FFT transformed quantitative EEG analysis of short term memory load

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ABSTRACT

Background: The EEG is considered as building block of functional signaling in the brain. The role of EEG oscillations in human information processing has been intensively investigated.

Purpose: To study the quantitative EEG correlates of short term memory load as assessed through Sternberg memory test.

Methods: The study was conducted on 34 healthy male student volunteers. The intervention consisted of Sternberg memory test, which runs on a version of the Sternberg memory scanning paradigm software on a computer. Electroencephalography (EEG) was recorded from 19 scalp locations according to 10–20 international system of electrode placement. EEG signals were analyzed offline. To overcome the problems of fixed band system, individual alpha frequency (IAF) based frequency band selection method was adopted. The outcome measures were FFT transformed absolute powers in the six bands at 19 electrode positions.

Results: Sternberg memory test served as model of short term memory load. Correlation analysis of EEG during memory task was reflected as decreased absolute power in Upper alpha band in nearly all the electrode positions; increased power in Theta band at Fronto-Temporal region and Lower 1 alpha band at Fronto-Central region. Lower 2 alpha, Beta and Gamma band power remained unchanged.

Conclusions: Short term memory load has distinct electroencephalographic correlates resembling the mentally stressed state. This is evident from decreased power in Upper alpha band (corresponding to Alpha band of traditional EEG system) which is representative band of relaxed mental state. Fronto-temporal Theta power changes may reflect the encoding and execution of memory task.

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Introduction

The EEG is considered as building block of functional signaling in the brain. The role of EEG oscillations in human information processing has been intensively investigated.¹ Brain oscillations at different frequencies in temporal and spatial domain, are considered as functional substrate for the higher-level information processing.

EEG power reflects the number of neurons that discharge synchronously, and is considered one of the markers of performance of cortical information processing. EEG Oscillations in different frequency bands are associated with different cognitive processes.^{1,2} Alpha oscillations are considered as marker of attention, alertness and task load.¹ Recent study findings suggest that alpha frequency play active role in storage of information in visual working memory and modulations of these oscillations predict successful short-term visual memory encoding.^{3,4} The Theta oscillations are associated with attentional processing^{5–9} and working memory operations.^{10–14}

Working memory (WM) may be conceptualized as the use of attention to manage the short-term memory load.¹⁵ Many variants of the Sternberg memory scanning paradigm have been used to study WM.¹⁶ Through the Sternberg memory paradigm, gradually increasing load of short term memory can be investigated. Quantitative EEG signal analysis can give insight into the global measure of functional brain states generated during gradually increasing load of short term memory. The present study explored the EEG signatures of dynamic global functional brain states induced during the Sternberg memory paradigm.

Methods

The study was conducted on 34 male healthy volunteers (age 18–30 years; mean $\pm$ SD, 24 ± 3.2). The participants with any history of substance abuse, smoking, alcohol, or those known to be having any medical disease or undergoing treatment for any medical condition were excluded. Ethical clearance for the study was taken from the ethics committee for human subjects. The participants were briefed about the study and informed written consent for participating in the study was obtained.

Sternberg Memory Test (MEMSCAN)

The program MEMSCAN runs a version of the Sternberg memory scanning paradigm. On each trial, a set of digits is first presented to be remembered. The memory set is then replaced by a plus-sign and, after a short delay, a probe digit. The subject's task is to respond as quickly as possible whether the probe was a member of the memory set or not. The memory load in the task ranged from 1–6 digits.

EEG signal acquisition and analysis

Participants were asked to clean their head with shampoo without any conditioner or oil on the day of testing. An electrode impedance of less than 5 kohm was achieved by cleaning with alcohol swab followed by rubbing with "SKINPURE" skin preparation gel (supplied by Nihon Kohden). Silver-Silver Chloride (Ag-AgCl) disc type electrodes of 5–7 mm diameter with long flexible lead were placed on the scalp according to the 10–20 international system with the help of "Elefix" paste for EEG (supplied with Nihon-Kohden). EEG signal was acquired on RMS EEG-19 Superspec system at a sampling frequency of 256 Hz using high (0.5 Hz), low (99 Hz) and notch (50 Hz) pass filters.

Signal analysis

Signals were analyzed offline. Movement and eye blink artifacts were identified visually and the respective stretch of EEG was excluded from analysis. Ten epochs of 2 second duration were selected from artifact free region from Baseline eye open and during Sternberg memory test (MEMSCAN) condition. The outcome measures were FFT transformed absolute power in six bands at 19 electrode positions. Average of 10 epochs of eye open condition and Sternberg memory test were statistically compared and analyzed.

To overcome the problems of fixed band system, Individual Alpha Frequency (IAF) based frequency band division method was used.¹ To determine IAF, FFT (Fast Fourier Transformation) was applied on baseline epochs at PZ electrode position. The peak power frequency among 8–12 Hz was designated as Individual Alpha Frequency. Frequency bands were determined individually for each subject by using IAF as the cut-off point between the lower and upper alpha band. Six EEG frequency bands were analyzed: (1) Theta band: IAF- 4Hz to IAF - 6 Hz (2) Lower 1 alpha band: IAF – 2 Hz to IAF- 4 Hz (3) Lower 2 alpha band: IAF to IAF-2 Hz (4) Upper alpha band: IAF to IAF + 2 Hz (5) Beta band: IAF + 2 Hz to 30 Hz (6) Gamma band: 30 Hz to 99 Hz. Average of 10 epochs of different conditions were analyzed for **Absolute Power (AP)** which is Root mean area under power spectrum of a given band, expressed in microvolts squared.

Statistical Analysis

The statistical analysis was done using STRATA Software. The distribution of the data was found to be non- Gaussian type; therefore non parametric test (Wilcoxon Signed-rank) was applied. Comparison of MEMSCAN and Basal Eye Open data (Absolute Power) was done by paired *t*-test, and the *p* value less than 0.05 was considered significant and has been represented as * and *p*<0.01 as **.

Results

In the present study Sternberg memory test was selected as intervention for the short term memory load. EEG powers in various bands during short term memory load were compared with eye open alert state of recording. Findings in different frequency bands are as follows (Table 1):

Theta band

Short term memory load showed **increased** absolute power mainly in the Fronto-Temporal regions (F3, FZ, F4, and T6) of theta band only. Rest of the electrode positions did not show any significant change.

Lower 1 alpha band

Short term memory load showed increased absolute power mainly in the Fronto-Central regions (F4, C4) only. Rest of the electrode positions did not show any significant change.

Table 1: Effect of short term memory load on Absolute Power as compared to basal eye open alert condition:

Electrode	Theta	L1 Alpha	L2 Alpha	U Alpha	Beta	Gamma
FP1				_*		
FP2						
F3	+*			_**		
FZ	+**					
F4	+*	+**		_**		
F7				_*		
F8						
C3				_**		
CZ						
C4		+*		_**		
T3				_**		
T4				_**		
T5				_**		
T6	+**			_*		
P3						
PZ						
P4						
O1				_*		
O2				_*		

(+) Indicates an increase and (-) indicates a decrease.
p value less than 0.05 is represented as * and *p*<0.01 as **

Upper alpha band

Short term memory load showed **decreased** absolute power in most of the electrode positions (FP1, F7, F3, F4, C3, C4 T3, T4, T5, T6, O1, O2) of the upper alpha band, however power of FP2, FZ, F8, CZ, P3, PZ and P4 electrode positions did not show any significant change.

Lower 2 alpha, Beta and Gamma band

Short term memory load showed **no significant** power change as compared to basal eye open alert condition in Lower 2 alpha, Beta and Gamma band in all electrode positions.

Discussion

In the present study, Sternberg memory was selected as a model of short term memory load. The task of Short term memory load was associated with interesting pattern of power changes in various alpha and theta bands. We found decreased power in Upper alpha band and increased power in Theta band & Lower 1 alpha band (Fronto-Central region) during the task. While Lower 2 alpha, beta and Gamma band power remained unchanged.

Since the work of Hans Berger (1873–1941), Alpha waves represent wakeful relaxation state, predominantly originating from the occipital lobe of brain. Recent studies of IAF based Alpha sub band (Lower 1 alpha, Lower 2 alpha and Upper alpha band) show significant active power changes during the performance of tasks. The different sub bands within the Alpha frequency may reflect different aspects of the memory task, like attention, sensory-semantic processing and active storage of information.^{1,3,4}

Frontal midline theta has been reported during WM tasks¹⁷ attentional processes^{5–9} and tasks requiring memory retention & mental imagery.¹⁸ Lower 1 alpha band represent an index level of internalized attention, alertness and expectancy.¹⁹ In our Sternberg memory task alertness, expectancy and internalized attention are the key cognitive processes. Thus increased power in Theta and Lower 1 alpha band in present study may reflect the neural basis of dynamic functional signaling required during the execution of short term memory load. On the other hand decreased power in Upper alpha band may be reflective of desynchronization in neuronal assembly caused by superimposed gradual building up of mental stress and performance anxiety with the progression of task.

In present study we have found no significant changes in the power of Beta and Gamma bands. Gamma oscillations are important building blocks of synchronization of electrical activity of the brain and reflect local processing within short-range connections.^{20,2} No change in Frontal Gamma especially over the Frontal and Central areas is suggestive of fall in attention during heavy attention demanding task.²¹ Gradual fall in attention may be result of mental stress and fatigue with progression of task.

The EEG changes showed an interesting pattern which was quite different than wakeful alert state. An increase in the Theta power suggests increased memory load during the memory task. Theta power rises sharply when working memory is required, maintained throughout the memory task, and decreases when working memory is no longer required.^{22,1} A decrease in Upper alpha power compared to eye open resting condition suggests an increase in semantic memory related desynchroni-

zation.^{23,1} On the other hand, an increase in the Lower 1 alpha power and no change in Lower 2 alpha power may suggest a decrease in the alertness level and no change in expectancy (two components of attention).^{23,1} No change in Lower alpha power may reflect the increased efforts (and probably difficulties) of subject to maintain a state of alert wakefulness.²⁴ It was also found that in contrast to subjects with high sustained attention, low sustained attention subjects who have difficulties to inhibit environmental stimuli show a significantly large proportion of Lower alpha power.²⁵ An increase in Lower alpha power occurs only when they are not allowed to fall asleep and when they are forced to stay awake.

In summary, during the memory task in the present study, an increase in the (semantic) long-term memory performance with encoding of new information was taking place (Theta synchronization) while the subject's attention was low (no change in Lower 2 alpha and Gamma band and increased power in Lower 1 alpha at Fronto-Central leads) while participant was trying hard to perform (Upper alpha desynchronization). It is suggested that the encoding of new information is reflected by Theta oscillations in Hippocampal-Cortical feedback loops, whereas search and retrieval processes in (semantic) long-term memory are reflected by Upper Alpha oscillations in Thalamo-Cortical feedback loops.¹

Finally, the results of the study may be context specific to the type of participants selected and their perception of the Sternberg memory scanning paradigm in the lab settings. Short term memory load have distinct electroencephalographic correlate suggestive of mentally stressed state. This is evident from decrease power in Upper alpha band (corresponding to Alpha band of traditional EEG system) which is band of relaxed mental state. Therefore decreased power in the Upper alpha may be considered as the true representative of the fixed band Alpha of the old system.

Increased power in the Theta band and in the Lower 1 alpha band in various Fronto-Temporo-Central Leads may be required in various sub-processing (i.e. encoding, alertness, expectancy and retrieval) of short term memory load.

Authorship contribution

Yogesh Singh: Design of study, Acquisition, Interpretation and Drafting, **Jayvardhan Singh:** Drafting of article, **Ratna Sharma:** Concept and design of study and interpretation, **Anjana Talwar:** Concept and design of study, critical important revision.

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