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Research article

Automatic detection of orientation variance

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ABSTRACT

Rapid extraction of the overall statistics of the visual scene is crucial for the human ability to rapidly perceive the general 'gist'. The aim of this work was to investigate if there exists neural evidence for such a process i.e. automatic, unattended detection of overall statistical differences between scenes. In order to do this, Visual Mismatch Negativity (vMMN), an early evoked neural response component, was measured. We presented a sequence of sets of oriented patterns of a given (random) mean orientation and varied the variance of the orientations of the patterns, so that some sets contained similar orientations (ordered) or the orientations were random (disordered). These two types of sets of patterns were presented in an oddball sequence such that one type occurred often and the other was a rare, unexpected stimulus. We found a significant vMMN in response to a randomly oriented stimulus amongst more ordered stimuli, which suggested that humans perceive 'ordered' vs 'disordered' scenes categorically. We conclude that by manipulating the variance of the orientations contained within each stimulus we are able to show that this property is automatically encoded in visual neural response.

1. Background

Visual Mismatch Negativity (vMMN), an early evoked neural response component, is elicited automatically (i.e. even when the stimuli are unattended) when an 'unexpected' (termed 'deviant') visual stimulus appears amongst a series of expected (termed 'standard') stimuli − this kind of sequence is termed an oddball paradigm. VMMN has been suggested to reflect automatic pattern detection over a sequence and may reflect the processing of categories [1]. Recent research has suggested that we are able to rapidly extract overall scene meaning (referred to as 'gist') in a first-pass analysis that is not reliant on detailed analysis of individual parts of the image. It has been suggested that the way we are able to process the gist of a scene rapidly is via the use of summary scene statistics, such as average properties and the variance of properties in the scene [2,3]. Suggested properties that may vary in their statistics across natural scenes are spatial frequency content and orientation distributions [3]. This rapid extraction of global properties suggests that they may be encoded automatically, but so far no neural evidence for this exists. More recent work based on a review of behavioural evidence has suggested that these ensemble statistics are used by the visual system to test hypotheses about whether the distribution of features of different scenes differ [4]. A further recent behavioural study demonstrates how the learning of ensemble statistics develops over time [5].

We examined whether vMMN would be sensitive to orientation scene statistics (even whilst not attending to the presented scene). This signature would show a detection of a difference in orientation variance, thus demonstrating quick automatic initial extraction of this property. vMMN has been shown to be a marker of rapid learning of stimulus properties, but it is not known if it is sensitive to differences in the distributions of visual features within scenes. We test whether the orientation variance of scenes is a stimulus category that can be learnt in order to build up an expectation − and hence detect deviations from the expected stimulus. By using vMMN we can measure neural responses when the detection of the scene statistics is not task relevant and hence find a neural correlate for this automatic encoding, mapping on to behavioural results.

We presented a set of oriented Gabor patterns of a mean orientation randomly chosen for each stimulus in a sequence, and varied the width of the standard deviation of the orientations of the patches within stimuli, so that some sets had more similar orientations within them (ordered) or the orientations contained in the set were random (disordered). The orientations were drawn from a Gaussian distribution, so we can also think of variance as orientation entropy, which is directly related to the log of the standard deviation (s.d.). As the orientations and positions of the Gabor patterns were also chosen randomly for each stimulus, there should be no localized adaptation to a specific orientation. In order to examine the automacity of the encoding we also

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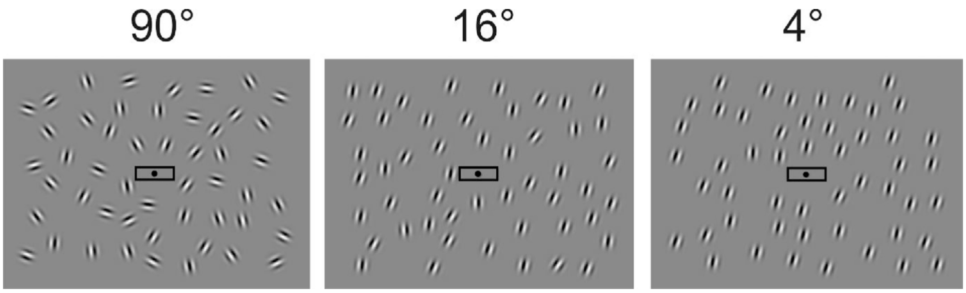

Fig. 1. The three types of stimuli used in our main oddball conditions. The numbers indicate the standard deviation (s.d.) of the distribution the orientations are drawn from. The ones drawn from a 90° s.d. distribution are in effect random orientations, 16° and 4° s.d. produce more ordered patterns (the mean orientation shown here for both is 75°). The mean orientation was randomly selected on each trial, only the variance was manipulated to form standard and deviant stimuli.

had a central task that required continuous monitoring of a moving dot and keeping it within a box using a joystick − thus rendering the stimulus changes outside the window of attention. See Fig. 1. Each of the three standard deviation conditions were paired in an oddball paradigm, each playing the role of deviant in one condition and standard in the reverse condition. When calculating vMMN we only compared responses to the same stimulus, contrasting the response to when it appeared frequently (standard) to when it appeared rarely (deviant). In an additional condition we interleaved a random mixture of orientation variances to check how this fundamental property alters the ERP waveform per se and to ascertain the role of prediction in any vMMN observed, as in this case no prediction should occur, as all orientation variances are equally likely [9].

2. Methods

2.1. Participants

Fifteen volunteers (eight women; mean age: 22.9; s.d. = 2.4 years) with no pre-existing neurological conditions and normal or corrected to normal vision participated in the study for monetary compensation. The number of participants was based on previous studies that measure the well-established vMMN component. Written consent was obtained from all participants prior to the experimental procedure. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Committee of Ethics of the Psychology Institutes in Hungary.

2.2. Electroencephalographic (EEG) recording and analysis

Electroencephalographic activity was recorded from 61 locations (Ag/AgCl electrodes, EasyCap, Synamps2 amplifier, NeuroScan recording system) according to the extended 10–20 system (DC–100 Hz, 500 Hz sampling rate). The online reference electrode was on the nose tip; ground electrode was attached to the forehead. The horizontal EOG was recorded with a bipolar configuration between electrodes positioned lateral to the outer canthi of the two eyes. The impedance of the electrodes was kept below 10 kΩ. The activity was re-referenced offline to the average electrode activity. The EEG signal was bandpass filtered off-line (0.1–30 Hz cut off frequency). The EEGlab [6] Matlab [7] based software package was used for the ERP analysis.

Epochs of 500 ms, starting from 100 ms before the stimulus onset, were averaged separately for the standard, deviant and control stimuli. Trials with an amplitude change exceeding ± 100 uV on any channel were rejected from further analysis.

Event related potentials (ERPs) for deviants were calculated from the average of 114 epochs, ERPs for standards were calculated from the average of 472 epochs (standards that appeared immediately after a deviant were not used).

We predefined our electrodes of interest as electrodes Oz and POz, which should serve as a good representations of the posterior activity. Because vMMN is a well-established phenomenon we were also able to pre-define a time interval of interest between 150 ms and 250 ms after stimulus onset. We used these predefined electrodes and time interval as the comparison in the control condition. We conducted statistics (see below) on the ERP amplitude averaged over this time period.

2.3. Stimulus presentation and design

Stimuli were presented on a linearized CRT monitor of 1024 × 768 resolution, with a refresh rate of 75 Hz. Participants were seated at 110 cm distance. Stimuli were created in Matlab [7] using the Cogent 2000 package (developed by the Cogent 2000 team at the FIL and the ICN) and Cogent Graphics (developed by John Romaya at the LON at the Wellcome Department of Imaging Neuroscience). Background luminance was 36 cd/m^2 mid-gray.

In the EEG recording session there were 6 oddball sequences with 90°/16, 90°/4° and 4°/16° s.d. paired, with each taking the role of standard (frequent) in one sequence and deviant (infrequent) in another. See Fig. 2 for an illustration of the 90°/4° oddball sequence with the 90°s.d. stimuli forming the deviant stimuli and 4° s.d. stimuli playing the role of standards. 16.5% of the stimuli were deviants, with 3–7 standards in between (the number in between varied randomly). In the equal probability control condition 0°, 4°, 8°, 16°, 24° and 90° s.d. appeared randomly interleaved, with each s.d. appearing an equal proportion of times, 16.5%.

Each one of the 7 (6 oddball, 1 control) conditions was repeated over two runs, with the first run of each example appearing in the first half of the experiment, and the second run in the second half of the experiment, but within the halves of the experiment runs were randomly ordered. This meant we could keep runs to about 5 min long.

The orientations and positions of the Gabor patterns were chosen randomly on each trial, avoiding repetition. Mean orientation was randomly chosen from [15° 45° 75° 105° 135° 165°] and for each mean orientation there were 5 versions with different random positions for the Gabor patches. This means one category of stimulus (i.e. one orientation s.d. value) was represented by 6 × 5 = 30 different images

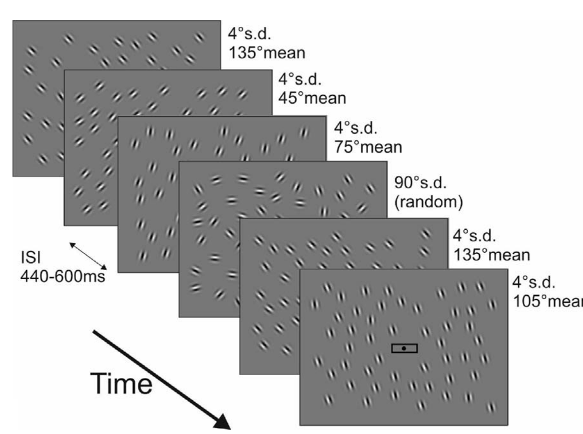

Fig. 2. A schematic illustration of the oddball sequence in which the 4° s.d. stimuli were the standard stimuli and the 90° s.d. stimuli were the deviant stimuli. The locations of the Gabor patterns varied randomly as did the mean orientation on each presentation, only the s.d. of the orientations was varied systematically to create standard and deviant stimuli.

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