

EEG and eye-events relating to perceptual switching in the Necker cube

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Abstract

We studied perceptual switching in relation to EEG and eye-events such as blinks and saccades during 240 second continuous presentations of the Necker cube. Participants indicated switches by button presses. At several moments prior to, during, and after the button presses, the frequency of EEG and eye-events deviates significantly from the average. The results indicate that perceptual switching processes belong to a number of distinct categories. Eye-events have multiple properties in the process; some facilitate perceptual switching and the other are consequences of it. The pattern of EEG shows discrete variety depending on the properties of the eye-events.

This study deals with perceptual switching in ambiguous figures, for which observers frequently report two distinct interpretations. When such a figure is presented continuously for a period of time, observers report spontaneous switching between the interpretations. As perceptual switching occurs without any changes to the figure itself, this phenomenon is eminently suitable to study how the intrinsic dynamics of the brain influences our perception.

In a previous study (Nakatani, 2006), we investigated perceptual switching by recording the electroencephalogram (EEG). We observed that prior to a switch response, transient periods of gamma band phase synchronization occur between parietal and frontal areas. Gamma band synchrony between widespread areas is considered important for binding of distributed feature representations. The synchronization we observed may, therefore, indicate the recruitment of resources for perceptual switching.

In all the cases where gamma band synchrony was observed, as the synchronized activity appeared between parietal and frontal areas, it is clear that the intrinsic dynamics leading to a switch resides in the higher cognitive areas. Our previous results have shown, however, that perceptual switching-related synchrony is not uniform in terms of the underlying brain events. We could classify synchrony patterns into four distinct categories. Two of them occurred in combination with alpha band activity in the occipital area. In these cases alpha band activity followed gamma band synchronization, we may infer that perceptual switching in the Necker cube sometimes, but not always, involves a renewed reading out of sensory information. When no activity is observed in occipital area, the information represented in parietal and frontal areas is still sufficient to induce the switching.

Gamma band synchrony was observed in only about 60% of the switching processes. The question, therefore, should arise: what happens in the remaining cases? We propose that here, unlike the previous cases where top-down processes are involved, switching occurs as a result of internal perturbations of the visual system at lower level. We propose that transient changes of the visual input resulting from eye-events such as blinks or saccades could cause these internal perturbations. We, therefore, analyzed roles of eye-events in the switching

process.

Method

Participants

Six participants (1 male and 5 females, aged 21-34) with normal or corrected-to-normal vision participated in this study. Participants gave their written informed consent. The Research Ethics Committee of our institute had approved this study.

Experimental design

The experiment consisted of two conditions: the experimental perceptual switching (PS) condition and the stimulus initiated (SI) condition. Each session consisted of the first 4 minutes of the PS-condition and the second 4 minutes of the SI-condition.

In the PS-condition, a Necker cube was continuously presented as a white line-drawing on a black ground. The stimulus was shown at eye-height on a flat-panel monitor in a dark sound proof room for 4 minutes. Participants were at a distance of 85 cm from the monitor; size of the stimulus was 5.0 degrees of visual angle. Participants pressed a response button corresponding to the perceived switching direction. They pressed the button with their dominant hand whenever their visual percept of the Necker cube reversed but not when it merely became inconsistent or vague.

In the SI-condition, two biased version of the Necker cube were presented alternately at the same location. Each cube was continuously presented for a variable time interval of 5.0-10.0 seconds (mean: 7.5 seconds). Whenever it was detected that one figure was changed into the other, participants pressed the appropriate button.

Eye-events measurement

Eye-events (blinks and saccades) were measured with an SMI Eyelink system in three participants and an SMI Eyelink 1000 system in the others. Both systems are video-based eye-tracking systems. In the first case, a head-mounted camera with a sampling frequency of 250 Hz was used for eye-tracking. We used a chin rest to suppress head movement. In the other case, a camera with a sampling frequency of 500 Hz was mounted on a fixed device that also contained the chin rest.

Time series of eye-event probabilities

If a certain eye-event is time-locked to the switch response, time series of eye-event probabilities would show a peak at a specific time corresponding to the eye-event. We calculated eye-event probabilities time series for each individual participant in both the PS and SI-conditions. The eye-events we considered were blinks and saccades. They were analyzed separately. Choosing the button press responses as the reference (0 ms), we calculated the probability of an eye-event within 100 ms width bin with 50 ms overlap.

Time series of eye-events may contain several peaks. In order to simplify characterizing each peak, we divided the time domain into three phases. The "pre-switching"

phase was -1300 ms to -700 ms from button press responses, the "switching" phase was -700 ms to 0 ms, and the "post-switching" phase was 0 ms to 600 ms.

EEG measurement

Ag/AgCl electrodes were placed on O1, O2, P3, Pz, P4, F3, Fz, F4 recording sites in accordance with the international 10/20 system. When the SMI EYELINK 1000 system was used for eye-events measurement, additional electrodes were placed on C3, Cz, C4 recording sites. Reference and ground electrodes were placed on left and right ears of each participant, respectively. Signals were digitized at 500 Hz.

Continuous wavelet transform

After eye-event related artifacts in EEG recordings were reduced with independent component analysis, we produced scalograms by a continuous wavelet transform. The mother function of the transform was the complex Gabor function. Amplitude of EEG in the time-frequency domain was normalized by the mean amplitude at each frequency.

Detection of EEG relating to perceptual switching

We had previously observed that the switching-related gamma band synchrony shows a discrete variety of activity patterns (Nakatani, 2006). Here, we consider the possibility that the same happens for the switching process that involves eye-events. This would imply that a certain eye-event could have a different functional role, depending on the pattern of the switching process. We consider that the pattern of the switching process reflects the pattern of EEG. The pattern of EEG, therefore, shows discrete variety depending on the roles of the eye-events.

For detection of the switching-related EEG, we analyzed scalograms that accompanied each peak of interest in eye-events probabilities time series. Scalograms were aligned with eye-events or button press responses. In these scalograms we observe multiple transient periods of synchronization. We consider whether some of these patterns are systematically related to the switching. We reasoned that if this is the case, then we should be able to detect some of these patterns to occur jointly in the aligned scalograms with greater than chance probability. In our previous study, we observed switching-related synchrony patterns consisting of pairs of transient periods of synchrony when scalograms were aligned with respect to button presses. Here, we tested the possibility that the same happens; i.e. a pair of transient period of EEG appearing jointly when the scalograms are aligned with respect to an eye-event. We divided scalograms aligned with eye-events or button press responses into small segments. The size of each segment was 100 ms in width and 0.5 Hz in height. We compared the unconditional probability that a period of activity appears in a certain segment with the conditional probability that a period of activity appears in the segment given that period of activity appears in a certain other segment and compared this to the chance probability using the method of surrogate data. Details of the analysis are provided in Nakatani (2006).

Results and Discussion

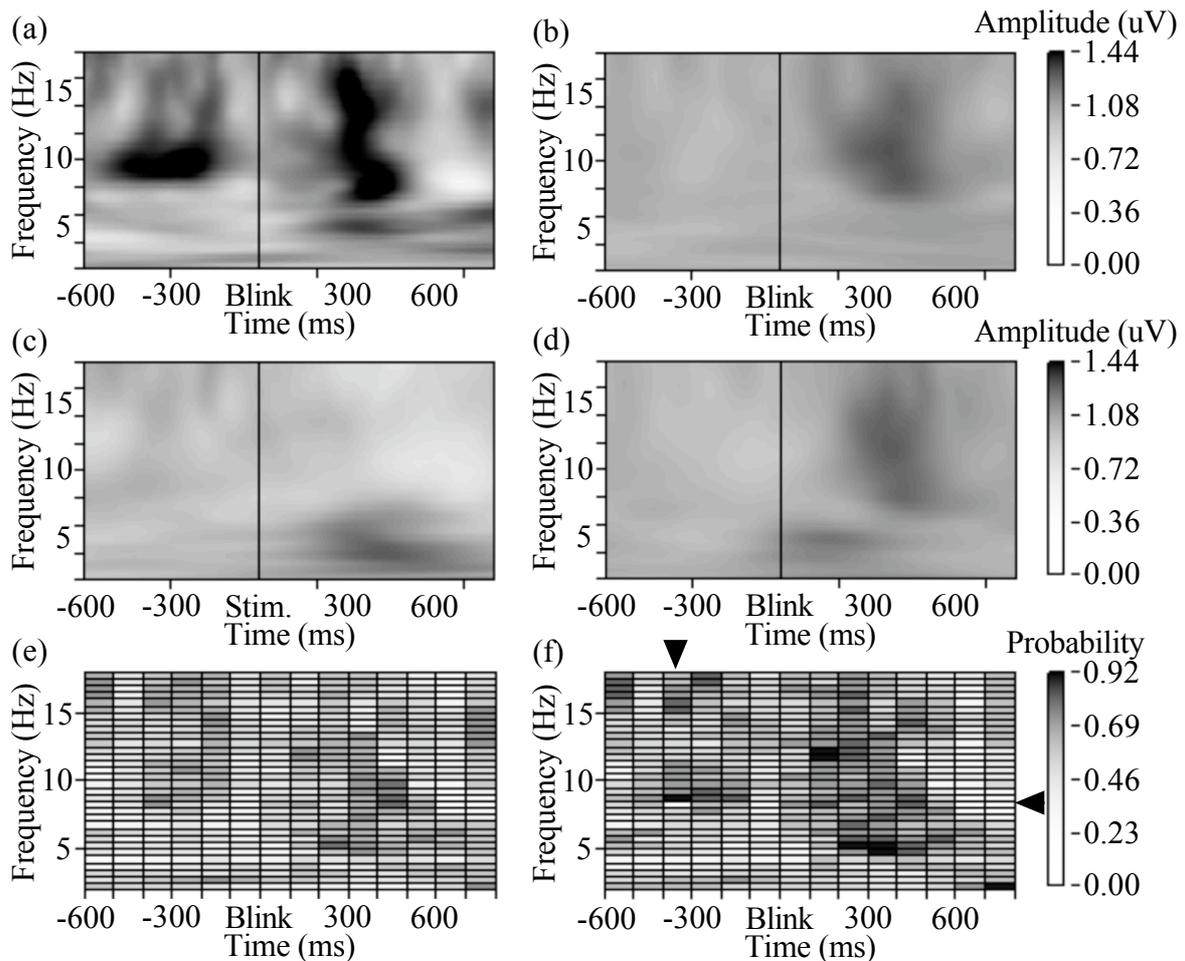


Fig. 1. EEG at parietal area (Pz). (a) When the switching events involved a blink at -1100 ms to -1000 ms from the button press responses in the PS-condition, corresponding Pz-recordings were aligned with blink-onset and were averaged. (b) Pz-recordings in the PS-condition were aligned with blink-onset and averaged. Blinks at -1100 ms to -1000 ms from the responses were excluded. (c) Pz-recordings in the SI-condition were aligned with change of presented stimulus and were averaged. (d) Pz-recordings in the SI-condition were aligned with blink-onset and were averaged. (e) Time-frequency plot of probability that the activity occurred at each segment when the switching events involved a blink at -1100 ms to -1000 ms from responses in the PS-condition. (f) Time-frequency plot of conditional probability that the activity occurred at each segment given that the activity occurred at one segment indicated by arrows when the switching events involved a blink at -1100 ms to -1000 ms from responses in the PS-condition.

Fig.1 shows EEG recorded at parietal area (Pz) of a participant. Fig.1(a) is the average Pz-recordings aligned with blink-onset in the PS-condition when a switching event involved a blink at "pre-switching" phase, 1050 ms prior to a button press response. Three periods of activity could be observed. One appeared in the alpha band before blink-onset and the others in the delta and alpha bands after blink-onset, respectively. For comparison, Fig.1(b) shows the average Pz-recordings aligned with blink-onset in the PS-condition in cases where no blinks occurred at 1050 ms prior to a button press responses. Here, alpha band activity occurred after blink-onset. This activity is simply caused by blinking. The other two periods

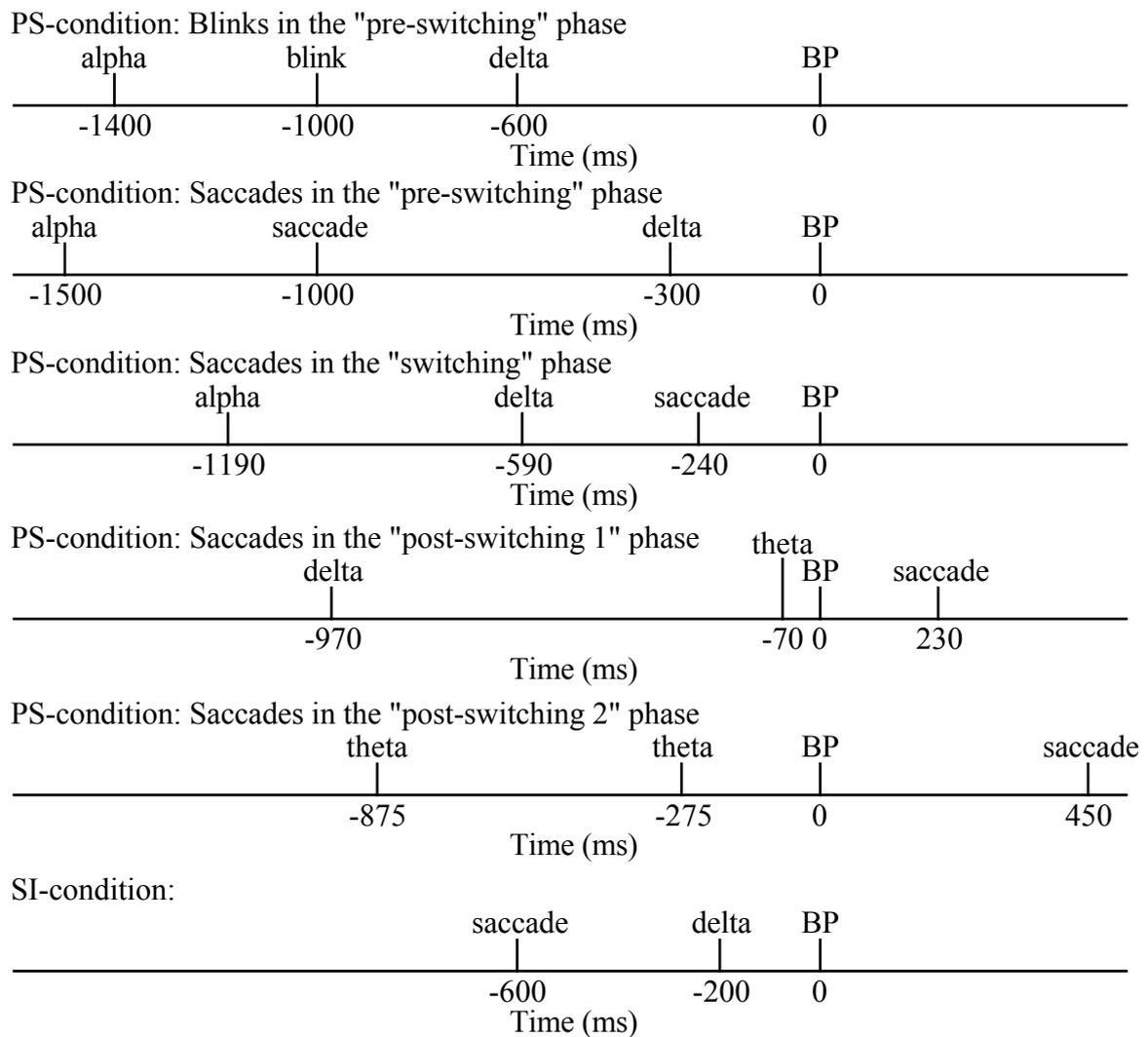


Fig. 2. Time course of eye-events and EEG, aligned with timing of button press responses ("BP"). The switching-related activity consisted of pair of transient periods of activity. "alpha", "delta" and "theta" indicate timing of alpha, delta and theta bands activity, respectively. "blink" and "saccade" are onsets of blinking and saccades. "stimulus" is timing of change of the presented stimulus in the SI-condition.

of activity in Fig.1(a), therefore, might be specific to perceptual switching process.

Figs.1(c),(d) show the average Pz-recordings in the SI-condition, aligned with change of presented stimulus and blink-onset, respectively. Fig.1(c) shows that change of the stimulus caused delta band activity which is similar to that in the PS-condition in Fig.1(a), This activity, therefore, may be identified as relating to the change of percept. Alpha band activity in Fig.1(d) was caused by blinking in the SI-condition. This activity was similar to that in the PS-condition in Fig.1(b).

In Fig.1(a), we observed both alpha band activity before blink-onset and delta band activity after blink-onset. We investigated whether the two activities appeared jointly, in pairs. Fig.1(e) shows time-frequency plot of probability that the activity occurred at each segment in the PS-condition when a switching event involved a blink at 1050 ms prior to a button press response. Fig.1(f) shows a time-frequency plot of the conditional probability of activity, given that activity occurred in the segment indicated by arrows. The location of the

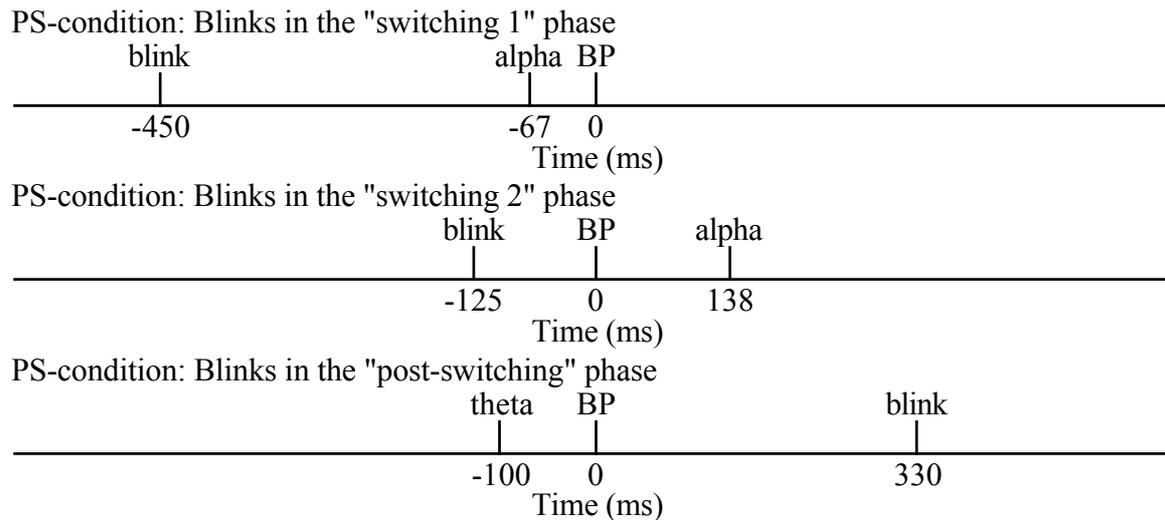


Fig. 3. Time course of eye-events and EEG, aligned with timing of button press responses ("BP"). The switching-related activity was observed as a single periods of activity.

segment is corresponding to where alpha band activity appeared in Fig.1(a). Segments of delta band activity in Fig.1(f) showed higher probabilities than those in Fig.1(e). We may, therefore, conclude that delta band activity appeared jointly with alpha band activity.

We analyzed EEG activity corresponding to blinks or saccades. Patterns of EEG could be roughly classified into two categories. One consisted of a pair of transient activity periods which appeared jointly with eye-events. This pattern appeared when blinks occurred in the "pre-switching" phase or when saccades occurred. A diagram of these courses of events is shown in Fig.2. The other consisted of a single transient period of activity. This pattern of activity appeared when blinks occurred in the "switching" or "post-switching" phases. The diagram in Fig.3 shows this course of events.

Based on time course of EEG, the "post-switching" phase for saccades could be divided into two, the "post-switching 1" phase and the "post-switching 2" phase. Periods of delta and theta band activity appeared in the "post-switching 1" phase whereas two periods of theta band activity appeared in the "post-switching 2" phase. The "switching" phase for blinks could be also divided into two, the "switching 1" phase and the "switching 2" phase. Alpha band activity preceded the button press responses in the "switching 1" phase whereas it followed the responses in the "switching 2" phase.

Our results indicate that both blinks and saccades have multiple roles in the switching process. As reaction times to a simple visual stimulus are, roughly speaking, usually shorter than 600 ms, eye-events in the "pre-switching" phase may be related to the initiation of the switching. The ones in the "switching" phase may be considered as related to the facilitation of the switching process. As eye-events in the "post-switching" phase occurred after the responses, they are possibly aftereffects of the switching. Furthermore, eye-events with different roles were distinguished by patterns of EEG that accompany them.

References

- Nakatani, H., & van Leeuwen, C. (2006) Transient synchrony of distant brain areas and perceptual switching in ambiguous figures. *Biological Cybernetics*, 94, 445-457.