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Autism, Attention, and Alpha Oscillations: An Electrophysiological Study of Attentional Capture

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ABSTRACT

BACKGROUND: Autism spectrum disorder (ASD) is associated with deficits in adaptively orienting attention to behaviorally relevant information. Neural oscillatory activity plays a key role in brain function and provides a high-resolution temporal marker of attention dynamics. Alpha-band (8–12 Hz) activity is associated with both selecting task-relevant stimuli and filtering task-irrelevant information.

METHODS: The present study used electroencephalography to examine alpha-band oscillatory activity associated with attentional capture in 19 children with ASD and 21 age- and IQ-matched typically developing children. Participants completed a rapid serial visual presentation paradigm designed to investigate responses to behaviorally relevant targets and contingent attention capture by task-irrelevant distractors, which either did or did not share a behaviorally relevant feature. Participants also completed 6 minutes of eyes-open resting electroencephalography.

RESULTS: In contrast to their typically developing peers, children with ASD did not evidence posterior alpha desynchronization to behaviorally relevant targets. Additionally, reduced target-related desynchronization and poorer target detection were associated with increased ASD symptomatology. Typically developing children also showed behavioral and electrophysiological evidence of contingent attention capture, whereas children with ASD showed no behavioral facilitation or alpha desynchronization to distractors that shared a task-relevant feature. Lastly, children with ASD had significantly decreased resting alpha power, and for all participants increased resting alpha levels were associated with greater task-related alpha desynchronization.

CONCLUSIONS: These results suggest that in ASD underresponsivity and impairments in orienting to salient events within their environment are reflected by atypical electroencephalography oscillatory neurodynamics, which may signify atypical arousal levels and/or an excitatory/inhibitory imbalance.

Keywords: Alpha, Attention, Autism, EEG, Event-related desynchronization, Resting state

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Given the infinite number of objects and events to which one can attend and the finite nature of the human brain's processing capacity, a key function of attention is to select items for further processing. To function adaptively, we must select and respond to behaviorally relevant information within our environment, while filtering irrelevant details. This selection may occur reflexively to salient items within the environment (i.e., bottom-up modulation), may be based on the goals of the individual (i.e., top-down control), or, more commonly, may reflect the integration of these two processes. Contingent attentional capture—when a stimulus-driven shift of attention (e.g., looking at a person in a bright yellow sweater) is contingent on a preexisting top-down attentional setting (e.g., searching a crowd for your friend in the yellow hat)—is one such example of a combination of top-down and bottom-up processes (1). Thus, this form of attentional orienting, which is a focus of the present study, may provide insight into both top-down and bottom-up systems.

Autism spectrum disorder (ASD) is associated with early and pervasive deficits in selective attention (2), including impaired bottom-up (3) and top-down (4) modulation of attention. Children with ASD have deficits filtering irrelevant information (5–7), which may be due, in part, to increased perceptual capacity (8–10). Prior research has also demonstrated that individuals with ASD are atypically overfocused (11,12), possibly linked to a narrower attentional spotlight (13,14) and deficits in increasing attentional breadth (15,16). These more fundamental deficits in nonsocial attentional processes may result, for example, in reduced orienting of attention to behaviorally relevant stimuli in children with ASD [e.g., (17,18)] and have important implications for the development of the disorder (2).

Neural oscillatory dynamics play a key role in brain function and are associated with a variety of perceptual and cognitive processes (19). In particular, event-related synchronization (ERS) and event-related desynchronization (ERD) of the alpha band (8–12 Hz) have been associated with perception and awareness (20), visual spatial orienting (21), filtering irrelevant information (22), and working memory (23). Neural responses linked to enhancing or selecting external

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information are associated with greater alpha-band desynchronization, whereas responses related to suppressing or filtering external stimuli are associated with increased alpha synchrony (24). The neural generators underlying modulation in alpha power are currently unknown; however, animal (25) and human pharmacological (26–28) challenge studies suggest that inhibitory gamma-aminobutyric acidergic (GABAergic) interneurons drive synchrony in electroencephalography (EEG) oscillations. An excitatory/inhibitory neural imbalance that involves reduced GABAergic inhibition has been hypothesized to be a primary feature in the neurobiology of ASD (29,30). Reduction in GABA levels in ASD has been supported by both histological (31,32) and in vivo (33,34) measurements. Therefore, investigating synchronized neural oscillations within the alpha band may be of particular interest in ASD.

Although findings from studies investigating alpha power using resting EEG have been inconsistent, a recent review suggests that ASD is more commonly associated with decreased resting alpha power (35). For example, infants at high risk for ASD (36) as well as children (37,38) and adults (39) with ASD have shown reduced power in the alpha-band frequencies. Studies examining task-related changes in alpha power in ASD have reported reduced alpha-band ERS, indicative of impaired suppression of task-irrelevant sensory information (5), reduced ERD during the preparation and execution of a motor control task (40), and increased frontal ERS, which may be related to the use of alternative strategies in ASD (41). Together, these findings suggest that ASD is associated with spontaneous and task-related differences in alpha power.

Our goal in the present study was to further investigate the pathophysiological mechanisms associated with atypical attention in ASD using behavioral, eye-tracking, and electrophysiological measures. Given the links among alpha oscillatory activity, GABAergic inhibitory function, and attentional processes outlined previously, and their relationship to ASD, the present study examined spontaneous and task-related changes in alpha power associated with attentional capture. We have previously showed that children with ASD exhibit 1) reduced target-related activation in the right temporal parietal junction, a key node in the ventral attentional network, and 2) attentional capture by irrelevant information that did and did not share a task-relevant feature (42). Therefore, in the present study we hypothesized that compared with their typically developing (TD) peers, children with ASD would show reduced alpha-band ERD to behaviorally relevant targets and no difference in ERD to distractors regardless of whether they shared a task-relevant feature. Additionally, that resting alpha power would be reduced in ASD and that lower resting state alpha-band power would be associated with reduced task-related alpha desynchronization and insensitivity to behaviorally relevant information.

METHODS AND MATERIALS

Participants

Twenty-one children with ASD and 21 age- and nonverbal IQ-matched TD children participated. After exclusion of two children with ASD for poor task performance (accuracy $<$ 2 SD below the mean), the final sample included 19 ASD and 21 TD children (Table 1). Clinical diagnoses were confirmed using the

Table 1. Participant Characteristics

	ASD	TD	*t* Value	*p* Value
n (Boys:Girls)	19 (17:2)	21 (17:4)	–	–
Handedness	18 right; 1 left	17 right; 4 left	–	–
Age, Years	14.4 (1.6); 12.4–17.8	14.3 (1.4); 12.0–16.8	0.23	.82
Verbal IQ	109 (19); 72–147	107 (10); 87–126	0.38	.71
Nonverbal IQ	109 (15); 81–140	108 (10); 90–129	0.16	.87
SRS Total Score (T Score)	78 (10); 57–94	42 (5); 35–52	14.77	$<$ .001
ADOS				
Communication	3 (1); 0–5	–	–	–
Social interaction	8 (3); 3–14	–	–	–
Repetitive behavior	2 (2); 0–6	–	–	–

Values are mean (SD); range unless otherwise indicated. IQ was determined using the Wechsler Abbreviated Scale of Intelligence (70).

ADOS, Autism Diagnostic Observation Schedule; ASD, autism spectrum disorder; SRS, Social Responsiveness Scale; TD, typically developing.

Autism Diagnostic Interview–Revised (43), the Autism Diagnostic Observation Schedule (ADOS) (44), and expert clinical judgment according to DSM-5 criteria. Children with ASD-related medical conditions (e.g., fragile X syndrome, tuberous sclerosis) were excluded. Participants in the TD group had no reported personal or family history of ASD and were confirmed via parent report to be free of ASD-related symptoms or any other neurological or psychiatric conditions. Normal color vision was confirmed for all participants using the Ishihara Tests for Color Deficiency (45). Informed assent and consent were obtained from all participants and caregivers in accordance with the University of California, San Diego, and San Diego State University Institutional Review Boards.

Experimental Paradigms

Rapid Serial Visual Presentation. The rapid serial visual presentation (RSVP) paradigm was modified from Serences *et al.* (46) and was similar to Keehn *et al.* (42) (Figure 1). To simplify the task for younger participants, it included numbers instead of letters, presented in three simultaneously varying streams. The task was to identify red numbers appearing in the central stream of colored numbers. Participants were instructed to look only at the central stream and respond with their dominant hand, using a two-choice button-box, pressing the left button if the target (i.e., red number) was a low number (i.e., 0–4) or the right button if the target was a high number (i.e., 5–9). Digits presented in the peripheral streams were gray in most trials (Supplemental Table S1); colored distractors appeared infrequently in either left or right peripheral streams and were either the same color as the target color (TC) (red) or a nontarget color (NTC) (green) that never appeared in the center stream. On target-present trials, a red number occurred in the center stream on the third frame with or without the appearance of TC or NTC peripheral distractors (which were presented on either the left or the right for all four frames). For target-absent trials, no red number appeared in the center stream with the appearance of either TC or NTC peripheral distractors (which appeared for all four frames). Lastly, null