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Top-down control of MEG alpha-band activity in children performing Categorical N-Back Task

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Abstract

Top-down cognitive control has been associated in adults with the prefrontal-parietal network. In children the brain mechanisms of top-down control have rarely been studied. We examined developmental differences in top-down cognitive control by monitoring event-related desynchronization (ERD) and event-related synchronization (ERS) of alpha-band oscillatory activity (8–13 Hz) during anticipation, target detection and post-response stages of a visual working memory task. Magnetoencephalography (MEG) was used to record brain oscillatory activity from healthy 10-year-old Children and young Adults performing the Categorical N-Back Task (CNBT). Neuropsychological measures assessing frontal lobe networks were also acquired. Whereas Adults showed a modulation of the ERD at the anticipatory stages of CNBT and ERS at the post-response stage, Children displayed only some anticipatory modulation of ERD but no ERS at the post-response stage, with alpha-band remaining at a desynchronized state. Since neuropsychological and prior neuroimaging findings indicate that the prefrontal-parietal networks are not fully developed in 10-year olds, and since the Children performed as well as the Adults on CNBT and yet displayed different patterns of ERD/ERS, we suggest that children may be using different top-down cognitive strategies and, hence, different, developmentally apt neuronal networks.

Keywords

top-down control of alpha-band activity; cognitive development; dorsal visual cortical network; visual Categorical N-Back Task; magnetoencephalography

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1. Introduction

Top-down cognitive control is driven by a set of task-related rules. Commonly, it refers to the influence of information stored at higher neuronal centers upon sensory perceptual and motor networks, and serves the selection of target stimuli and responses. Top-down control is overtly revealed in brain activation related to anticipation of a target. Such anticipatory activation may engage task-specific networks related to spatial localization, object categorization, or maintenance of working memory (Mishkin and Ungerleider, 1983; Martin, Ungerleider, Haxby, 2000; Worden, Foxe, Wang, Simpson, 2000; Rizzolatti and Matelli, 2003; Serences, Schwarzbach, Courtney, Golay, Yantis, 2004). The neural network that has been associated with visual top-down control encompasses lateral (dorsal frontal, inferior parietal) and medial (cingulate, temporal-occipital) cortical regions (Corbetta and Shulman, 2002; Serences and Yantis, 2006; Shulman, Corbetta, Buckner, Raichle, Fiez et al., 1997; Buckner and Carroll, 2001; Raichle, MacLeod, Snyder, Powers, Gusnard, Shulman 2001). Mental chronometry studies have suggested varying degrees of frontal-parietal engagement at different stages of cognitive tasks (Sternberg, 1969; Halgren, Boujon, Clarke, Wang, Chauvel, 2002; Posner, 2005). To our knowledge, neuroimaging data on the chronometry of top-down anticipatory processing in children has not been reported. Here we investigate the developmental differences in parietal-occipital activity related to top-down attentional control employed during consecutive stages of a visual working memory task.

The visual working memory task we used, Categorical N-Back Task (CNBT) (Ciesielski, Lesnik, Savoy, Grant, Ahlfors, 2006), is a new variant of the classical n-back working-memory task (Gevins and Cutillo, 1993). It was designed (by KTC) as a computer game for children (Ciesielski et al., 2004). As a working memory paradigm it refers to time-limited processes of active memory representation of knowledge that is accessible later for further manipulation (Baddeley, 1986). Thus, CNBT is a complex object-working memory paradigm, well suited for dissection of cognitive stages comprising stringent attentional focusing, active memory encoding, anticipation of a target according to internalized rules, cognitive categorical judgment and motor response. CNBT maximizes demands for executive reasoning, while holding memory demands constant. Effective manipulation of mental representations, actively held “on line”, while inhibiting irrelevant events has been found to be a valid indicator of mental flexibility and cognitive development (Gevins and Smith, 2000; Johnson et al., 2001). During CNBT the subject was required to respond to the target (raccoon) when at least two stimuli prior to the target belonged to a designated category of animals. Presentation of multiple consecutive pictures of animals served as a prompt, gradually increasing the subject's anticipation and, therefore, the attentional readiness for target detection and response. Thus, CNBT is a temporal cueing paradigm in which allocation of attentional resources can be monitored during its chronometric stages: anticipatory (two-back and one-back before target, 2BT, 1BT), target detection (T), and post-response (PR). Thus, correct performance on CNBT relies on effective top-down management of preparatory cues and control of response to targets.

We used magnetoencephalography (MEG) to examine developmental differences in top-down attentional control reflected in the modulation of alpha-band (8–13 Hz) activity at different stages of CNBT. Alpha-band activity has been found to be a sensitive indicator of cognitive task demands (Gevins, Zeitlin, Doyle, Yingling, Schaffer, Callaway, Yeager, 1979; Gevins, Smith, McEvoy, Yu 1997; Lisan and Idiart, 1995; Nunez, Wingeier, Silberstein, 2001). Early studies showed a systematic reduction of alpha in tasks with increasing memory loads (Gevins et al., 1979). Reduction of alpha, subsequent to extrinsic or intrinsic events was termed event-related desynchronization (ERD), whereas an increase in alpha was termed event-related synchronization (ERS) (Pfurtscheller and Aranibar, 1977). It has been suggested that the modulation of alpha-band activity reveals the cognitive strategies used by individual subjects during effortful anticipatory processing and represents a voluntary inhibitory activation of task

irrelevant networks (Gevins and Cutillo, 1993; Foxe, Simpson, Ahlfors, 1998; Smith and Jonides, 1999; Worden et al., 2000).

Electrophysiological and neuroimaging evidence on the developmental trajectory in top-down attentional processing is scant. Evidence suggests that the facility for top-down attentional modulation at early stages of sensory processing continues to change during childhood and early adolescence (Bunge et al., 2002; Taylor, Chevalier, Lobaugh, 2003; Poggel and Strasburger, 2004), and that those developmental changes show task and stimulus specific characteristics (Greenaway and Plaisted 2005). Similar findings have been reported in studies on top-down attentional control in children, as reflected in oscillatory activity (Klimesch et al., 2001; Krause et al., 2001). Studies in adults have focused on spatial cortical distribution and increased coherence of alpha and theta (3–7 Hz) activity during attentional tasks (Gevins and Smith, 2000; Babiloni et al., 2005a). Thalamo-cortical and cortical-cortical networks involving the parietal-occipital cortex have been associated with alpha generators (Steriade and Llinas, 1988; Pfurtscheller, 1992; Hari and Salmelin, 1997; Schnitzler and Gross, 2005). In the present study we examined child-adult differences in performance and in modulation of parietal activity within the alpha band during consecutive stages of the object working memory task, the CNBT.

Based on our earlier fMRI studies with CNBT we expected the speed and performance accuracy in children to be similar to adults (Ciesielski et al., 2006). In children anatomical evidence indicates that posterior brain regions are maturing earlier than other regions (Huttenlocher, 1990; Sowell, Thompson, Leonard, Welcome, Kan, Toga, 2004; Gogtay, Giedd, Lusk, Hayashi, Greenstein et al., 2006), and that alpha as the earliest developing frequency band has still not matured at age 10–12 years (Krause et al., 2001; Krause, Pesonen, Hamalainen, 2007). Thus, we expected that the pattern of top-down parietal alpha modulation will be similar in children and adults. However, the outcome of top-down cognitive strategies is determined by maturation of distributed brain networks, including the frontal-parietal. Since frontal components of the latter network are not fully developed until late adolescence (Harnishfeger, 1995; Atkinson, Braddick, Rose, Searcy, Wattam-Bell, Bellugi, 2005; Ciesielski et al., 2006), their immaturity might have contributed to different ERD/ERS patterns of alpha-band activity in children and adults, whether both perform equally well, or not. Considering that the trajectory of cognitive development progresses from sensory-motor to internalized ability to predict (Piaget, 1971; Luciana and Nelson, 1998), we expected most prominent differences between children and adults at the anticipatory task stages.

2. Materials and Methods

2.1. Participants

Twelve healthy right-handed volunteers participated in the study: six 10-year old Children (9y3mo–10y5mo; mean 9y9mo; 3 males/3 females) and six young Adults (20y3mo–27y8mo, mean 23.9; 3males/3females). We used rigorous criteria to select healthy Children and Adults. All subjects participated in a neuropsychological session several weeks prior to the MEG testing. Psychometric IQ in WAIS and WISC testing (Children mean: 118, $\pm$ 9; Adults: 120, $\pm$ 11) were complemented by neuropsychological assessment. Results from tests measuring attention, memory, executive inhibitory control, and adaptive behavior were compared with age norms. Subjects with cognitive abnormalities, ongoing substance abuse or neuroleptic medication were excluded. A sample of neuropsychological data related to functions essential for performance on working memory tasks is presented in the current study: the Stroop Word-Color Interference test, the Wisconsin Card Sorting Test, and the Rey-Osterrieth Complex Figure Test: Copy, Immediate Recall and Delayed Recall (Lezak, 1998; Spreen and Strauss, 1998). A clinical interview enclosed the prenatal and early postnatal development, current academic functioning, and the family screening for developmental, neurological, and

psychiatric disorders. The inclusion criteria involved: IQ and neuropsychological performance within the normative age range, with no discrepancy exceeding 2.5 SDs between individual tests; no personal or family history of neurological, developmental, or psychiatric DSM-IV disorders from Axis 1 or Axis 2. The study was approved by The Institutional Review Board for Human Research at the Massachusetts General Hospital, Boston.

2.2. Categorical N-back Task

We used a variant of the n-back working memory task (Gevins and Cutillo, 1993), the Categorical N-Back Task (Ciesielski, Lesnik, Ahlfors, Savoy, Baedorf 2004; Ciesielski et al., 2006). Seventy two commercially available color drawings of different objects (humans, buildings, cars, fruits, plants, etc.) and animals (mammals, birds, reptiles, fish, insects) were presented consecutively, in random order (Figure 1). Small crosses were randomly interleaved between the pictorial stimuli to provide a fixation point and irregularity of timing. A drawing of a raccoon served as the n-back target. When the target was presented, the subject was required to press a button, but only if at least two drawings prior to the raccoon belonged to the category of animals. The subject was required to press another button with the left forefinger if the raccoon was preceded by any other combination of stimuli. This task posed a strong demand on the top-down inhibitory control and on flexibility of fast decision-making.

The task parameters used were identical to our earlier fMRI study (Ciesielski et al., 2006): stimulus duration 500 ms, Inter-Stimulus Interval (ISI) 500 ms (except 1500 ms for post-target to provide the children time to press the button), a visual angle of the stimuli ~ 3.4 deg vertically and ~ 2.6 deg horizontally. The luminance of the white background was 1600 cd/m^2 and the average luminance of the stimuli was 340 cd/m^2 , with approximate figure/background Weber contrast -0.78 . The Presentation program (Neurobehavioral Systems, Albany CA) was used for stimulus presentation. Each run consisted of 124 stimuli (25% raccoons, $\sim 23\%$ of other animals, 22% non-animals, 30% crosses). Each participant completed ten runs covering three different tasks; we only present data from the four runs that encompassed the CNBT. The total recording time for all tasks was about 40 minutes.

2.3. Magnetoencephalography data acquisition

MEG signals were recorded using a Vectorview™ system (Elekta Neuromag, Finland), which comprises 306 sensors arranged in triplets of two planar gradiometers and one magnetometer. The measurements were carried out in a magnetically shielded room (Imedco AG, Switzerland). Head movements were controlled using a chinstrap. The precise location of the head with respect to the sensors was determined with four head-position indicator coils on the scalp at the beginning of each run. A head-based MEG coordinate frame was established by locating fiducial landmarks (nasion and pre-auricular points) with a Polhemus Fastrak 3D digitizer. The data were digitized at 600 Hz with an anti-aliasing low-pass filter set at 200 Hz. The visual stimuli were presented on a back-projection screen placed 1.7 m in front of the subject. Eye movements and blinks were monitored with vertical and horizontal EOG.

2.4. Temporal-Spectral Evolution (TSE) Analysis of MEG data

ERD/ERS measures were obtained in each individual subject using the following steps:

1. The raw MEG data were band-pass filtered to 8–13 Hz (CFT-based finite impulse response, zero phase, cosine squared tapers) and rectified (i.e., the absolute value of the signal was taken).
2. To construct the event-related TSE waveforms (Salmelin and Hari, 1994) band-pass filtered and rectified epochs were averaged ranging from -3500 ms before, to 2000 ms after the onset of the Target-Raccoon. Epochs containing eye movements and

blinks with EOG exceeding 150 μ V peak-to-peak were excluded from the averages. Only trials with correct responses were included in the analysis.

3. The TSE waveforms from 24 parietal-occipital MEG sensors were combined into a single waveform by taking the root-mean-square value at each time point across the sensors.
4. The TSE waveforms were normalized through computing the relative difference with respect to a baseline value. The baseline was defined as the mean TSE value within the time-window from -400 to -100 ms preceding the onset of the 2BT stimulus. Thus, the normalized TSE waveforms show task-induced changes in alpha-band activity relative to the pre-2BT baseline.
5. The normalized TSE waveforms were analysed using four 300-ms time-windows of interest. Three windows were defined from 300–600 ms after the onset of the stimuli: two animal prompt prior to the target (2BT), one animal prompt prior to the target (1BT), and the target (T). The fourth window was defined after the post-target-response (PR) from 1400–1700 ms. We excluded the first 300 ms post-stimuli to avoid the confound of visual evoked responses immediately following each stimulus and to capture the maximal ERD after each stimulus, consistent with prior studies (Klimesch, Doppelmayr, Rohm, Pollhuber, Stadler 2000).
6. The mean values of the normalized TSE waveforms within each of the four time-windows were computed for each subject. Negative and positive values of these measures represent Event-Related De-synchronization (ERD) and Event-Related Synchronization (ERS), respectively.

2.5. Statistical Analysis

A pooled two-sample t-test was used for between-group comparisons between the ERD/ERS measures for the time-windows 2BT, 1BT, T, PR in Children and Adults. Within-group comparisons were based on paired t-tests involving the ERD/ERS measures for the 2BT, 1BT and PR time-windows contrasted to the ERD/ERS measures for the T time-window. All p -values were based on two-sided tests, with no adjustment for multiple comparisons. In recognition of a small sample size we also did the analysis using the nonparametric Wilcoxon-Mann-Whitney test for the between-group comparisons and the Wilcoxon signed rank test for the within-group comparisons.

3. Results

3.1. Behavior

No significant differences between the Children and Adults were found in the performance on the CNBT (Table 1A). The mean response accuracy was high in both groups (Children: 90.7%; Adults: 94.7%) ranging in individual subjects and ranging in individual subjects between 86% to 96%, which corresponds to 36 – 39 correct trials from 42 available. The mean RTs were 436 ms for Children and 401 ms for Adults.

Table 1B displays results of neuropsychological tests. No significant differences between children and adults were observed in the numbers of accurately reproduced elements in the Rey-Osterrieth Complex Figure Test, measuring visual-spatial organization and memory. Children performed significantly worse in the Wisconsin Card Sorting Test, displaying a higher mean of perseverative responses (Children: 15.2; Adults: 5.8). In The Stroop Color-Word Interference Test, children displayed a significantly lower number of correct identifications of conflict color-word stimuli (Children: 27.3; Adults: 58.0).

3.2. Spectrum of raw MEG data

In a preliminary analysis we compared the spectra of the raw MEG data for Children and Adults Figure 2 indicates that the peak in the alpha-band parietal-occipital alpha was at slightly lower frequency in Children (10 Hz) than in Adults (12.0–13.0 Hz). The amplitude of the alpha-band oscillations was considerably larger in Children than Adults.

3.3. Task-related modulation of the ERD/ERS measure

The scalp distribution of the Temporal-Spectral Evolution (TSE) waveforms during task performance (Figure 3) showed the largest event-related changes in the parietal-occipital sensors. The normalized parietal-occipital TSE waveforms (Figure 4) showed a prominent suppression of ERD in the alpha-band activity after each stimulus presentation in both Children and Adults. After the response to target (PR) the normalized TSE in Adults increased above the baseline level (ERS), whereas in Children the normalized TSE remained below the baseline (ERD).

Between-group statistical analysis—Table 2 shows a significant difference between Children and Adults for ERD/ERS measures in the PR time-window [$t=2.67$, $df=10$, $p=0.024$; nonparametric $p=0.026$]. No other between-group contrasts reached statistical significance.

Within-group statistical analysis—For each time-window 2BT, 1BT and PR, the ERD/ERS measures were compared to those measures obtained in the time-window T. These analyses were conducted separately for the Children and Adults. In Adults a significant difference was found between PR vs. T ($t=5.11$, $df=5$, $p=0.004$; nonparametric $p=0.031$). The difference between 2BT vs. T reached the following levels in Adults: $t=2.77$, $df=5$, $p=0.039$; nonparametric $p=0.059$, and in Children: $t=2.98$, $df=5$, $p=0.031$; nonparametric $p=0.059$. No other within-group contrasts reached statistical significance.

The mean ERD/ERS for each of the time-windows of interest are shown in Figure 5. In the PR window the ERS is prominent in Adults, but in Children ERD perseveres.

4. Discussion

We examined top-down attentional modulation of alpha-band oscillatory activity related to three different stages of the visual working memory task, in 10 year old children and young adults. the CNBT, the anticipatory stage, target detection, and post-response. Although the sensory, bottom-up information was identical in both children and adults, the pattern of top-down event-related alpha modulation was different. In adults, the proximity of the anticipatory stimuli to the forthcoming target was reflected in a gradual increase in ERD of alpha suggesting an active preparatory state for target detection. In children a lesser modulation of alpha was exhibited during anticipatory stages, but a major difference emerged after response to the target. Thus, in contrast to our primary hypothesis about the most prominent differences between children and adults to be displayed at the anticipatory task stages, the major group differences in alpha modulation were demonstrated at the post-response stage. Here alpha-band in adults synchronized to above baseline level, whereas in children it remained at a desynchronized state below the baseline. Therefore, in adults the post-target ERD was followed by an ERS, whereas in children the ERD protracted long after the response was made, suggesting a persistent state of readiness. However, one must be aware, that these post-response group-differences in the modulation of alpha are not just effects occurring on the final post-response stage of the task. The post-response final effect may be a cumulative outcome of differences in stimulus processing, baseline alpha, and other intrinsic processes, each affecting the alpha-band activation in a mode specific to a particular developmental level.

The allocation of attentional resources in visual working memory tasks has been broadly studied (Jonides, Schumacher, Smith, Koeppe, Awh, Reuter-Lorenz et al., 1998; Smith and Jonides, 1998), but little is known about the attentional resources allocated to anticipatory strategies preceding targets in adults (Corbetta and Shulman, 2002) and almost nothing is known in children. Thus, the current study elucidates the development of processing stages in visual working memory. The modulation of anticipatory alpha in adults suggests a more refined interplay between allocation of attentional resources to task-relevant networks related to anticipatory stages, and inhibition of irrelevant processing at the post response stages. This view is consistent with the early attentional capacity models (Broadbent, 1958; Kahneman, 1973; Norman and Bobrow, 1975), and more recent “biased competition” model (Desimone and Duncan, 1995; Kastner, Pinsk, De Weerd, Desimone, Ungerleider, 1999). In the biased competition model, the stimulus-related competing groups of neurons were suggested to be biased by top-down inhibitory control of irrelevant neuronal activation, or “selective lateral inhibition” (Konorski, 1967). The gradual increase of ERD as by, reflecting a top-down controlled increase in preparatory activation, appears consistent with such fine-tuned inhibitory/excitatory interplay (Gevins et al., 1997). Furthermore, it has been shown using the Granger causality technique that greater directed influence is generated from frontal eye fields to inferior parietal sulcus, than the reverse, providing anatomical support for top-down frontal-parietal attentional flow. Such increased causality was predictive of correct behavioral performance (Bressler, Tang, Sylvester, Shulman, Corbetta, 2008). Thus, frontal-parietal networks are essential for visual top-down attentional control, and consequently, less flexible modulation of the parietal alpha-band in children may reflect immaturity of those networks.

Alternatively, the lower modulation of alpha in children may result from difficulty in internalizing task rules since the top-down voluntary control strictly follows a set of rules. This, however, is less feasible, because children performed with a speed and accuracy that was comparable to adults. Furthermore, the effect we see in children in this study may also result from a broad scalp distribution of channels with low alpha. This also seems unlikely, because in such a case the differences between adults and children would be more uniform across all stages of the task (2BT, 1BT, T, and PR). Our data points in the opposite direction showing the variation of alpha determined by variable task stages. Consistently, age-driven differences in brain activation accompanied by accuracy of performance similar to adults are one of the most consistent findings in our developmental neuroimaging studies (Ciesielski et al., 2006).

During the developmental trajectory the cortical-cortical networks develop late, in parallel with formation and deepening of sulci and increasing complexity of the cortical surface (Nolte, 2008). Capacity of visual processing and responding is progressing concurrently with development of subcortical-cortical and cortical-cortical loops (Johnson, Mareschal, Csibra, 2001). The frontal brain areas begin to reach functional and structural maturity only during late adolescence (Happaney, Zelazo, Stuss, 2004; Luciana and Nelson, 2003; Sowell, Thompson, Leonard, Welcome, Kan, Toga, 2004). Since the anticipatory pre-target stages in CNBT rely on the proficiency of the frontal-parietal dorsal network, engaged in top-down attentional control (Corbetta and Shulman, 2003), their immaturity may contribute to reduced flexibility in attentional modulation of alpha-band across the task epoch, including the response stage. Consistent with this view is the lower performance in children on tests commonly related to frontal lobes (Wisconsin Card Sorting and in Stroop Word-Color Interference Tests). Consistent with the above are prior studies in adults demonstrating a stronger coupling of alpha oscillations between parietal-occipital and frontal areas in visual working memory tasks. Higher alpha amplitude was shown in trials preceding “seen” than “not seen” trials (Buchel and Friston, 1997; Babiloni, Vecchio, Bultrini, Romani, Rossini, 2006). Since the modulation of synchronous changes characterizing the connectivity of functional brain networks has been linked to cognitive strategies (Buzsaki, 2007), one possible explanation of child-adult differences is that children may use a different set of attentional strategies, and, possibly

different developmentally available networks. Our prior studies point to participation of the earlier developing striatum and cerebellum (Ciesielski, Lesnik, Benzel, Hart, Sanders 1999; Ciesielski et al., 2006) closely anatomically and functionally related to the parietal cortex (Clower, Dum, Strick, 2005; Hoshi, Tremblay, Feger, Carras, Strick 2005; Schmahmann and Pandya, 1997).

The low sensitivity of parietal alpha oscillations to cognitive top-down modulation may be yet another reason for the brain-behavior dissociation in children (Krause et al., 2007; Petersen and Eeg-Olofson, 1971). Although caution in interpretation is in order, one may ponder whether the post-response ERS of alpha in adults reflects a return to an idling neuronal state, or, alternatively, to an active inhibitory state within the task-unrelated networks (Jensen, Gelfand, Kounios, Lisman, 2002; Worden et al., 2001). It has been proposed that ERS of alpha, exhibited after the task is completed, would be representative of a widely activated cortical-cortical network, which allows a quick flexible shift to local information processing after the stimulus is presented (Babiloni et al., 2005b; Nunez, Wingeier, Silberstein, 2001). In children such flexibility may be missing. Their ERD at the post-response stage, suggests a lower sensitivity of alpha activity to the task context and slower recovery of baseline alpha. In the present study we did not analyze frontal ERD/ERS, because little alpha-band activity was observed in the prefrontal sensors, and we were concerned about sensory-motor mu rhythm from the nearby precentral motor regions.

In summary, our results suggest significant top-down modulation of ERD/ERS in alpha-band activity during the anticipatory and post-response time-windows of the CNBT working memory task in adults, and paucity of such task-related modulation in children. Since both groups performed with similar speed and accuracy, it is tempting to consider engagement of different strategies and different neuronal networks in children. Such alternative developmental networks may be encompassing the earlier maturing striatum and cerebellum (Goldman, 1974; Ciesielski et al., 1999; 2006). Indeed, the modulation of synchronous changes characterizing the connectivity of functional posterior brain networks have been linked to variation in cognitive strategies (Krause et al., 2001; Buzsaki, 2007). The parietal-occipital alpha-band activity is considered to be an universal functional property of the brain, as it correlates with stimulus-evoked activation in many sub-cortical and cortical networks (Steriade and Llinas, 1988). Here, we provide developmental support for the emerging novel models of the inferior parietal cortex as an essential component for on-line episodic-recall in working memory (Vilberg and Rugg, 2008), and as a center (“hub”) comprising connections from all major control networks (Buckner, Andrews-Hanna, Schacter, 2008). A search for developmentally apt top-down visual control networks engaged in modulation of parietal-occipital alpha-band activity merits further investigation.

Research Highlights

1. The prefrontal-parietal networks associated with top-down cognitive control in adults are not matured in 10-year olds, yet children perform well on visual-working memory tasks.
2. We use magnetoencephalography (MEG) to monitor in children and adults event-related desynchronization (ERD) and synchronization (ERS) of parietal-occipital alpha-band oscillatory activity (8–13 Hz) during top-down anticipatory, target detection and post-response stages of the Categorical N-Back Task (CNBT).
3. Since Children performed as well as the Adults on CNBT and yet displayed developmentally distinct, task-stage-determined patterns of ERD/ERS we suggest

that children may be using different top-down cognitive strategies and, hence, different, developmentally apt neuronal networks.

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Figure 1.

Experimental paradigm: The Categorical N-Back Task (CNBT). Images of animals and non-animated objects were presented sequentially. Each consecutive image was presented for 500 ms, except for the blank image (plain screen) that lasted 1000 ms. The subjects were asked to press one of two buttons whenever an image of a raccoon (Target, T) appeared: right button if the two images preceding the target belonged to the category of animals, left button otherwise. The total time available for the subjects to respond to the target was 2000 ms. 2BT: two animals before the Target, 1BT: one animal before the Target.

Frontal **Parietal-Occipital** **Figure 2.**

Frequency content of the raw MEG data for individual subjects. The spectra were averaged over 24 frontal and 24 parietal-occipital sensors.

Figure 3.

Event-related Temporal-Spectral Evolution (TSE) waveforms for a Child (red) and an Adult (blue), displayed for 204 planar gradiometer MEG sensors. The 24 parietal-occipital sensors, that were pooled into subsequent analysis, are marked by the shading. Vertical lines indicate the onset time of the target-raccoon.

Figure 4.

Normalized parietal-occipital TSE waveforms, group-averaged across Children and Adults. Vertical dashed lines indicate the onset times of visual stimuli. Shaded rectangles show the 300-ms time-windows used to obtain the ERD/ERS measures: 2BT- two before target, 1BT - one before target, T - target, PR - post-response.

Figure 5. ERD/ERS measures in Children and Adults for each of the four time-windows: 2BT-two before target, 1BT - one before target, T - target, PR - post-response.

Means and (standard deviations) for between-group comparisons of behavioral data. A: Accuracy [% correct] and RT [s] from performance on the CNBT
B: Raw scores from the neuropsychological tests

Table 1

		Adults	SD	Children	SD	t(df=10) <i>p</i>	Non-par. <i>p</i>
A. CNBT	% Correct	94.70	(6.02)	90.72	(6.12)	[1.13] n.s.	n.s.
	RT	0.401	(0.09)	0.436	(0.14)	[−.50] n.s.	n.s.
B. R-OCFT	# corrects Copy	30.50	(2.17)	30.25	(2.23)	[0.20] n.s.	n.s.
	Immediate Recall	26.67	(2.94)	21.42	(7.03)	[1.69] n.s.	n.s.
	Delayed Recall	26.00	(4.24)	22.25	(5.65)	[1.30] n.s.	n.s.
	Persevera t. Errors	5.83	(2.71)	15.17	(4.26)	[−4.52] 0.001	0.005
WCST							
STROOP W.-CTT	Word/colo r # Correct	58.00	(10.77)	27.33	(7.99)	[5.60] 0.001	0.006

CNBT Categorical N-Back Task; R-OCFT Rey-Osterieth Complex Figure Test; WCST Wisconsin Card Sorting Test; Perseverative errors; STROOP WC IT Stroop Test (word-color version only)
Statistics from t-test (parametric) and Wilcoxon signed rank test (non-parametric) last two columns; Accepted level of significance: *p*<0.05

Table 2

Alpha-band ERD/ERS measures for time-windows of CNBT

Time-windows	Adults	Children	[t (df=10)] <i>p</i>	<i>Non-par. p</i>
2BT	−0.099 (0.178)	−0.163 (0.172)	[0.64] n.s.	n.s.
1BT	−0.170 (0.186)	−0.187 (0.196)	[0.15] n.s.	n.s.
T	−0.220 (0.135)	−0.299 (0.182)	[0.85] n.s.	n.s.
PR	0.086 (0.083)	−0.082 (0.130)	[2.67] 0.024	0.026

Between-group comparisons for each time-window: Statistics from t-test [*t* values in square parentheses] and from non-parametric Wilcoxon-Mann-Whitney test.

Time windows: 2BT two (animals) before target; 1BT one (animal) before target; T target; PR post response. Accepted level of significance $p < 0.05$.