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**Authors**

Jaime, Mark
McMahon, Camilla M
Davidson, Bridget C
et al.

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# Reduced Temporal-Central EEG Alpha Coherence during Joint Attention Perception in Adolescents with Autism Spectrum Disorder

**Mark Jaime**[1], **Camilla M. McMahon**[2], **Bridget C. Davidson**[3], **Lisa C. Newell**[4], **Peter C. Mundy**[5], and **Heather A. Henderson**[6]

[1]Indiana University-Purdue University–Columbus, Division of Science, 4601 Central Avenue, Columbus, IN, USA 47203

[2]Hamilton College, Psychology Department, 198 College Hill Road, Clinton, NY, USA 13323

[3]University of Texas – Austin, Department of Psychology, 1 University Station – A8000, Austin, TX, USA 78712

[4]Indiana University of Pennsylvania, Department of Psychology, 1020 Oakland Avenue, Indiana, PA, USA 15705

[5]University of California – Davis, MIND Institute, 2825 50th Street, Sacramento, CA, USA 95817

[6]University of Waterloo, Department of Psychology, 200 University Ave. W., Waterloo, ON, Canada N2L 3G1

## Abstract

Although prior studies have demonstrated reduced resting state EEG coherence in adults with autism spectrum disorder (ASD), no studies have explored the nature of EEG coherence during joint attention. We examined the EEG coherence of the joint attention network in adolescents with and without ASD during congruent and incongruent joint attention perception and an eyes-open resting condition. Across conditions, adolescents with ASD showed reduced right hemisphere temporal–central alpha coherence compared to typically developing adolescents. Greater right temporal–central alpha coherence during joint attention was positively associated with social cognitive performance in typical development but not in ASD. These results suggest that, in addition to a resting state, EEG coherence during joint attention perception is reduced in ASD.

**Keywords**

EEG coherence; joint attention; brain connectivity; cortical connectivity; joint attention network connectivity; neurocognitive features of joint attention in ASD; adolescents with ASD; adolescent autistic brain

Several theoretical models of autism spectrum disorder (ASD) propose that aberrant neural organization during early development results in altered neural connectivity and trajectories of social and communicative development (e.g., Belmonte et al., 2004; Courchesne & Peirce, 2005a, 2005b; Just, Cherkassky, Keller, & Minshew, 2004; Just, Cherkassky, Keller, Rajesh, & Minshew, 2007). Altered cortical connectivity in ASD has been posited to result from atypical brain overgrowth and neural pruning during critical periods of experience-dependent neurodevelopment (see Courchesne et al., 2005a for a review). Although there is a substantial body of literature indicative of cortical under-connectivity in individuals with ASD during a resting state (e.g., Cherkassy, Kana, Keller, & Just, 2006; Coben, Clarke, Hudspeth, & Barry, 2008; Lazarev, Pontes, Mitrofanov, & deAzevedo, 2013), language processing (Jones et al., 2010; Just et al., 2004; Kana, Keller, Cherskassky, Minshew, & Just, 2006), working memory (Koshino et al., 2005, 2008), affective processing (Wicker et al., 2008), perceptual processing (Darmala et al., 2010; Villalobos, Mizuno, Dahl, Kemmotsu, & Muller, 2005), and executive functioning (Just et al., 2007), there is also evidence of cortical over-connectivity during rest, imitation, and memory performance (e.g., Lynch et al., 2013; Uddin et al., 2013; Shih et al., 2010; Noonan et al., 2009). Studies have also reported both increased and decreased cortical connectivity in individuals with ASD that appears to be mediated by the frequency of neural oscillations and distance between cortical networks (e.g., Kitzbichler et al., in press). Attempts to understand the nature of connectivity in the autistic brain is further complicated by the fact that there is high variability in the methodological approaches used to examine connectivity and that developmental and experiential processes can modify the functional connectivity of cortical systems over time (e.g., Kana et al., 2014; Uddin, Supekar, & Menon, 2013).

The goal of this study was to examine differences in cortical connectivity during joint attention—a primary and early emerging impairment in autism (Mundy & Newell, 2007). Early joint attention—or the ability to socially coordinate visual attention and share a point of view with another person—is critical for the structural and functional development of the social brain and associated social cognitive competencies characterizing typical development (Mundy, Sullivan, & Mastergeorge, 2009). Theoretically, joint attention depends on the efficient integration of self- and other-related information and therefore requires coordinated activity and integration between neural systems involved in the perceptual processing of faces and eye gaze (e.g., Grelotti et al., 2005; Dalton et al., 2005; Hoffman & Haxby, 2000), experiential awareness of self (e.g., Ehrsson, Holmes, & Passingham, 2005; Radanovic et al., 2002), and representations of others' mental states (e.g., Baron-Cohen et al., 1999; Castelli, Happé, Frith, & Frith, 2000; Gallagher & Frith, 2003). The cortical systems that have been associated with these processes include areas such as medial frontal cortex, parietal cortex, superior temporal sulcus (STS), and fusiform gyrus (e.g., Adolphs, 2009; Saxe, 2006). Previous neuroimaging studies examining the neural correlates of joint

attention reveal elevated levels of activity in medial frontal and temporal–parietal areas in typically developing adults (Williams, Waiter, Perra, Perrett, & Whiten, 2005). Furthermore, the spatial congruence between a model's direction of gaze and the location of a target during joint attention experience has been shown to modulate activity in the STS. That is, when participants were scanned while they observed a model's gaze that was incongruent with the location of the target STS activity increased in typically developing adults but not in adults with ASD (Pelphrey, Singerman, Allison, & McCarthy, 2003; Pelphrey, Morris, & McCarthy, 2005).

In a more recent study by Redcay et al. (2013), the authors used a novel virtual social partner fMRI paradigm to examine the cortical correlates of initiating and responding to joint attention (Mundy et al., 2009) relative to non-social attention. The authors reported that, unlike in typical development, adults with ASD showed undifferentiated activity in posterior STS and dorsal medial prefrontal cortex in response to joint attention vs. non-social attention. Taken together, prior neuroimaging studies suggest that the neural systems that subserve joint attention in ASD may not be reactive to the social significance of joint attention and also suggest that joint attention-eliciting paradigms may have the sensitivity to differentiate individuals across the autism spectrum. For example, using a similar joint attention-eliciting paradigm, Swanson, Serlin, and Siller, (2013) reported that typically developing children with more features of the broad autism phenotype produced altered patterns of visual attention to the model's face as well as the target of shared attention during joint attention perception.

A potential neurocognitive index of social impairment that has yet to be explored is altered functional integration between cortical systems involved in joint attention (e.g., Lombardo et al., 2010; Mundy, Gwaltney, & Henderson, 2010). We therefore examined functional connectivity between frontal–parietal, frontal–occipital, temporal–central, and temporal–parietal cortices—systems posited to be integral in social information processing—in higher functioning adolescents with ASD during a joint attention task. The paradigm chosen for this study was developed by Williams et al. (2005) and has established validity in neuroimaging studies of joint attention. Equally important evidence has recently been reported in this journal that the joint attention paradigm used in this study is sensitive to the broad autism phenotype (Swanson et al. 2013).

The paradigm presents participants with a congruent joint attention condition in which a model directed his gaze towards targets across multiple trials and an incongruent joint attention condition in which the model directed his gaze away from a target across trials. We assessed cortical connectivity using electroencephalographic (EEG) coherence, an index of the synchronous activity between distinct neural assemblies (Nunez & Srinivasan, 2006). Coherence is a statistical estimate of the amount of phase stability between two EEG time series and is computed by normalizing the ratio of the auto-spectra and cross-spectra. Coherence is represented with numerical values between 0 and 1. Higher values represent greater synchronous activity between distinct neural systems whereas lower values represent reduced or non-synchronous activity between distinct neural systems (Nunez & Srinivasan, 2006). EEG power—an index of the magnitude of oscillatory neural activity—was also examined post hoc. Given that EEG coherence is a measure of the degree of synchronous

oscillatory activity between distinct neural systems, there is a possibility that increased neural activity can inflate the values of EEG coherence. Therefore, we examined whether any differences in EEG coherence between adolescents with ASD and typically developing adolescents was driven by diagnostic group differences in EEG power. Although there have been studies that have examined resting EEG power in ASD (e.g., Coben et al., 2008; Mathewson et al., 2012), no studies have examined EEG power during joint attention. Finally, because joint attention involves attentional processes and the integration of self- and other-related information, we focused on alpha and beta band coherence—frequency bands that have been linked to attentional and cognitive processes, respectively (e.g., Mulholland, 1969; Ray & Cole, 1985).

To date, prior studies have only examined resting state EEG coherence in individuals with ASD (Murias et al. 2007; Coben et al., 2008; Mathewson et al 2012). To our knowledge, this is the first study to examine EEG coherence during joint attention in adolescents with ASD. Based on previous work suggesting that cortical systems involved in social attention are modulated by the congruity of joint attention in typical development but not in ASD (Pelphrey et al., 2005; Redcay et al., 2013), we hypothesized that this undifferentiated activity in response to congruent vs. incongruent joint attention may be due to poor functional integration of the joint attention network in ASD. We therefore expected adolescents with ASD to show reduced EEG coherence within cortical areas associated with social information processing relative to typically developing adolescents. In addition, we also expected that typically developing adolescents, but not adolescents with ASD, would show greater EEG coherence during incongruent relative to congruent joint attention perception as this condition presumably elicits increased processing demand (Pelphrey et al., 2005; Redcay et al., 2013). Moreover, we expected a positive association between cortical connectivity during joint attention perception and social cognitive ability in typically developing adolescents, but not in adolescents with ASD. This prediction was based on the theoretical conception that individuals with ASD have a history of atypical experience-dependent neurodevelopment, characterized by varying degrees of functional disorganization and poor integration of the joint attention system across the autism spectrum (e.g., Belmonte et al. 2004; Lewis & Elman, 2008). Therefore, we did not expect functional EEG coherence and social cognitive ability to be associated in the sample of adolescents with ASD.

## Methods

### Participants

High-functioning adolescents with ASD—Verbal Comprehension Index of 70 or higher on the Wechsler Intelligence Scale for Children – IV (WISC-IV; Williams, Weiss, & Rolfhus, 2003)—were recruited from the University of Miami/Nova Southeastern University Center for Autism and Related Disabilities. A typically developing group of adolescents was recruited from Miami-Dade public schools. Adolescents in the ASD group had a diagnosis of ASD from a community mental health professional. Each participant's diagnostic status was verified in the lab using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) and the Social Communication Questionnaire (SCQ; Berument, Rutter, Lord, Pickles, & Bailey, 1999). The ADOS was administered by trained doctoral students and

graduate-level research staff with experience in developmental assessments. Cutoff scores of 7 on the ADOS and 13 on the SCQ were required for inclusion in the ASD group. A total of 52 (24 ASD; 28 TD) adolescents participated in this study. After verification of diagnosis, 1 adolescent did not meet criteria for ASD on the ADOS and 3 typically developing adolescents met the cutoff score on the SCQ, these adolescents were not included in the analyses. An additional 15 adolescents—7 with ASD—were not included in the analyses because of missing EEG data due to technical problems during acquisition. The final sample consisted of 33 (16 ASD; 17 TD) adolescents. The groups did not differ on age, $t(31) = -.384$, $p = .703$, performance IQ, $t(31) = 0.638$, $p = .528$, verbal IQ, $t(34) = -1.74$, $p = .093$, or gender distribution, $\chi^2 (1, N=33)= .510$, $p = .475$. A summary of descriptive data is provided in Table 1. Study procedures were approved by the University Institutional Review Board. All adolescents and their parents provided informed assent and consent, respectively.

### Social Cognition Measure

The Reading the Mind in the Eyes Test (Eyes Test; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) was administered to each participant. This test is a measure of social sensitivity and examines an individual's ability to attribute mental states from minimal cues (e.g., small area around the eyes). For this test, participants were shown 28 pictures of the eye region of a face and then asked to select one of four words that best described what the person in the picture was thinking or feeling. The number of pictures in which the participant correctly identified the corresponding affective word resulted in the Eyes Test's total score. Higher scores on this test indicate higher social cognitive ability.

### EEG and Eye Tracking Equipment

EEG was obtained with a 128-channel Electrical Geodesics Inc. (EGI) system consisting of Geodesics Sensor Net, Net Amps, and Net Station software (Electrical Geodescis Inc., Eugene, OR). A Tobii ×50 eye tracker (Tobii Technology, Inc., Sweden) and its proprietary software (Clearview version 2.7.1) was used to quantify visual fixation time to the joint attention stimuli.

### Joint Attention Stimuli

The stimuli used in this study were 12 consecutive joint attention-eliciting video clips. These videos consisted of a red dot appearing and disappearing at the four corners of the screen and a human model situated in the center of the screen. As the red dot appeared in each corner the model subsequently gazed (with the eyes and head) at one of the corners. In the congruent condition, the model gazed at the corner in which the red dot appeared. In the incongruent condition, the model gazed in a different corner of the screen from the corner in which the red dot appeared (Figure 1). Each video clip lasted 30 seconds and began with the model's initial gaze directed at the center of the screen (gazing at the observer), followed by four gaze shifts to each of the corners of the screen, and a final gaze directed at the center of the screen again. Each gaze to the corner, as well as the initial and final gaze, was approximately 4.5 seconds in duration. The 12 consecutive video clips alternated between the congruent and the incongruent version of joint attention. The time interval between videos was approximately 1 s. The order of the two video conditions was semi-randomized —each participant viewed 1 of 4 possible orders. For each order, half of the videos presented

were the congruent joint attention version and half were the incongruent joint attention version.

## Procedure

**EEG Data Acquisition—**The experiment began by first applying the EEG net on the participants. Then the Tobii ×50 eye-tracker was calibrated using a 5-point calibration grid. Before the video stimulus was played the participants were instructed to follow the red dot appearing in the video with their eyes. No other instruction or feedback was provided to participants. Videos were then played using the Tobi eye-tracker's proprietary software, Clearview 2.7.1. EEG data was continuously recorded during the 12 consecutive video presentations. Impedances were kept below 50 kΩ and EEG data was sampled at 500 Hz and filtered using a 0.1 – 200 Hz analog filter. All 128 channels were continuously recorded, using the Cz electrode as a reference, and a 30 Hz low-pass digital filter. During acquisition event markers were manually inserted using Net Station in order to indicate when the congruent and incongruent videos occurred. After the video trials were completed, an additional 5 minutes of eyes open resting EEG was obtained in a second recording; this served as a baseline comparison to the joint attention conditions. In the eyes open resting condition adolescents were instructed to fixate to a picture of a small circle on the wall. This duration of time was chosen to approximate the duration of time of the joint attention video presentations.

**EEG Data Preparation—**Subsequent to acquisition, the EEG data were imported into the EMSE Software Suite (Source Signal Imaging, San Diego, CA) and re-referenced to an average reference. Eye blink artifact was visually inspected and segments of data containing deflections greater than 150 µV relative to baseline were marked for exclusion from coherence and power analyses. The EEG data was also visually inspected for ocular movement deflections of 50 µV relative to baseline, ocular flutter, or muscle movement artifact. Segments of EEG data containing these artifacts were marked for exclusion from the coherence and power analyses. Individual channels were identified as bad and removed if the amplitude of the channel exceeded 200 µV, had zero variance, or appeared bad during more than 20% of the EEG data file. EEG data files that contained more than 10% bad channels were removed from the analysis. If an individual EEG data file contained two or fewer bad channels, the channels were corrected with the EMSE spatial interpolation filter. Participants' data were excluded from the study if the total proportion of data retained after artifact removal was less than 60%. The proportion of data retained did not differ between diagnostic groups, $t(30) = -1.06$, $p = .296$.

The data were prepared for coherence and power analyses by first demarcating the twelve 30 s segments of continuous EEG data into six segments for the congruent condition and six segments for the incongruent condition. A Fast Fourier Transform with a Hanning window of 2 seconds and a 50% overlap was then applied to the artifact-free portions of the EEG data segments. Based on literature linking attentional and cognitive mechanisms with alpha (8–12 Hz) and beta (13–25 Hz) frequency band activity, respectively, only these frequency bands were examined (e.g., Mulholland, 1969; Ray & Cole, 1985).

**EEG Coherence**—Coherence was computed using the EMSE (Source Signal Imaging, San Diego, CA) coherence function, which is based on a standard coherence estimate definition (see Nunez & Srinivasan, 2006). For each participant, a measure of EEG coherence was computed separately for each joint attention condition (congruent/incongruent). This was done by computing an average coherence across all segments of EEG data belonging to congruent video presentations and computing an average coherence across all segments of EEG data belonging to incongruent video presentations. Coherence was computed across the 5 min eyes open resting condition. We were specifically interested in assessing coherence between frontal–parietal, frontal–occipital, temporal–central, and temporal–parietal cortices; areas postulated to be involved in joint attention and in the processing of social cues (e.g., Mundy et al., 2009; Mundy & Jarrold, 2010; Saxe, 2006). First, sensors in the 128-channel Geodesic Sensor Net (Electrical Geodesics, Inc.) that corresponded to sensor positions of the international 10/20 placement system (Jasper, 1958) were identified according to Electrical Geodesics, Inc. technical specifications. Electrodes pairs were then selected based on Homan, Herman, and Purdy's (1987) electrode placement correlates of cortical location. Accordingly, left and right hemispheric coherence was computed between the following electrode sites: (1) F3–P3 and F4–P4 (left and right frontal–parietal sensors, respectively), (2) F3–O1 and F4–O2 (left and right frontal–occipital sensors, respectively), (3) T7–C3 and T8–C4 (left and right temporal–central sensors, respectively), and (4) T7–P3 and T8–P4 (left and right temporal–parietal sensors, respectively) (see Figure 2).

**Post hoc Measures**—The following measures were examined post hoc to rule out alternative explanations for differences in EEG coherence between adolescents with ASD and typically developing adolescents.

**EEG Power**—EEG power during joint attention was computed post hoc using the EMSE software (Source Signal Imaging, San Diego, CA) power spectrum density function. For each participant, power was computed for each EEG segment. Segments belonging to each of the two joint attention conditions (congruent, incongruent) were then averaged together. Alpha and beta power was computed in the following electrodes: left and right frontal (F3 and F4, respectively), left and right central (C3 and C4, respectively), left and right temporal (T7 and T8, respectively), left and right parietal (P3 and P4, respectively), and left and right occipital (O1 and O2, respectively).

**Visual Fixations**—The Tobii ×50 eye-tracker was used to quantify each participant's total amount of fixation time to the entire area of the monitor. Areas of interest were then drawn around the face area and corners of the screen (Figure 1) and the proportion of visual fixation time to the face and corner areas was calculated by dividing the total amount of fixation time within each area of interest (face, corners) by the total amount of fixation time to the entire area within the monitor (including areas of interest). This proportion measure was computed separately for each condition.

## Results

Coherence was examined with two separate repeated measures ANOVAs—one for the alpha band and one for the beta band—with region (frontal–parietal, frontal–occipital, temporal–central, temporal–parietal), condition (congruent, incongruent, eyes-open rest), and hemisphere (left, right) as within-subjects factors and diagnostic group (typical development, ASD) and order (1, 2, 3, 4) as between-subjects factors. Repeated measures ANOVAs performed on both the alpha and beta coherence measures revealed no significant main effects or interactions with order. Since there was no evidence of order of stimulus presentation effects on EEG coherence, this factor was not included in the subsequent report of results. Mauchly's test for the repeated measures ANOVA performed on the alpha and beta band coherence measures revealed that the assumption of sphericity had been violated. Therefore, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity where appropriate in analyses of these data. Coherence measures are summarized in Table 2.

### Alpha Coherence

The repeated measures ANOVA conducted to examine the effects of diagnostic group on alpha coherence during joint attention perception revealed a main effect for diagnostic group, $F(1, 31) = 4.50$, $p = .042$, $\eta_p^2 = 0.127$, and a main effect of region, $F(1.90, 32) = 241$, $p < .001$, $\eta_p^2 = 0.886$. As can be seen in Figure 3 the adolescents with ASD displayed lower indices of alpha band coherence than the typically developing adolescents. However, both groups displayed more evidence of temporal–parietal or central coherence than frontal–parietal or occipital coherence. These main effects were qualified by a region by diagnostic group interaction, $F (3, 29) = 3.04$, $p = .033$, $\eta_p^2 = 0.089$, as well as condition by region interaction, $F(3.15, 26) = 3.49$, $p = .003$, $\eta_p^2 = 0.101$. To examine the region by diagnostic group interaction, four separate post hoc ANOVAs (one for each region) were performed with condition and hemisphere as within-subjects factors and diagnostic group as the between-subjects factor. Results revealed a significant reduction in temporal–central alpha coherence in adolescents with ASD relative to typically developing adolescents, $F(1, 31) = 5.34$, $p = .028$, $\eta_p^2 = 0.172$, across conditions (Figure 3). The post hoc ANOVAs for the other regions were not significant. The region by condition interaction was examined with a series of Bonferroni adjusted paired-sample $t$-tests. These tests examined alpha coherence between conditions per each region resulting in a total 12 paired-sampled t-tests. Results of these stringent tests revealed no significant differences in regional EEG alpha coherence between conditions. However, when the Bonferroni correction was removed, temporal–central alpha coherence was significantly greater in the eyes open resting condition than the congruent, $t(32) = -2.42$, $p = .021$, and incongruent, $t(32) = -2.46$, $p = .020$, joint attention conditions.

### Beta Coherence

There were main effects of condition, $F(1.30, 30) = 12.1$, $p < .001$, $\eta_p^2 = 0.281$, region, $F(1.55, 29) = 119$, $p < .001$, $\eta_p^2 = 0.793$, and hemisphere, $F(1, 31) = 5.68$, $p = .023$, $\eta_p^2 = 0.1550$; however, there were no significant interactions or diagnostic group differences. Main effects were examined with pairwise comparisons. These tests revealed that there were

significant differences between beta band coherence for the eyes-open resting ($M = .24$), incongruent joint attention ($M = .22$), and congruent joint attention ($M = 0.21$) conditions. In addition, there were significant differences between beta band coherence for the temporal–central ($M = .54$), temporal–parietal ($M = 0.32$), frontal–parietal ($M = .07$), and frontal–occipital ($M = .05$) regions. Finally, beta coherence was also significantly greater in the left ($M = .24$) relative to the right ($M = .21$) hemisphere.

### EEG Coherence and Social Cognition

Correlation analyses were conducted for each diagnostic group separately to examine the relationship between coherence for each region per hemisphere during joint attention (averaged across congruent and incongruent conditions) and social cognitive performance on the Eyes Test. Correlations were performed separately for alpha and beta band coherence. These analyses revealed that right hemisphere temporal–central alpha coherence was positively correlated with scores on the Reading the Mind in the Eye Test for the typically developing group, $r(17) = .58$, $p = .014$, but not for the ASD group, $r(16) = -.052$, $p = .847$ (Figure 3).

### Post hoc Measures

**EEG Power**—We examined EEG power post hoc to rule out the possibility that differences in power between adolescents with ASD and typically developing adolescents were driving diagnostic group differences in coherence. Power was examined with two separate repeated measures ANOVAs—one for the alpha band and the other for the beta band—with region, hemisphere, and condition (congruent, incongruent) as within-subjects factors and diagnostic group as the between-subjects factors. Two separate correlation analyses (for the alpha and beta band) were also performed between power (averaged across all electrodes examined in this study) and coherence (averaged across regions and hemispheres). The repeated measures ANOVA performed on the alpha power data revealed a main effect of diagnostic group indicating that adolescents with ASD displayed higher alpha power ($M = 2.14\ \mu V$) compared to typically developing adolescents ($M = 1.28\ \mu V$), $F(1, 31) = 5.05$, $p = .032$, $\eta_p^2 = 0.140$. The repeated measures ANOVA performed on beta power revealed a main effect of region, $F(3.01, 28) = 3.101$, $p = .030$, $\eta_p^2 = 0.091$. There was also a hemisphere by diagnostic group interaction, $F(1, 31) = 4.78$, $p = .036$, $\eta_p^2 = 0.134$, which indicated that adolescents with ASD had greater beta power in the left hemisphere ($M = .22\ \mu V$) than the right hemisphere ($M = .17\ \mu V$) and typically developing adolescents had greater power in the right hemisphere ($M = .12\ \mu V$) than the left hemisphere ($M = .11\ \mu V$). However, there was a marginally nonsignificant main effect for diagnostic group in beta band power, $F(1, 31) = 3.95$, $p = .056$, $\eta_p^2 = .113$. Correlation analyses did not reveal any significant association between power and coherence in the alpha and beta band, $r(33) = -.194$, $p = .278$ and $r(33) = -.266$, $p = .135$, respectively.

**Visual Fixations**—Visual fixation time to video presentations was also examined post hoc to rule out the possibility that differences in visual attention between adolescents with ASD and typically developing adolescents affected diagnostic group differences in coherence. The proportion of visual fixation time was examined in a condition (congruent, incongruent) by area of interest (face, corners) repeated measures ANOVA with diagnostic group as the

between-subjects factors. Results revealed a main effect of condition, $F(1, 26) = 5.86$, $p = .023$, $\eta^2 = .184$, and area, $F(1, 26) = 5.36$, $p = .029$, $\eta^2 = .171$. The main effect of condition revealed that, across groups, adolescents spent a greater proportion of time fixated on the areas of interest (face, corners) during the congruent condition ($M = .15$) than the incongruent condition ($M = .12$). The main effect of area revealed that, across groups, adolescents spent a greater proportion of time fixated to the corners ($M = .16$) than the face area ($M = .11$). There were however no significant interactions or between-subjects effects. Taken together, these results suggest that adolescents in both groups were performing the task according to instruction, which was to follow the red dot. However, the increased fixation time to the areas of interest (face, corners) during congruent videos relative to incongruent videos suggests that the incongruent videos diverted participants' gaze away from the areas of interest.

## Discussion

In this study, the EEG coherence of adolescents with and without ASD was examined while they observed congruent and incongruent joint attention videos. Coherence during an eyes open resting condition was also computed and used as a baseline comparison. We were specifically interested in connectivity among cortical areas involved in joint attention and social information processing (e.g., Mundy et al., 2009; Mundy & Jarrold, 2010; Saxe, 2006). Our findings suggest a general reduction in alpha coherence in adolescents with ASD relative to adolescents with typical development. This study's findings are similar to prior studies that have reported reduced alpha coherence in adults and children with ASD (Coben et al., 2008; Murias et al., 2007). Moreover, a significant region by diagnostic group interaction revealed that alpha band hypocoherence in adolescents with ASD was more pronounced within medial temporal cortex during social attention and during eyes open rest.

There was also a significant condition by region interaction which revealed increased temporal–central alpha coherence in the eyes open resting condition relative to the joint attention conditions. This may be an indication of subtle differences in attentional processes between conditions. For example, fixating to a small dot on a wall (as in the eyes open resting condition) is presumably not as engaging as attending to dynamic videos. Thus, the eyes open resting condition may have required participants to exert a greater degree of top-down attentional control in order to maintain fixated on the target. Interestingly, there is literature that has implicated medial parietal and temporal areas in the top-down control of visual attention (Corbetta & Shulman, 2002). One study has shown that reduced functional connectivity within the precuneus—one of the midline structures of the default mode network—is associated with the degree of sustained attention impairment among patients with traumatic brain injury (Bonnelle et al., 2011). In a previous fMRI study, Fox et al (2005) has identified a functional network—consisting of medial temporal cortex, intraparietal sulcus, and precentral sulcus—that shows increased activation during resting-state tasks such as fixating to a crosshair, resting with eyes closed, and resting with eyes open. In summary, subtle differences in attentional processing between the eyes open resting condition and joint attention perception could have modulated coherence within medial temporal areas.

Contrary to our prediction, congruent/incongruent joint attention did not modulate alpha or beta EEG coherence differentially for each diagnostic group. One possible explanation for the lack of a diagnostic group by condition effect may be due to the instructions provided (i.e., follow the dot). For example, in the incongruent trials the task instructions may have precluded participants from attributing an intention behind the actor's gazes averted from the target because participants were likely focused on performing the task correctly. Perhaps allowing participants to visually explore the video freely and without instruction would have been more effective at eliciting mentalizing during the perception of the joint attention videos and in turn revealed differences in coherence between the congruent and incongruent conditions. It also should be noted, however, that the incongruent joint attention condition has been observed to be as sensitive or more sensitive to the individual differences associated with the broad autism phenotype (Swanson et al. 2013). Thus, it may be that both conditions elicit neural activation patterns that are important to understand in research on ASD.

There was also no diagnostic group difference in frontal–parietal or frontal–occipital coherence. One explanation for this result may be that the task used in this study involved attention orienting. Therefore, the lack of group differences may suggest that adolescents with ASD have a functionally intact frontal–parietal attention-orienting network (Posner & Peterson, 1990). This is in agreement with existing studies that have demonstrated relatively unaffected attention orienting in children with ASD (e.g., Kylliainen & Hietanen, 2004; Haist et al., 2005; Pruett et al., 2010; Senju et al., 2004; Swettenham et al., 2003). However, it is also the case that the type of gaze following measure of joint attention used in this study may not be especially sensitive to frontal–parietal connectivity (Mundy & Jarrold, 2010), and that a comparison of initiating joint attention behavior may have more potential to observe activation of the frontal–parietal control network (Mundy, in press).

Across groups, beta band coherence was also significantly greater between short-range regions (temporal–central, temporal–parietal) than long range-regions (frontal–occipital, frontal–parietal) and greater within the left hemisphere than right hemisphere. The difference between short-range and long-range beta coherence reflects the fact that volume conduction and axonal fiber length can inflate coherence at shorter inter-electrode distances (see Thatcher, Krause, & Hrybyk, 1986; Nunez & Srinivasan, 2006). However, the greater left hemisphere beta coherence observed across diagnostic groups is not consistent with a prior study, which demonstrates greater resting-state right hemisphere coherence compared to left hemisphere coherence in a large sample of typically developing children and adolescents (e.g., Thatcher et al., 1986). Coben et al. (2008) has also reported decreased left vs. right intrahemispheric coherence in an ASD sample, but only for the delta, theta, and alpha frequency bands. These contradictory findings coupled with a lack of prior studies on EEG coherence during joint attention makes interpretation of the increased left hemispheric beta coherence difficult.

In this study the reduced alpha coherence during joint attention in adolescents with ASD is likely not attributed to reduced visual attention or to a reduction in alpha power. Specifically, a post hoc analysis of visual fixation time revealed that allocation of visual attention to the stimuli was similar across diagnostic groups. Moreover, alpha coherence during joint

attention was not associated with alpha power during joint attention. Taken together, these results suggest a genuine reduction in alpha coherence during joint attention in adolescents with ASD relative to typically developing adolescents. It is interesting to note however that although alpha coherence was reduced in the ASD group, alpha power was significantly greater in the ASD group relative to the typically developing group. To date, little is known about EEG power during joint attention. However, there have been a limited number of studies that have examined EEG power in other nonsocial conditions; these studies present mixed results. For example, an early study of EEG power in autism has reported elevated levels of alpha power during sleep in children with autism compared to typically developing children (Ogawa et al., 1982). Other work has demonstrated no differences in alpha power between children with ASD and children with typical development (Coben et al. 2008). More recently, Mathewson et al. (2013) has demonstrated that during an eyes closed condition alpha power in adults with ASD did not differ from typically developing adults but did show elevated levels in the ASD group when the condition was with eyes open. Thus, more research is needed to understand the role of EEG alpha power during joint attention in ASD.

Consistent with our hypothesis, EEG coherence—specifically right temporal–central alpha coherence—during the perception of joint attention-eliciting videos was positively associated with social cognitive performance in typically developing adolescents, but not in adolescents with ASD. In interpreting this lack of association caution must be exercised because of the possibility of type two error in studies with modest sample sizes, especially in correlation analyses. Nevertheless, the lack of association in the ASD group may reflect a tendency of children with ASD to display idiosyncratic patterns of functional neural network organization (Minshew & Keller, 2010). This may lead to heterogeneity of variance whereby the meaning of individual differences in neurocognitive markers in ASD differ within the sample and differ from the meaning of variance on other samples. For example, Figure 4 shows that the four children with ASD who had the lowest scores (11 & 12) on the Reading the Mind in the Eyes Test displayed either very low, medium, or very high right temporal–central alpha coherence. However, for the rest of the ASD sample the scatter plot data in Fig. 4 suggests the bivariate relation is still variable but appreciably more like the typical pattern of increasing temporal–central alpha coherence with higher social cognitive task scores. Thus, the ASD sample appeared to display higher inter-individual variability in functional connectivity, with little evidence of an association between joint attention related connectivity and social cognition in children with very low Reading the Mind in the Eyes task scores. Alternatively, the association observed in the control sample supports the hypothesis of a significant overlap in the development the neural networks for joint attention and social cognition in typical development (Mundy, 2003).

Neurodevelopmental conceptions of ASD suggest that early aberrant neuronal growth and differentiation results in weakened connectivity among critical systems involved in social information processing (e.g., Courchesne 2005b; Just et al., 2004; Quartz, 1999). This may in turn result in atypical patterns of social experience, such as joint attention, which can exacerbate an already compromised social brain network. Previous computational modeling of neural networks from the prenatal period to approximately four years of age provide support that a deviation from the typical neurodevelopmental trajectory, characteristic of

autism, leads to altered cortical connectivity (Lewis & Elman, 2008). Thus, the underconnectivity observed in adolescents with ASD in this study may reflect an interaction between structural abnormalities brought about during earlier periods of neurodevelopment and altered experience-dependent processes. Interestingly, studies have reported subtle anatomical abnormalities in the temporal lobes in children with ASD (Boddaert et al., 2004) characterized by a bilateral decrease in grey matter and a right hemispheric decrease in white matter concentrations, as well as differences in the position of the superior frontal sulci, right Slyvian fissure, and right STS in children and adolescents with ASD (Levitt et al., 2003). These structural abnormalities in temporal cortex may give rise to inefficient integration in other areas of the joint attention network.

There are several limitations to the current study. The use of visual inspection to reject electroculographic artifact is prone to human error and an automated correction algorithm would have been more appropriate (Croft & Barry, 2000). Furthermore, the reduced regional EEG coherence in adolescents with ASD observed in both joint attention and resting conditions may imply that it is not specific to joint attention perception, rather to a more general cortical underconnectivity. However, we would like to point out that the current study lacked an appropriate nonsocial comparison—one in which participants observed a similar set of videos but without a model gazing at the red dot. Perhaps the use of a nonsocial comparison instead of an eyes open resting condition would have revealed differences between a joint attention and a nonsocial condition. Given that prior work has reported reduced resting-state alpha EEG coherence in individuals with ASD relative to controls (Coben et al., 2008; Murias et al., 2007)—and within brain areas that coincide with the perception of congruent and incongruent joint attention (Williams, et al., 2005)—it is also possible that the results of this study reflect reduced alpha EEG coherence across two functionally independent systems. Nevertheless, relating the present findings primarily to joint attention should be done with caution.

In line with an emerging literature that consistently implicates cortical underconnectivity during various cognitive processes as a critical feature of ASD (e.g., Assaf et al., 2010; Damarla et al., 2010; Lazarev et al., 2013; Minshew & Keller, 2010), the findings from this study suggest that cortical underconnectivity may underlie joint attention impairments in ASD. This study also provides preliminary support for the current model of joint attention impairment of autism—one of a problematic integration between neural representations of self- and other-referenced information (Mundy et al., 2009, Mundy & Jarrold, 2010). The consequence of this neural disturbance is increased information processing demand and decreased integration among interactive neural systems involved in social and communicative exchanges. Thus, higher functioning adolescents with ASD may have limited neurocognitive resources to efficiently deal with the processing demands of a dynamic social context. This study was however an initial step towards characterizing the nature of cortical connectivity of the autistic brain during joint attention. More research is needed to bolster current models that posit that an aberrant connectivity of the joint attention network is a characteristic of ASD.

## Acknowledgments

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Congruent

Incongruent

**Figure 1.**
Screen captures for the congruent gaze (left) and incongruent gaze (right) joint attention eliciting videos. Boxes represent the areas of interest which comprise the corners (a) and the face (b).
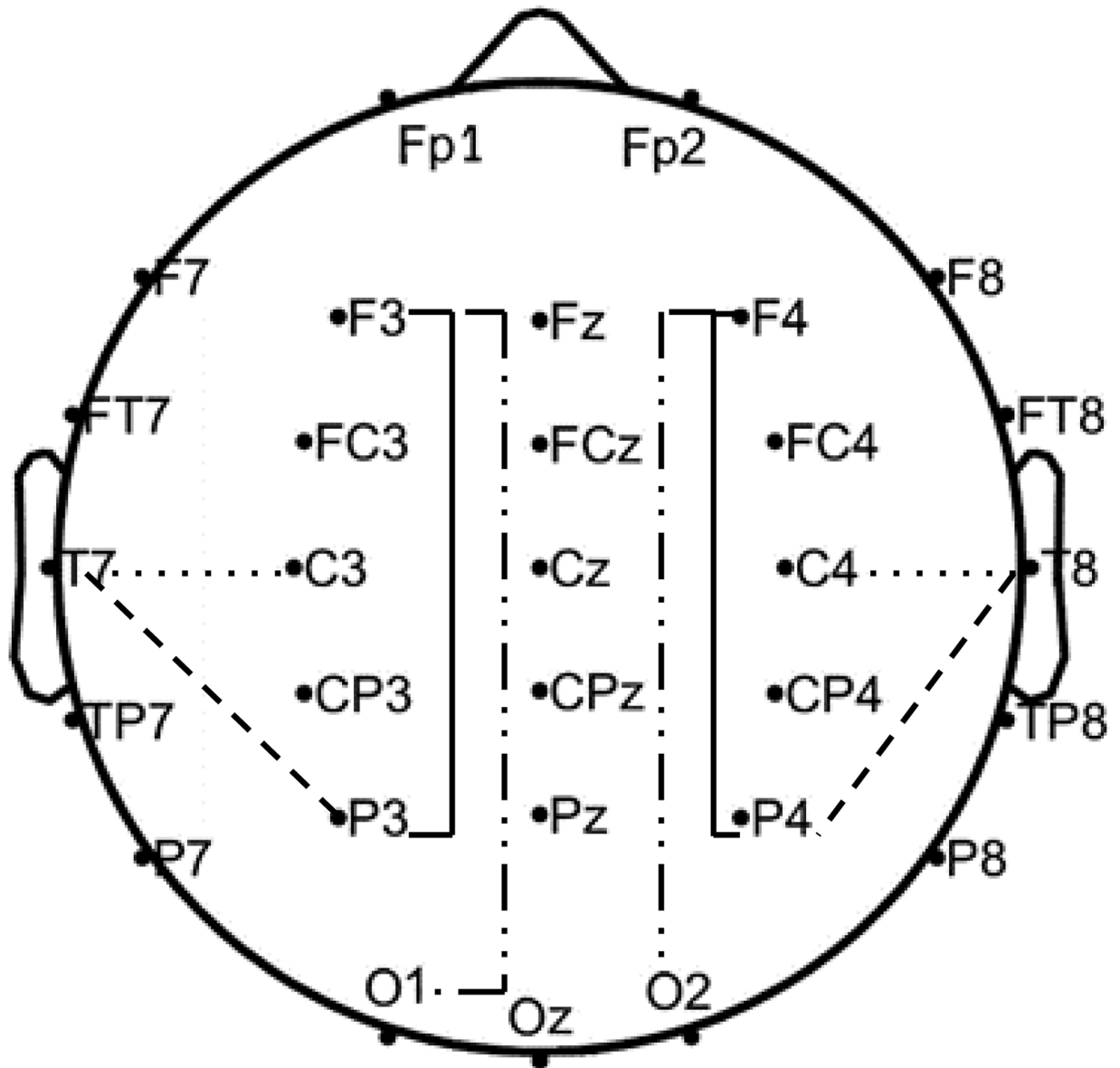
# Anterior



**Figure 2.**
A top view illustration of electrode pairs used to compute coherence for left and right frontal–parietal (solid lines), temporal–central (dotted lines), temporal–parietal (dashed lines), and frontal–occipital (dashed and dotted lines) cortical areas.
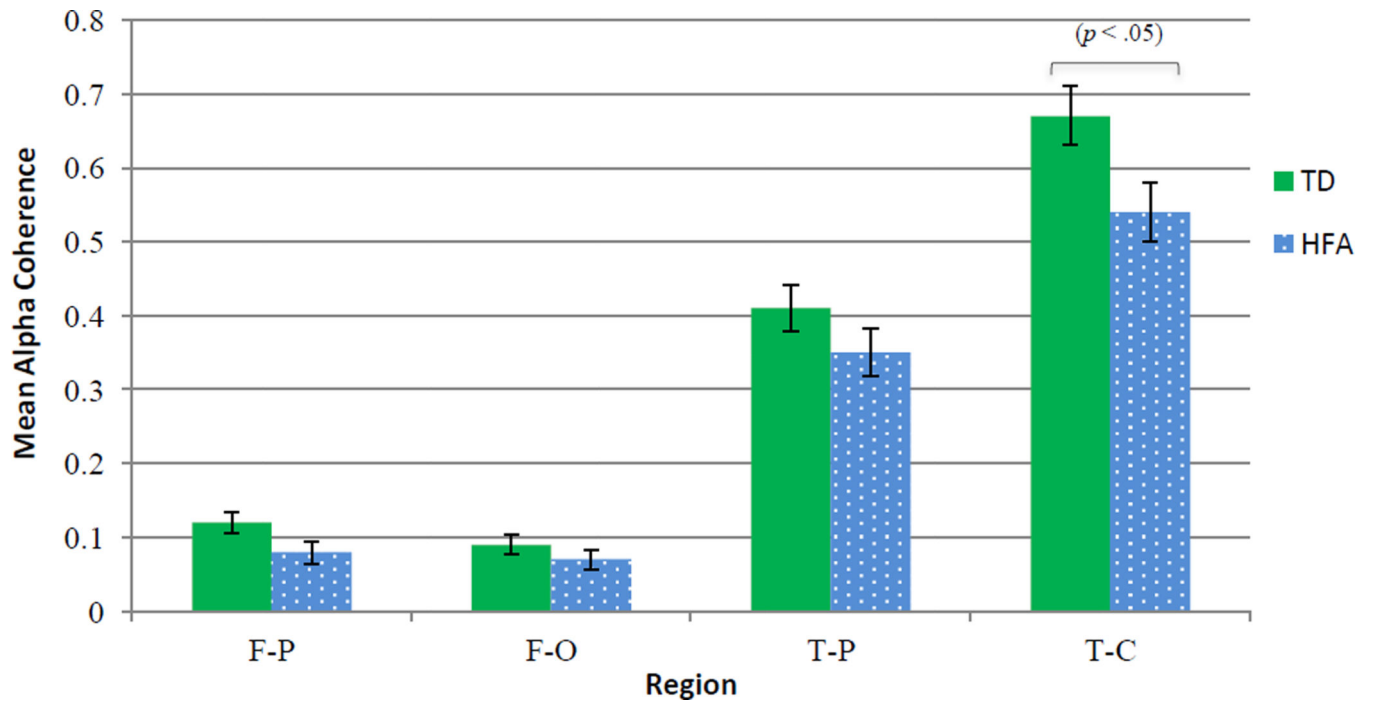
**Figure 3.**
Mean alpha coherence (and standard error) per region and diagnostic group. F-P (frontal-parietal), F-O (frontal-occipital), T-P (temporal-parietal), T-C (temporal-central).
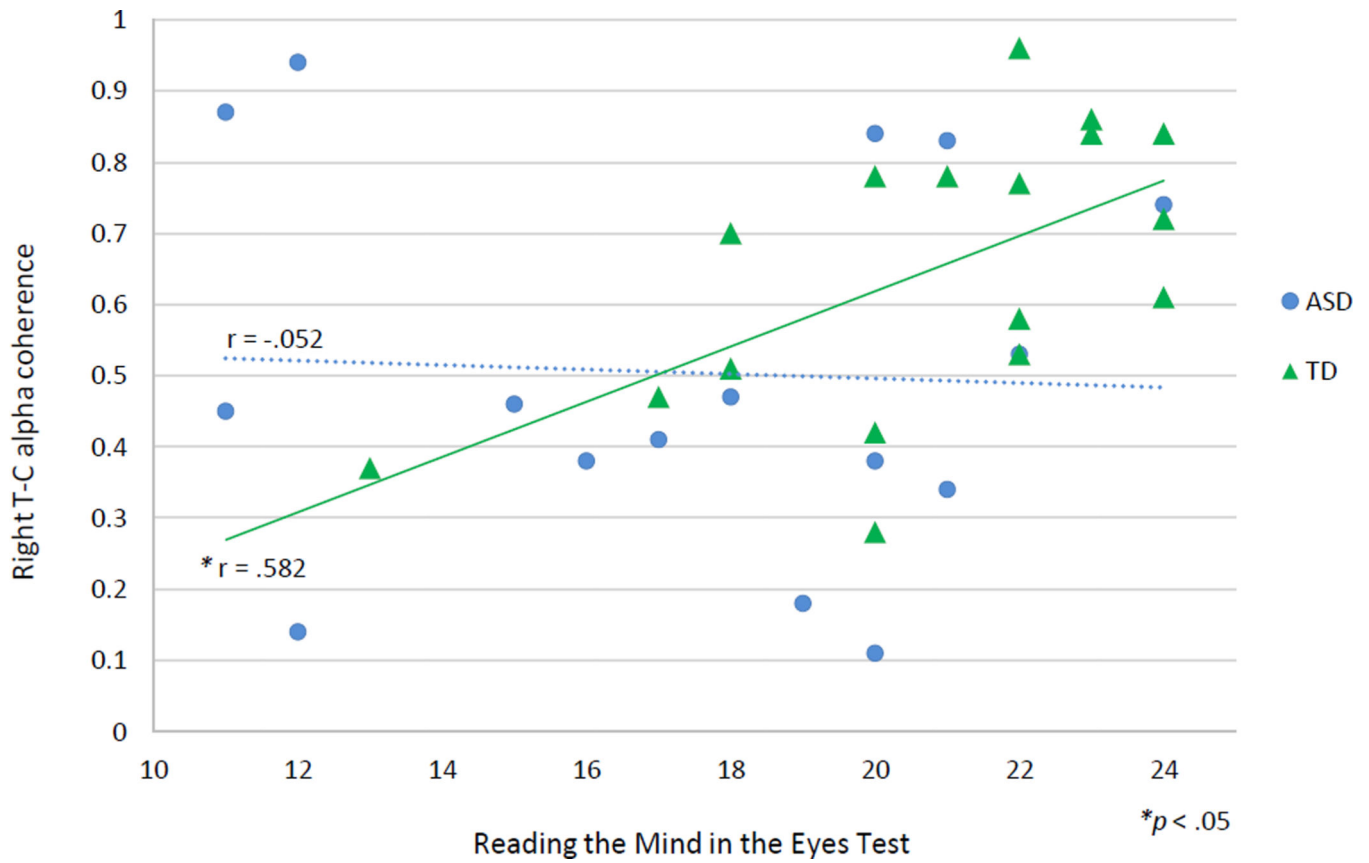
**Figure 4.**
Right temporal-central EEG alpha coherence as a function of scores on the Reading the Mind in the Eyes test.

**Table 1**

Means (and standard deviations) of age in years, verbal IQ, performance IQ, and the Reading the Mind in the Eyes Test scores.

|  | ASD (*N* = 16, 2 females) | TD (*N* = 17, 6 females) |
|---|---|---|
| Age | 16.2 (2.29) | 16.5 (1.94) |
| VIQ | 99 (14.6) | 108 (14.8) |
| PIQ | 106 (13.2) | 103 (16.8) |
| Eyes Test | 18.0 (4.13) | 20.8 (2.95) [*] |

[*] *p* < .05 *t*-test

**Table 2**

Means for left/right hemisphere alpha and beta regional coherence (and standard deviation) per condition.

| Dx | Region | Frequency | Congruent | Incongruent | Rest (eyes open) |
|---|---|---|---|---|---|
| ASD | F-P | α | .10 (.07) / .06 (.06) | .10 (.09) / .08 (.08) | .09 (.07) / .12 (.16) |
| | | β | .06 (.04) / .04 (.03) | .07 (.04) / .05 (.08) | .06 (.06) / .10 (.11) |
| | F-O | α | .08 (.05) / .06 (.05) | .08 (.05) / .06 (.04) | .09 (.07) / .06 (.05) |
| | | β | .05 (.05) / .04 (.04) | .05 (.05) / .04 (.04) | .05 (.05) / .05 (.04) |
| | T-C | α | .53 (.22) / .49 (.28) | .51 (.26) / .51 (.26) | .54 (.23) / .63 (.23) |
| | | β | .40 (.27) / .34 (.29) | .40 (.28) / .34 (.27) | .55 (.23) / .46 (25) |
| | T-P | α | .39 (.19) / .29 (.12) | .41 (.18) / .30 (.12) | .35 (.15) / .32 (.14) |
| | | β | .35 (.21) / .20 (.13) | .34 (.22) / .20 (.12) | .32 (.22) / .28 (.11) |
| TD | F-P | α | .18 (.21) / .08 (.07) | .16 (.13) / .08 (.07) | .12 (.12) / .10 (.08) |
| | | β | .11 (.10) / .06 (.06) | .11 (.09) / .06 (.06) | .10 (.09) / .06 (.06) |
| | F-O | α | .09 (.08) / .08 (.07) | .09 (.08) / .08 (.07) | .09 (.07) / .10 (.07) |
| | | β | .05 (.05) / .04 (.03) | .05 (.04) / .04 (.03) | .07 (.07) / .06 (.06) |
| | T-C | α | .67 (.20) / .66 (.17) | .68 (.20) / .63 (.23) | .72 (.16) / .69 (.19) |
| | | β | .51 (.28) / .43 (.27) | .53 (.25) / .48 (.25) | .55 (.23) / .52 (.24) |
| | T-P | α | .42 (.21) / .41 (.18) | .42 (.20) / .40 (.21) | .42 (.18) / .37 (.16) |
| | | β | .35 (.20) / .43 (.27) | .32 (.19) / .34 (.19) | .38 (.18) / .37 (.14) |

Frontal-parietal (F-P), frontal-occipital (F-O), temporal-central (T-C), and temporal-parietal (T-P).