

DIFFERENT PROPERTIES OF FREQUENCY BAND ACTIVITIES UNDERLIE THE DIFFERENTIAL PROCESSING OF FIGURE-GROUND AND HOMOGENEOUS DISPLAYS

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Abstract

14 participants performed a perceptual learning task requiring the detection of a target defined by contrast-polarity. VEPs were recorded before and after the learning sessions, and learning-related changes on phase-locked frequency components analyzed. Increased amplitude in early-P3 was observed in the target-present condition, concurrent with increased amplitude of delta-activity. In the target-absent condition, decreased amplitude in late-P3 and reduced latency of N4 were found instead, concurrent with decreased latency of both delta and theta activities/Delta-activity has been related to the inhibition of non-relevant neural activity, and theta-activity associated with Hebbian learning (strengthening of synchronous synapses). Both mechanisms may play a role in the target-enhancement and distracters-exclusion effects documented along the learning process. Outcomes suggest that target-present and target-absent conditions are processed differently after the first 250-300 ms following stimulus onset, and that their differential processing relies on distinct aspects of the same phase-locked oscillatory activities.

In a previous work (Grieco & Oliveira, 2010) it was found that perceptual learning along a task requiring the detection of a target defined by contrast polarity exhibited different properties according to whether the target was present (TP condition) or absent (TA condition).

Three aspects of the behavioral data argued for a difference in mechanisms underlying performance in these two conditions: (1) *Dissociations found between objective accuracy and subjective confidence*: even if initially associated with a more accurate performance, the TA condition gave rise to significantly lower confidence ratings. Conversely, despite being initially less accurate in the TP condition, participants expressed greater confidence in their responses. (2) *The patterns of response time (RT)*: RT was significantly higher in the TA condition both at the beginning and at the end of the learning sessions, but it decreased more with practice than in the TP condition. (3) *The transfer effects obtained when the contrast-polarity of target and distractors was reversed*: in the TP condition performance was decreased below the level recorded prior to learning, which suggested an inhibitory mechanism selective for contrast-polarity. The beneficial effects of learning were instead fully transferred in the TA condition, despite the change in contrast polarity, which pointed towards a non-selective mechanism to contrast polarity, perhaps the inhibition of similar elements.

In addition to this, EEG recordings performed at the beginning and after the learning sessions disclosed differences among the TA and TP conditions as regards the late components (namely, P3 and N4) of visual evoked potentials (VEPs). These differences, however, only emerged after learning (Grieco, & Monica Oliveira, 2011), suggesting that changes due to learning may rely on mechanisms associated with the generation of the P3-N4 complex.

The goal of the present study is to further delve into the relations of these two conditions (TA and TP) with electroencephalographic patterns recorded at occipital sites.

More specifically, it is aimed at understanding whether the temporal and spatial properties of the oscillatory rhythms of VEPs play a role in the differential processing of TA and TP displays.

Assessing neuronal oscillatory patterns during the execution of a visual task is currently recognized as a way to tackle aspects of brain activity relevant for both perceptual and cognitive processing. In the last few decades, a growing number of studies have been devoted to highlighting the role of oscillatory brain activities, as defined by frequency bands, in cognitive functions. Available evidence shows the alpha-band activity (8-14 Hz) to be the dominant rhythm in the human scalp. Alpha-band oscillations have been linked with internally-directed cognitive processes (Suanseng et al. 2005). Beta-frequency activity (12-30 Hz) has been associated with memory rehearsal (Tallon- Baudry et al., 2001) and gamma-frequency oscillations (30-70 Hz) with feature binding and attentional or sensorial selection. Delta-band oscillations (0.5-3.5 Hz), considered to index sleep states, have also been associated with selective attention, signal detection, signal matching, and decision making (Basar-Eroglu et al, 1992). Theta-band oscillations (3.5-8 Hz), on their turn, have been related to the phase-encoding of spatial information in the hippocampus, and with cognitive learning processes (Miller, 1991).

Given that our study employed a perceptual learning paradigm conjoined with a signal detection task, it might be expected that, in case the differences found among TA and TP had an expression in brain oscillatory rhythms, they would be mainly expressed in the range of delta and theta frequency bands.

Method

Stimuli

Stimuli consisted of arrays of 4 x 4 elements, subtending an area of 6 x 6 deg at 70 cm viewing distance. The target was a Gabor patch of 0.8 deg, embedded in a field of mirror-image elements with a collinear arrangement. The target was present in half the trials, and its position in the array was randomly varied across trials. Representative stimuli of the target-present and target-absent conditions are illustrated in Fig. 1 (respectively, left and right panels).

Design, procedure and analysis

The learning experiment obeyed a repeated measures design comprising several blocks of 160 trials, each corresponding to 2 (target conditions: present, TP; absent, TA) × 5 (exposure durations: 13-26-39-52-65ms) × 16 (target position in the array). Participants were 14 naïve undergraduate students at the University of Coimbra (aged 18 to 25). Instructions required them to rate their confidence about the presence/absence of the target on a four levels scale (1-absent, absolutely sure; 4-present, absolutely sure). They performed 4-5 blocks of trials a day for 4 days (thus, 16 to 20 blocks in total). Each trial started by the presentation of a fixation screen for 1000 ms, which was immediately followed by the test stimulus. After the stimulus offset, a grey screen was displayed and remained visible until the subject's response.

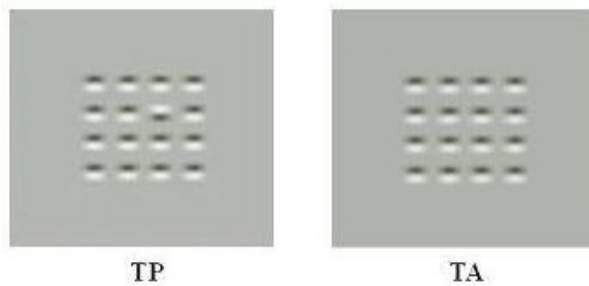


Figure 1. Illustration of stimuli arrays: *Left panel:* TP (target-present). *Right panel:* TA (target-absent).

EEG was recorded in the first and the last learning sessions for conditions with exposure durations of 26 and 65 ms. Ag-AgCl electrodes were placed at scalp locations Oz, O₁ and O₂ (10-20 IS), all referenced to the right ear mastoid. One additional EOG channel was used for artefact control. Data were collected at a sample rate of 200 Hz using 100B Biopac amplifiers, with a band-pass filter of 0.1-35 Hz. Each time epoch included a 150 pre-trigger period and extended for 1 s after the trigger. The subjects' task was to signal the presence/absence of the target. Response only became possible upon the presentation of a 'response display', which appeared after the EEG registration window was over.

Eye-blink effects were removed using the ocular artefact reduction module of *AcqKnowledge 4.1*. All epochs were furthermore visually inspected for artefacts. The EEG signal was filtered for the alpha (from 8 to 13 Hz), beta (13 to 30 Hz), gamma (36-44 Hz), delta (0.5-44 Hz) and theta (4-8 Hz) frequency bands (via the automated filtering module of *AcqKnowledge 4.1*). EEG epochs were averaged for each of the four involved experimental conditions (TP and TA, before and after learning) and baseline corrected to the mean of the pre-trigger period, following which the amplitudes and latencies of the VEPs components in each frequency band were measured. These measures were analyzed with repeated measures ANOVA having *exposure duration*, *session* (first and last) and *target-condition* (TA and TP) as within factors.

Results and Discussion

VEPs corresponding to the TP conditions registered at the beginning (TP-first) and at the end (TP-last) of the learning sessions are displayed in the upper row of Panel 2A in Figure 2, together with their associated event-related oscillations (EROs) in the frequency bands (FBs) alpha (α), beta (β), gamma (γ), delta (δ) and theta (θ) (below, second to sixth row). Waveforms for the TA conditions are displayed likewise in Panel 2B. Presented waveforms were averaged across exposure durations (26 and 65 ms).

The effects of learning (comparisons between the first and last session) upon the amplitude and the latency of VEPs' components may be summarized as follows: a significant increase in the amplitude of P_{3a} (the early component of P3 complex) occurred in the TP condition. As for TA, a significant decrease of amplitude in both the P_{3b} and the N₄ components was observed, along with a decrease in latency of N₄.

Figure 2 shows that learning modulates the EROs. However, the differences in amplitude and latency of the β - and γ -components were not significant between the first and last sessions. Learning had some effect on α -components, though it only reached significance for the exposure duration of 65 ms; this effect consisted in an overall reduction of peak amplitudes and an overall increase of negative deflections (NDs). In addition, a significant

difference between TP and TA in the alpha-latency of late ND (around 400-500 ms), observed in the first learning session, was vanished in the last session.

For delta-EROs, learning had the effect of increasing the amplitude of δ_3 components (the higher peak at P_3 latency) in the TP condition ($p < 0.001$), while latencies remained unchanged. In contrast, latencies decreased at both δ_3 ($p < 0.005$) and δ_4 (ND at N_4 latency, $p < 0.001$) in the TA condition. For theta-EROs, practice reduced the latency ($p < 0.02$) of later components θ_4 and θ_5 (the higher peak at P_3 latency and the ND at N_4 latency). Though they did not differ significantly, these reductions were larger in the TA condition.

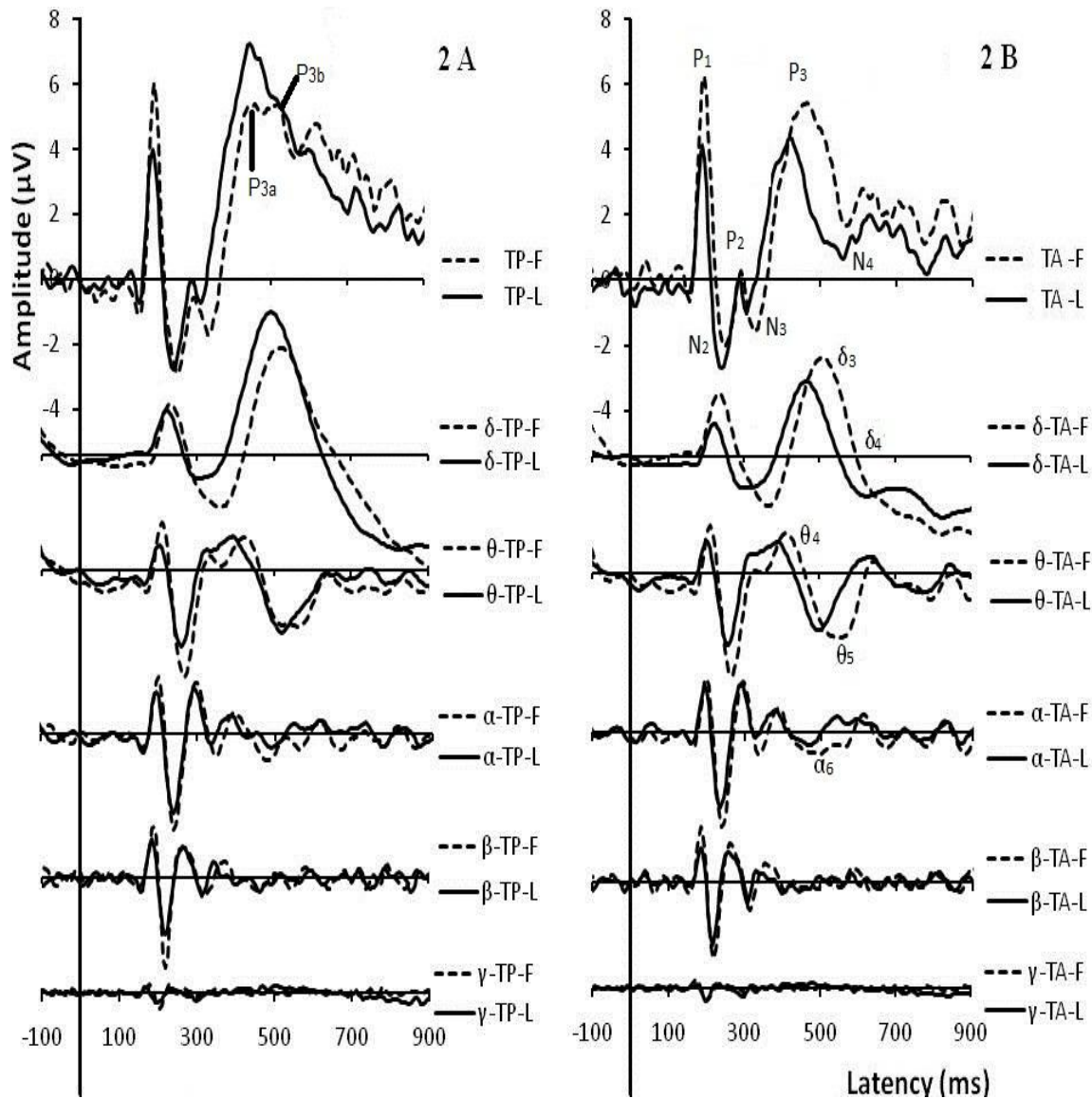


Figure 2. Visual-evoked potentials (waveforms in the top row) and event-related oscillations in the delta (δ), theta (θ), beta (β), alpha (α) and gamma (γ) frequency bands respectively. F and L in the legend refer to the first (dashed line) and last (full line) learning sessions. *Left Column (2A):* target-present (TP); *Right Column (2B):* target-absent (TA).

Inspection of the graphs shows that, albeit not by a significant amount, practice did reduce somewhat the amplitudes of frequency band components at early latencies, before P_3 . The reduction was the same regardless of whether a distinct target is present among mirror-

imaged background elements or not. This is consistent with the idea that, at early latencies, TP and TA processing share the same neural mechanisms.

The differential processing of figure-ground (TP) and homogeneous elements (TA) displays is evidenced, instead, at later latencies, and appears to involve different properties of frequency band activities in the relevant VEPs components. While in the TP condition the amplitude increase of the early P_3 component appears to be mainly determined by delta-activity, the effects of learning on the P_{3b} and N_4 components in the TA condition are mainly due to the decrease in latencies of both delta and theta late components.

Delta and theta frequency bands are reported to be the most stable constituents of human P300 components (Basar-Eroglu et al. 1992). Delta-band oscillations have long been considered to index states of sleep. The progressive change in delta activity observed in EEG from alertness to sleep has been associated with inhibitory mechanism ('Class I inhibition') responsible for the inactivation of excitatory processes, which results in a relaxed state, as in sleep. However, the high correlation reported between the occurrence of delta-waves during the performance of a task and proficiency in the task execution has led to the postulation of a second kind of inhibitory mechanism. This distinct inhibitory mechanism ('Class II inhibition') would selectively suppress non-relevant neural activity for the task (Vogel et al. 1968). Basar-Eroglu et al. (1992) have associated synchronized delta activity observed at P300 latencies in ERP oddball paradigms with signal matching, decision making and surprise. The distinctive component observed in the theta-band 300 ms after the target presentation in oddball experiments has been interpreted as reflecting mechanisms of selective attention (Basar-Eroglu et al. 1992). EEG studies in humans have found high phase coherence between the theta-rhythm measured at several cortical sites and that measured at the hippocampus. Since coherence between two electrode sites is supposed to be measuring interactions between two neural populations, Miller (1991) proposed that the cortical-hippocampal theta interaction might reflect the Hebbian processes of synaptic strengthening. This process may select patterns of loops going up from the hippocampus to the cortex and back again to the hippocampus. Indeed, an increase in theta frequency during motor or verbal learning has already been documented (Lang et al. 1987).

Given that the transfer effects for targets with reversed polarity (see above) suggested the exclusion of distractors as the mechanism responsible for improvements in the TP condition (Grieco & Oliveira, 2010), the amplitude increase in the δ_3 component observed for TP may reflect the enhanced saliency of target perception due to the inhibition of non-relevant neural activity.

On the other hand, the most salient effect of practice in TA was a dramatic increase in confidence ratings. Based on this data we have previously suggested (Grieco & Oliveira, 2010) that some attentional source was recruited during learning in order to achieve a more confident perception of target's absence. This attentional mechanism, acting to reduce spurious signals potentially attributable to target's presence, might be associated with the changes in delta and theta oscillatory activities and with the change observed in the α_6 late-component for TA displays.

Overall, outcomes indicate that, at an early stage, processing of TP and TA rely on the same neural mechanisms. Figure-ground and homogeneous displays processing are different 300 ms after the stimulus onset, and they rely on different physical properties of the neural activity that generate the P_3 complex. The synchronised neural activity in the delta frequency band, which essentially shapes the P_{3a} component of VEPs, may reasonably be associated with signal enhancement in TP processing. The decrease in latencies of both delta and theta late-components, found in TA processing, may in turn be conjectured to associate with neural activity mediating conscious perception.

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Acknowledgements: this work was supported by Grant C2008-IPCDVS/02 accorded to the first author by the Portuguese Foundation for Science and Technology