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# Lateralized modulation of posterior alpha oscillations in children

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ABSTRACT

The evidence for a functionally inhibitory role of alpha oscillations is growing stronger, mostly derived from studies in healthy adults investigating spatial attention. It remains unexplored if the modulation of alpha band oscillations plays a similar functional role in typically developing children. The aim of this study was to characterize alpha modulations in children in relation to attentional performance. To this end, the posterior alpha activity (8–12 Hz) in children between 7 and 10 years old was measured using EEG while they performed a visuospatial covert attention task. We found that the alpha activity decreased in the hemisphere contralateral to the attended hemifield, whereas it relatively increased in the other hemisphere. In addition, we found that the degree of lateralized alpha modulation predicted performance on the attention task by negatively predicting the response time on invalid trials. Of note, children who were behaviorally less influenced by spatial cueing also were children with a clear lateralized alpha modulation pattern, with a significantly stronger alpha lateralization in the left hemisphere than children who were influenced more by spatial cueing. In addition, a bias to the right visual field such as that commonly observed in children, was significantly smaller or absent in the children influenced least by spatial cueing. Among all children, the magnitude of this visual field bias was positively related to the ability to modulate alpha activity. In conclusion, we have shown that the pattern of alpha oscillations modulated by attention is already present in 7–10 year old typically developing children. Although a similar pattern is observed in adults, the consequences for behavior are different. The fact that alpha modulation is already present at this age opens up the possibility of using hemispheric alpha lateralization as a tool to study the physiological basis of attention deficits in clinical disorders such as ADHD.



## Introduction

Allocation of attention requires a focus on relevant and simultaneous suppression of irrelevant information (Posner and Petersen, 1990). Increasing evidence has demonstrated that allocating spatial attention is associated with regional specific modulation of alpha oscillations (8–12 Hz). These oscillations have been suggested to gate streams of information through the brain network by means of functional inhibition (Klimesch et al., 2007; Thut and Miniussi, 2009; Snyder and Foxe, 2010), a process described by the 'alpha inhibition hypothesis' (Jensen and Mazaheri, 2010). The functional role of alpha activity in healthy adults has particularly been studied using visuospatial covert attention cueing paradigms based on variations of Posner's paradigm (Posner, 1980). In most electroencephalography (EEG) and magnetoencephalography (MEG) investigations of covert spatial attention, a cue directs attention to the left or right visual hemifield, which allows for investigating the alpha power in the hemispheres processing the attended and unattended visual hemifields. The key finding has been that posterior alpha power increases ipsilateral and decreases contralateral to the attended visual hemifield, respectively inhibiting or facilitating the information flow (Worden et al., 2000; Sauseng et al., 2005; Kelly et al., 2006; Thut et al., 2006; Händel et al., 2011; Bengson et al., 2012; ter Huurne et al., 2013). High alpha power over task-irrelevant regions linked to the processing of the unattended information, has proved to be of crucial importance for optimal attentional performance (Romei et al., 2010; Händel et al, 2011). Whether similar modulations of posterior alpha power can be observed in children is not known yet.

While rudimentary forms of attentional functions are already present at birth and further develop during the very first year of life (Colombo, 2001), the ability to allocate attention keeps developing throughout childhood (Rueda, 2013). For instance, orienting of attention seems to improve from 6 or 7 years onwards by gaining the ability

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to disengage attention when necessary (Schul et al., 2003; Wainwright and Bryson, 2005). The fully developed attentional network has been proposed to involve two main systems: 1) a largely bilateral dorsal fronto-parietal system that is involved in goal-directed stimulus-response selection, and 2) a right-lateralized ventral system, that directs the attention to salient unexpected stimuli. The ventral system is thought to work as an alerting mechanism engaging the dorsal system when unexpected stimuli are detected (Corbetta and Shulman, 2002). We propose that in Posner's cueing paradigm, the dorsal system enables early orienting towards a cued location and the ventral system is required for shifting attention towards 'surprise' targets in the uncued hemifield. According to the alpha inhibition hypothesis, we would be able to measure lateralized alpha modulation during the preparation interval, when goal-directed allocation of attention is expected.

It is unclear whether children display lateralized posterior alpha modulation with spatial attention similar to adults and whether changes in alpha power relate to behavioral performance. The aim of this study was to investigate how alpha modulations observed in children relate to previous observations in adults. To this end, we investigated the modulation of oscillatory brain activity as recorded by EEG in relation to behavioral performance of 7 to 10 year old typically developing children performing a visuospatial covert attention task.

## Materials and methods

### *Participants*

Data were acquired in the context of a clinical trial investigating alpha oscillations in children with and without ADHD (ClinicalTrials.gov identifier NCT01932398). The study was approved by the local Medical Ethics Committee (http://www.cmoregio-a-n.nl/) and conducted in accordance with the Declaration of Helsinki. All parents gave written informed consent, children gave oral assent. Here we reported information relevant to the present study only, focusing on typically developing children, i.e. not the children with ADHD.

Children in the age range from 7 to 10 years old were recruited from primary schools in the area of Nijmegen, the Netherlands. Children were included if they never had a psychiatric, neurological, or cardiovascular disease or serious motor or perceptual handicap; and if their estimated IQ was above 80. If an intelligence test had not taken place over the past two years, two subtests (i.e. Vocabulary and Block Design) of the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991; Dutch version: de Kort et al., 2002) were administered to estimate the intelligence. The Child Behavior Checklist (CBCL; Verhulst et al., 1996) was used to rule out the presence of clinical behavior. Data were collected between April 2012 and June 2014. Parents received reimbursement for travel costs and children received a present.

Twenty-seven right-handed children were included in this study. Data from three children were excluded ($N = 2$ technical problems, $N = 1$ task performance below chance level). Three other children were identified to have very few correct responses on the invalid trials (10.2 ± 15.9%). Data from these children were rejected for further analyses because 1) it was not possible to calculate behavioral performance on invalid trials and the subsequently derived cueing effect based on response time (RT) for these children since RTs for invalid trials were lacking, 2) these children responded significantly faster ($N = 3$: 262.61 ± 31.14 ms) on the available valid trials than the other children ($N = 20$: 571.22 ± 104.59 ms) ($t(21) = 4.987$, $p < .001$), suggesting they used a different strategy. Final analyses were therefore conducted using data of the remaining 21 children (mean age, 9.11 ± 1.29; 42.9% boys; estimated IQ, 119.23 ± 17.63).

### *Study procedure*

All measurements were performed at the Donders Centre for Cognitive Neuroimaging, Nijmegen, the Netherlands. Children and their parents visited the institute twice. First, if not available, intelligence was estimated. Furthermore, the first visit was used to explain and practice the visuospatial covert attention task, subsequently referred to as *the attention task*. This practice session was conducted while tracking the eyes to train the children to keep fixated at the center, but without EEG measurement. During the second visit the attention task was performed while tracking the eyes and recording the EEG. In addition, two resting state EEG sessions, in which the child was instructed to sit quietly for 2 min with eyes open and 2 min with eyes closed, were recorded during the second visit. Analyses of these data are not presented here.

### *The attention task*

An adjusted version of Posner's cueing paradigm for spatial orienting of attention was used (Posner, 1980), in which the goal was to save a fish from being eaten by a shark (Fig. 1). The task was programmed and presented using the software package Presentation (Neurobehavioral Systems, Albany, CA). The task started with a 1 min introduction video in which a shark recapped the most important instructions. Trials started with a pre-cue period (500 ms) with a shark presented at each side of the screen and a fish presented centrally. The child viewed the screen from a 50 cm distance creating an angle of 5.5 degrees with the innermost edge of the target figures. Note that the most informative part of the target was between the edge (5.5 degrees) and the middle of the target figures (13.1 degrees). The child was instructed to fixate at the fish in the middle of the screen and to sit as quietly as possible throughout the task. Influences of movement on the eye tracker and EEG recordings were shown to the child in advance to illustrate the importance of sitting still. An attentional cue was presented in a 200 ms interval, in which the fish shifted gaze towards the left or the right shark indicating the side of the upcoming target if validly cued or indicating the opposite side if invalidly cued. In the next period (1000–1500 ms

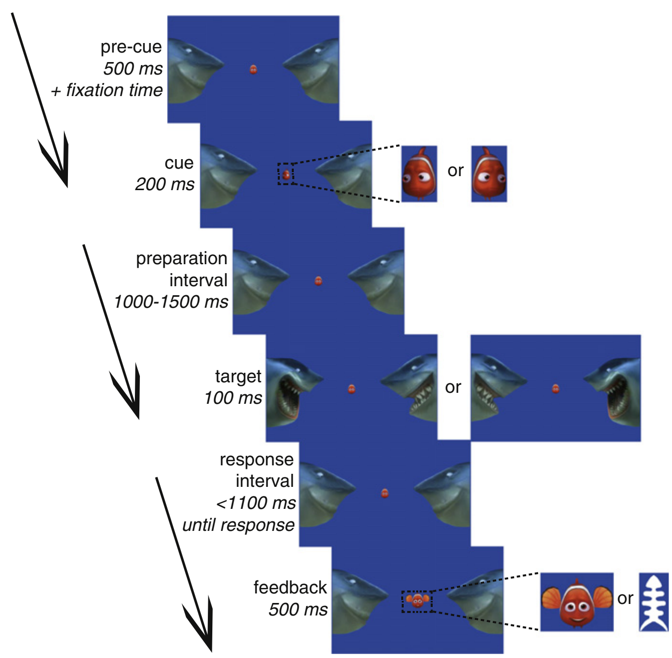


**Fig. 1.** The attention task. After a neutral pre-cue period in which a fish and two sharks were presented on the screen, children were cued to attend to the left or the right visual hemifield while keeping fixation at the centrally presented fish. After a 1000–1500 ms preparation interval, both sharks opened their mouths; one more so than the other. Children had to report which shark had the widest opened mouth. In 75% of the trials the widest opened mouth was in the cued visual hemified (*valid cue trial*), whereas in 25% surprise trials the mouth was widest opened in the other hemifield (*invalid cue trial*). Following a correct response within the response interval, a happy fish was presented. For incorrect responses, the fish was replaced by a fishbone.