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The effects of ongoing distraction on the neural processes underlying signal detection

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ABSTRACT

Distraction can impede our ability to detect and effectively process task-relevant stimuli in our environment. Here we leveraged the high temporal resolution of event-related potentials (ERPs) to study the neural consequences of a global, continuous distractor on signal-detection processes. Healthy, young adults performed the dSAT task, a translational sustained-attention task that has been used across different species and in clinical groups, in the presence and absence of ongoing distracting stimulation. We found the presence of distracting stimuli impaired participants' ability to behaviorally detect task-relevant signal stimuli and greatly affected the neural cascade of processes underlying signal detection. Specifically, we found distraction reduced an anterior and a posterior early-latency N2 ERP component (~140–220 ms) and modulated long-latency, detection-related P3 components (P3a: ~200–330 ms, P3b: 300–700 ms), even to correctly detected targets. These data provide evidence that distraction can induce powerful alterations in the neural processes related to signal detection, even when stimuli are behaviorally detected.

1. Introduction

The ability to detect task- and goal-relevant stimuli is a critical cognitive function at play almost continuously in daily life. The presence of distracting stimuli can challenge our ability to successfully detect and process relevant stimuli in our environment. Here, we studied how a global, continuous distractor influences the brain's processing of task-relevant signals.

This work uses a translational sustained attention task, the distractor Sustained Attention Task (dSAT; Demeter et al., 2013, 2008). This task requires participants to report the presence or absence of a brief, variable-duration visual signal stimulus during either a baseline, no-distraction condition (SAT) or in a distractor condition (dSAT) designed to increase the demands on attentional control. Originally developed in rodents, this task has been used to study the role of the cortical cholinergic system in mediating attention (e.g., Gill et al., 2000; McGaughy et al., 1996). Cholinergic projections from the basal forebrain to prefrontal cortex are necessary for attentional functions (see review by Hasselmo and Sarter, 2011). Cholinergic neurotransmission in right prefrontal cortex in particular is critical for signal detection (Gritton et al., 2016; Howe et al., 2013; Martinez and Sarter, 2004; Parikh et al., 2007). Additionally, cholinergic neurotransmission in right prefrontal and posterior parietal cortex is theorized to mediate attentional control functions that are engaged when attention is challenged, such as when distraction is present (Broussard et al., 2009; Gill et al., 2000; Kozak et al., 2006; St Peters et al., 2011b). Converging evidence from human functional magnetic resonance imaging (fMRI) work using the dSAT has shown attentional performance during distraction activates a right-lateralized frontoparietal network. This network includes a region in the right middle frontal gyrus (Brodmann's Area 9) that is sensitive to both the attentional demands imposed by distraction (Demeter et al., 2011) and to endogenous cholinergic capacity (Berry et al., 2015).

Several fMRI and electroencephalography (EEG) studies using different attention paradigms have also investigated distraction's effects on the neural processes mediating attentional control and target detection processes. fMRI work using visual search paradigms and flanker tasks, for example, have identified regions in dorsal frontoparietal cortex and in right middle frontal gyrus in particular as being especially important for responding to the attentional demands of distraction (Leber, 2010; Marini et al., 2016). Mirroring the right-lateralized frontal activation pattern seen in the fMRI literature, we have recently identified a right-lateralized frontal event-related potential (ERP) activation in response to transient distractor stimuli (Demeter and Woldorff, 2016). Broadly, these frontal activations are often interpreted as reflecting attentional control processes designed to filter or suppress distractor stimuli (Zanto and Rissman, 2015). Beyond this attentional control-related activation in frontal cortex, our recent ERP study also

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demonstrated that brief distractors presented during the presentation of a task-relevant target stimulus could decrease the amplitude of the central parietal P3b ERP component evoked by that target stimulus (Demeter and Woldorff, 2016). Other ERP studies have found distractor stimuli can influence the amplitude of early-latency (150–250 ms) N2 activity over occipital cortex and subsequent P3a activity over frontocentral cortex (Berti and SchrÖger, 2001). In addition, it has been reported that successfully ignoring salient distractors evokes a lateralized occipital ERP component known as the “PD”, which has been found to be a marker of attentional suppression (Gaspar and McDonald, 2014).

While these earlier studies used discrete distractor stimuli, ongoing distraction can also impinge upon attentional performance. For instance, evidence from cross-modal ERP studies has shown that ongoing, concurrently-presented distractor streams in one modality can influence attentional processing of task-relevant stimuli in another modality (Bendixen et al., 2010; Gherri and Eimer, 2010). Within the visual modality, Müller and Hübner (2002) examined whether spatial selective attention could successfully ignore one of two spatially overlapping, centrally-presented information streams. They found that spatial selective attention could successfully ignore the irrelevant stream, even when that irrelevant stream was presented physically on top of the relevant stream, suggesting the attentional spotlight can assume more complex shapes than just a single unitary beam. While this work adds to our understanding about how we can selectively direct our attentional focus, Müller and Hübner did not manipulate the presence versus absence of their irrelevant stimulus streams, nor did they study how continuous distraction affects the neural cascade of processes related to detecting task-relevant targets.

Here, we examined the behavioral and neural consequences of a global, continuous visual distractor on detecting and processing task-relevant visual target signals. Behaviorally, we predicted distraction would impair participants' task accuracy, in line with other studies using the dSAT (e.g., Berry et al., 2015; Demeter et al., 2013, 2011, 2008). Neurally, we predicted that distraction would disrupt the neural cascade of processes related to detecting signal stimuli. Specifically, in line with previous ERP studies involving target-detection paradigms, we predicted that detected signal stimuli would elicit early sensory responses over visual cortex followed by an N2-P3 complex, a functionally-linked set of ERP subcomponents temporally delineating the neural stages of identifying and classifying task-relevant target stimuli (see review by Patel and Azzam, 2005). Based on our previous investigations with brief, transient distractors (Demeter and Woldorff, 2016), we predicted that distraction would reduce or delay these activations. To preview our results, we did not find any effects of distraction on the earliest sensory processing activity (P1 component). In line with our predictions, we did find that distraction reduced and delayed early-latency negative-going activity (the anterior and posterior N2 subcomponents) and later-latency positive-going activity (the P3a subcomponent). However, at longer-latencies the P3b subcomponent was enhanced in amplitude in the presence of distraction, suggesting a late compensatory process. These data thus provide a detailed window into the effects of continuous, within-modality distraction on the neural processes mediating target detection.

2. Methods

2.1. Participants

Thirty-seven young adults were recruited from Duke University and the surrounding community. Participants were screened for medications and neurological or psychiatric conditions known to affect cognition, vision, or hearing, and for minimal levels of English proficiency. Nine participants were excluded due to having excessive artifacts in the EEG data (> 40% of epochs excluded for conditions of interest) or inability to follow task instructions (including falling asleep, failure to respond at the appropriate time in the task, etc.). This left a final dataset of 28 healthy, young adults (17 males, 24 right-handed, aged M: 24.36 yr, SD: 5.00 yr). Participants were compensated at a $15.00 hourly rate. Prior to initiating any experimental procedures, all participants provided written informed consent as approved by and in accordance with Duke University's Institutional Review Board policies.

2.2. SAT/dSAT paradigm

The SAT/dSAT paradigm (Demeter et al., 2008) was modified in order to make it amenable to EEG data collection and analysis (Fig. 1). For each trial of the SAT condition without distraction, participants fixated on a dark gray central square on a light gray background. After an initial monitoring period (867 or 1400 ms duration, randomly), participants were presented with either a signal event (the fixation square filled in with a dark gray square, durations of 17, 33 or 50 ms, all durations with equal probability) or a nonsignal event (the fixation square remained unfilled). The signal and nonsignal events occurred with equal likelihood and in a randomized order across trials. After a delay period (467 or 733 ms, randomly), participants were presented with an auditory response cue. Participants then had up to 1000 ms to make a buttonpress response to indicate whether the signal was or was not presented on that trial (left and right index fingers indicating presence versus not; button assignment counterbalanced across participants). Participants received auditory feedback on their response accuracy (tones assigned to correct and incorrect responses counterbalanced across participants).

In the dSAT condition with distraction, participants performed the exact same task, but now with a black-and-white checkerboard flashing in the background. The flashing checkerboard background was generated by alternating between a standard light-gray background and a black-and-white checkerboard background screen at a frequency of 15 Hz. The black-and-white regions of the checkerboard flipped in color with each checkerboard presentation. The screen area immediately adjacent to the position of signal or non-signal presentation stayed light-gray and did not display the flashing checkerboard distractor. Signal and non-signal events were jittered relative to the flashing background screens. That is, signal and non-signal event onsets were randomly distributed in time throughout the period encompassed by one cycle of the flashing distractor screens, thereby greatly reducing 15-Hz steady state visual evoked potential (SSVEP) activity from the flashing checkerboards on the ERPs to the signal and non-signal events. Identical presentation timings for signal and non-signal events were also used for the SAT condition where background screens were all a constant light gray.

Participants completed thirty-two 2.5 min blocks of SAT or dSAT (block order pseudo-randomized) while scalp EEG was recorded. Block order was constrained so that there were no more than 3 blocks in a row of the same task condition and so that equal numbers of SAT and dSAT blocks were presented in the first and second half of the experimental session. Participants completed 49 trials per block.

2.3. Data acquisition and analysis

EEG data were acquired using a 64-channel active-electrode system (Brain Vision BrainAmp MR Plus with actiCAP Control Box, Brain Products, Gilching Süd, Germany), mounted on a customized