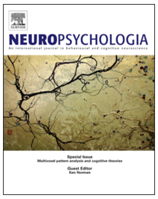
Neuropsychologia 65 (2014) 18–24

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia



# Oddball distractors demand attention: Neural and behavioral responses to predictability in the flanker task[☆]

Abigail Noyce[a,b,*], Robert Sekuler[c]

[a] Department of Psychology, Brandeis University, 415 South St., Waltham, MA 02254, USA
[b] Department of Psychological and Brain Sciences, Boston University, 64 Cummington Mall, Boston, MA 02215, USA
[c] Volen Center for Complex Systems, Brandeis University, 415 South St., Waltham, MA 02254, USA

ARTICLE INFO

*Article history:*
Received 24 June 2014
Received in revised form
12 September 2014
Accepted 2 October 2014
Available online 14 October 2014

*Keywords:*
vMMN
MMN
Flankers task
Temperament
Expectation
Individual difference

ABSTRACT

Predictable and unpredictable distractors may differentially affect attention. We adapted the Eriksen flanker task by manipulating the probability with which specific flankers occurred. Subjects reported the orientation of briefly-presented targets while attempting to ignore four flanking items. Flankers had either standard (90% of trials) or oddball (10%) orientations. Congruent and incongruent configurations were equiprobable, as were target orientations. Oddball flanker orientations substantially enhanced congruency effects: performance was best when the target was congruent with oddball flankers and worst when it was incongruent. We recorded scalp EEG while subjects performed the task, and later computed ERPs timelocked to stimulus onset. Oddball flanker orientations evoked a visual mismatch negativity (vMMN). Subjects' temperament predicted individual differences in vMMN magnitude. Orientation sensitivity predicted larger vMMNs; attentional selectivity predicted smaller. Behavioral and vMMN results indicate that subjects exploit distractor predictability to support more-effective active inhibition; oddballs disrupt this strategy. Despite subjects' attempts to ignore the flankers, unexpected distractors strongly influence neural responses and behavioral performance.

## 1. Introduction

The natural environment's predictable spatial and temporal regularities allow the human brain to operate in a predictive, feedforward mode (Bar, 2009). This ability to extend environmental structure to predict forthcoming stimuli facilitates many cognitive tasks, from identifying objects (Biederman et al., 1982) to planning and executing behaviors (Maryott et al., 2011) to appropriately allocating attention (Posner, 1980). Most research into predictive processing has considered the impact of regularities among a task's targets, a focus that is entirely understandable, as such regularities clearly facilitate cognitive performance. However, little work has been done on regularities among task-irrelevant distractors. Everyday experience suggests that, for example, it is easier to ignore a train whistle that blows at the same time every day than to ignore one that occurs at random. Further, we know that attention plays two complementary roles in cognition. We direct attention to targets and we withdraw attention from, or perhaps actively inhibit, distractors (James, 1890). If predictable distractors facilitate such inhibition, we should find enhanced attentional selectivity when distractors are predictable, and impaired selectivity when they are irregular. In order to investigate this proposition, we measured the behavioral and neural consequences of both predictable and oddball distractors.

Our study adapted the Eriksen flanker task (Eriksen and Eriksen, 1974), which entails interference between conflicting visual information. Specifically, the flanker task requires subjects to focus visual attention on a single target, such as a left-facing or right-facing chevron, while attempting to ignore surrounding items. The flanking distractors can either match or differ from the target, and the congruency between the flankers and the target influences the accuracy and reaction time with which subjects can report the target's orientation (e.g. Eriksen and Eriksen, 1974; White et al., 2011). Despite subjects' attempts to ignore the distractors, flankers that are incongruent with the central target interfere with processing, leading to reduced speed and accuracy on those trials (Schmidt and Dark, 1998). We modified the flanker task by manipulating the frequency with which different distractors appeared, creating predictable and oddball flankers.

To supplement our behavioral measures, we drew on event-related brain potentials (ERPs), which provide a direct measure of neural activity time-locked to specific events (Luck, 2005). Because

---

[☆] Author Note: Supported by CELEST, an NSF Science of Learning Center (SBE-0354378). Stephanie Bond and Brian Dorfman assisted with experiment coding, data collection, and analysis.

[*] Corresponding author at: Department of Psychological and Brain Sciences, Boston University, 64 Cummington Mall, Boston, MA 02215, USA.
Tel.: +1 617 440 3640.
*E-mail addresses:* anoyce@bu.edu (A. Noyce), sekuler@brandeis.edu (R. Sekuler).

http://dx.doi.org/10.1016/j.neuropsychologia.2014.10.002
0028-3932/© 2014 Elsevier Ltd. All rights reserved.

we were interested in the effects that oddball flankers might have, we focused on one particular ERP component, the visual mismatch negativity (vMMN). This is an early, negative-going deflection in the ERP that occurs in response to occasional deviant elements within a sequence of visual stimuli that obey some regularity (Czigler, 2007; Pazo-Alvarez et al., 2003). The vMMN is analogous to the well-known auditory mismatch negativity (MMN), which is theorized to be generated in auditory cortex when a predictive signal from prefrontal areas is disconfirmed by incoming sensory information (Garrido et al., 2009; Wacongne et al., 2012). The auditory and visual MMNs arise regardless of the focus of subjects' attention, and are even elicited when subjects are attending to stimuli in a different sensory modality (Näätänen et al., 1993; Stefanics et al., 2011).

We measured the visual mismatch negativity in order to characterize the neural response to infrequent distractors that subjects are actively attempting to ignore. We then assessed correlations between the neural responses, the behavioral effects of the frequent and infrequent distractors, and individual differences in temperament. We hypothesized that infrequent distractors would evoke a visual mismatch negativity, and that they would lead to an outsize flanker congruency effect, due to the difficulty of suppressing attention to unpredictable flankers.

An area of growing interest among cognitive neuroscientists is the nature and origins of individual differences in neural activity and behavioral effects. One potential source of such differences is variability in emotional, motor, and attentional reactivity (Kagan, 2003; Rothbart, 2007). Performance on the flanker task requires attentional separation of stimuli whose appearance and spatial selection are very similar. If occasional oddball flankers disrupt this separation, individual differences in sensitivity or reactivity to sensory input may predict the degree of such disruption. We thus hypothesized that differences in temperament would predict differences in the extent to which oddball flankers enhance the flanker congruency effect. Further, the vMMN indicates that oddball stimuli are being processed, despite attention being directed away from them (Stefanics et al., 2011; Näätänen et al., 2007), and we thus hypothesized that individual differences in temperament would predict the magnitude of the vMMN response to deviant distractors.

## 2. Methods

### 2.1. Subjects

Twenty members of the Brandeis University community (15 females, age range 18–21) participated in this study. All were right-handed (mean score on the revised Edinburgh Handedness Inventory 89.49, SD = 12.85). Two other subjects completed one experimental session but did not return for the second; their data were discarded.

### 2.2. Experimental task

We developed a modified Eriksen flankers task using chevron stimuli (Eriksen and Eriksen, 1974). Chevron stimuli have frequently been used in the flankers task to minimize reliance on verbal processes and literacy (e.g. Dye et al., 2009; Emmorey et al., 2008; Hajcak and Foti, 2008; Mayr et al., 2003; White et al., 2011; Wylie et al., 2007). The basic trial structure is shown schematically in Fig. 1A. On each trial, subjects were presented with an array of five chevrons that were displayed for 50 ms and were not masked upon offset. They were instructed to report whether the central chevron was facing to the left or to the right. We will refer to this central chevron as the *target*, and the two chevrons on each side of it as the *flankers*. The four flankers were always consistently oriented, and the central chevron's orientation was equiprobably congruent or incongruent with its flankers. After a subject's response, a fixation cross was displayed for an inter-trial interval of 1000 ms before the next trial display appeared. Subjects viewed the display from a difference of approximately 57 cm, and were instructed to maintain fixation on a central cross. Each chevron subtended approximately 1.4° visual angle, and the full array extended to an eccentricity of 4.7° to the left and right of the fixation point.

In order to maintain more-consistent error levels across subjects and conditions, subjects received feedback about their performance after every thirty trials (after Hajcak and Foti, 2008). If the subject had responded correctly on between 75% and 90% of those trials, the feedback was "You're doing great!" If accuracy was lower than 75%, the feedback instructed the subject to increase their accuracy; if it was above 90%, the feedback instructed the subject to respond more quickly.

Trials were randomly distributed among four conditions in a two-by-two design, as shown in Fig. 1B. The first factor governed the orientation of the four flanker chevrons. On ninety percent of trials, the flanker chevrons had one orientation (the Standard orientation) and on ten percent of trials they had the other (the Oddball orientation). The second factor governed the relationship between the central target and the flankers. On half of trials, the target was Congruent with the flankers, and on half it was Incongruent. Left-facing and right-facing targets were equally frequent, and the orientations comprising Standard and Oddball flankers were counterbalanced within subjects.

On approximately 13% of trials, a burst of auditory white noise was presented after either stimulus presentation or after response, to elicit startle reactions. Startle blink was measured via electromyography; however, we observed no effects of timing or trial type on startle blink magnitude and those data are not presented here.

### 1.1. Procedures and analyses

#### 2.2.1. Procedures

Each recording block comprised 510 trials, with the first thirty discarded as practice. Each subject completed two blocks with left-facing flankers as the Standard orientation and two with right-facing flankers. These four blocks were completed in two separate recording sessions; the order of blocks was counterbalanced across subjects. By the end of the experiment, each subject had completed 2040 trials, 1920 of which were included for analysis.

Subjects filled out an anonymous questionnaire after each recording session, confirming that they got reasonable amounts of sleep, were not under the influence of any psychoactive substances, and had no medical history, such as a head injury or neurological diagnosis, which would lead us to exclude their data.

#### 2.2.2. Behavioral measures

Subjects' reaction times and responses were recorded from each trial and analyzed. We computed accuracy and median reaction time for each of Congruent Standard, Incongruent Standard, Congruent Oddball, and Incongruent Oddball conditions as well as Vincentile reaction times and accuracy for each condition (Vincent, 1912; Ratcliff, 1979).

After the end of their final experimental session, subjects completed the Adult Temperament Questionnaire Short Form (ATQ). This instrument's 77 items form several self-report scales describing temperament factors (Evans and Rothbart, 2007). We selected two factors that seemed likely to capture task-relevant aspects of temperament: attentional control and orienting sensitivity. Attentional control refers to the capacity to focus attention, and to shift attention as desired. "It's often hard for me to alternate between two different tasks," is an example of a reverse-scored attentional control item. Orienting sensitivity refers to awareness of low-intensity environmental and self-generated stimuli and experiences. "I often notice visual details in the environment," is an example of an orienting sensitivity item. We hypothesized that the attentional control would account for some variability in people's task performance, and that both factors would relate to variability in the ERPs elicited by Oddball and Standard stimuli.

#### 2.2.3. EEG recording and analyses

A high-density EEG system (Electrical Geodesics, Inc., Eugene, OR) with 129 electrodes sampled scalp electroencephalographic signals at 250 Hz using a high-impedance amplifier. Signals were recorded for later, off-line analysis. At the start of each experimental session, all channels were adjusted for scalp impedance below 50 kΩ impedance; after one experimental block, channel impedences were measured and, if needed, returned to at most 50 kΩ scalp impedance before the subject completed the session.

After recording, EEG data were preprocessed using the EEGLAB Matlab toolbox (Delorme and Makeig, 2004). Continuous EEG signals were bandpass filtered to between 0.25 and 100 Hz using a first-order Butterworth filter. A 60 Hz notch filter was also applied to the continuous data, to reduce line electrical noise. Stimulus onset flags were shifted by 36 ms to correct for delay introduced by the amplifier's antialiasing filter. The data were then broken into epochs that were time-locked to stimulus onset and lasted from 236 ms before stimulus onset to 464 ms after. Epochs containing muscle artifacts, eye movements, and bad channels were identified by visual inspection and rejected. Independent components analysis allowed us to isolate eye blink activity, which was subtracted from the data. Data were again visually inspected for artifacts not corrected by the previous two processes. The number of trials per condition remaining after data cleaning are shown in Table 1. Finally, data were re-referenced to the average voltage, and averaged across trials and sessions to create a subject average ERP for each condition.

To compare ERPs evoked by trials with Oddball flankers to those evoked by trials with Standard flankers, we used a data-driven, non-parametric clustering