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Using P300 to Evaluate the Effect of Object Color Knowledge in Novelty Detection

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ABSTRACT

Background & Objective: In an oddball experiment, the context in which novel stimuli are presented affects characteristics of novelty P3, i.e. as long as there is a difficult task in which the difference between standard and target stimuli is small, recurrent presentation of a highly discrepant stimulus can lead to P300 highly similar to novelty P3. Effect of stimulus properties on P300 has also been previously examined and it has been shown that it plays a significant role in P300 topography, its amplitude and latency.Here we have examined the effect of surface color of objects of high color-diagnosticity in a visual oddball paradigm.

Materials & Methods: In two separate conditions, we used pictures of fruits as target and novel stimuli. In condition one, novel stimuli were pictures of fruits in their canonical colors. In the second condition, novel stimuli were the same photo filtered to have a different non-canonical color. P300 was compared among these conditions.

Results: Both target P3 and novelty P3 were detected in the two conditions but no significant difference was evident between conditions.

Conclusion: This result suggests that comparing to shape information; color cue does not play a significant role in detecting context novelty.

Introduction

P300 as an event-related brain potential has long been investigated and for the past forty years a rich literature has been provided about its cognitive significance and possible neural generators (Friedman et al. 2001; Polich 2004; Linden 2005).

The signal was first elicited during an Oddball paradigm in which rare “target” stimuli were presented randomly in a train of frequently appearing “standards” (Sutton et al., 1965). In their paradigm, subjects were previously instructed to respond to the targets or silently count them while the standard had to be ignored. A positive going wave peaking in a range of 300-600 post-

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P300 & object color knowledge

stimulus was detected in the ERPs. Adding distracters to the stimuli lead to a three-stimulus paradigm in which apart from “Target P3” or P3b with central-parietal topographic distribution, a “Novelty P3” was recorded in trials in which novel, task –irrelevant distracters were presented (Courchesne et al., 1975). This novelty P3 had a frontal-central distribution and a shorter peak latency comparing to P3b. It has been suggested that P3b reflects working memory update i.e. reactivation of working memory template of targets upon target stimulus presentation (Donchin, & Coles, 1988). Novelty P3 then could be attributed to involuntary capture of attention, as an indicator of novelty detection and neural electrical activity of orienting response (Friedman et al., 2001; Sokolov, 1963; Goldstein et al., 2002).

Although the original oddball paradigm were consisted of simple acoustic tones, similar results have shown that P3 is modality-independent and as an endogenous cognitive ERP can be retrieved by auditory, visual and tactile stimuli, (Knight, 1984, Ranganath & Rainer, 2003), and even by omission of a stimulus in a series of task-relevant stimuli (Ruchkin, 1988).

Another question was the effect of context in which task-relevant or task-irrelevant infrequent stimuli (i.e. targets and novels) were presented on the elicited P3 which was addressed by Polich and colleagues (Comerchero & Polich, 1998; Katayama, & Polich, 1998) who showed that novelty P3 is context dependant in the sense that when the target/standard discrimination is difficult and task-demanding, repeated presentations of one rare non-target stimulus in a series of standards and targets could lead to a novelty P3-like deflection in the ERP, which could be manipulated by varying the salience of rare non-targets upon its context. Therefore they showed that it is novelty per se which leads to P300 anteririzaltion (Fabiani, & Friedman, 1995).

The stimuli used by Polich et al., like most other visual oddball experiments conducted previously, consisted of simple drawings of geometric shapes, random noise patches or other synthetic arbitrary shapes. Comprehensible advantages of such simple stimuli have lead to a rather standard paradigms also adopted by clinical and neuropsychological investigations (Linden, 2005).

Apart from context, effect of stimulus characteristics upon variations of p300 is an equally valid question which has recently been posed by Gaeta and others (Gaeta et al., 2003; Cycowicz, & Friedman 2003; Debener et al.). In their works, complex novel environmental sounds were used as targets in a group of trials while simple tones where non-target distracters and by comparing these trials with the ones in which target stimuli were simple tone and novels were complex environmental sound they showed that stimulus properties also play a role in P300 topography, amplitude and latency.

In visual modality, surface color of the stimulus is a feature which is of significance in various ways. Color is an effective cue for identification and selection of relevant objects (Anllo-Vento, 1998). Although most theories of object recognition value shape information in object recognition and categorization, some theories account for the role of an object’s surface properties, like color and texture, in representations (Krauskkopf et al., 1982; Buchsbaum, & Gottschalk, 1983). Hawken & Gegenfurtner (1999) showed that color has significant impact on the recognition of objects with high color-diagnosticity, i.e. objects that consistently appear in a typical color. As shown by Hansen and Colleagues (Hansen et al., 2006) memory color of objects is important in perception and recognition of objects which have typical canonical colors in everyday life. The stimuli they used were fruits and they showed that subjects tended to perceive them in their prototypical color. Some neuropsychological evidences, from two patients J.B. and I.O.C showed that although they have intact knowledge of shape information and normal color perception but they were unable to match objects with their prototypic colors (Gegenfurtner, 2003; Miceli et al., 2001).

Although the evolutionary advantage of color vision is unclear (Gegenfurtner, & Rieger, 2000), cognitive advantage of applying color cues for recognition of objects that have high color-diagnosticity has usually been explained (Gegenfurtner, & Rieger, 2000; Wichmann et al., 2002) in an evolutionary framework, e.g. the importance of detecting red ripe fruit against green foliage in case of fruits.

Hence it seems quite sound to pose a question about the novelty or deviance of colored objects, especially when they have high color-diagnosticity, as they are presented in a discrepant color. This is the main question of our report.

Since another observation about novelty P3 is its decrease during the recording sessions with recurrent presentations of novel stimuli, habituation effect on novelty P3 was also assessed in this experiment (Kazmerski & Friedman 1995).

Methods

Subjects

Ten healthy male adult subjects were recruited from university students (Mean age: 23, Min: 19, Max: 31). All subjects signed informed consent and reported to be free from neurological or psychiatric disorders, normal or corrected-to-normal vision and right-handed. Data from two additional subjects were excluded from the analysis due to non-correctable blinking artifacts and technical problems during recording.

Stimuli & Task

A set of eleven photos of fruits were selected from Hemera Photo-Objects (http://www.hemera.com), all in natural shape and color. Pictures were resized to have the same number of pixels corresponding to a predefined standard size; Then for both conditions, vis. natural and synthetic, two other categories of stimuli were made in the following fashion (Figure 1).

Subjects were seated in a dark and sound-attenuated room facing a PC monitor at a distance of 100 cm. Participants were instructed to fixate on a cross centrally located on a white background. Each stimulus was presented for 100 ms with an inter-stimulus interval of 1000 ms Before the test starting subjects went through a training phase in which they would get acquainted with both natural and target stimuli. In training a group of 20 pictures (16 standards and 4 targets) would be shown to participants and they were instructed to respond as quickly and accurately as they could to target stimuli by pressing the button with their right forefingers on a response box. Test trials would start only in case the subjects could detect 85% of the target stimuli and respond to them within 1000 ms. Otherwise the training would continue for another twenty stimuli block. Once subjects passed the training, test trial would start comprising of a series of 160 standard, 10 target and 10 novel pictures. Stimuli were presented in a pseudorandom sequence in which no target or novel stimuli would precede each other. Novel pictures appeared randomly on either side of the screen. Reaction time and error rates were recorded.

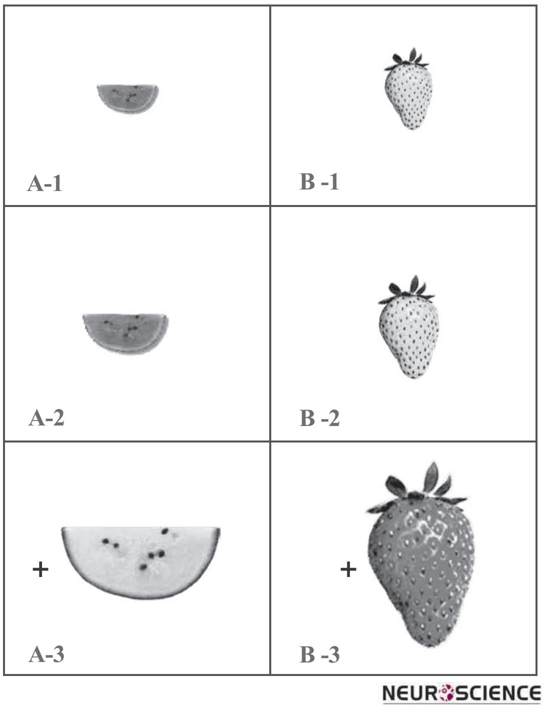

Fig. 1: Stimuli in order of their categories

A: Canonical context in which **1.** Standard stimulus is a 100% size of the picture of a fruit, canonical color, center, **2.** Target stimulus is a 120% standard size, canonical color, center

3. Novel stimulus is a 250% standard size, non-canonical color, side

B: Non-canonical context in which 1. Standard stimulus is a 100% size of the picture of a fruit, non-canonical color, center, 2. Target stimulus is a 120% standard size, non-canonical color, center

3. Novel stimulus is a 250% standard size, canonical color, side

EEG Recording

The electroencephalogram (EEG) was recorded continuously from 32 scalp sites using high input impedance amplifier and Ag/AgCl electrodes mounted in an electrode cap. The electrode positioning on the scalp was according to the 10-20 international system. Electrodes on the Right side of the scalp were: FP2, F8, FT8, T8, TP8, P8, F4, FC4, C4, CP4, P4; on the Central side: FZ, FCZ, CZ, CPZ, PZ; on the Left side: FP1, F3, FC3, C3, CP3, P3, F7, FT7, T7, TP7, P7; and on Occipital: O1, OZ, O2.

To ensure that fixation was maintained, the horizontal and vertical EOGs were also recorded. Vertical EOG was recorded bipolarly from electrodes placed below and above the left eye, whereas horizontal EOG was recorded bipolarly from electrodes placed on the outer canthi of the two eyes.

Reference lead was linked to bilateral mastoids. All electrode impedances were reduced with a band pass of 0.05 to 30 Hz and digitized at 1000 Hz (0.024 Micro volt per precision) for later off-line analysis.

Data Analysis

EEG data analysis was performed using EEGLAB (version 4.515), a freely available open source toolbox running under MATLAB version 7 (The Mathwork Inc.), (Delorme, & Makeig, 2004).

First, data were down-sampled to 250 Hz to save later computation time. Data epochs were extracted (-200 to 800 ms) and baseline was corrected (-200 to 0 ms). Trials contaminated by eye or body movements were rejected. Artifact rejection by extreme value was used before averaging to discard epochs in which eye movement, blinking, excessive muscle potentials or amplifier blocking occurred. The criterion for artifact rejection was a peak-to-peak amplitude exceeding ±40 microvolts of EOG and HOG electrodes, and the rejection rate was about 15%. ERP epochs were averaged off-line from 200 ms before to 800 ms after stimulus onset. The peak latencies of the P3s were measured on the difference waveforms in a range of 270-770 ms post-stimulus. Average amplitude in the same range was measured as P3 amplitude. Since no laterality effect was expected, only data from the midline electrodes were statistically analyzed. Also to facilitate evaluation of the frontal-to-parietal scalp topography, five regions of interest: Frontal, Fronto-Central, Central, Parieto-Central, and parietal were defined (Table 1).

	Electrode Sites
Frontal	F3, FZ, F4
Central	FCZ, CZ, CPZ
Parietal	P3, PZ, P4
Left	FC3, C3, CP3
Right	FC4, C4, CP4

Table 1. Regions of interest

In addition, averages were generated separating for the first three and last three presentations of target and novel stimuli in both contexts to assess habituation. Independent sample T-test for behavioral data and repeated measures analysis of variance were performed on P3 component indices. Greenhouse-Geisser correction (ε) correction factor for lack of sphericity was applied when appropriate.

Results

Behavioral Data

The task was performed equally well in the two conditions by all subjects (Table 2). Reaction times exceeding ±3 standard deviations were excluded from RT independent sample t-test. The mean reaction time was slightly longer in non-canonical context, but the difference was not significant.

	Canonical context	Non-canonical context
% Hit	86	83
% False alarm*	< 0.1	< 0.1
Mean RT	464 ms	475 ms

Table 2. Reaction time & performance accuracy during the task

*False alarm to standard.

Electrophysiological Result

Figure 2 shows grand mean ERP waveforms in canonical and non-canonical conditions. As expected, in both conditions, P300 was generated for target stimuli with a more central-parietal topography. Again in both conditions, novelty P3 with a larger peak amplitude and shorter peak latency than target P3s could be detected in

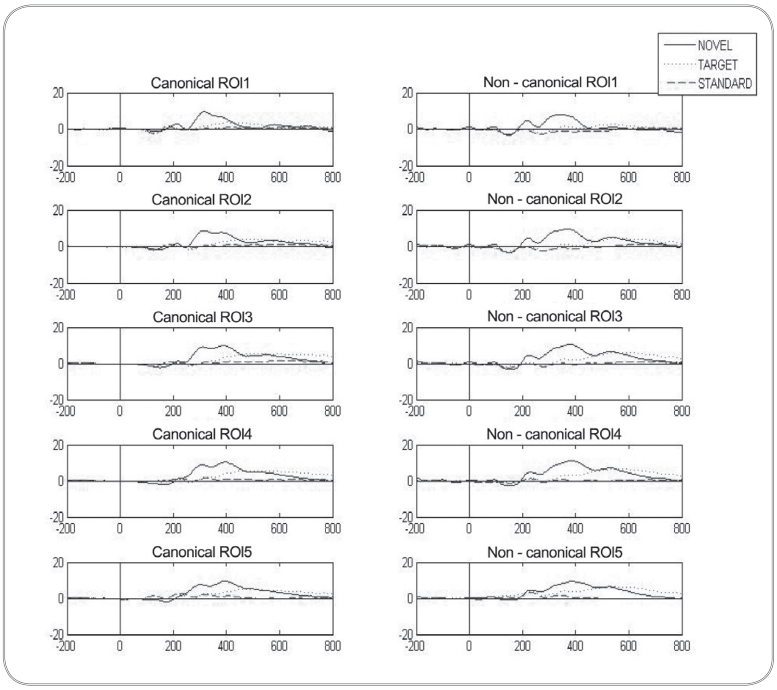

Fig.2: ERPs for standard, target, and novel stimuli in five regions of interest from front to back (1 to 5) in canonical and non-canonical conditions

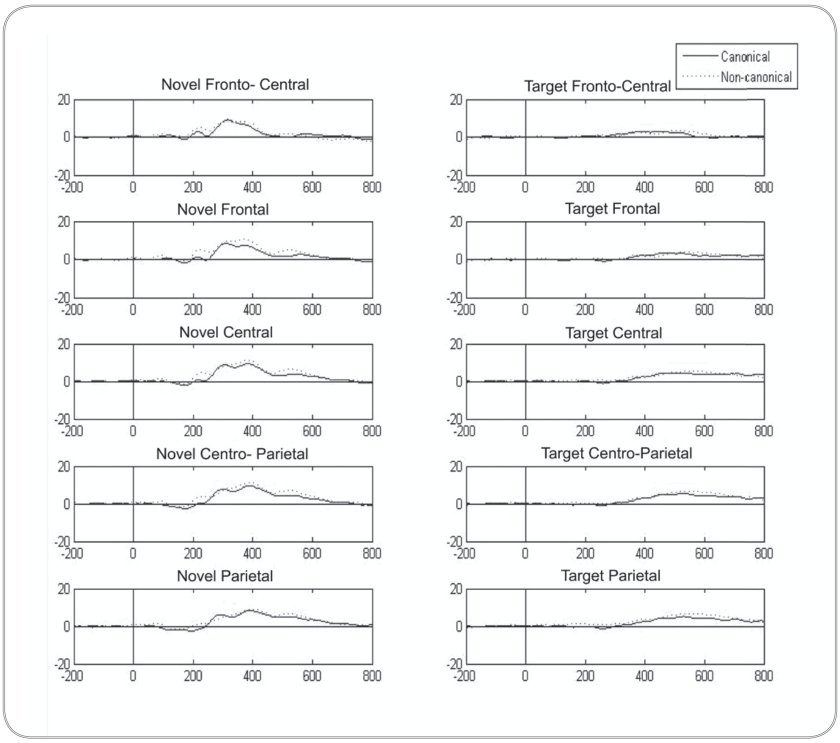

Fig.3: Difference waves isolating P300 in target and novel stimuli in five regions of interest from front to back (1 to 5) in canonical and non- canonical conditions

trials where novel task-irrelevant stimuli were presented to subjects. Novelty P3 had a more frontal topography compared to target p3 (Figures 2 and 5).

Since standard stimuli were different in the two different experimental conditions (fruit in its canonical color vs. fruit in its non-canonical color) difference waves (Picton et al., 2000) were applied to better isolate P300 (Figures 3-4). Also, given the fact that in our experiment, p3 amplitude and latency were computed by averaging, difference waves were applied to better isolate components (Steve Luck, 2005). In the left panel of figure 3, novelty p3 is compared in canonical vs. non-canonical condition in all the five regions of interest. As can be seen, there is little difference in the waveforms and their topographic distribution. The same pattern is apparent for the target stimuli (Figure 3, right panel).

Repeated measure analysis of variance was performed on P3 amplitude and P3 latency data. All analysis of variance employed Greenhouse-Geisser corrections to the degrees of freedom. The results showed a significant difference in P3 amplitudes in different regions of interest (F (4, 13)=11.47, ε =0.365, p < 0.05). Also there was a main effect of stimulus type which was near-significant (p < 0.1). Although in the second condition mean P3 amplitude was larger than canonical condition for both types of stimuli, this pattern did not lead to a significant difference (p>0.1). Same statistics were applied to P300 latencies. As can be seen in figure 2, as it could be expected, novelty P3 had shorter peak latency in both conditions; however there was no significant difference among conditions (F (4, 13) =1.3, ε=0.42, p>0.1). We also looked for habituation effect on trials where novel distracter stimuli were presented. Fig 6 shows that unlike the first condition habituation had occurred in the

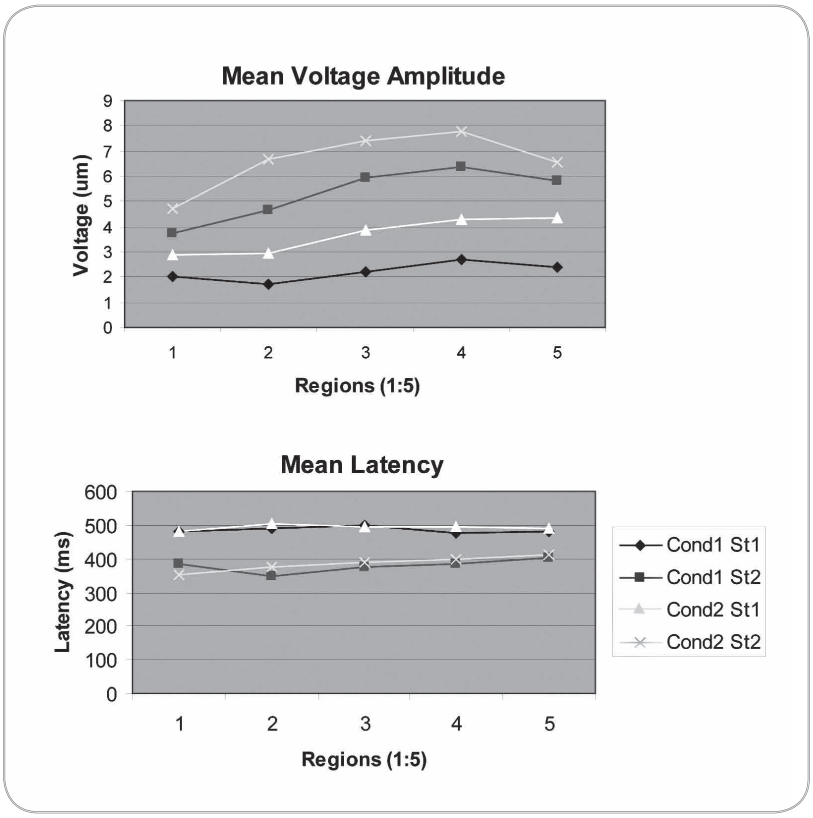

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Fig. 4: Mean voltage amplitude in the regions of interest from front to back (1 to 5) for target stimuli (St1) and novel stimuli (St2) in canonical & non-canonical conditions (Cond1 and Cond2, respectively) (above panel); Mean p3 latency in the regions of interest from front to back (1 to 5) for target stimuli (St1) and novel stimuli (St2) in canonical & non-canonical conditions (Cond1 and Cond2, respectively) (above panel)

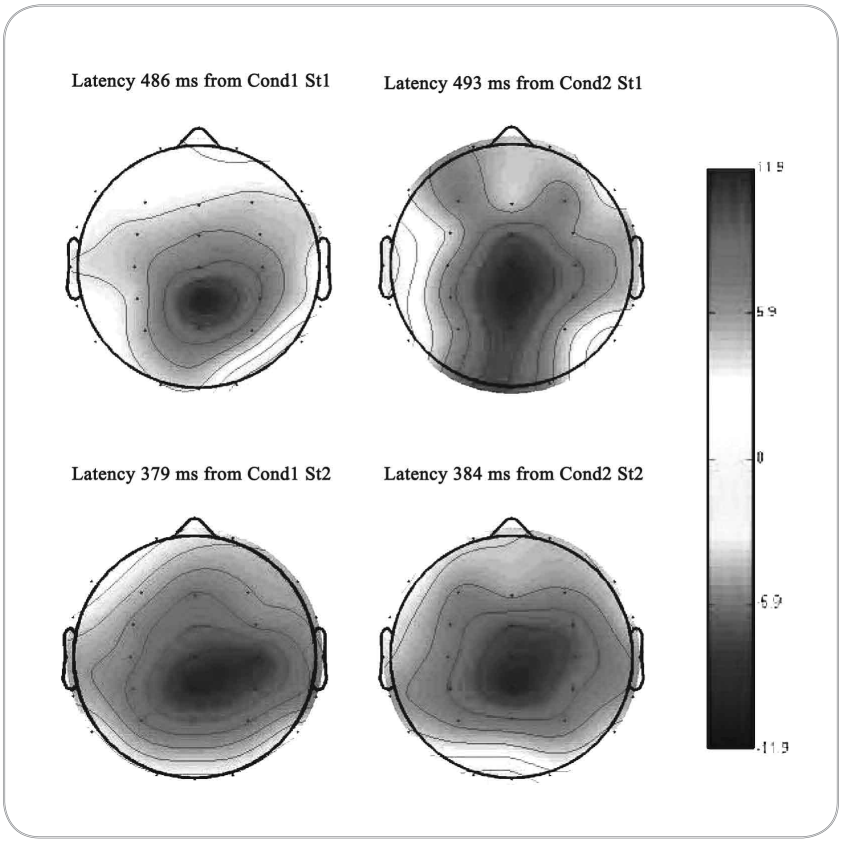

Fig. 5: Voltage maps for p300 based on difference waves, in: canonical condition (Cond1), target stimuli (St1) (above left); canonical condition (Cond1), novel stimuli (St2) (below left); non-canonical condition (Cond2), target stimuli (St1) (above right); non-canonical condition (Cond2), novel stimuli (St2) (below right).

second condition i.e., P3 peak amplitude for the last sequence of novel stimuli in the second condition was much less than the first sequence (F (4, 5) = 2.9, ε=0.45, p=0.12).

Discussion & Conclusion

Our question was about the difference in novelty p3 characteristics when high-color-diagnostic familiar objects (fruits) were presented having non-canonical color in a series of the same photos of fruits with natural color vs. the condition in which canonical colored photos of fruits were non-target distracter stimuli in a series of photos with non-canonical colors. This was addressed by assessing three well known characteristics of p300: its amplitude, latency and habituation.

The fact that we obtained p300 leaning more towards parietal regions for target stimuli and rather more central in distracter trials is in accordance with the previous reported results on p3 (Friedman et al., 2001). This was accompanied by a near significant difference among stimulus types which could be considered as a replication of paradigms in which one single highly discrepant stimulus had led to novelty p3. As various authors (Demirlap, 2001; Polich, & Comerchero 2003) have shown task difficulty plays a crucial role in such paradigms, lack of statistical significance in this case might be due to our relatively simple task.

It has been suggested that both physical properties of the novel stimuli and the context in which it is presented affect novelty p3 (Ranganath, & Rainer, 2003). Since the deviance of non-target distracter stimulus comparing to its context was the same in both canonical and non-canonical conditions (Figure 1) any difference between p3 characteristics among the conditions could be attributed to the physical properties of the stimulus. However this notion was not supported by comparing the amplitude and latency in different conditions. Yet, results

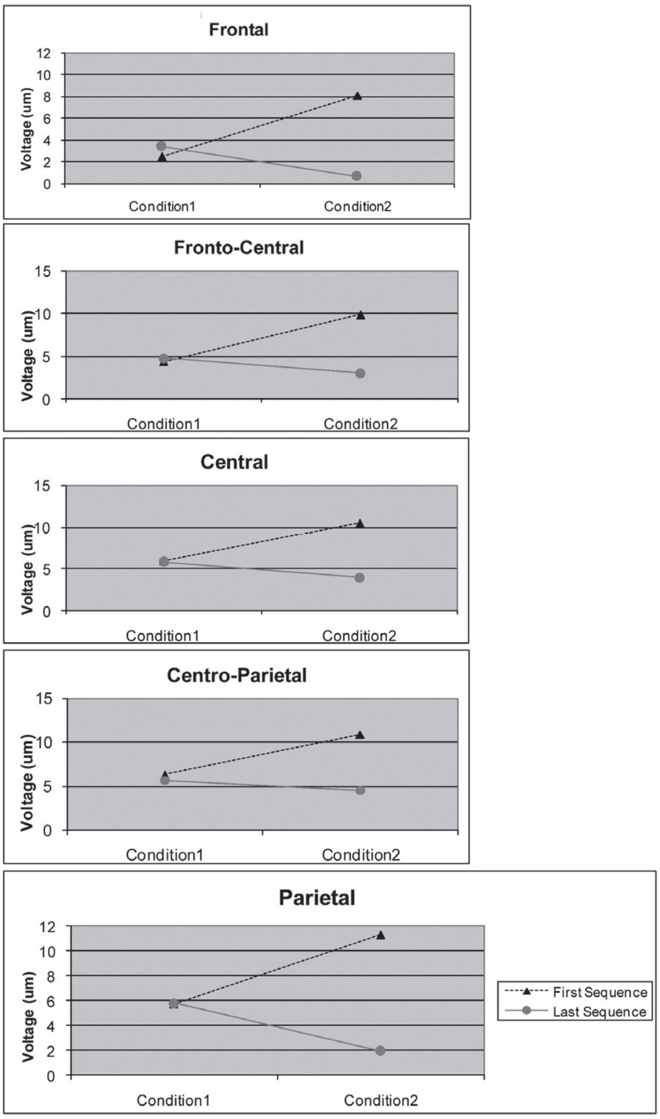

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Fig. 6: Habituation effect for novel stimuli (mean voltage amplitude in the first sequence vs. the sequence) in all the five regions of interest compared between the conditions (**condition1:** canonical context and **condition2:** non-canonical one)

obtained from statistical analysis of habituation effect, showed near-significant difference among conditions, which could be explained in the following fashion. It seems that natural novel stimulus presented in synthetic context matches with its representation in the central-parietal regions, and gradually as subject becomes familiarized the p300 amplitude dramatically decreases. In contrast, synthetic non-target distracter did not have such representational advantage; hence, subject should try to recognize and categorize it as distracter as hardly in the last sequences as in the first ones, because no recognition facilitation occurred due to previous existing representation. It could be another supportive finding for the conclusion that physical property of novel stimuli plays a role in novelty p3 elicitation along with the context they are presented in.

As we are currently investigating, more controls on stimuli will lead us to properties with more salient effect on novelty detection.

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