Brain functional organization of regulatory and information-related components of working memory in adults and 7-8-year-old children. An EEG coherence study

Функциональная организация регуляторных и информационных компонентов рабочей памяти у взрослых и детей 7-8 лет. Анализ когерентности ритмов ЭЭГ

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What is working memory?

N. Cowan's (1995) model of WM

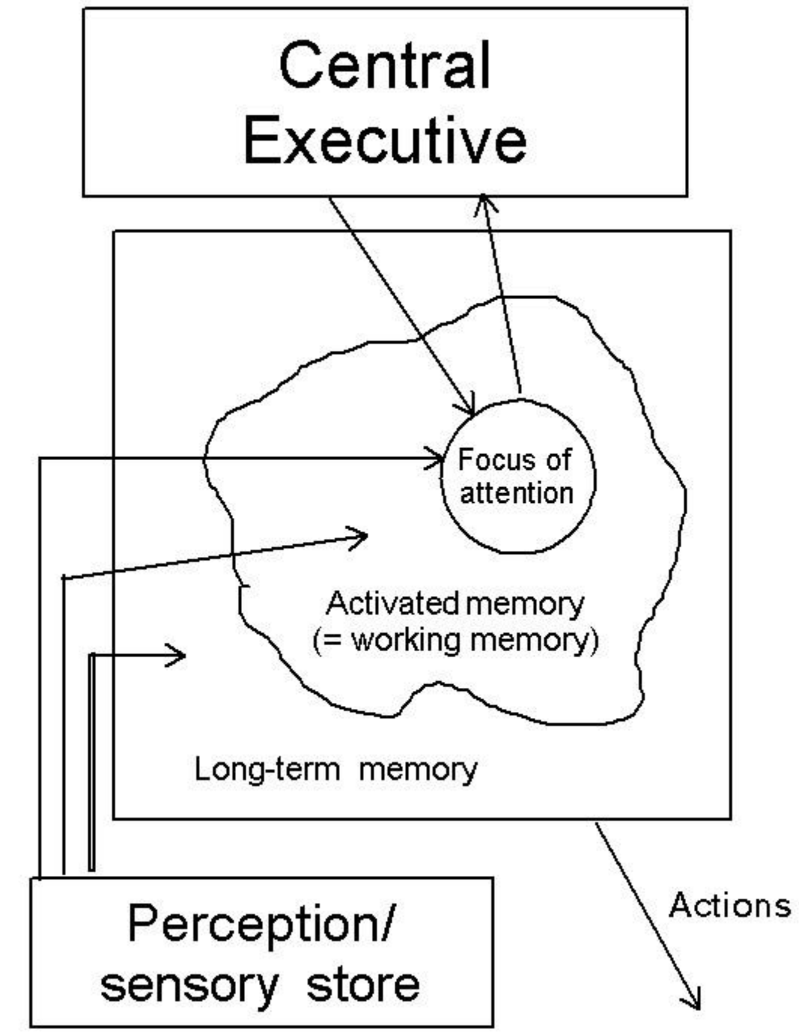


Figure from http://psych.la.psu.edu/cogcourses

Working memory (WM) is the cognitive operation that underlies our ability to temporarily maintain and manipulate information that is no longer accessible in the environment in order to guide behavior (Baddeley 1986).

Baddly & Hitch (1974) multicomponent model of WM

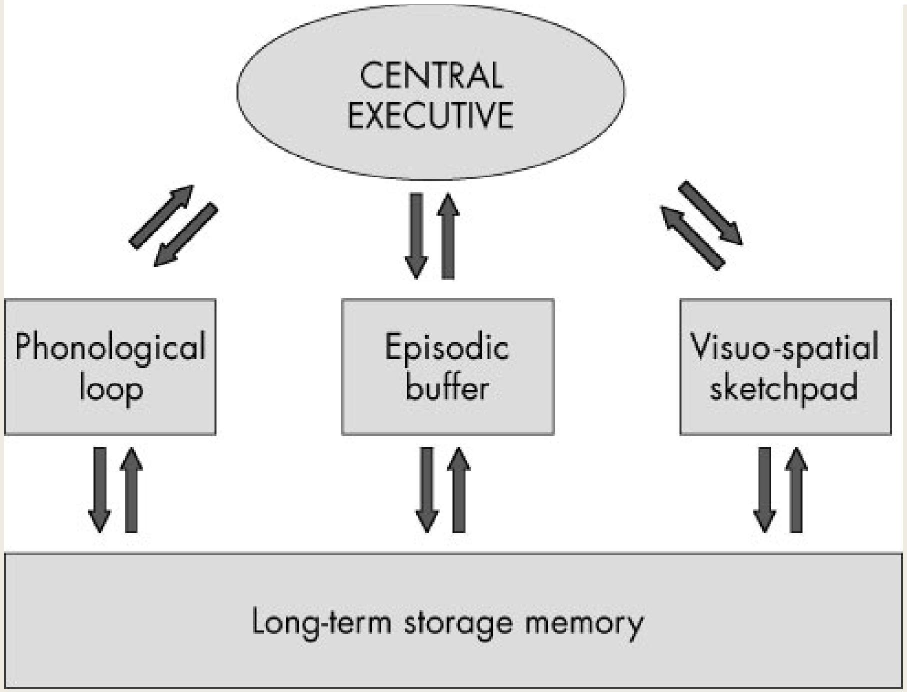


Figure from www.isrc.umbc.edu/HCIYandbook/Figures/ 02-03.html

Delay Network (fMRT data) :

Prefrontal cortex together with **Parietal cortex** bias activity in specific regions of the visual association cortex to maintain the representation

Premotor cortex and **Caudate** provide perception–motor integration

Thalamus (mediodorsal nucleus) maintains a stimulus representation in the absence of visual stimulation

Hippocampus, parahippocampus and amygdala activate long-term memory networks essential for binding the stimulus representation within the context of previous representations

Visual cortices are sites of perceptual representation

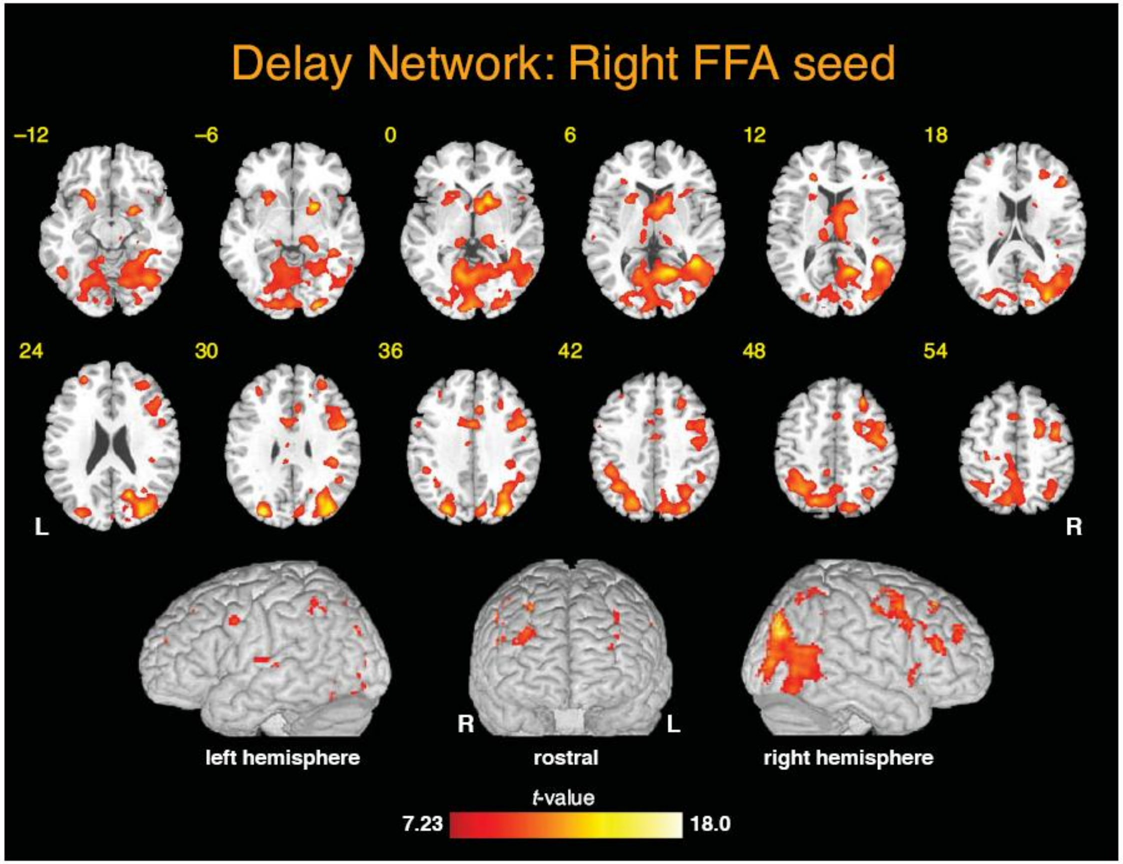
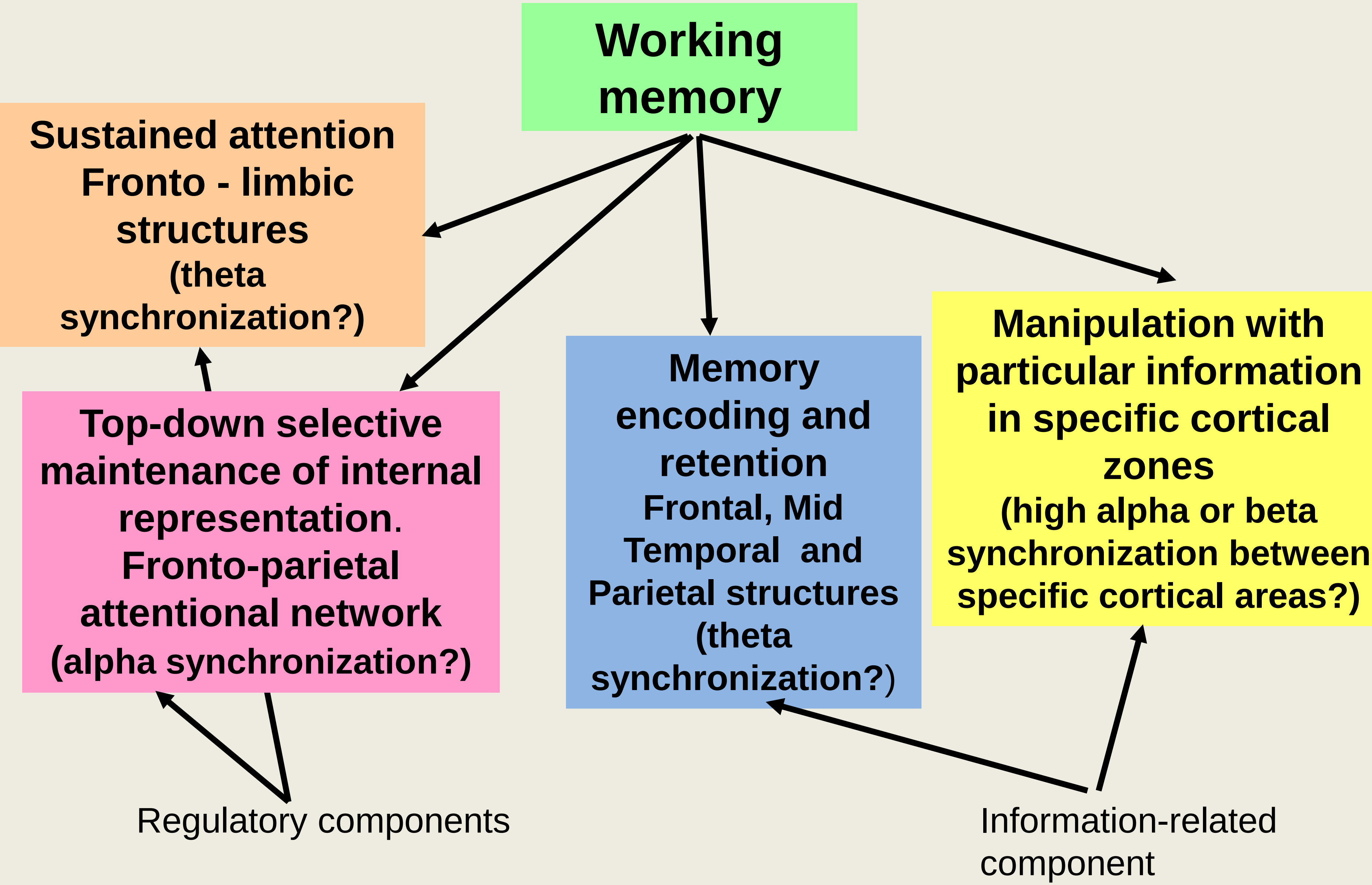
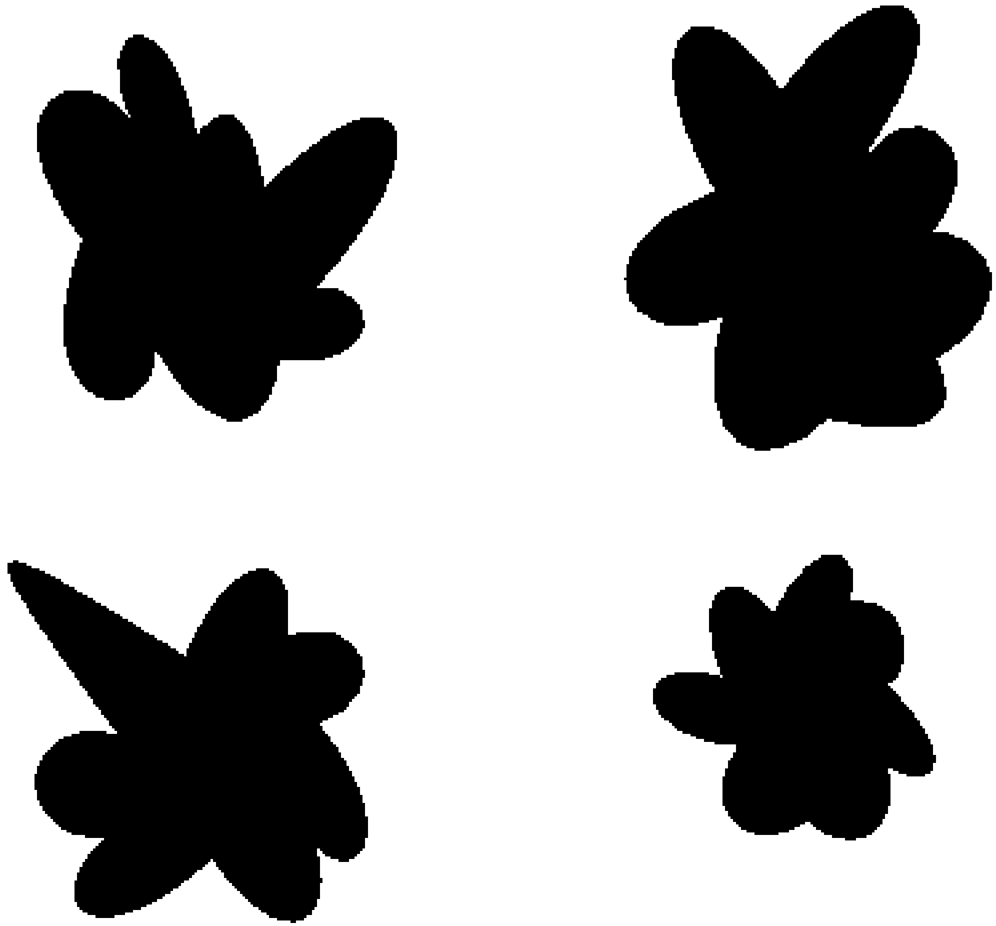


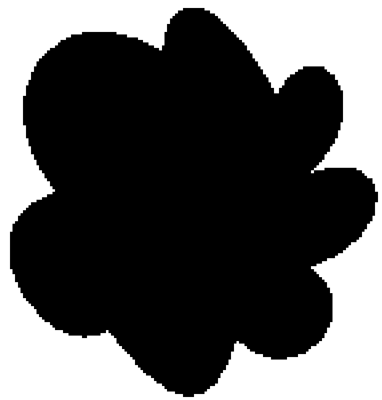
Figure 4. Delay period right fusiform face area (FFA) seed correlation map ($N = 17$). Activations are thresholded at $p < .05$ (corrected) and are shown overlaid on both axial slices and a three-dimensionally rendered MNI template brain. The color scale indicates the magnitude of the t values.

Functional connectivity during working memory maintenance. Gazzaley et al., *Cognitive, Affective, & Behavioral Neuroscience 2004, 4 (4), 580-599*

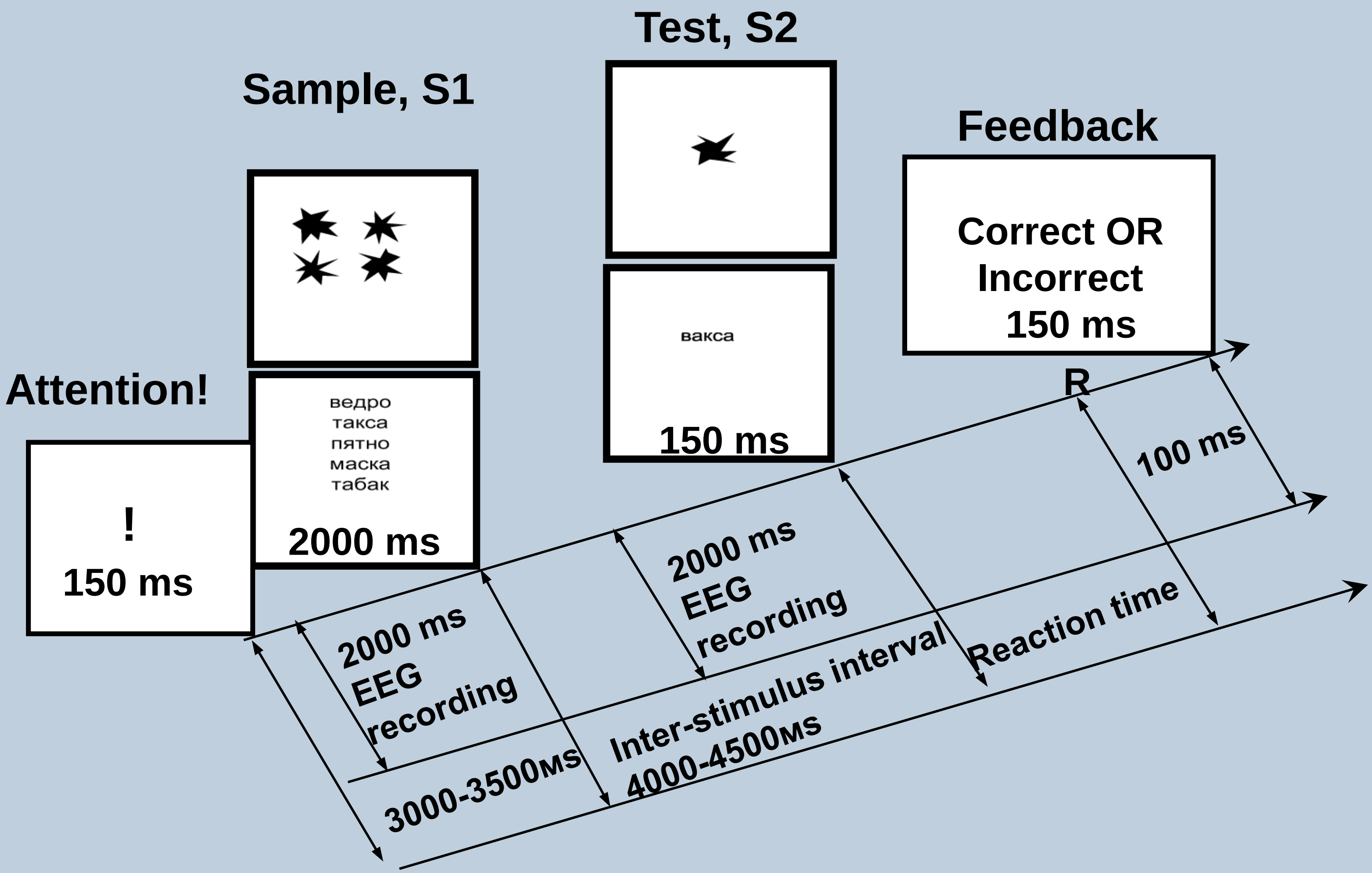
Hypothetical components of working memory brain functional system







The time diagram of an experimental trial



EEG was recorded from 16 active leads with digitally linked ears reference in the following three **experimental conditions**:

Background - rest state of with eyes closed (60 s)

S1 – 2 s before all first stimuli (sample) – nonspecific sustained attention

S2 –2 s before all test stimuli – WM state (only correct trials were used for further stat. analysis)

EEG processing

Vector Autoregressive Model (VAR) of the 14-th order was fit to every individual artifact-free 2 sec long EEG segment

VAR-coefficients were used to compute individual estimates of complex-valued coherence function

$$C_{km}(f) = \frac{S_{km}(f)}{\sqrt{S_{kk}(f) S_{mm}(f)}} = |C_{km}(f)| e^{i(\varphi_m - \varphi_k)}$$

$$C_{km}(f) = |C_{km}(f)| \cos(\varphi_m - \varphi_k) + i |C_{km}(f)| \sin(\varphi_m - \varphi_k)$$

Based on the complex-valued coherence function the ordinary coherence function $|C_{km}(f)|^2$ and its squared imaginary part

$$J_{km}(f) = |C_{km}(f)|^2 \sin(\varphi_m - \varphi_k)^2$$ were computed

Averaged across all cross-conditions estimates of

$|C_{km}(f)|^2$ and $J_{km}(f)$ functions .

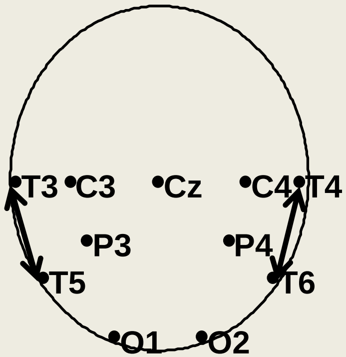
were subjected to further statistical analyses.

(Notle, 2004)

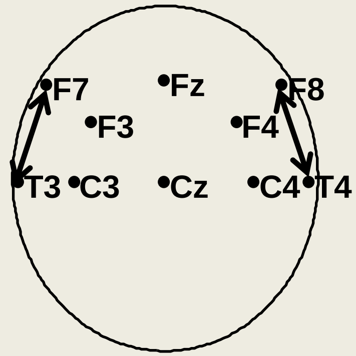
Separate RM ANOVA schemes for different types of pairs of leads were used

Intra-hemispheric

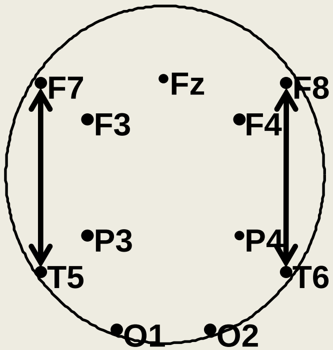
1. Short posterior (12 pairs)



2. Short anterior (14 pairs)

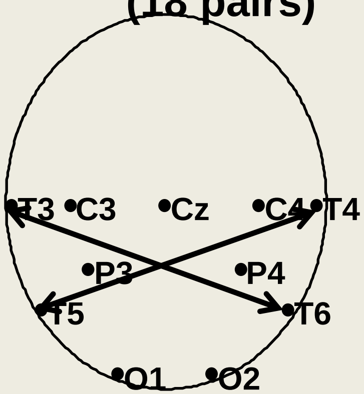


3. Long (9 pairs)

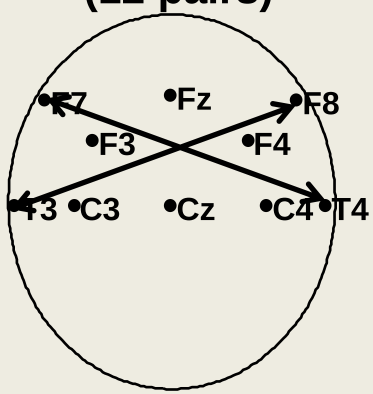


Cross-hemispheric and inter-hemispheric

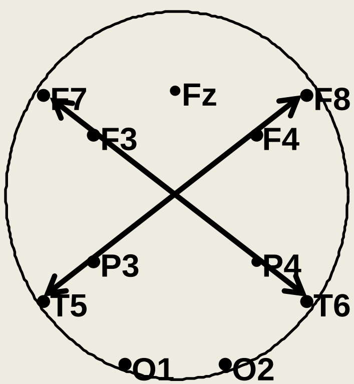
4. Short posterior cross-hemispheric (18 pairs)



5. Short anterior cross-hemispheric (12 pairs)

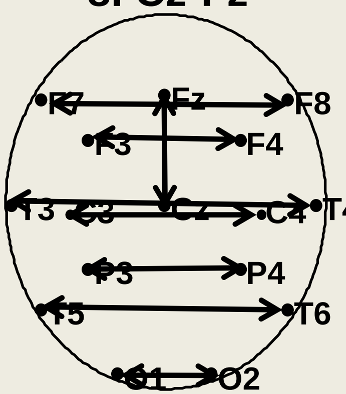


6. Long (12 pairs)



7. Inter-hemispheric (7 pairs)

8. Cz-Fz



RM ANOVA DESING: condition (3 levels – Bkg, S1, S2) * EEG range (3 levels) * hemisphere (2 levels) * location * group (2 levels)

Significant Within-Subjects Effects

1. Condition-dependent EEG rhythms synchronization differs between theta, alpha and beta ranges for all types of pairs of leads

Source	***Pairs of leads***							
	Intra-hemispheric			***Cross-hemispheric***			***Inter-hemispheric***	**Cz-Fz**
	long	***short posterior***	***short anterior***	***long***	***short posterior***	***short anterior***		
Condition *range	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.003**

2. Frequency- and condition-specific changes of EEG rhythms synchronization are different in adults and children. Group differences concern long-distant and short posterior connections

Condition* range* group	**0.039**	**0.025**		**0.025**	**0.016**		**P = 0.09**	

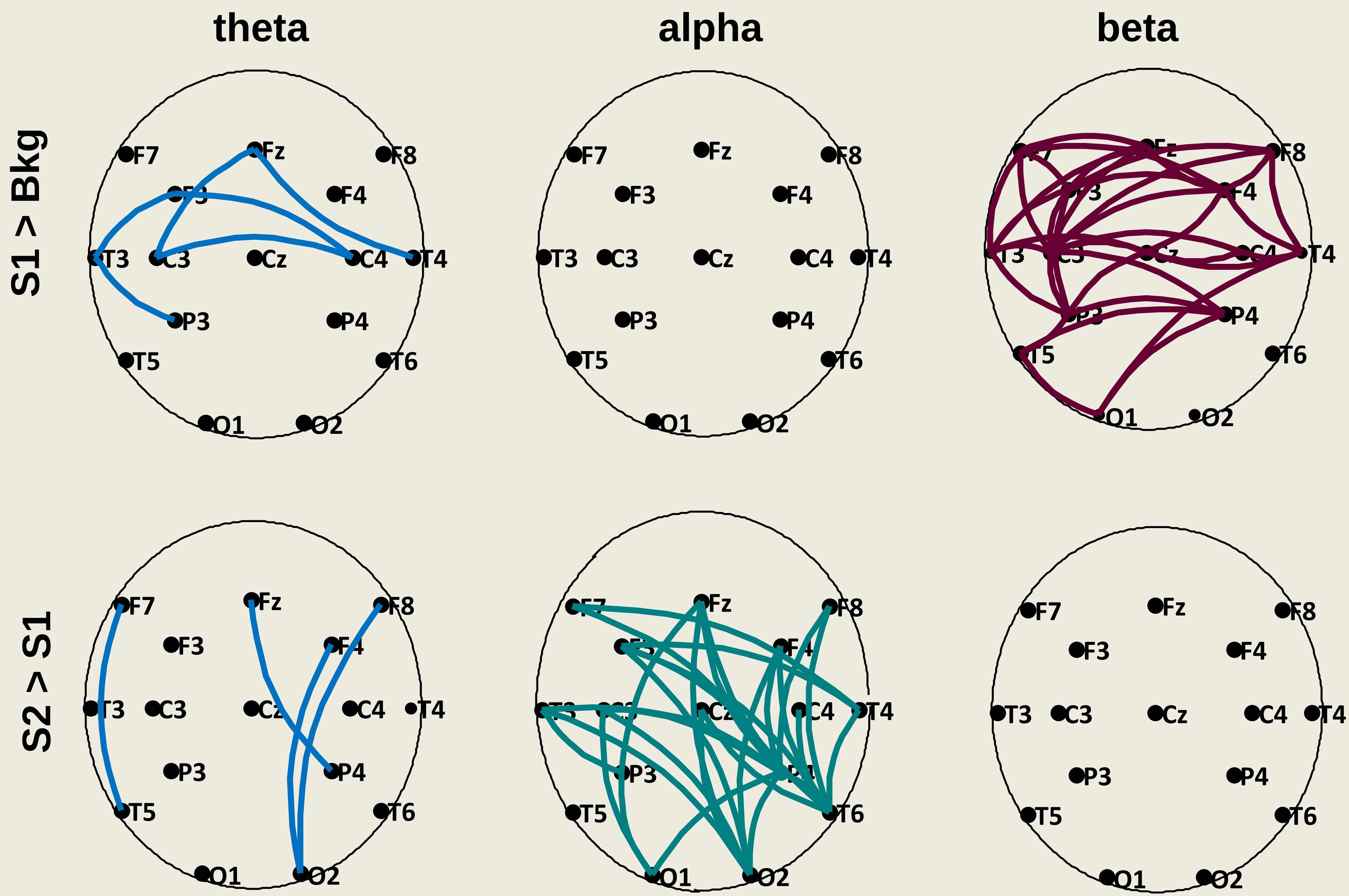
3. EEG rhythms synchronization in various experimental conditions depends not only on frequency range but also on location of pairs of leads. It concerns all short intra- and cross-hemispheric connections as well as inter-hemispheric connection. In addition, there are hemispheric differences in short posterior intra-hemispheric pairs of leads

Source	***Pairs of leads***							
	Intra-hemispheric			***Cross-hemispheric***			***Inter-hemispheric***	**CzFz**
	long	***short posterior***	***short anterior***	***long***	***short posterior***	***short anterior***		
Condition* range*location		**0.0001**	**0.0001**		**0.0001**	**0.007**	**0.0001**	
Condition* range* hem* location		**0.0001**						

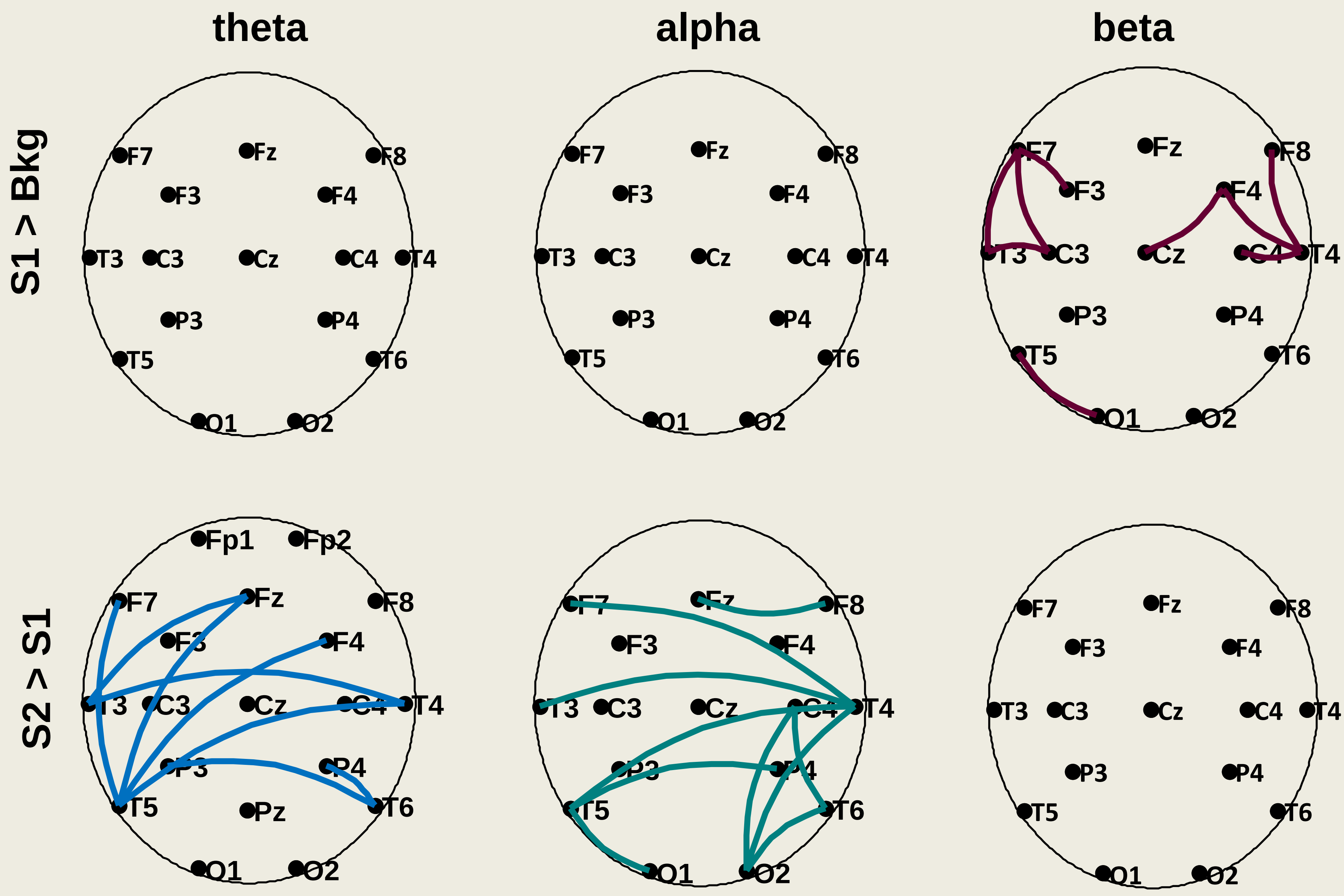
4. Frequency- and topography-specific EEG rhythms synchronization in various experimental conditions differs between adults and children in short anterior intra-hemispheric connections.

Condition* range*location *group			**0.029**					

Significant differences of ImCoh values (T-test, p <0.05) in adults



Significant differences of ImCoh values (T-test, p <0.05) in children



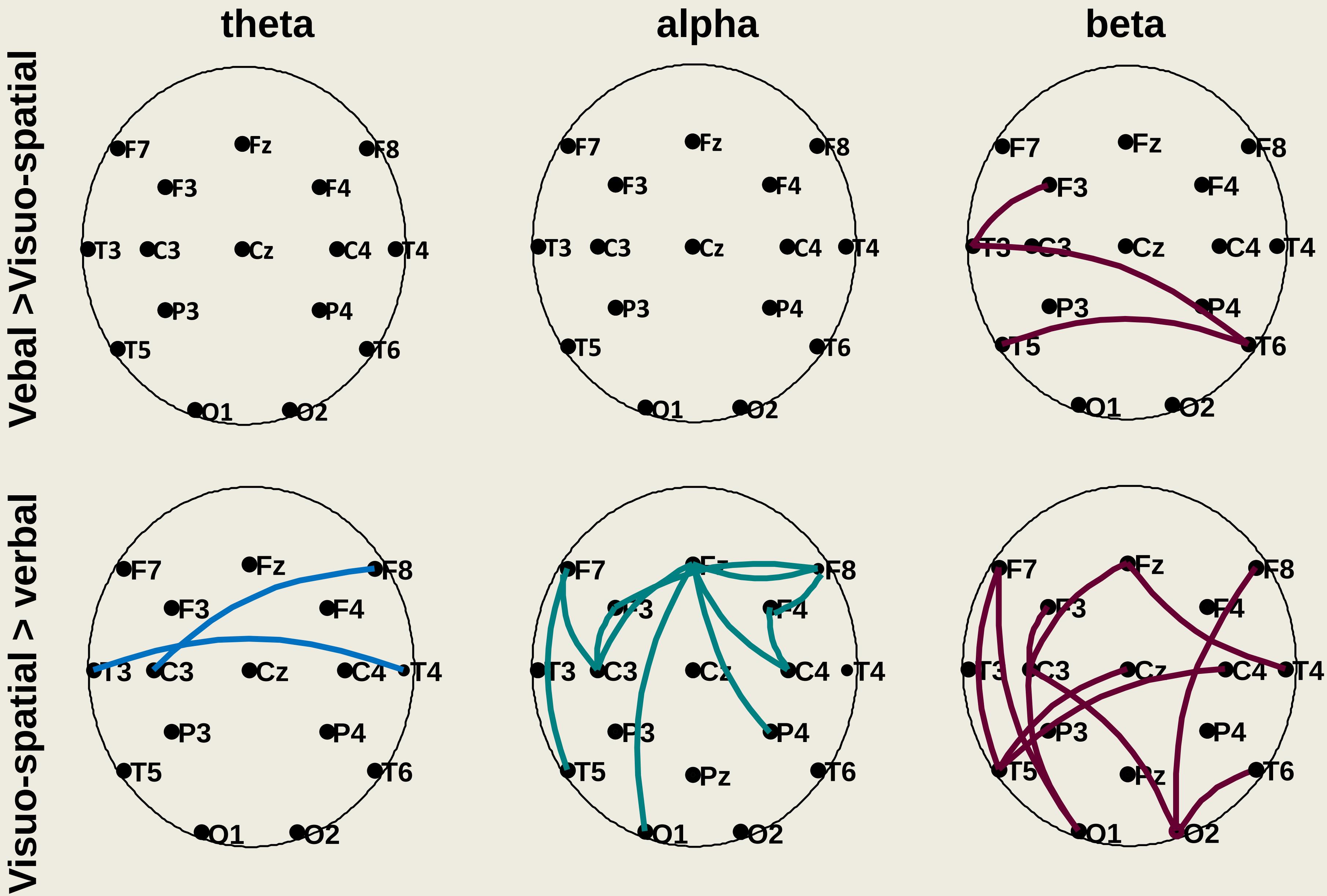
RM ANOVA DESING: condition (2 levels –Verbal WM, Visuo-spatial WM) * EEG range (3 levels) * hemisphere (2 levels) (variable) * location (variable) * group (2 levels)

Significant Within-Subjects Effects

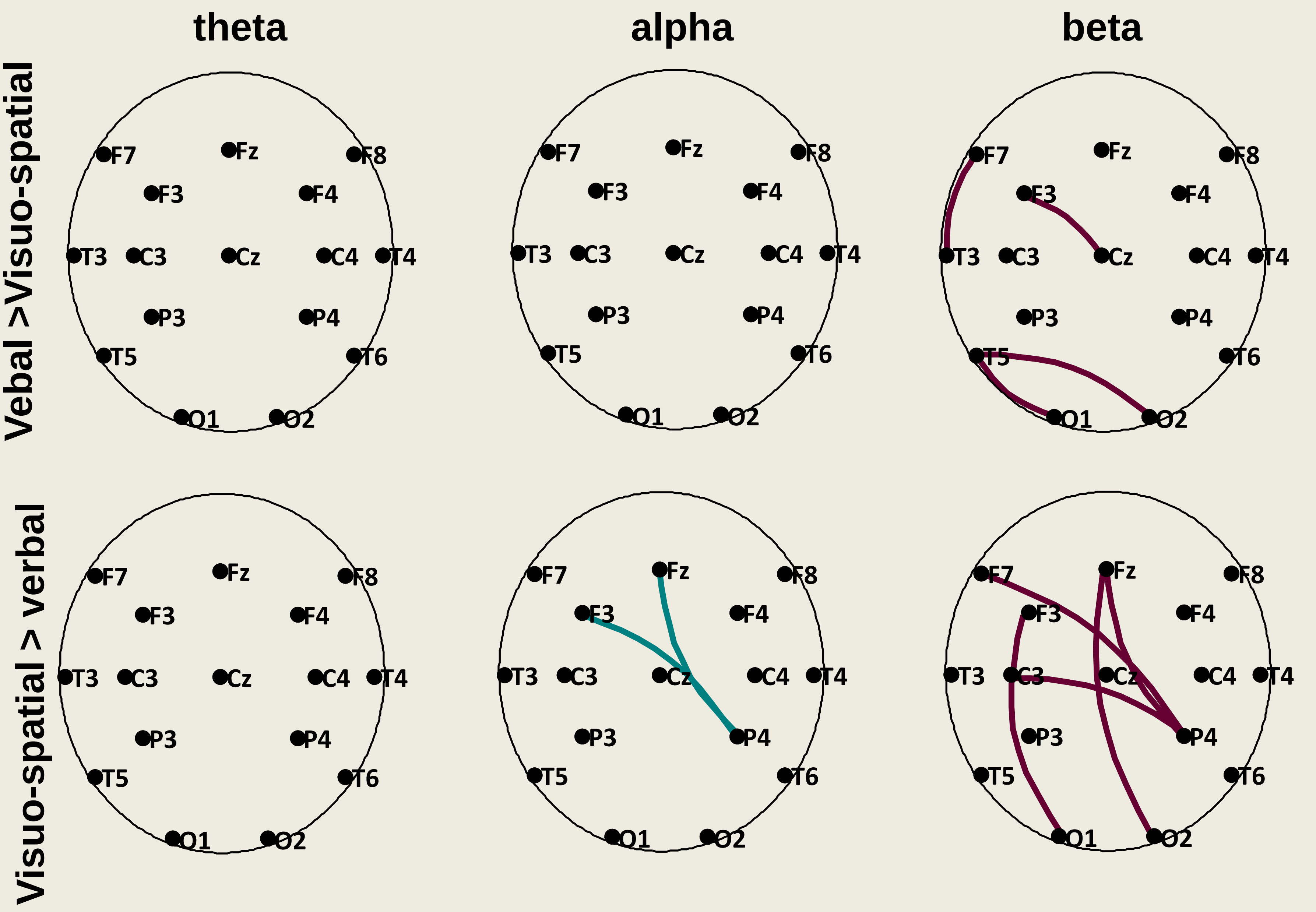
1. There are frequency-specific differences between EEG rhythms synchronization in visuo-spatial and verbal tasks in intra-hemispheric short anterior connections .
2. The differences of this kind depend on topography of leads in both intra-hemispheric and cross-hemispheric short posterior connections. In addition, there are hemispheric differences in posterior region.

Source	***Pairs of leads***							
	Intra-hemispheric			***Cross-hemispheric***			***Inter-hem***	**CzFz**
	long	***short posterior***	***short anterior***	***long***	***short posterior***	***short anterior***		
Condition* range			**0.014**					
Condition * range* location		**0.036**			**0.038**			
Condition * range* hem* location		**0.001**						

Significant differences of ImCoh values (T-test, p <0.05) in adults



Significant differences of ImCoh values (T-test, p <0.05) in children



Conclusions:

➢Theta, alpha and beta brain oscillatory systems play a specific role in providing sustained attention, top-down selective maintenance of internal representation, memory retention and manipulation with specific information during working memory

➢Frequency and topographically-specific changes in EEG rhythms synchronization related with experimental condition were found both in adults and children

➢Comparing with adults, 7-8-year-old children demonstrate less involvement of frontal zones in maintenance of sustained attention and less activation of fronto-parietal system of selective endogenous attention in processes of working memory. On the contrary, memory retention system is more active in children than in adults

Possible directions of further factorial experimental study of WM brain organization:

❖Varying the number of information units or time delays to control memory load

❖Using experimental condition with and without distractors to control selective endogenous attention

❖Using different kinds of stimuli in tasks with equivalent difficulty to control the specific information processing

Thank you!

EEG rhythms and working memory

EEG Rhythm	*Topography*	*Correlation with WM operations*	*References*
THETA	Frontal and Posterior	Retention of information	Sarnthein et al, 1998; Stein et al., 1999; Weiss, Rappelsberger, 2000; Ruchkin, 2002; Sauseng et al., 2005
	Frontal, Posterior and MidTemporal	Memory load and memory retrieval	Klimesch et al., 1999; Gevins and Smith, 2000; Tesche, Karhu, 2000; Raghavachari et al., 2001; Jensen and Tesche, 2002; Dorfler et al., 2001; Molle et al, 2002; Jakobs et al.,2006; Klimesch et al., 2006
	Midline Frontal	Sustained attention	Ishihara and Yoshii, 1972; Asada et al., 1999; Ishii et al., 1999; Kubota et al., 2001,
ALPHA	Parietal, Central	Retention of information, memory load	Jensen et al., 2002; Schack, 2005
	Frontal, Posterior, Modality-specific zones	Modality-specific selective anticipatory attention	Machinsky et al, 1990; Machinskaya, 1998, 2006
LOW BETA (13-20 Hz)	Frontal, Central	Selective anticipatory attention, effort control	Liang et al., 2002; Sommerfeld, 2001
	Frontal, Parietal	Complexity of information to be stored in WM, comparison processes	Kohler, 2001, Sommerfeld, 2001