Investigating N2pc for its potential in BCI applications

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ABSTRACT

The present study investigated the use of N2pc (Negativity around 200 ms in posterior contralateral) ERP for its potential use in brain computer interface applications. To the best of our knowledge, the N2pc feature has never been investigated in this context before. All existing N2pc research is mainly focused on the psychological aspects of N2pc as a neural correlate of spatial attention. In this paper, a two phase research is described which culminated in the final BCI application. Exploratory offline tests were conducted in the first phase to identify the challenges involved in using N2pc for BCI. This was followed by the development of an online audio based game in the second phase, controlled by the N2pc in the EEG signals. Both online and offline studies used single trial classification. The results of the study implicates that N2pc has a very promising future with regards to its use in a robust two or three class BCI.

1. Introduction

The human visual system is frequently confronted with complex visual scenes containing multiple objects, and accurate perception under these conditions poses significant computational problems. The identification of target information may be improved by suppressing competing information originating from the surrounding distractor items. Several studies have identified an ERP component that may be related to this attentional filtering process with a highly contralateral scalp distribution. This ERP typically consists of an increase in negative voltage over visual cortex contralateral to the location in space to which subjects are attending; if subjects pay attention to the left side of the visual field, the ERP appears in the right hemisphere of the brain, and vice-versa. This characteristic makes it a useful tool for directly measuring the general direction of a person's attention (either left or right) with fine-grained temporal resolution. This component occurs in the latency range of the second major negative visual ERP component (N2, ca. 200-300 ms poststimulus) and is therefore labeled "N2pc" to denote its latency range and its occurrence at posterior contralateral scalp sites (Heinze, Luck, Mangun & Hillyard (1990); Luck, Fan & Hillyard (1993); Luck & Hillyard (1994); Luck & Hillyard (1990a)).

The N2pc component has typically been observed in response to target items embedded within displays containing nontarget items that may need to be filtered in order to allow correct discrimination of the target. Various studies have explored what factors would modulate the N2pc using a visual search paradigm in which subjects had to report the presence of a target object in a display (e.g., a green box or a horizontal bar). The research confirmed that the N2pc appeared contralateral to attended stimuli, and furthermore found that it did not appear when subjects saw only one object at a time or had to spread their attention over all the items in the display. These data led the experimenters to believe the N2pc corresponds to a filtering process that occurs whenever people focus attention on one object while ignoring others. Subsequent investigation into the N2pc manipulated the number of items in the array and found that a display with as few as two objects elicits the component. Because an object cannot pop out and attract attention in a two-item display, experimenters concluded that the N2pc must reflect top-down, controlled processes of directing attention (Eimer, 1996). MEG studies has been used to localize the N2pc primarily to lateral extrastriate cortex and inferotemporal visual areas, such as V4 (Hopf, S.J. & Girelli, 2000).

The current study focuses on using N2pc activity for brain computer interface application. As far as we know, no BCI applications exist that use N2pc. The rest of the article de-

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scribes the offline and online development phases of incorporating N2pc in 2 class BCI application.

2. Offline

This section describes offline development phase of the N2pc based BCI.

2.1. Methods

2.1.1. Stimuli

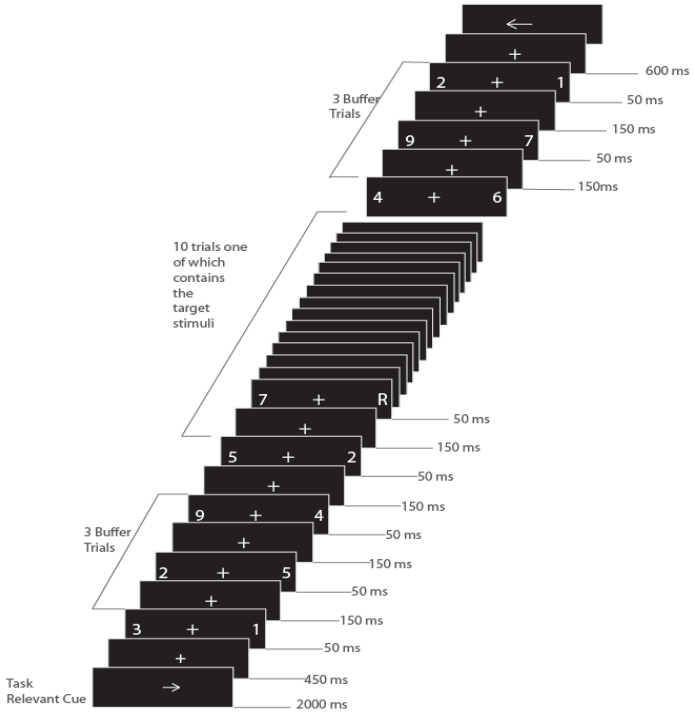
Although there a number of way in which an N2pc could be elicited, however, the only paradigm suitable for a BCI seems to be the Rapid Serial Visual Presentation (RSVP) paradigm. In this paradigm, two sequences of 16 distractor digits (0-9) were presented in each trial. One of the sequences was presented on the left visual while the other was presented in the right visual field. A target stimuli in the form of an 'L' or 'R' would pop up in the left and right stream respectively, once in each trial. Participants were asked to press Left CTRL key when they saw the letter 'L' in the left stream during left trials, and to press right CTRL key when they saw the letter 'R' in the right trials. To make sure the subjects never missed a target stimuli, it was never presented in the first three buffer trials. The target stimuli were always presented randomly once in the 10 trials that followed the initial three buffer trials. To avoid eliciting temporally overlapping ERPs, three buffer trials were used at the end as well. This was to make sure that N2pc from a previous trial dies down completely before another ERP is elicited in the subsequent trial. Each stimulus item (target and distractor) was presented for 50 ms followed by a pause of 150 ms in which only the fixation cross was shown. 50 ms was chosen because studies have shown that this duration elicits the highest N2pc (Brisson & Jolicœur, 2007). Each trial was preceded by a 2000 ms cue, followed by a 450 ms fixation cross (see Figure 1). Subjects were asked to blink as much as they want during the time cues were being presented but not during the presentation of rapid streams.

The stimulus presentation was automatically paused after every 9 trials. The subject had to press Spacebar on the keyboard to resume the stimulus. This semi self-paced stimulus presentation allowed subjects to move or take as long a break as they wanted during the experimental procedure.

2.1.2. Apparatus

Neurobehavioral Systems Presentation® software (Version 14.9, www.neurobs.com) was used for stimulus presentation. The participants were seated 70 cm in front of a 20 inch LCD monitor (Samsung Syncmaster 203D, refresh rate: 60Hz). Fluorescent lights were always kept on during stimulus presentation.

Figure 1: Timeline of the Rapid Serial Visual Presentation (RSVP) paradigm



Two sequences of digits are presented simultaneously on the left and right visual field. The first and last three trials do not contain any target. The target is presented randomly in one of the middle 10 trials. Each trial contains in total of 16 stimulus presentation. Only one target is presented on each side in each trial. The target in left stream is 'L' and the target or right side is 'R'

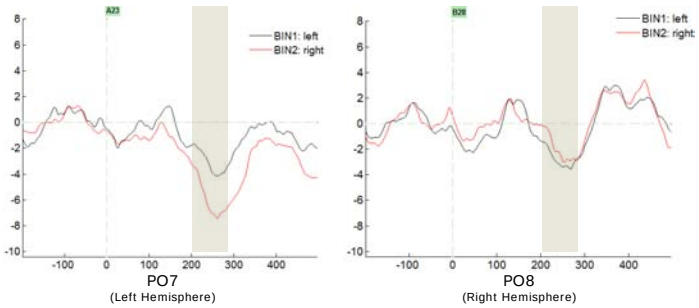
2.1.3. Participants

Two volunteers participated in the experiment, all participants had normal or corrected-to-normal vision. Both participants performed a total of 750 trials

2.1.4. EEG Data Acquisition

High density EEG was recorded at 256 Hz from a 64 electrode Biosemi cap with active electrodes using ActiveTwo data acquisition systems. Apart from that two mastoid electrodes were used but were later dropped from analysis due to high amount of muscle artifacts. To help identify and reject trials distorted by saccadic artifacts, two external electrodes were used 1cm lateral to the outer canthi to measure horizontal EOG (electrooculogram). Similarly, two more electrodes, 1 cm above and below the left eye, were used to record vertical EOG to help identify and reject trials distorted by blink artifacts. All electrode offsets were maintained below ± 25 range by monitoring them in the ActiView software.

Figure 2: Grand Averaged ERP Plot



The left plot shows grand averaged ERP over the left hemisphere electrode PO7. The N2pc is highest for right trials in the contralateral electrodes in the left hemisphere. Similarly, the N2pc is highest in right plot for left trials. Note: Negativity has been plotted downwards.

2.1.5. EEG Data Analysis

EEGLAB (Delorme & Makeig, 2004) in conjunction with ERPLAB toolbox, was used for offline analysis of the EEG data to help locate and identify the N2pc ERP. The EEG recordings were re-referenced to the common average reference derivation and low pass filtered with a 30 Hz Half-Power(-3 dB) Butterworth filter. Bipolar hEOG and vEOG were derived from the unipolar channels. These bipolar EOG channels were then used to identify eye artifacts. Epochs were then extracted till 500 ms after the target stimulus onset. A pre-stimulus interval of 200 ms was used for baselining. To remove trials containing saccadic artifacts, step artifact rejection criteria was used with a threshold of 100 uV and full width moving window size of 200 ms and a step size of 50 ms. To reject trials with blink artifacts, moving window peak-to-peak rejection criteria was used with a threshold of 100 uV and full width moving window size of 200 ms and a step size of 100 ms. After cleaning the data, the left and right target trials were averaged to get an average ERP for each subject. These average for each subject were subsequently averaged again to obtain a grand averaged ERP. These are shown in Figure 2. The ERP show that the N2pc for left trials is highest in the contralateral electrode(PO8) compared to the ipsilateral electrode(PO7). Similarly the N2pc for right target trials is higher in the contralateral electrode (PO7) compared to the ipsilateral electrode (PO8). The latency of the N2pc is between 200-310 ms as shown in the Figure 2.

2.1.6. Results

To classify the dataset, it was downsampled by a factor of 12 and time features between 210-310 ms were presented to the classifiers. Only temporo-parietal and occipital electrodes P7, TP7, P5, F3, FC3, PO7, P1, C3, PO3, P3, CP3, P9, O1, P8, TP8, P6, F4, FC4, PO8, P2, C4, PO4, P4, CP4, P10, O2 were used. Two classifiers, Linear Discriminant Analysis(LDA) and Support Vector Machine(SVM) with Linear Kernel were used to classify the dataset for each of the two subjects. The training and test proportions were set to 75 and 25 percent respectively. The results are presented in Table 1. The average accuracy using LDA and SVM is 74.1 % and 73.7 % respectively.

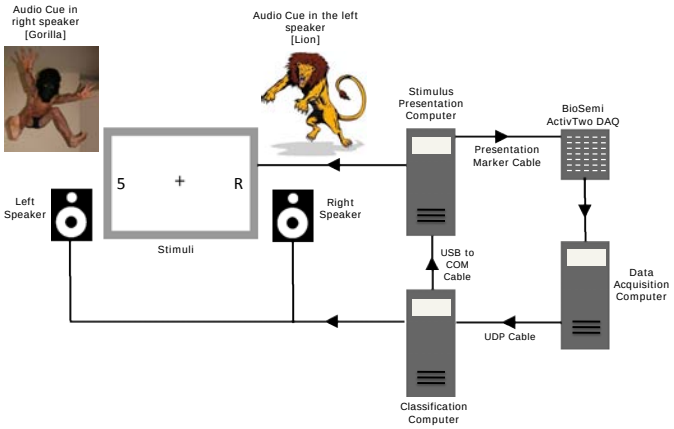
Table 1: Accuracy of online classification

Subject ID	LDA Accuracy [%]	SVM Accuracy [%]
1	70.9	73.3
2	77.2	74.2
Average	**74.1**	**73.7**

3. Online Experiment

After successfully eliciting and classifying N2pc in the offline study, it was decided to incorporate it in a simple proof of concept 2 class online BCI application.

Figure 3: Online BCI game based on N2pc BCI



A simple game based on N2pc activity. Audio cues are presented in the left or right speaker and depending on which speaker the cues is presented from, the user has to focus on the corresponding RSVP stream. This online BCI is based on single trial classification.

3.1. Methods

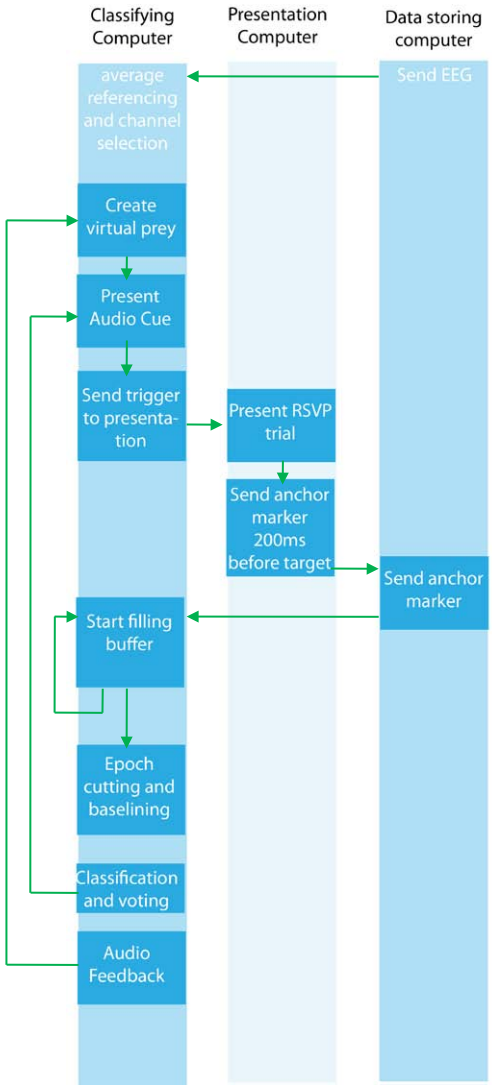
3.1.1. Stimuli

The online BCI application developed was called the 'Hunter Hunted' (see Figure 3). The subject is supposed to be a hunter under attack from animals like lions, tigers, eagles and bears. At the beginning of each trial, the subject would hear one of these animals in the left or right speaker. After that, the RSVP stimulus presentation would start and the subject would have to focus his attention at the RSVP stream

on the same side as the one where the audio was heard at the beginning of the trial. If the subject successfully focuses his attention on the correct stream and it was classified correctly, then the animal would be killed(presented with an audio feedback), otherwise not and the user would hear the same animal again in the next trial until it is successfully killed. The sounds were randomly distributed over the left and right speaker.

The RSVP stimuli for online study is essentially the same as the offline study with only some minor differences. Each trail in online study began with an audio cue in the left or right speaker instead of visual cue in the offline study. Furthermore, in the online study the right target was always 400ms after the left target. This helped in easier classification algorithm for online case.

Figure 4: Online BCI pipeline



3.1.2. *Apparatus*

Neurobehavioral Systems Presentation® software (Version 14.9, www.neurobs.com) was used for stimulus presentation. The participants were seated 70 cm in front of a 20 inch LCD monitor(Samsung Syncmaster 203D, refresh rate: 60Hz). Fluorescent lights were always kept on during stimulus presentation. Audio cues were presented from a Soundforce 2.0 speakerset, with the two speakers setup on both sides of the monitor.

3.1.3. *Participants*

One subject with normal vision participated in the experiment. The training session contained 120 trials with equal number of left and right trials. After the training session, the online prediction session started with approximately 50 trials.

3.1.4. *EEG Data Acquisition and Analysis*

High density EEG was recorded at 256 Hz from a 64 Electrode Biosemi cap with active electrodes using ActiveTwo data acquisition system. The data was streamed via TCP to the analysis computer running MATLAB® R2011a where it was re-referenced to common average. No filtering and artifact rejection/correction was applied in the online study. The EEG for one trial was divided into two subepochs, each epoch given to a separate SVM classifier. The subepoch around the left target stimulus containing the possible N2pc for left focus trial was given to one classifier and the subepoch around the right target stimulus possibly containing N2pc for the right focus trials was given to a second classifier. If both classifiers reported ERP activity including the N2pc or both no activity then it was considered as a misclassification. If the first classifier reported ERP and the second one did not, then the result was interpreted as a left focus and if the second classifier reported ERP while the first did not, then the result was interpreted as a right focus.

3.1.5. *Results*

To classify the dataset, it was downsampled by a factor of 12 and time features between 210-310 ms were presented to the SVM classifier. Only temporo-parietal and occipital electrodes P7, TP7, P5, F3, FC3, PO7, P1, C3, CP5, PO3, P3, CP3, P9, O1, P8, TP8, P6, F4, FC4, PO8, P2, C4, CP6, PO4, P4, CP4, P10, O2 were used.The online accuracy obtained are presented in the Table 2.

3.2. ***Discussion***

The results obtained in the offline study indicate that N2pc activity can be reliably classified on a single trial basis with relatively simple classifiers like SVM and LDA. The results

Table 2: Accuracy of offline classification

Subject ID	Accuracy of left classifier [%]	Accuracy of right classifier [%]	Overall Accuracy [%]
1	55.1	59.1	40.8

from online study are not very encouraging yet, probably because the online BCI still needs much more refinement. As no filter and artifact rejection/correction was implemented in the current online implementation, it is hoped that incorporating these two crucial stages in the pipeline would greatly increase the online classification accuracy. Furthermore, the current online implementation uses two classifier to classify the left and right trial subepochs. Using only one classifier could have led to a higher accuracy. The decision to use two classifiers was based on the assumption that classifying the ERP at two times would increase the accuracy and detection would be more certain. However, this decreases the accuracy for a 2 class classifier since both classifiers should agree.

*3.3. **Conclusion***

The results of this study purports that N2pc could be the next P300 of the BCI field. We have successfully shown that a 2 class BCI is possible using this RSVP paradigm. But it could also be modified to include a third rest class where the subject focuses on the central fixation cross.

Appendix A. Video Demo

(Loading N2pc Demo Video.....)

Demo video of our online BCI based on N2pc. Press play button to start paying the video. If the video does not show up the first time, then closed the pdf and reopen the document (Note: The video wont run unless you click one or the other option in Trust Manager popup and click PLAY)

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