

Theta-band amplitude, reaction time and task switching



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1. Abstract

The time course of theta-band amplitude during the cue–stimulus interval in a task-switching experiment is shown to be dependent on whether subjects were to switch or hold their current stimulus–response mapping, and on whether their subsequent responses were fast or slow. At a critical period about one second post-cue, a reduction in amplitude predicts faster responses for switch trials, while for hold trials high amplitude is followed by fast responses.

2. Introduction

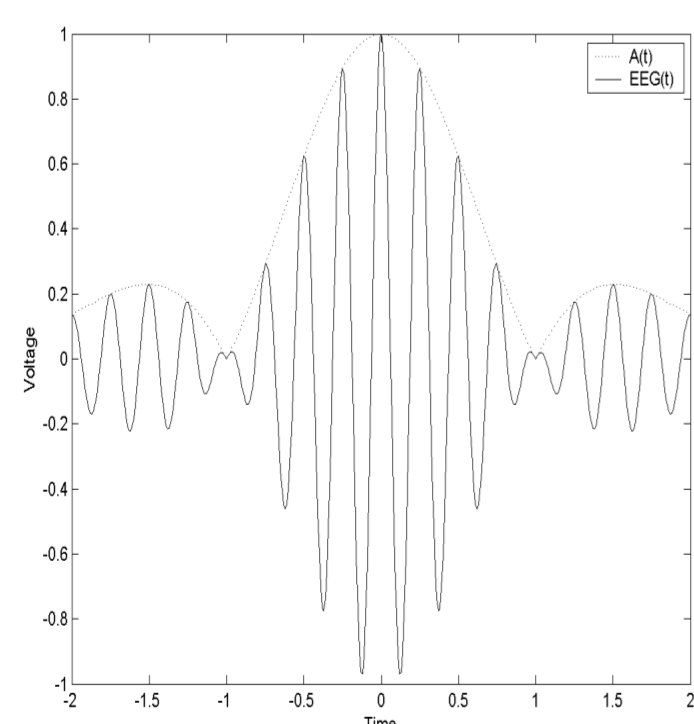
THETA band (5 - 7 Hz) oscillations in the EEG have been found to be associated with working memory [5] and memory retrieval [4]. Hippocampal theta frequency and amplitude covary with the speed and magnitude, respectively, of voluntary movements [6], and it has been argued that hippocampal theta band activity is involved in sensorimotor integration [1]. This frequency band might then be expected to play an important role when subjects exert control over temporary stimulus-response mappings, or task sets.

SWITCHING between task sets is associated with a cost in reaction time that persists even at long preparation intervals. Switch trials preceded by long preparation intervals have been shown to have a characteristic reaction time distribution [2]. This distribution can be modelled as a mixture of two trial types: trials when the correct task set is already prepared at stimulus presentation and trials on which the task set must be set up post-stimulus.

REACTION-time based definition of EEG segments, then, allows the time courses of theta-band amplitude during different preparatory conditions to be compared. Does theta-band amplitude show a different time course when subjects switch pre-stimulus, as determined by subsequent fast responses, compared to when they fail to switch pre-stimulus or are not required to switch, as on hold trials?

3. Method

WAVELET analysis allows changes over time of oscillatory amplitude to be measured. The underlying model of the time course of oscillations of frequency f in EEG data has the basic form $EEG(f, t) = A(t) * \cos 2\pi ft$. Given a frequency f , increases and decreases in the amplitude of signal components with a frequency around f can be plotted, as illustrated in figure 1A. The theta-band amplitude time courses at electrodes Fz, Cz, Pz and Oz were analyzed. Nine subjects were measured.



A

Trial	Cue	Mapping
1	...	A
2	"switch"	B
3	"switch"	A
4	"hold"	A
...

B

Figure 1: A - Amplitude function example. B - Task illustration

TWO stimulus–response mappings were used in the experiment. The 'A' mapping coupled the stimulus 'X' → left hand and 'O' → right hand. The 'B' mapping crossed these relations: 'X' → right hand, 'O' → left hand. The task used explicit cues to indicate whether a subject was to hold their current mapping or switch to the other mapping (figure 1B). "Switch" and "hold" cues were given by blue and gray asterisks. Subjects had 1500 ms to prepare between the cue and the imperative stimulus.

BINS of trials were created based on reaction time: the first bin contained the fastest 20% of the trials, the second bin the second fastest fifth, and so on. The reaction time bin was used as a marker for trials in the EEG analysis.

4. Results

TIME-course differences between switch and hold trials were found for the first ("fast") and third ("medium") reaction time bins (figure 2).

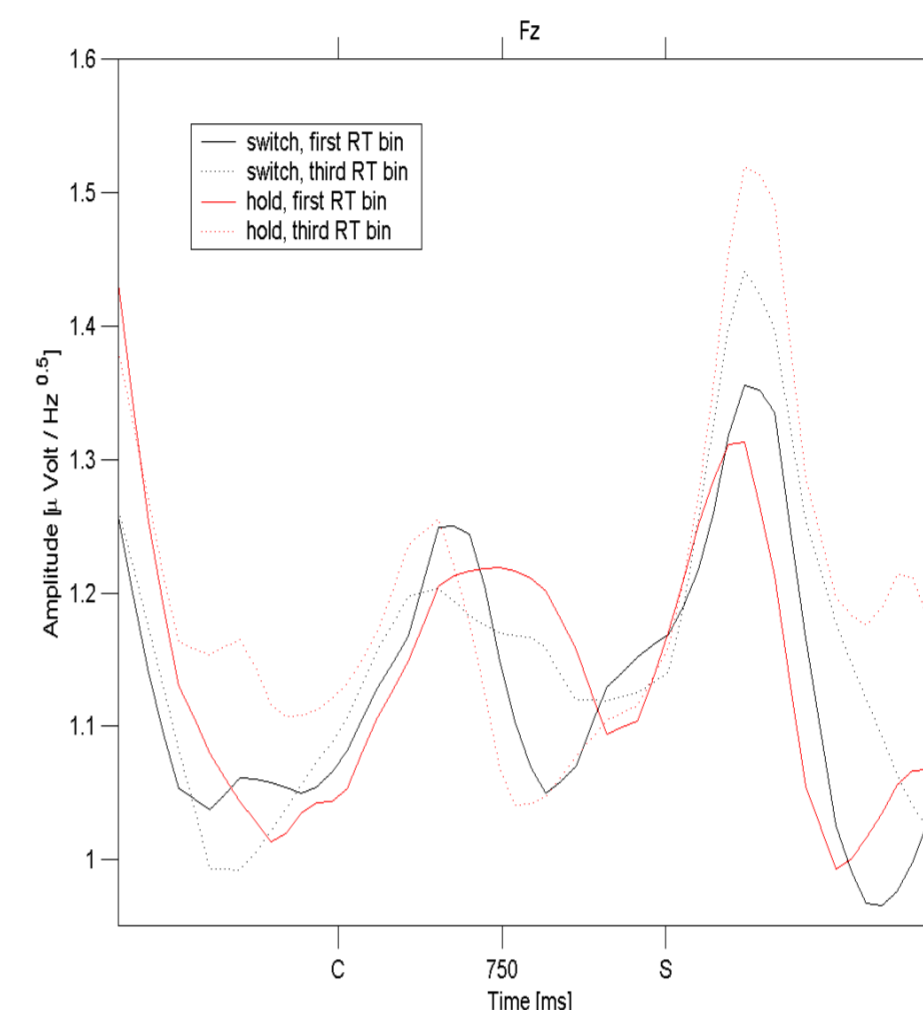


Figure 2: Theta-band time course. C = Cue, S = Stimulus

These effects were most clear at frontal electrode sites. Post-cue, all conditions show an increase in theta-band amplitude, but for fast switch trials and slow hold trials the amplitude drops, while in the other conditions it remains high. That is, whether high or low theta-band amplitude is found after the initial post-cue peak predicts faster response speed, but the prediction is reversed for switch and hold trials.

5. Discussion

THETA-band amplitude during the cue–stimulus interval was found to have a different relation with subsequent reaction time for switch and for hold trials. Switch trials were faster when theta amplitude dropped after the initial peak. In contrast, hold trials were faster when theta amplitude remained high for a longer period. In another experiment, in which subjects had to switch between tasks with different stimulus modalities, a similar effect was found when comparing switching to a visual versus switching to an auditory task [3]. Over visual cortex, switching to visual trials was associated with a transient increase followed by a decrease of theta-band amplitude. This pattern was absent when switching to auditory trials.

COMPETITION for phase is a mechanism that partially explains these results. We have implemented phase competition in a simulation of spiking neurons, hypothesizing that the essential mechanism of task set preparation is the competition between subsets of neurons within a cycle of recurrent inhibition [7]. During competition, a large set of neurons fires in phase. After competition is resolved, only the winning set oscillates, so that the summed activity of the neurons, as would be measured at the scalp, would rise as competition starts and fall as competition is resolved. A successful switch would be expected to quickly resolve the competition between the neuronal elements of the old and new task sets. Successful task set maintenance on the other hand may require reactivation, but not at the intensity necessary to destabilize the current task set. Further studies combining neuroimaging evidence with biologically plausible computational models may reduce cognitive concepts to precisely defined neuronal processes and their interactions with each other and the environment.

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