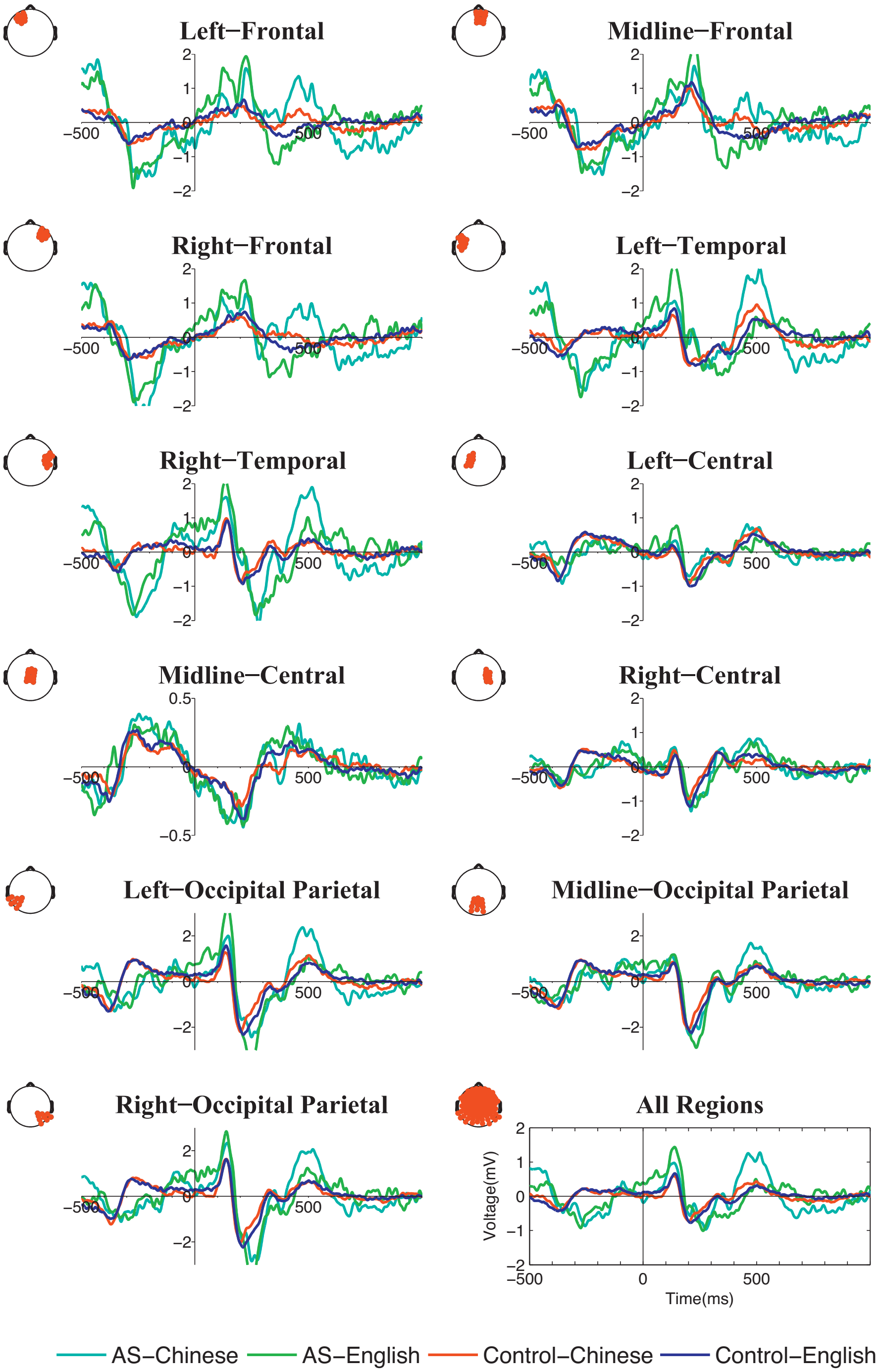

Fig. 1. The baseline corrected ERPs for the Chinese and English tasks at the eleven scalp regions, along with the averaged ERPs across all regions, in the control and AS groups. The baseline was the average ERPs in the −1600 ms to −850 ms interval before the stimulus onset. The baseline was examined for every subject by the phase-randomization test on the ERSPs supported by EEGLAB to make sure that there was no task related reaction during this time interval. The locations of EEG electrodes corresponding to each region are plotted on top of the left-hand side of each ERP plot.

3.2. ERPs results

Fig. 1 plots the baseline corrected ERPs for different scalp regions, and averaged ERPs across all regions for the two groups in the two language tasks. Table 1 shows the MANOVA results on the main interaction effects for the two groups, two language tasks and eleven scalp regions for different time intervals. As mentioned, the participant gender was considered as a covariate, and Table 1 only reports those significant results after controlling for the gender difference. With the Bonferroni correction for multiple comparisons, the post hoc test on marginal means in the −500 to −400 ms interval suggests that the control group has significant ERP increases in the frontal regions and significant ERP decreases in the occipital-parietal regions on both language tasks. This finding is consistent with the fMRI results which have indicated increased BOLD responses in the frontal regions and decreased responses in the posterior-parietal regions during the central eye-fixation period (e.g., Liou et al., 2012). The AS group, on the other hand, has significant ERP increases for both tasks in the frontal and temporal regions, but there is a lack of ERP decrease in the occipital-parietal regions. In the AS group, the magnitude of ERP increases in the frontal regions is much greater during the Chinese task compared to that during the English task. In the −300 to −100 ms interval, the control group has ERP decreases in the frontal and ERP increases in the occipital-parietal regions. The AS group has ERP decreases in the frontal and temporal regions, and there is a lack of ERP increases in the occipital-parietal regions.

In the 100–200 ms interval after the stimulus onset, language, region and their interactions are significant. The post hoc test suggests that the ERP increase is more pronounced in the right temporal and right occipital-parietal regions during both tasks, but the ERP increases additionally involve the left occipital-parietal region during the English task. In the 200–300 ms

Table 1
The MANOVA results on ERPs and ERSPs computed for the two language tasks at different time intervals in milliseconds. The main effects include group (GRP), language (LNG), and region (RGN), and the interaction effects include language × group, region × group, region × language, and region × language × group, respectively. The listed F values are those smaller than $\alpha = 0.05$.

Intervals (ms)	GRP	LNG	RGN	LNG × GRP	RGN × GRP	LNG × RGN	LNG × RGN × GRP
Event-related potentials							
[−500 to −400]	$F1,27 = 12.71$ $p = 0.001$	$F1,27 = 16.42$ $p < 0.001$	$F10,18 = 6.90$ $p < 0.001$	$F1,27 = 7.88$ $p = 0.009$	$F10,18 = 2.93$ $p = 0.023$	$F10,18 = 2.48$ $p = 0.045$	
[−300 to −200]	$F1,27 = 7.97$ $p = 0.009$		$F10,18 = 12.46$ $p < 0.001$				
[100–200]		$F1,27 = 5.21$ $p = 0.031$	$F10,18 = 6.55$ $p < 0.001$			$F10,18 = 3.37$ $p = 0.012$	
[200–300]			$F10,18 = 8.37$ $p < 0.001$			$F10,18 = 2.89$ $p = 0.024$	
[300–400]		$F1,27 = 9.78$ $p = .004$	$F10,18 = 6.35$ $p < 0.001$			$F10,18 = 3.00$ $p = 0.020$	
[400–600]	$F1,27 = 5.34$ $p = 0.029$	$F1,27 = 20.78$ $p < 0.001$	$F10,18 = 4.73$ $p = 0.002$	$F1,27 = 11.32$ $p = 0.002$		$F10,18 = 4.28$ $p = 0.004$	
Event-related spectral perturbations (1–4 Hz)							
[100–300]			$F10,18 = 3.63$ $p = 0.008$			$F10,18 = 3.25$ $p = 0.014$	
[400–600]		$F1,27 = 81.60$ $P < .001$	$F10,18 = 3.84$ $p = 0.006$	$F1,27 = 6.20$ $p = 0.019$			
[600–800]	$F1,27 = 4.82$ $p = 0.037$	$F1,27 = 23.37$ $p < .001$	$F10,18 = 5.30$ $p = 0.001$				
Event-related spectral perturbations (4–8 Hz)							
[100–300]	$F1,27 = 5.37$						$F10,18 = 2.69$ $p = 0.033$
[400–600]	$F1,27 = 6.16$ $p = 0.020$	$F1,27 = 14.29$ $p = .001$					
[600–800]	$F1,27 = 7.91$ $p = 0.009$	$F1,27 = 4.60$ $p = .041$					
Event-related spectral perturbations (8–12 Hz)							
[300–1000]	$F1,27 = 6.38$ $p = 0.018$		$F10,18 = 3.51$ $p = 0.010$				
Event-related spectral perturbations (12–16 Hz)							
[300–1000]			$F10,18 = 4.42$ $p = 0.003$				
Event-related spectral perturbations (16–20 Hz)							
[300–1000]			$F10,18 = 5.32$ $p = 0.001$				
Event-related spectral perturbations (20–25 Hz)							
[300–1000]			$F10,18 = 3.76$ $p = 0.007$				

interval, both groups have ERP increases in the frontal regions and decreases in the occipital-parietal regions, but these ERP increases and decreases are more pronounced during the English task. In the 300–400 ms interval, the language, regions, and language by region interactions are significant. The post hoc test suggests that the AS group shows ERP increases in the frontal regions during the Chinese task, but not during the English task. The control group has no significant ERP activities in this time interval. In the 400–600 ms interval, all the main effects and the language by group and language by region effects are statistically significant, which together suggest that this time interval can mostly distinguish functional differences between groups, between languages and among scalp regions. The post hoc test indicates that the Chinese task involves significant ERP increases in all scalp regions except for the midline and right frontal regions within this time interval, but the English task involves significant ERP decreases in the frontal regions and increases in the central and occipital-parietal regions. The AS group shows much stronger ERP increases in the temporal and occipital-parietal regions during the Chinese task, and has similar ERP activities as the control group during the English task.

In summary, the AS group shows significant frontal and temporal ERP increases, and the control group shows significant frontal increases and occipital-parietal decreases during the central eye-fixation period. In early stimulus detection, the English task involves more frontal, temporal and occipital-parietal (left and right) ERP increases and has similar patterns for both control and AS groups. The Chinese task shows similar frontal and temporal activities, but has smaller amplitude than the English task. In the 200–300 ms interval, both tasks and both groups have the fewest differences in their ERP activities, that is, significant frontal increases accompanied by significant occipital-parietal decreases during both tasks in both groups. In the 300–400 ms interval, none of the tasks and groups shows significant ERP activity, except for the significant frontal increases in the AS group during the Chinese task. ERP activity in the 400–600 ms interval primarily distinguishes differences between tasks and between groups. Within this time interval, the control group shows left hemisphere specialization (especially in the left temporal, left central and left occipital-parietal regions) during both Chinese and English tasks, and left specialization is more pronounced during the Chinese task. The AS group has similar ERP activity as the control group during the English task, but shows strong temporal (both left and right) and occipital-parietal ERP increases during the Chinese task.

3.3. ERSPs results

Figs. 2 and 3 plot the baseline-corrected ERSP for the Chinese task at different scalp regions in the control and AS groups. In the figures, the vertical axis shows frequency within the 1–35 Hz range, and the horizontal axis gives the time interval within the −500 to 1000 ms range. Figs. 4 and 5 plot the power spectrum within the same time interval and frequency range for the English task in the control and AS groups, respectively. The results from the MANOVA test on the ERSPs are also given in Table 1. Delta synchronization reflects brain activity directed to the search of violations in stimuli and to inhibition of incorrect behavioral responses (e.g., Basar, 1999; Knyazev, 2007). Delta synchronization can be observed in tasks involving stimulus comparison and the search for violations between a presented stimulus and a subject's mental images (Knyazev, 2012). An increase in delta power has been documented in a wide array of developmental disorders and pathological conditions. In our study, participants were asked to recognize the syntactic structure of sentences, that is, to compare a presented sentence with an ideal pattern of a syntactically correct sentence. Under such a condition, delta synchronization could be interpreted as an indicator of pattern recognition. The MANOVA test suggests that delta (1–4 Hz) synchronization has significant region effects in the 100–300 ms interval, and is more pronounced in the occipital-parietal regions, especially for the English task. Similar to the ERP results, the 400–600 ms interval can mostly differentiate language, and language by group interaction effects. The post hoc test with Bonferroni correction on multiple comparisons indicates that delta synchronization is much stronger across all scalp regions during the Chinese task than it is during the English task within this time interval. The AS group has much stronger delta synchronization than the control group across all scalp regions during the Chinese task, but during the English task, has slightly stronger delta synchronization in the frontal regions than the control group. In the 600–800 ms interval, delta synchronization has significant group, language and region effects. The post hoc test indicates that the Chinese task has stronger delta synchronization than the English task across all scalp regions for both groups within this time interval. The AS group has stronger delta synchronization than the control group across all scalp regions during the two tasks. Unlike the ERP activity, brain reactions in the 600–800 ms interval are observable only in the ERSP results.

Theta synchronization is an indicator of working memory processes and is correlated with selective attention (for review see Basar, 1999; Knyazev, 2007). According to Klimesch (1999), the encoding of new information is reflected by theta oscillations in hippocampo-cortical feedback loops. Theta synchronization in relatively short-term time intervals reflects the activation in hippocampal-cortical connections in working memory tasks and has been shown to be positively correlated with the ability to encode new information. Also, theta synchronization is an indicator of emotional recognition in the limbic system and frontal cortex (Aftanas & Golocheikine, 2001). On the other hand, theta desynchronization is normally detected along with lower-alpha desynchronization, and has been interpreted as an indicator of attention. In Table 1, the language and group effects are significant in the MANOVA test in the 400–600 ms interval. The post hoc test indicates that the control group shows strong theta desynchronization in the central and occipital-parietal regions during the Chinese task, and the same pattern of theta desynchronization appears in almost all scalp regions during the English task. In the AS group, however, the Chinese task induces strong theta synchronization in the frontal regions. The English task also induces a similar desynchronization pattern in the AS group as it does in the control group, but the amplitude in the AS group is not significant across all scalp regions. In the 600–800 ms interval, the group and language effects are also significant. The post hoc test

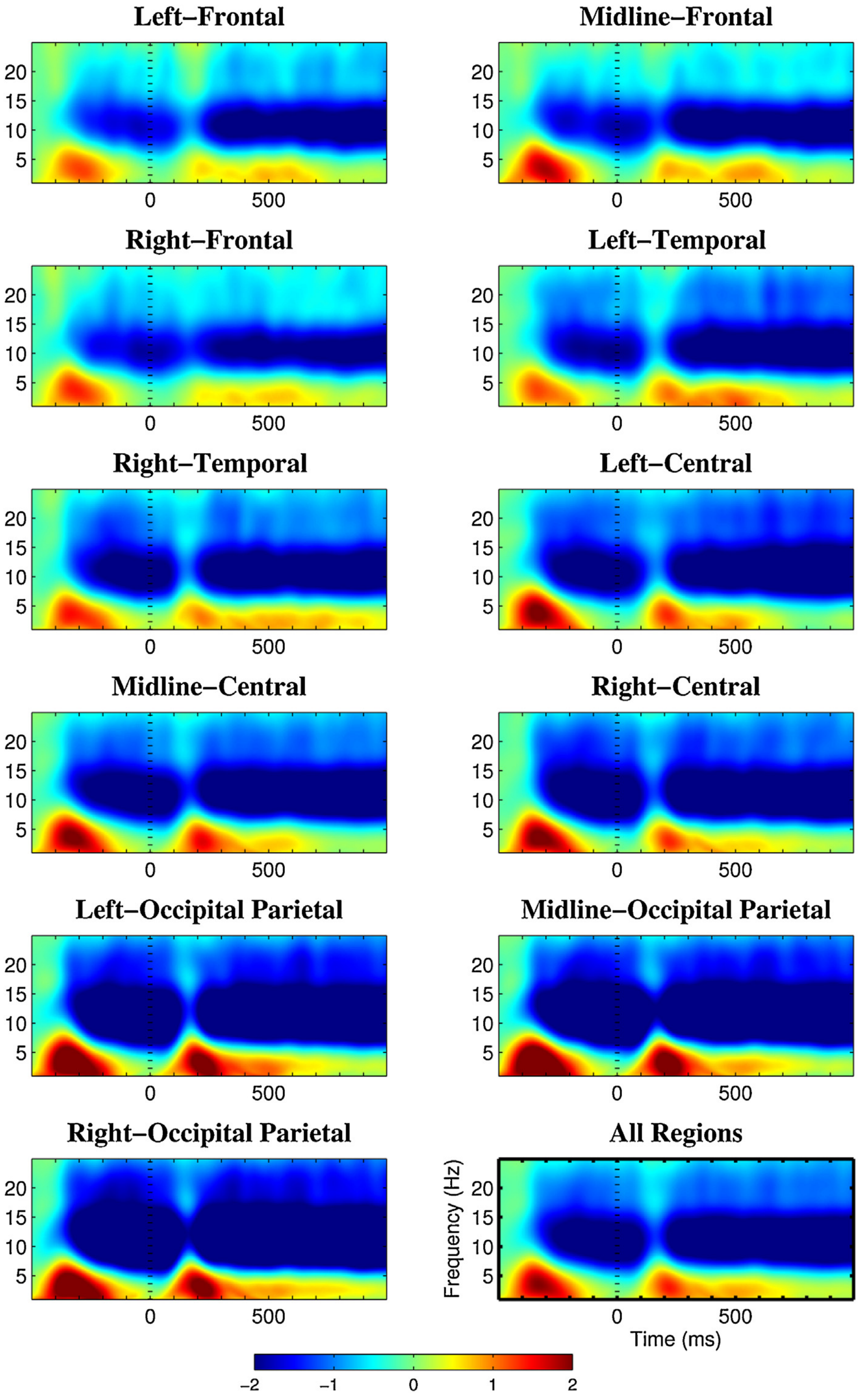

Fig. 2. The baseline corrected ERSPs for the Chinese task at the eleven scalp regions, along with the averaged ERSP across all regions, in the control group.

indicates that the control group has significant desynchronization in almost all scalp regions during the two language tasks. The AS group shows theta synchronization during the Chinese task, but none of the scalp regions has statistically significant theta activity.

Alpha desynchronization can be interpreted as an indicator of attention to visual stimuli, which tends to be consistent across different stages of decision making (Basar, 1999; Kilmesch, Doppelmayr, & Hanslmayr, 2006). In visual tasks, alpha desynchronization has the maximum amplitude in the posterior regions, but is also widely distributed with moderate

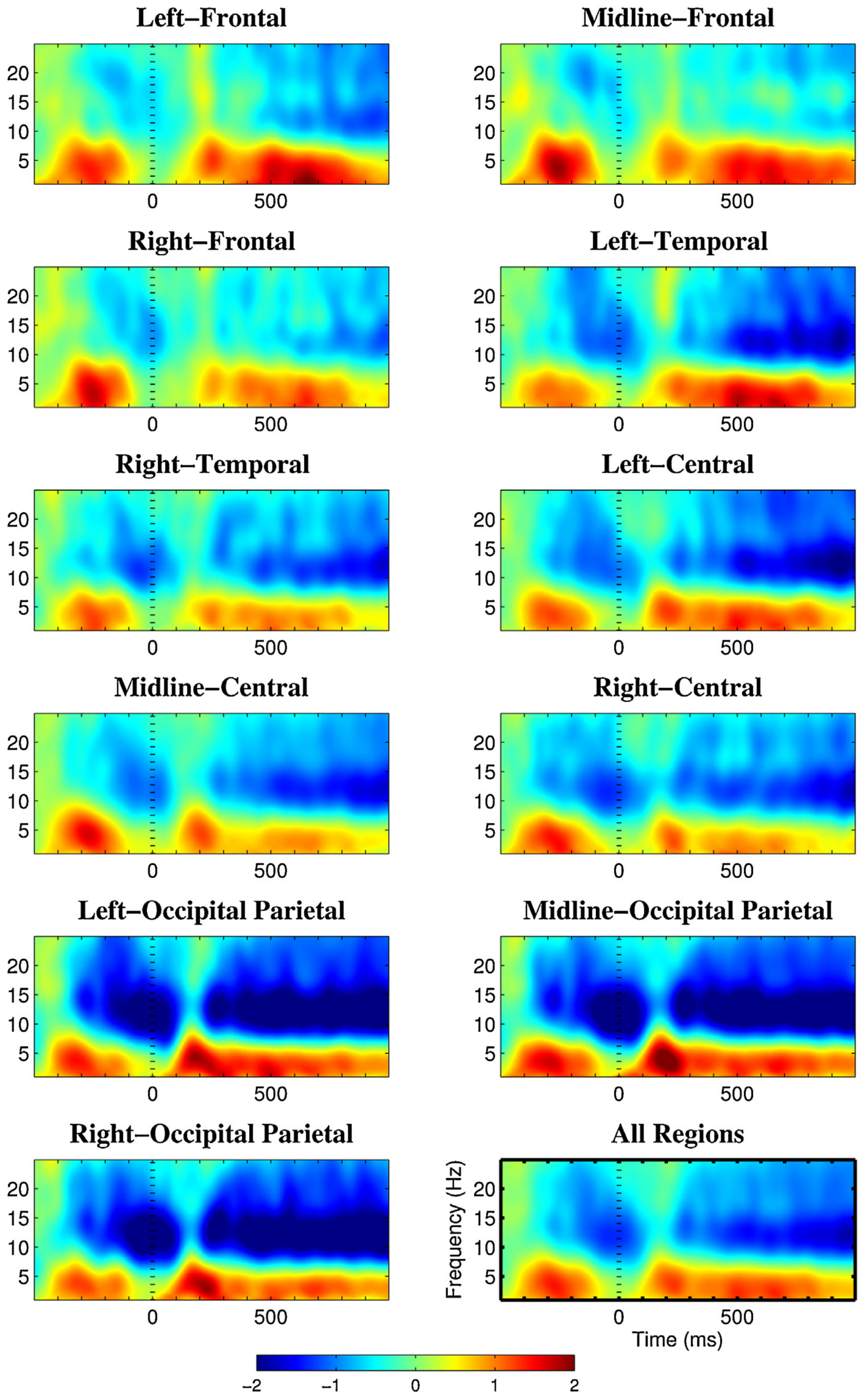

Fig. 3. The baseline corrected ERSPs for the Chinese task at the eleven scalp regions, along with the averaged ERSP across all regions, in the AS group.

amplitudes in other regions. It has been noticed that the lower alpha rhythm reflects unspecific processing demands such as attention (Klimesch, 1997; Klimesch, 1999). Studies on event-related changes have indicated that the upper alpha desynchronization is positively correlated with (semantic) long-term memory performance. The search and retrieval processes in (semantic) long-term memory are reflected by upper alpha oscillations in thalamo-cortical feedback loops. The MANOVA results for alpha (8–12 Hz) desynchronization in the 300–1000 ms interval suggest that the group and region

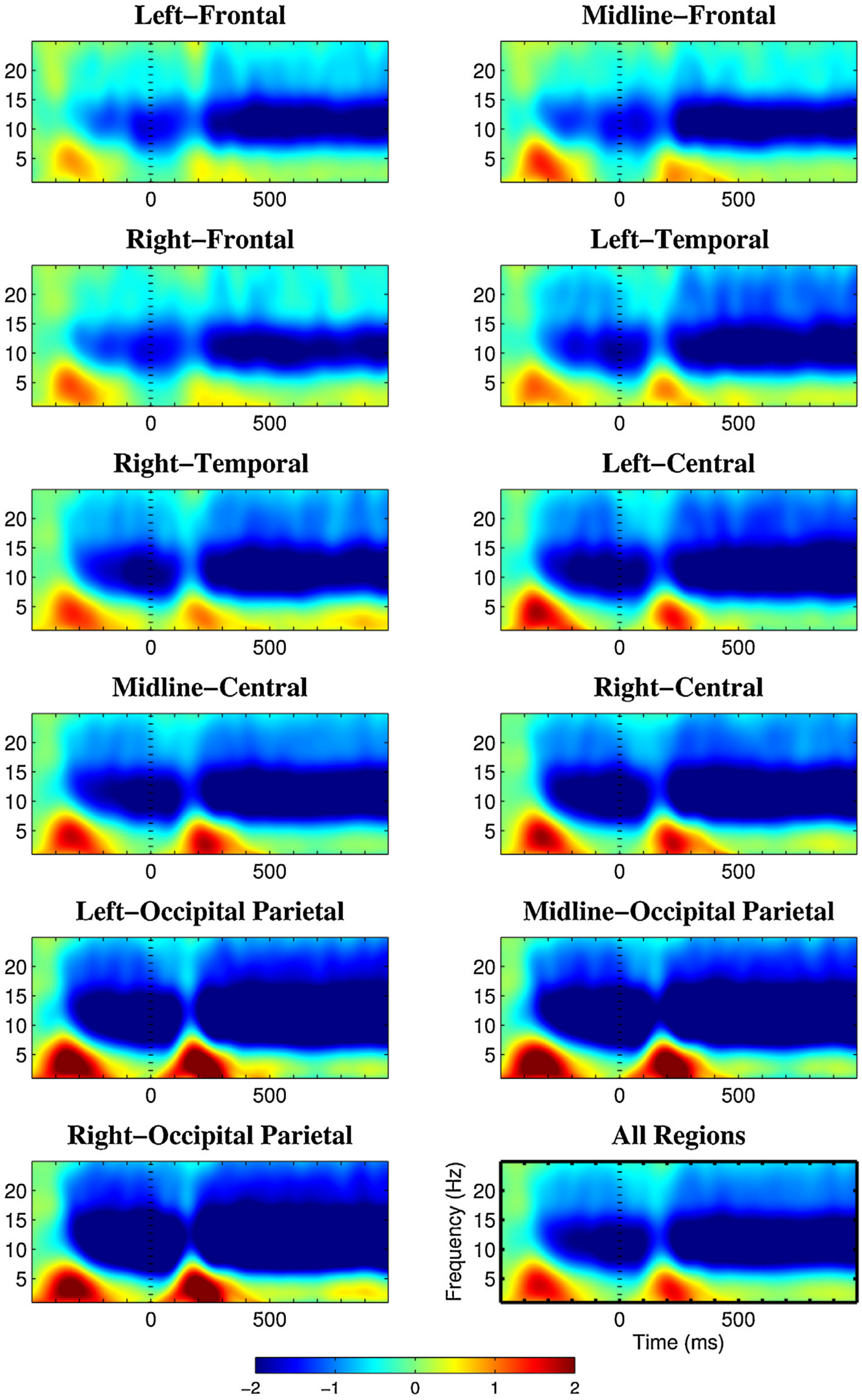

Fig. 4. The baseline corrected ERSPs for the English task at the eleven scalp regions, along with the averaged ERSP across all regions, in the control group.

effects are significant. The control group shows stronger alpha desynchronization than the AS group on both language tasks within this time interval. In general, alpha desynchronization is stronger in the occipital-parietal regions, followed by the central regions, and then by the temporal and frontal regions.

Brain oscillation in the beta band reflects the fast cortical processes of attention during task executions (Basar, 1999). Beta desynchronization normally follows activation in the motor areas and regulation of motions. The language tasks involve

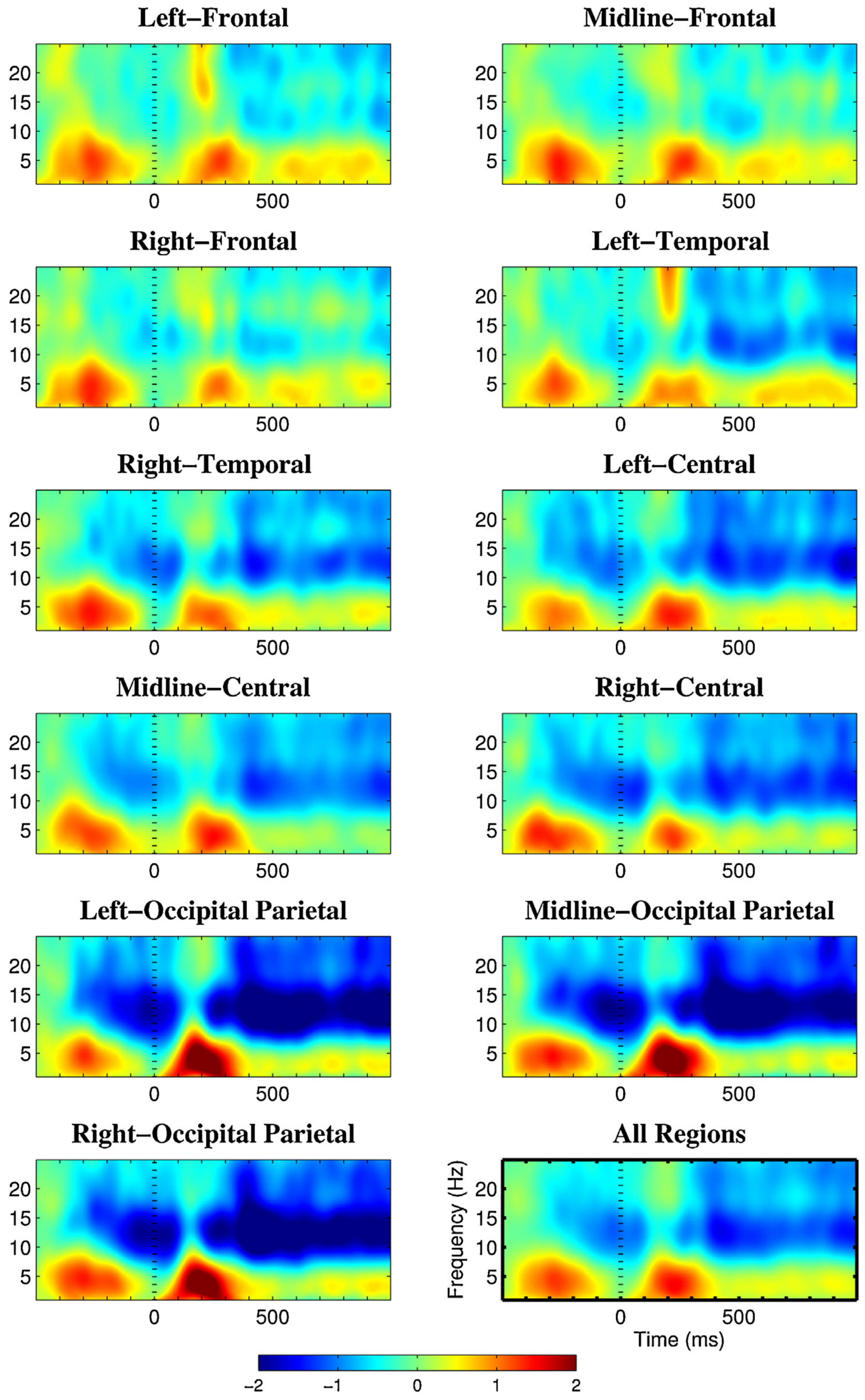

Fig. 5. The baseline corrected ERSPs for the English task at the eleven scalp regions, along with the averaged ERSP, across all regions, in the AS group.

complicated decisions and beta desynchronization corresponds to focused attention on task execution. Beta desynchronization also depends on individual characteristics such as gender, age, anxiety level, and other related factors (Aftanas & Pavlov, 2005; Razumnikova & Vol'f, 2007). Brain oscillations in the beta 1 (12–16 Hz), beta 2 (16–20 Hz) and beta 3 (20–25 Hz) ranges suggest only a significant region effect in Table 1. Similar to alpha desynchronization, desynchronization activity in these frequency ranges is strongest in the occipital parietal regions followed by the central and temporal regions, and then by the frontal regions. The two groups and two languages follow the same oscillatory pattern, but the control group has stronger desynchronization than the AS group (there is a minor difference between the two groups in beta 1 and beta 2), but the differences are not statistically significant.

In summary, delta synchronization in the early stage (100–300 ms) is pronounced in the occipital-parietal regions, which is similar during both language tasks in both groups. Delta synchronization in the later stage (400–600 ms) can mostly differentiate language and group differences; that is, the control group shows left specialization in the temporal and left occipital-parietal regions during the Chinese task, while the AS group has stronger delta synchronization than the control group in almost all scalp regions. However, within the 400–600 ms interval, neither group has significant delta synchronization during the English task. Delta synchronization during the Chinese task also lasts longer than 600 ms in the AS group, showing a similar pattern to that in the 400–600 ms interval; this implies that the semantic and syntactic processes could have taken longer time for the AS group. Theta desynchronization is pronounced in the occipital-parietal regions in the 400–600 ms interval for both tasks in the control group, but the AS group shows significant theta synchronization in the frontal regions during the Chinese task, and has no significant theta activity during the English task. Desynchronization in the alpha, beta1, beta2, and beta3 ranges is more pronounced in the occipital-parietal regions during both tasks in both groups, but on average, the control group has stronger alpha desynchronization than that of the AS group.

4. Discussion

The recognition of written sentences induces both speech and non-speech functions in the brain. Non-speech functions are associated with recognition of any visual stimuli such as visual perception, concentration of attention, use of long-term or working memory, and decision-making. Speech functions are engaged in sentence processing, such as phonological, syntactic and semantic recognition of speech. In this study, the ERP patterns, especially those in healthy controls, are generally consistent with those reported in the literature (Friederici, 2004; Hagoort, 2003; Hagoort et al., 2003; Kuperberg, 2007). The early P100 and N170 peaks in the 100–200 ms interval reach the highest in the occipital-parietal regions, and can be seen in the frontal and temporal regions. Previous work has suggested a relationship between early ERP peaks and phonological recognition of speech (Dujardin et al., 2011; Kast, Elmer, Jancke, & Meyer, 2010). For instance, P100 and N170 reflect initial processing of the language stimulus in its physical properties such as the form and size of letters, along with its colors and position in space (Maillard et al., 2011). The phonological structure of speech is also one of the physical parameters in the stimulus. Thus, the P100 and N170 peaks are more related to the bottom-up process in language perception and in phonological recognition. The frontal P300 peak in the 300–400 ms interval reflects the level of attention and readiness in reacting to the external stimulus (Näätänen, 1992), which is known as one of the top-down processes induced by a subject's motivation. In the ERP plots, P300 first occurs in the central eye-fixation period, suggesting a subject's readiness to the forthcoming task; it then appears after the stimulus onset, suggesting a subject's directed attention. The N400 and P600 peaks reach their maximum amplitudes in the left temporal region in the ERP plots. N400 has been shown to be associated with the semantic recognition of words and sentences, and P600, with syntactic recognition (Mueller, Hirotani, & Friederici, 2007; Friederici, 2004; Hagoort, 2003). In this study, the amplitude of P600, especially in the left temporal region, is much greater than that of N400, a fact which is task specific; that is, subjects were instructed to pay attention to the syntax rather than the semantic structures in the sentences. The P600 peak is therefore stronger than the N400 peak, and introduces more information on between-task and – group differences than does the N400 peak.

There are two grammatical properties of Mandarin Chinese that cause the language perceiver to do more interpretation of syntax and semantics than is required in European languages. First, Chinese is much more free in the degree to which a lexical word can serve different grammatical functions (Bisang, 2008). Second, when it comes to the transmission of information, many languages of East and Southeast Asia, including Chinese dialects, assign a higher role to semantics and language-external context and a lower role to syntax than is found among European languages (Huang, 2007; Huang, 1984). One result of these two factors is that economy of expression is favored over explicitness, leading to surface simplicity, but "hidden complexity," in which multiple syntactic possibilities must be explored in order to arrive at a semantic interpretation (Bisang, 2009). On the other hand, while English is not marked morphologically to the same extent as are many other European languages, nevertheless the use of word order, prepositions, verb agreement, etc. do explicitly encode syntactic relations. For example, in the English sentence: "A farmer feeds the cows", explicit syntactic information includes definiteness (*the*), indefiniteness (*a*), present tense, habitual aspect and third person singular subject (feed-*s*), as well as singular (farmer-Ø) and plural number (cow-*s*). Much of this information is missing from the equivalent Chinese sentence; that is, 農夫餵牛 (nóngfū weì niú; lit., "farmer feed cow"). Not explicitly mentioned are (in-) definiteness of subject and object, tense, aspect, and number of the subject (farmer) and object (cow). Furthermore, in Chinese writing, there are no spaces between lexical items, unlike English writing, where such spaces are required – different groupings of Chinese characters on the part of the reader can sometimes lead to alternate interpretations of the same sentence. Thus, in terms of encoding syntactic and lexical information, English is more explicit, while Chinese is more economical. For these reasons, the syntactic and orthographic structure of Chinese requires more work to be done by the perceiver.

In the EEG literature, there have been numerous studies on brain activity during recognition of speech in Chinese, and on comparing Chinese and Indo-European languages (Liu, Shu, & Wei, 2006; Qiu & Zhou, 2012; Yang, Perfetti, & Liu, 2010; Ye et al., 2006). These studies have shown that the inter-dependence between semantic and syntactic processing is stronger in Chinese than in English. It has been found that the amplitudes of N400 and P600 peaks are strongly correlated with each other in Chinese sentence recognition, but not in English sentence recognition. However, there is no such correlation in the amplitudes of early ERP peaks in any language. In general, most comparisons have suggested stronger ERP peaks in the later stage of language processing in Chinese than is found in English. In our data, early posterior peaks (100–200 ms) have higher amplitude during the English task than during the Chinese task, and later temporal peaks (400–600 ms) have higher amplitude during the Chinese task in both control and AS groups. MANOVA suggests stronger language differences in P600 than those in N400. For the participants in this study, it may be true that reading English sentences demands stronger relationships between visual and phonological recognition compared to reading Chinese sentences, leading to higher amplitude of early peaks in the English task. The P600 peak for healthy controls is related to late syntactic recognition, which was shown to have a stronger expression in native than in foreign languages in a study involving purely Indo-European languages (Friedrich et al., 2009). The N400 peak is related to semantic recognition (Friedrich & Friederici, 2006) and was not more strongly expressed in the subjects' native language (Mueller et al., 2007).

We have found strengthened brain reactions in AS subjects during syntactic error recognition in native Chinese, but not in English, as suggested by both ERP and ERSP results. Two alternative interpretations can be considered for these findings. First, the differences are related to whether a language is native or foreign. In this interpretation, the strengthened language processing in AS subjects can be attributed to earlier acquisition of the native language in childhood, and to more frequent use of the native language in ordinary life. The second possibility is that differences in brain reactions are indeed induced by differences in linguistic structure between Chinese and English. The atypical reactions in AS subjects could be resulting from the disorder due to the ambiguities of processing syntactic structures in Chinese sentences. In this study, we cannot clearly make a choice between two alternative interpretations of the results. Such a choice requires additional studies on bilingual AS patients without native Chinese background, and also on brain reactions of non-native Chinese speakers during comprehension of Chinese and native languages. The bilingual effects remain to be investigated further.

Native and foreign languages are acquired at different stages of individual development. It was found that early speech dysfunction relates to processing the native language, rather than foreign languages (Vygotsky, 1988, Vygotsky, 1993; Avila et al., 2004). However, the opposite situation (i.e., the dysfunction relates with foreign, rather than native languages) is also possible in adult patients (Heinemann & Assion, 1996). More importantly, the native language is connected with so-called internal speech, that is, an ability of verbal representation of external events in consciousness. In an earlier work, we hypothesized that AS subjects could have used internal speech in their native language as a compensatory mechanism for dysfunctions in recognition of facial emotionality (Yang et al., 2011). The compensatory processes might have also been exercised in recognition of sentences in the native (Mandarin Chinese) language. The semantic and syntactic processes, as revealed by delta synchronization, last longer during the Chinese task in the AS group, even though the between group differences in reaction times and response accuracy are not statistically significant. The between-group differences on the English task are not significant in the current experiment. This finding could be associated with the syntactic explicitness of English, which requires very little interpretation on the part of the reader. On the other hand, delta synchronization suggests that the recognition and interpretation of Chinese sentences are more difficult for AS subjects than for healthy controls. It has been noted that AS subjects have a functional disorder related to speech skills and recognition of patterns. In spite of this difficulty, they are able to compensate for deficits in stimulus processing by being more attentive to sentence structure. As seen in slow-wave (delta and theta) synchronization and the amplitude of frontal P300, the top-down activity suggests exactly a compensatory mechanism. In this interpretation, AS individuals have exercised more of the top-down activity when reading Chinese than when reading English, because inference is more difficult for them.

As mentioned, Asperger's syndrome is a functional disorder that can be compensated for by medical therapy or the mindfulness-based control. In the fMRI and EEG literature, the compensated subjects have shown "atypical" brain reactions in regions located in or near the striate or extrastriate cortex. Furthermore, spatial frequency of stimuli exerts a smaller effect on increasing alpha- and gamma-band power, but time to peak alpha-band power is reduced in subjects with AS. On the other hand, induced alpha-band power in regions located in or near the cingulate gyrus is increased in participants with AS (Milne et al., 2009). The atypical activity is the reason for the hypothesis on the compensated disorder when the existing dysfunctions are modulated by other brain processes for improving task performances (Yang et al., 2011). Our AS subjects have been successful with equal educational levels as the healthy controls. Behavioral data also indicate that AS subjects performed as well as control subjects on the language tasks. We hypothesize that an increase in top-down regulated attention plays a central role as a compensatory mechanism in language processing particularly in autism disorders.

This compensatory mechanism in AS subjects is observed in the Chinese task, but not in the English task. So, in the central eye-fixation period and early language processing stage, the AS subjects show strong ERP response in the frontal and temporal cortical areas, but have no responses in occipital-parietal cortex. On the other hand, healthy controls show positive responses in frontal and temporal areas and negative responses in posterior areas. The frontal response in the AS subjects is stronger for the Chinese task than for the English task. During concentration of attention, the posterior indexes reflect bottom-up processes related to activation of sensory areas of the visual cortex, whereas frontal and temporal ERPs reflect top-down processes related to control of attention (Näätänen, 1992). We can interpret our finding on the posterior ERP as an index of decreasing of bottom-up sensory processes in the AS subjects as compared with the healthy controls. However, the top-down process in the AS subjects is undamaged, as revealed in the fronto-temporal ERP. The strong magnitude in the frontal ERP during the Chinese task suggests that the AS subjects exercise strong concentration during recognition of errors in Chinese sentences. A similar effect has also been found during the post-stimulus interval. The frontal P300 is stronger for AS subjects than for healthy controls, but only under the Chinese condition. In other words, AS subjects need more attentional resources during the post-stimulus period than healthy controls during recognition of Chinese sentences, but there is no difference between the two groups during recognition of English sentences.

In later reactions (400–600 ms after sentence onset), the AS group again shows stronger increased activity than the control group during the Chinese task, and there is no between-group difference in the English task. MANOVA on ERSPs suggests not only increased amplitudes of delta synchronization, but also increased temporary duration in the 400–800 ms interval in the AS group during the Chinese task. Topologically, the increase of brain responses in the AS subjects is strongly expressed in left temporal cortical regions. If the increase in amplitude of early peaks is related to readiness for recognition of signals, late ERPs and ERSPs can be interpreted as activity which is directly relevant to recognition of syntactic patterns. In our case, the increase in this reaction in the AS subjects is an indicator of stronger involvement of brain resources (relative to controls) for the solution of a linguistic task in the native language. It confirms our theoretical hypothesis about strengthening of speech processes in the AS subjects.

Also, healthy controls have shown stronger brain activity in the left temporal (Broca's) area, whereas the AS subjects have relatively more symmetric EEG responses in the left and right cortex. This result closely corresponds to the finding by Knaus et al. (2010) who discovered a decrease in left lateralization in AS subjects in language task decisions. According to the data in (Nikolaeva et al., 1995) and (Leutin, 2001), an increase of right-hemispheric activity can often be detected under conditions of non-specific behavioral stress. For example, both studies found right-side activation in subjects who had recently moved into a different residence, or were living in unusual and difficult circumstances. In their interpretation, activation of right-hemispheric activity is an index of compensation of some difficulty by means of more intensive use of memory and attentional resources. Therefore, the finding of right-hemispherical increase in AS subjects also corresponds to the hypothesis of compensated disorder in such patients.

The experimental findings in this study may promote a better understanding of brain processes during recognition of written speech. The study has shown that recognition of syntactic structure in a sentence demands integration of several relatively independent brain processes – visual perception of symbols, phonologic recognition, syntactic and semantic recognition, concentration of attention and allocating memory resources. These processes are supported by individual anatomic substrata, and connected to different frequency ranges of brain oscillations. More importantly, these processes differ in their temporal features, as reflected in ERSP or ERP dynamics. Although the functional system engaged in recognition of different languages is quite similar, the amplitude and duration of different reactions vary between language conditions. In this study, for instance, the healthy controls show stronger responses in the ERSPs and ERP peaks in the posterior brain regions during the early stage in processing the English sentences. However, when processing Chinese sentences, peaks are stronger in the frontal and temporal brain regions during the later stages. Finally, the findings support the hypothesis that strengthening brain responses in Taiwanese AS subjects during recognition of syntactic errors in Chinese sentences relates to structural differences between Chinese and English; that is, autism spectrum disorder results in difficulties in implicit perception of Chinese syntax. However, strengthening of top-down regulated attention can partially compensate for this challenge. The compensatory mechanism is partially verified by the speed of reactions to Chinese sentences and the quality of task performance, which do not significantly differ between groups. If this interpretation is true, our findings can be reproduced in AS subjects by other pairings of languages that significantly differ in the explicitness of their syntax.

5. Conclusions

The study has compared differences in brain reactions of subjects with Asperger's syndrome and healthy controls during language tasks involving syntactic error detection. Between-group and – language differences have been found in both ERP and ERSP results. In the control subjects, the early reaction, which is related to visual and phonological recognition of written sentences, is stronger for English than it is in Chinese. In the AS subjects, additional top-down activation is observed in the frontal cortex under the Chinese condition, but not under the English condition. On the contrary, the late reaction, which is related to recognition of sentential syntax, is stronger when reading Chinese, than when reading English for both AS and control subjects. Although present in both populations, this effect is significantly greater in the AS group. In addition, the frontal top-down activation of slow-wave systems (delta and theta) reflects a strong level of attentional focus in AS subjects. In general, our results support the hypothesis that individuals with compensated Asperger's syndrome can cope with their disorders by means of focusing on some details of the stimuli.

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References

Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: High-resolution EEG investigation of meditation. *Neuroscience Letters, 310*, 57–60.

Aftanas, L. I., & Pavlov, S. V. (2005). Trait anxiety impact on posterior activation asymmetries at rest and during evoked negative emotions: EEG investigation. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology, 55*, 85–94.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders (4th ed., text revision)*. Washington, DC: American Psychiatric Association.

Asperger, H. (1994). Die 'Autistischen Psychopathen' im Kindesalter. In *Archiv fur Psychiatrie und Nervenkrankheiten, 117, 76–136. Translated by U. Frith (1991). In U. Frith (Ed.), Autism and Asperger syndrome* (pp. 37-92). New York: Cambridge University Press.

Attwood, T. (2008). *The complete guide to Asperger's syndrome*. London: Jessica Kingsley Publishers.

Avila, C., González, J., Parcet, M. A., & Belloch, V. (2004). Selective alteration of native, but not second language articulation in a patient with foreign accent syndrome. *NeuroReport, 15*(14), 2267–2270.

Aylward, E. H., Minshew, N. J., Goldstein, G., Honeycutt, N. A., Augustine, A. M., Yates, K. O., et al. (1999). MRI volumes of amygdala and hippocampus in non-mentally retarded autistic adolescents and adults. *Neurology, 53*, 2145–2150.

Baron-Cohen, S., Lombardo, M. V., Auyeung, B., Ashwin, E., Chakrabarti, B., & Knickmeyer, R. (2011). Why are autism spectrum conditions more prevalent in males? *PLoS Biology, 9*, e1001081.

Baron-Cohen, S., Ring, H., Chitnis, X., Wheelwright, S., Gregory, L., Williams, S., et al. (2006). fMRI of parents of children with Asperger Syndrome: A pilot study. *Brain and Cognition, 61*, 122–130.

Barttfeld, P., Wicker, B., Cukier, S., Navarta, S., Lew, S., & Sigman, M. (2011). A big-world network in ASD: Dynamical connectivity analysis reflects a deficit in long-range connections and an excess of short-range connections. *Neuropsychologia, 49*, 254–263.

Basar, E. (1999). *Brain function and oscillations. Vol. II: Integrative brain function, neurophysiology and cognitive processes*. Berlin: Springer.

Bastiaansen, M., & Hagoort, P. (2006). Oscillatory neuranal dynamics during language comprehension. *Progress in Brain Research, 159*, 179–196.

Bisang, W. (2008). Grammaticalization as an areal phenomenon – The case of East and mainland Southeast Asian languages and its consequences for concepts of complexity and maturation. *語言學論叢[nl]Yuyanxue Luncong, 38*, 64–98.

Bisang, W. (2009). On the evolution of complexity – Sometimes less is more in East and mainland Southeast Asia. In Sampson, G., Gil, D., & Trudgill, P. (Eds.), *Language complexity as an evolving variable*. (pp.34–49). .

Church, C., Alisanski, S., & Amanullah, S. (2000). The social, behavioral, and academic experiences of children with Asperger Syndrome. *Focus on Autism and other Developmental Disabilities, 15*, 12–20.

Clement, F., & Belleville, S. (2010). Compensation and disease severity on the memory-related activations in mild cognitive impairment. *Biological Psychiatry, 68*, 894–902.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9–21.

Di Martino, A., Kelly, C., Grzadzinski, R., Zuo, X. N., Mennes, M., Mairena, M. A., et al. (2011). Aberrant striatal functional connectivity in children with autism. *Biological Psychiatry, 69*, 847–856.

Dick, F., Dronkers, N. F., Pizzamiglio, L., Saygian, A. P., Small, S. L., & Wilson, S. (2005). Language and the brain. In M. Tomasello & D. I. Slobin (Eds.), *Beyond nature–nurture: Essay in honor of Elizabeth Bates* (pp. 237–260). Mahwah, NJ: Lawrence Erlbaum.

Dujardin, T., Etienne, Y., Contentin, C., Bernard, C., Largy, P., Mellier, D., et al. (2011). Behavioral performances in participants with phonological dyslexia and different patterns on the N170 component. *Brain and Cognition, 75*, 91–100.

Duverger, H., Da Fonseca, D., Bailly, D., & Deruelle, G. (2007). Theory of mind in Asperger syndrome. *Encephale, 33*(4 Pt 1), 592–597.

Dziobek, I., Fleck, S., Rogers, K., Wolf, O. T., & Convit, A. (2006). The 'amygdala theory of autism' revisited: Linking structure to behavior. *Neuropsychologia, 44*, 1891–1899.

Ecker, C., Suckling, J., Deoni, S. C., Lombardo, M. V., Bullmore, E. T., Baron-Cohen, S., et al. (2012). Brain anatomy and its relationship to behavior in adults with autism spectrum disorder: A multicenter magnetic resonance imaging study. *Archives of General Psychiatry, 69*, 195–209.

Egawa, J., Watanabe, Y., Kitamura, H., Endo, T., Tamura, R., Hasegawa, N., et al. (2011). Reduced thalamus volume in non-right-handed male patients with autism spectrum disorders. *Psychiatry and Clinical Neurosciences, 65*, 395.

Elmer, S., Meyer, M., Marrama, L., & Jäncke, L. (2011). Intensive language training and attention modulate the involvement of fronto-parietal regions during a non-verbal auditory discrimination task. *European Journal of Neuroscience, 34*(1), 165–175.

Fischer, K. W., Bernstein, J. H., & Immordino-Yang, M. H. (2007). *Mind, brain and education in reading disorders*. Cambridge: Cambridge University Press.

Fombonne, E. (2003). Epidemiological surveys of autism and other pervasive developmental disorders: An update. *Journal of Autism and Developmental Disorders, 33*, 365–382.

Forstmann, B. U., van den Wildenberg, W. P., & Ridderinkhof, K. R. (2008). Neural mechanisms, temporal dynamics, and individual differences in interference control. *Journal of Cognitive Neuroscience, 20*, 1854–1865.

Friederici, A. D. (2004). Event-related brain potential studies in language. *Current Neurology and Neuroscience Reports, 4*, 466–470.

Friedrich, M., & Friederici, A. D. (2006). Early N400 development and later language acquisition. *Psychophysiology, 43*(1), 1–12.

Friedrich, M., Herold, B., & Friederici, A. D. (2009). ERP correlates of processing native and non-native language word stress in infants with different language outcomes. *Cortex, 45*(5), 662–676.

Gillberg, C. (1991). Clinical and neurobiological aspects of Asperger's syndrome in six families studied. *Autism and Asperger's Syndrome*, Cambridge: Cambridge University Press pp. 122–146.

Griswold, D. E., Barnhill, G. P., Myles, B. S., Hagiwara, T., & Simpson, R. L. (2002). Asperger Syndrome and academic achievement. *Focus on Autism and other Developmental Disabilities, 17*, 94–102.

Hagoort, P. (2003). Interplay between syntax and semantics during sentence comprehension: ERP effects of combining syntactic and semantic violations. *Journal of Cognitive Neuroscience, 15*, 883–899.

Hagoort, P., Wassenaar, M., & Brown, C. M. (2003). Syntax-related ERP-effects in Dutch. *Brain Research. Cognitive Brain Research, 16*, 38–50.

Hardan, A. Y., Girgis, R. R., Adams, J., Gilbert, A. R., Keshavan, M. S., & Minshew, N. J. (2006). Abnormal brain size effect on the thalamus in autism. *Psychiatry Research, 147*, 145–151.

Hardan, A. Y., Girgis, R. R., Adams, J., Gilbert, A. R., Melhem, N. M., Keshavan, M. S., et al. (2008). Brief report: Abnormal association between the thalamus and brain size in Asperger's disorder. *Journal of Autism and Developmental Disorders, 38*, 390–394.

Heinemann, F., & Assion, H. J. (1996). Language regression to the mother tongue in polyglot patients with acute psychosis. *Nervenarzt, 67*(7), 599–601.

Hirschfeld, G., & Zwitserlood, P. (2011). How vision is shaped by language comprehension – Top-down feedback based on low-spatial frequencies. *Brain Research, 1377*, 78–83.

Howlin, P., & Yates, P. (1999). The potential effectiveness of social skills groups for adults with autism. *Autism, 3*, 299–307.

Huang, C.-T.J. (1984). On the distribution and reference of empty pronouns. *Linguistic Inquiry, 15*, 531–574.

Huang, Y. (2007). *The syntax and pragmatics of anaphora: A study with special reference to Chinese*. Cambridge: Cambridge University Press.

Jansson-Verkasalo, E., Ceponiene, R., Kielinen, M., Suominen, K., Jäntti, V., Linna, S.-L., et al. (2003). Deficient auditory processing in children with Asperger Syndrome, as indexed by event-related potentials. *Neuroscience Letters, 338*, 197–200.

Kast, M., Elmer, S., Jancke, L., & Meyer, M. (2010). ERP differences of pre-lexical processing between dyslexic and non-dyslexic children. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology, 77*, 59–69.

Kilmesch, W., Doppelmayr, M., & Hanslmayr, S. (2006). Upper alpha ERD and absolute power: Their meaning for memory performance. *Progress in Brain Research, 159*, 151.

Kleinhans, N. M., Richards, T., Johnson, L. C., Weaver, K. E., Greenson, J., Dawson, G., et al. (2011). fMRI evidence of neural abnormalities in the subcortical face processing system in ASD. *NeuroImage, 54*, 697–704.

Klimesch, W. (1997). EEG-alpha rhythms and memory processes. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology, 26*, 319–340.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research. Brain Research Reviews, 29*, 169–195.

Klin, A., Volkmar, F. R., & Sparrow, S. S. (2000). *Asperger Syndrome*. New York: Guilford Press.

Knaus, T. A., Silver, A. M., Kennedy, M., Lindgren, K. A., Dominick, K. C., Siegel, J., et al. (2010). Language laterality in autism spectrum disorder and typical controls: A functional, volumetric, and diffusion tensor MRI study. *Brain and Language, 112*, 113–120.

Knyazev, G. G. (2007). Motivation, emotion, and their inhibitory control mirrored in brain oscillations. *Neuroscience and Biobehavioral Reviews, 31*, 377–395.

Knyazev, G. G. (2012). EEG delta oscillations as a correlate of basic homeostatic and motivational processes. *Neuroscience and Biobehavioral Reviews, 36*, 677–695.

Koechlin, E., Ody, C., & Kouneiher, F. (2003). The architecture of cognitive control in the human prefrontal cortex. *Science, 302*, 1181–1185.

Kujala, T., Lepisto, T., Nieminen-von Wendt, T., Naatanen, P., & Naatanen, R. (2005). Neurophysiological evidence for cortical discrimination impairment of prosody in Asperger Syndrome. *Neuroscience Letters, 383*, 260–265.

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension: Challenges to syntax. *Brain Research, 1146*, 23–49.

Langen, M., Leemans, A., Johnston, P., Ecker, C., Daly, E., Murphy, C. M., et al. (2012). Fronto-striatal circuitry and inhibitory control in autism: Findings from diffusion tensor imaging tractography. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 48*, 183–193.

Lazar, A. S., Lazar, Z. I., Biro, A., Gyori, M., Tarnok, Z., Prekop, C., et al. (2010). Reduced fronto-cortical brain connectivity during NREM sleep in Asperger syndrome: An EEG spectral and phase coherence study. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology, 121*, 1844–1854.

Leutin, V. P. (2001). Characteristics of healthy population among the migrants to the North. *International Journal of Circumpolar Health, 60*, 580–585.

Lewine, J. D., Andrews, R., Chez, M., Patil, A. A., Devinsky, O., Smith, M., et al. (1999). Magnetoencephalographic patterns of epileptiform activity in children with regressive autism spectrum disorders. *Pediatrics, 104*, 405–418.

Liou, M., Savostyanov, A. N., Simak, A. A., Wu, W. C., Huang, C. T., & Cheng, P. E. (2012). An information system in the brain: Evidence from fMRI BOLD responses. *Chinese Journal of Psychology, 54*, 1–26.

Liu, Y., Shu, H., & Wei, J. (2006). Spoken word recognition in context: Evidence from Chinese ERP analyses. *Brain and Language, 96*, 37–48.

Maillard, L., Barbeau, E. J., Baumann, C., Koessler, L., Bénar, C., Chauvel, P., et al. (2011). From perception to recognition memory: Time course and lateralization of neural substrates of word and abstract picture processing. *Journal of Cognitive Neuroscience, 23*, 782–800.

Makeig, S., Bell, A. J., Jung, T. P., & Sejnowski, T. J. (1996). Independent component analysis of electroencephalographic data. *Advances in Neural Information Processing Systems,* 145–151.

Matson, J. L., Kozlowski, A. M., Hattier, M. A., Horovitz, M., & Sipes, M. (2012). DSM-IV vs DSM-5 diagnostic criteria for toddlers with autism. *Developmental Neurorehabilitation, 15*, 185–190.

McAlonan, G. M., Suckling, J., Wong, N., Cheung, V., Lienenkaemper, N., Cheung, C., et al. (2008). Distinct patterns of grey matter abnormality in high-functioning autism and Asperger's syndrome. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 49*, 1287–1295.

Milne, E., Scope, A., Pascalis, O., Buckley, D., & Makeig, S. (2009). Independent component analysis reveals atypical electroencephalographic activity during visual perception in individuals with autism. *Biological Psychiatry, 65*, 22–30.

Mishra, R. K. (2009). Interaction of language and visual attention: Evidence from production and comprehension. *Progress in Brain Research, 176*, 277–292.

Morgan-Short, K., Steinhauer, K., Sanz, C., & Ullman, M. T. (2012). Explicit and implicit second language training differentially affect the achievement of native-like brain activation patterns. *Journal of Cognitive Neuroscience, 24*, 933–947.

Mueller, J. L., Hirotani, M., & Friederici, A. D. (2007). ERP evidence for different strategies in the processing of case markers in native speakers and non-native learners. *BMC Neuroscience, 2*, 8–18.

Murias, M., Webb, S. J., Greenson, J., & Dawson, G. (2007). Resting state cortical connectivity reflected in EEG coherence in individuals with autism. *Biological Psychiatry, 62*, 270–273.

Murphy, C. M., Deeley, Q., Daly, E. M., Ecker, C., O'Brien, F. M., Hallahan, B., et al. (2012). Anatomy and aging of the amygdala and hippocampus in autism spectrum disorder: An in vivo magnetic resonance imaging study of Asperger Syndrome. *Autism Research: Official Journal of the International Society for Autism Research, 5*, 3–12.

Näätänen, R. (1992). *Attention and brain function*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Nacewicz, B. M., Dalton, K. M., Johnstone, T., Long, M. T., McAuliff, E. M., Oakes, T. R., et al. (2006). Amygdala volume and nonverbal social impairment in adolescent and adult males with autism. *Archives of General Psychiatry, 63*, 1417–1428.

Nikolaeva, E. I., Oteva, E. A., Leutin, V. P., Maslennikov, A. B., Osipova, L. P., & Nikolaeva, A. A. (1995). Relationships between left hemisphere predominance and disturbances of lipid metabolism in different ethnic groups. *International Journal of Cardiology, 52*, 207–211.

O'Connor, K., & Kirk, I. (2008). Brief report: Atypical social cognition and social behaviours in autism spectrum disorder: A different way of processing rather than an impairment. *Journal of Autism and Developmental Disorders, 38*, 1989–1997.

Pierce, K., Müller, R. A., Ambrose, J., Allen, G., & Courchesne, E. (2001). Face processing occurs outside the fusiform face area in autism: Evidence from functional MRI. *Brain, 124*, 2059–2073.

Pijnacker, J., Geurts, B., van Lambalgen, M., Buitelaar, J., & Hagoort, P. (2010). Exceptions and anomalies: An ERP study on context sensitivity in autism. *Neuropsychologia, 48*, 2940–2951.

Qiu, Y., & Zhou, X. (2012). Processing temporal agreement in a tenseless language: An ERP study of Mandarin Chinese. *Brain Research, 1446*, 91–108.

Rabinovich, M. I., Afraimovich, V. S., Bick, C., & Varona, P. (2012). Information flow dynamics in the brain. *Physics of Life Reviews, 9*, 51–73.

Razumnikova, O. M., & Vol'f, N. V. (2007). Gender differences in interhemisphere interactions during distributed and directed attention. *Neuroscience and Behavioral Physiology, 37*, 429–434.

Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science, 306*, 443–447.

Rossi, S., Gugler, M. F., Friederici, A. D., & Hahne, A. (2006). The impact of proficiency on syntactic second-language processing of German and Italian: Evidence from event-related potentials. *Journal of Cognitive Neuroscience, 18*, 2030–2048.

Rüschemeyer, S. A., Zysset, S., & Friederici, A. D. (2006). Native and non-native reading of sentences: An fMRI experiment. *Neuroimage, 31*(1), 354–365.

Saalasti, S., Tiippana, K., Katsyri, J., & Sams, M. (2011). The effect of visual spatial attention on audiovisual speech perception in adults with Asperger syndrome. *Experimental Brain Research. Experimentelle Hirnforschung. Experimentation Cerebrale, 213*, 283–290.

Salmond, C. H., de Haan, M., Friston, K. J., Gadian, D. G., & Vargha-Khadem, F. (2003). Investigating individual differences in brain abnormalities in autism. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences, 358*, 405–413.

Saracino, J., Noseworthy, J., Steiman, M., Reisinger, L., & Fombonne, E. (2010). Diagnostic and assessment issues in autism surveillance and prevalence. *Journal of Developmental and Physical Disabilities, 22*, 317–330.

Schumann, C. M., Hamstra, J., Goodlin-Jones, B. L., Lotspeich, L. J., Kwon, H., Buonocore, M. H., et al. (2004). The amygdala is enlarged in children but not adolescents with autism; the hippocampus is enlarged at all ages. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 24*, 6392–6401.

Singh, N. N., Lancioni, G. E., Singh, A. D. A., Winton, A. S. W., Singh, A. N. A., & Singh, J. (2011). Adolescents with Asperger syndrome can use a mindfulness-based strategy to control their aggressive behavior. *Research in Autism Spectrum Disorders, 5*, 1103–1109.

Stiles, J., Bates, E. A., Thal, D., Trauner, D., & Reilly, J. (2002). Linguistic and spatial cognitive development in children with pre-and perinatal focal brain injury: A ten-year overview from the San Diego longitudinal project. *Brain Development and Cognition,* 272–291.

Tabachnick, B. G., & Fidell, L. S. (1996). *Using multivariate statistics*. New York: HarperCollins College.

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language, 9*, 182–198.

Thal, D. J., Marchman, V., Stiles, J., Aram, D., Trauner, D., Nass, R., et al. (1991). Early lexical development in children with focal brain injury. *Brain and Language, 40*, 491–527.

Tiinanen, S., Maatta, A., Silfverhuth, M., Suominen, K., Jansson-Verkasalo, E., & Seppanen, T. (2011). HRV and EEG based indicators of stress in children with Asperger syndrome in audio–visual stimulus test. *Conference proceedings: . . .Annual international conference of the IEEE engineering in medicine and biology society. IEEE engineering in medicine and biology society. Conference* (pp. 2021–2024).

Via, E., Radua, J., Cardoner, N., Happé, F., & Mataix-Cols, D. (2011). Meta-analysis of gray matter abnormalities in autism spectrum disorder: Should Asperger disorder be subsumed under a broader umbrella of autistic spectrum disorder? *Meta-analysis, 68*, 409.

Vygotsky, L. S. (1988). Volume 1: Problems of general psychology including the volume thinking and speech. In R. W. Rieber & A. S. Carton (Eds.), *The collected works of L.S. Vygotsky*. New York: Plenum Press.

Vygotsky, L. S. (1993). Volume 2: The fundamentals of defectology, abnormal psychology and learning disabilities. In R. W. Rieber & A. S. Carton (Eds.), *The collected works of L.S. Vygotsky*. New York: Plenum Press.

Whitney, C., Grossman, M., & Kircher, T. T. (2009). The influence of multiple primes on bottom-up and top-down regulation during meaning retrieval: Evidence for 2 distinct neural networks. *Cerebral Cortex, 19*(11), 2548–2560.

Williams, J. H. (2008). Self-other relations in social development and autism: Multiple roles for mirror neurons and other brain bases. *Autism Research: Official Journal of the International Society for Autism Research, 1*, 73–90.

Williams, J. H., Waiter, G. D., Gilchrist, A., Perrett, D. I., Murray, A. D., & Whiten, A. (2006). Neural mechanisms of imitation and 'mirror neuron' functioning in autistic spectrum disorder. *Neuropsychologia, 44*, 610–621.

Wingfield, A., & Grossman, M. (2006). Language and the aging brain: Patterns of neural compensation revealed by functional brain imaging. *Journal of Neurophysiology, 96*(6), 2830–2839.

Woodard, J. L., Seidenberg, M., Nielson, K. A., Antuono, P., Guidotti, L., Durgerian, S., et al. (2009). Semantic memory activation in amnestic mild cognitive impairment. *Brain, 132*, 2068–2078.

Yang, H. H., Savostyanov, A. N., Tsai, A. C., & Liou, M. (2011). Face recognition in Asperger syndrome: A study on EEG spectral power changes. *Neuroscience Letters, 492*, 84–88.

Yang, C. L., Perfetti, C. A., & Liu, Y. (2010). Sentence integration processes: An ERP study of Chinese sentence comprehension with relative clauses. *Brain and Language, 112*, 85–100.

Yasuhara, A. (2010). Correlation between EEG abnormalities and symptoms of autism spectrum disorder (ASD). *Brain & Development, 32*, 791–798.

Ye, Z., Luo, Y. J., Friederici, A. D., & Zhou, X. (2006). Semantic and syntactic processing in Chinese sentence comprehension: Evidence from event-related potentials. *Brain Research, 1071*, 186–196.

Yvert, G., Perrone-Bertolotti, M., Baciu, M., & David, O. (2012). Dynamic causal modeling of spatiotemporal integration of phonological and semantic processes: An electroencephalographic study. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 32*, 4297–4306.