No EEG Evidence for Subconscious Detection During Rapid Serial Visual Presentation

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Abstract*—Electroencephalography (EEG) is widely used to study visual and auditory perception. It has the benefit of high temporal resolution allowing one to detect the earliest moments of neural processing of a stimulus. In some detection tasks EEG signals precede overt behavioral response by as much as 200 ms, i.e. at times when stimuli may not yet have been consciously detected by the subjects, leading some to speculate that EEG may reveal also subconscious target detection. We thus asked if there are EEG signals associated with detection of a stimulus even in the absence of an overt (conscious) report. Rapid Serial Visual Presentation (RSVP) of images elicits strong EEG responses shortly after a target image is presented and these evoked responses can be detected on a single trial basis using dedicated pattern recognition techniques previously developed. Here we record EEG during RSVP where we vary detection performance by varying presentation parameters such as eccentricity or size of the target on an image. We find that under these manipulations the behavioral detection performance of subjects largely tracked the detection of evoked responses in the EEG. More specifically, we show that EEG detection performance is high for those trial in which subject successfully report the presence or absence of a target, while EEG detection performance is indistinguishable from chance when subjects failed to provide a correct response. In short, when the subjects sees the target, we also see this in their EEG; if the subjects do not see the target then their EEG remains also unafected by the target stimulus. In summary, contrary to the often-held believe, we have found no EEG evidence for subconscious detection of a target stimulus during RSVP.

I. Introduction

Electroencephalography (EEG) has been used to study human behavior since the beginning of the 20*th* century (Hans Berger in 1924 published the first human EEG reports [1]). It has been used in a wide variety of paradigms to assess the brain's health [2], localize regions of the brain that are activated in particular tasks and the time profiles of activation.

Psychologist have long been using behavior response – reaction times, detection rates, emotional reactions, etc. – in order to study cognitive processes, in particular conscious decision processes.

Since the discovery of the visual evoked potentials (VEP) [3] there have been a variety of studies relating stimulus properties with evoked potentials. Most of these studies are not concerned with conscious perception of the stimuli. Stimuli are often simple and sufficiently strong to always elicit an evoked potential, for example, the onset of a flash, or a sound [4]. Thus, often experimental stimuli do not require higher-order levels of perception.

Stimuli that are surprising or novel to a subject can elicit a response in the EEG known as the P300 [5] (positive potential 300ms after stimulus presentation). In a paradigm known as Rapid Serial Visual Presentation (RSVP) this signal has been used as a neural signature for a subject's neural processing during target detection along with earlier and later responses evoked after stimulus presentation [6], [7]. Linear discriminant analysis has been used to detect these evoked response signatures [8]. A question that remains unanswered is to what extent these discriminant signals are part of a conscious cognitive process or whether some of them are independent from conscious perception. Will these signals be there every time the target is presented? Or will they rather depend on the conscious perception of the target by the subject.

To answer this question we designed a set of experiments with variable behavioral detection rate. We varied task difficulty by placing the targets at various eccentricities and using varying object sizes. Increasing difficulty increases the number of incorrect responses by the subject. With this we aim to dissociate the presence of a target from a subject's conscious perception of the target. And this will be used to assess the neural processing of conscious detection of a target in this task.

II. Methods

Subjects: A total of 6 volunteer subjects with normal or corrected-to-normal vision participated in the visual search experiments. The average age was 29 ± 7, with 1 females and 5 males. A total of 13 psychophysics sessions were collected (some subjects participated in two separate paradigms). In 6 of the 13 sessions EEG was collected simultaneously. Experiments were approved by the Institutional Review Board of The City College of City University of New York and subjects gave informed consent prior at the beginning of the experiment.

Search Paradigm: The task for the subjects was to look at a screen while a sequence of 20 aerial images taken over a large metropolitan area were shown in rapid succession (Figure 1). Each image was presented for a short period (100 ms). Subjects had to detect a particular object which appeared in only one image in the sequence (a circle with an

H indicating a helicopter landing site). Subjects were asked after the sequence was finished if they had seen the target by pressing a button. In each trial sequence there was a 50% chance of the target to be present. Target and distractor sequences were presented in random order.

To study the effect of eccentricity and size, two types of images were shown. In the first, we tested how distance of the target from the center of screen affected performance of target detection. In the second, we studied the effect of size in performance of detection of target. Note that trials began with a cross at the center of the screen for 500 ms and subjects were asked to fixate on the cross.

Images were cropped from a larger aerial image and either contained (target) or did not contain a target (distractor). The individual images were cropped in six different sizes (from 100x100 to 600x600 pixels) but images covers always the same visual angle on the screen. In the eccentricity paradigm, images were cropped at 300x300 pixels from the original image. Targets were placed at any location: from the center of the image and up to distance of 8.8 degrees of visual angle from the center. For the size, increasing number of pixels reduced the size of the target on the screen and increased the amount of distracting information. Targets were placed at a constant 5.5 degree of visual angle from the center of the screen. Trials were grouped by size to avoid fast transition between images with very different spacial distribution. Due to the need to generate many targets from a limited set in the original larger aerial image, we generated rotated and flipped image of each target and distractors. In this way, the total number of distinct targets was over 1000 and the total number of distinct distractors was over 2000.

In both paradigms the experiment consisted of 4 or 5 blocks of 50 to 100 trials, subjects would have a short break in between trials. In the eccentricity paradigm the different condition were tested in one block. For the size paradigm due to the different spatial frequency each block had a fix size. The data for eccentricity and size conditions were recorded in separate days and different recording sessions.

EEG Recording and events: EEG was recorded at a sampling frequency of 1024 Hz with an Active2 system (BioSemi, Amsterdam, The Netherlands) using 64 electrodes placed on the scalp according to the 10/20 standard international system. EEG and the image presentation were synchronized by a common time marker, issued by the display software (E-prime, Psychology Software Tools, Inc., PA, USA) at trial, distractors and target onset indicating the identity of the image. Subject responses were also recorded as event markers in the EEG.

Signal Processing: All data analysis was performed using MATLAB (MathWorks, Natick,MA). The data was preprocessed using a 4th order band-stop filter 58-62Hz and 118-122Hz, to remove 60Hz and 120Hz power-line interferences. To remove DC drift a 4th order butter-worth high-pass filter with a cutoff frequency of 0.5Hz was used. Eye movements were not taken into account given that subject were asked to fixate at the center of the screen during the period of the trials.

Data Analysis: Data was analyzed for each subject individually. The EEG data for each trial was epoched based on the target image onset time. For target trials (sequences containing a target image) this will be the target image. For distractors trials (sequences not containing a target in any image) this is a random distractors image. The trial sequences were then labeled as Target or Distractor on the basis of the trial sequence containing a target image or not. Each trial is also labeled as a correct or incorrect trial based on the response of the subject.

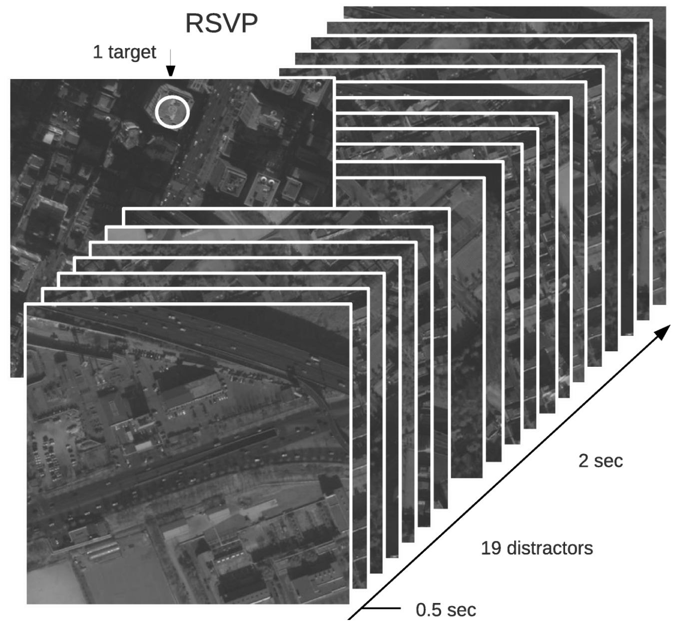

Fig. 1: **Schematics of the RSVP task:** each trial starts with a cross being presented at the center of the screen for 500 ms. This is followed by a sequence of 20 images at 10Hz. In each sequence there is a 50% chance that a target will be present in one image. The target is shown here in the white circle. The subject reports whether they saw the target or not only after the sequence is finished.

Behavior performance is reported computing the true positives and the false positives fractions. For the behavior performance the detection rate was calculated as the ratio between the correctly reported target over the total number of targets for that condition.

At first data was analyzed separately for different eccentricities and different target sizes. Neural signature were analyzed using Linear Discriminant Analysis (LDA) applied separately for multiple windows in time of 50 ms duration spanning from 50 ms to 500 ms after the target image was presented following the procedure described in [8]. These classifier outputs were then again submitted to a LDA in order to provide a single classification output per image. For the training of the classifier only the true positives and half of the distractors were used for each condition. For testing all the target trials were included along with the other half of the distractors and performance is reported as the area under the ROC curve, Az. All error bars were calculated approximately as the standard error, $\sigma \approx sqrt(Az * (1 - Az)/N)$ (as in Figure 2 and 3), where N is the total number of trails used to compute Az and significance is determined with a student-t test on $t = Az/\sigma$ with N degrees of freedom.

For the second analysis trials were grouped across eccentricities but separated by whether subjects gave correct or incorrect responses. For correct trials this includes true positives (when subject correctly detected the target) and true negatives (when subject did not report a target when there was no target). For incorrect trials this includes false negatives (when subject did not report a target when there was one), false positives (when there was no target and subject reported a target). We computed the Az scores for the correct trials by training and testing using leave-one-out cross-validation. For the incorrect trials Az score, we trained with the correct trials and tested with the incorrect trials to see if there was any remaining discriminant activity independent of conscious perception of target.

III. Results

Subjects search for targets (helipads from aerial images) in a RSVP paradigm, with varying target positions and size. In each trial subjects were instructed to fixate at the center of the screen and respond whether they had seen the target or not. In each trial 20 aerial gray-scale images were shown at 10Hz, and each trial had a 50% chance of containing a single image with a target. In the first paradigm the difficulty of the detection varied with the location of the target, placed at five different visual angles from the center of the screen. In the second paradigm we tested the effect of size on target detection. We varied the target size by changing the area covered by each image – the larger the area the smaller the target. In the eccentricity and size tasks we collected 8 and 5 data-sets respectively. For the EEG recording we recorded a total of 6 EEG data-set: 4 for eccentricity and 2 for size.

Behavior: Figure 2 shows individual performance detection rates for each subject as a function of eccentricity. The detection rate is computed by the number of detected targets over the total number of target trials. When the target is centered the performance for all subjects is above 90% which would be expected. The performance decreases to 50% when the target is placed further away then 4 degrees of visual angle from the center of the screen and this is consistent across subjects. For all subject it is possible to observe a significant decrease in the detection rate for targets that are located at 8 degrees. In these cases the detection rate falls between 30% and 50%. The dashed line is the false-detection rate. These results suggest that target location is important. However, detection can still be accomplished to some extent at lower efficiency using the peripheral visual field. This is interesting considering the target is presented only for a very short period of time.

Figure 3 shows results for 5 data-sets with varying target size. The targets were placed at 5.5 degrees distance from the center of the screen at random orientation. For the bigger targets detection is almost 90% for all the subjects. For smaller targets the performance decreases to 20% to 40%. The false-positives rate (dashed-line) is very low for all subjects and all conditions, so that specificity is overall very high. The false-positive rate is determined across all the target sizes and eccentricities. This value reveals that subjects have high specificity for target detection even at low detection rates. We conclude that specificity is not affected by target detection difficulty.

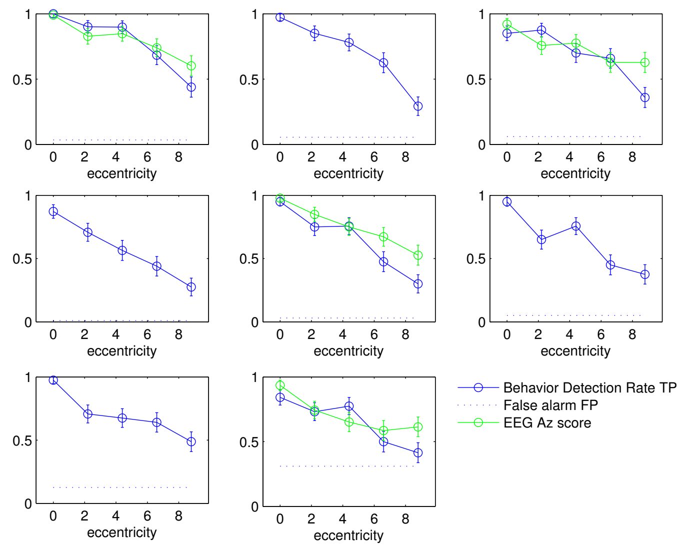

Fig. 2: **Behavioral detection rate in RSVP decreases with target distance from the center of the screen and this is mirrored by the EEG detection performance**: Behavioral detection rate (blue) and Az scores based on EEG (green, where available), for each subject. Az scores were computed per condition using true positives and true negatives and tested with target and distractor trials. The performance of the classifier drops as the performance of the subject decreases. This suggests that the difference captured in EEG between targets and distractors is a signature not of the target presence, but of a conscious cognitive process.

Neural correlates: Figure 2 and 3 show the results for four and two subjects recorded in the eccentricity and size paradigm respectively. In both cases we recorded EEG while the subjects were being presented with images at 10Hz. One can see that behavioral detection performance and the EEG classifier performance both drop with eccentricity. This suggests that the neural response that is responsible for the discrimination between targets and distractors is not an unconscious process, but rather a signal that results from a conscious perception.

To test if the neural signatures were indeed linked to the correct responses on individual trails, we compared the performance of the classifier when subject consciously perceived the target vs when they failed (Figure 4). For 3 of the eccentricity data-sets we grouped correct and incorrect trials (unfortunately the other data-set were no longer available when we did this analysis). Then we tested classifier performance in these subsets. The Az score for the correct responses are significantly above chance for all three data-sets. Yet, for the incorrect trial there was no detectable neural signature capable

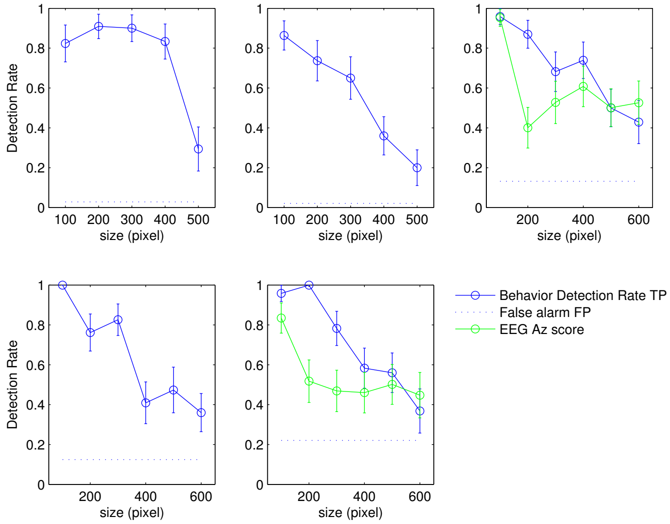

Fig. 3: **Behavioral detection performance in RSVP decreases with reduced object size**. Behavioral detection rate (blue) and EEG-based Az scores (green, where available), for each subject. As images increase in resolution the target becomes smaller (image covers a constant area on the screen).

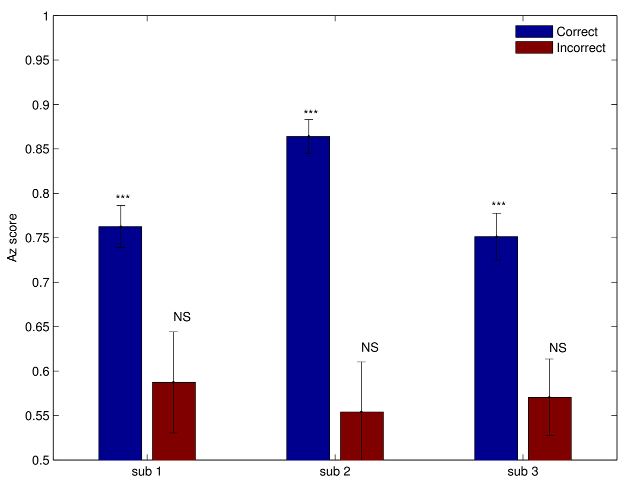

Fig. 4: **EEG-based detection of targets is high for correct trials but fails when subjects do not report the target:** Data shown for 3 subjects on the eccentricity task. Classifier was trained on correct trials only, and tested on correct trials with leave-one-out cross-validation, and separately on incorrect trails. For the correct trials Az score are significantly different from chance for all subjects ($p < 0.0001$). For the incorrect trials Az are indistinguishable from chance ($p = 0.13$, 0.34 and 0.10 respectively).

of target discrimination ($p > 0.1$). These results give a clear indication that in this paradigm there was no evidence for subconscious EEG signal for target detection in RSVP.

IV. Conclusion

We conclude from the eccentricity results that the target distance from the center of the screen correlates with a decrease in the capacity to detect the target in RSVP tasks. Based on the size results we conclude that a decrease in target size in the periphery causes a decrease in the capacity to detect target. Yet, despite the decrease in performance, the peripheral visual field is sufficient to perform detection of the tested stimuli even at presentation durations as short as 100ms.

The results on neural signatures first indicate that the discriminant activity in EEG may reflect a conscious process because Az scores and the behavioral detection performance have a similar trend. Perhaps the neural signatures are not a byproduct of some low-level process of target recognition, but are an effect of the higher-order perception mechanism, that the subject is able to experience.

The last comparison between correct and incorrect trials, supports the hypothesis that there is no subconscious process underlying the EEG signatures of target detection in this paradigm. More generally these results supports the hypothesis that higher order neural processes are being assessed by the EEG and that there are no signals associated with subconscious processing in the EEG.

This work opens the doors for further analysis on the general problem of conscious perception in the context of visual perception. Here we tested mainly true positives against false negatives, and results show a difference in the EEG related to correct perception. However an interesting question arises from these results, namely, what is the difference between true positives and false positives? The latter represent the case in which subjects "thought" they saw a target when truly no target was present. By lowering a subjects specificity future studies could aim to uncover the neural correlates of such illusory percepts.

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