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Neuronal effects of auditory distraction on visual attention

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ABSTRACT

Selective attention in the presence of distraction is a key aspect of healthy cognition. The underlying neurobiological processes, have not, however, been functionally well characterized. In the present study, we used functional magnetic resonance imaging to determine how ecologically relevant distracting noise affects cortical activity in 27 healthy adults during two versions of the visual Sustained Attention To Response Task (SART) that differ in difficulty (and thus attentional load). A significant condition (noise or silence) by task (easy or difficult) interaction was observed in several areas, including dorsolateral prefrontal cortex (DLPFC), fusiform gyrus (FG), posterior cingulate (PCC), and pre-supplementary motor area (PreSMA). Post hoc analyses of interaction effects revealed deactivation of DLPFC, PCC, and PreSMA during distracting noise under conditions of low attentional load, and activation of FG and PCC during distracting noise under conditions of high attentional load. These results suggest that distracting noise may help alert subjects to task goals and reduce demands on cortical resources during tasks of low difficulty and attentional load. Under conditions of higher load, however, additional cognitive resources may be required in the presence of noise.

1. Introduction

The ability to selectively attend to relevant stimuli in the environment while ignoring salient distractors is a key component of cognition. Thousands of drivers are killed each year in the United States due to “inattention” (www.census.gov), including accidents caused by environmental distraction. Attention deficit hyperactivity disorder, for which symptoms include being easily distracted (Wolraich, 2006), exerts a “significant negative impact of quality of daily life, including work, social life, and relationships” (Rösler, Casas, Konofal, & Buitelaar, 2010). In schizophrenia, the inability “to choose which sources of input should be attended” is a debilitating cognitive symptom and has recently been suggested as an essential biomarker for treatment intervention (Luck, Ford, Sarter, & Lustig, 2012).

To a large extent, the effect of irrelevant noise on task performance has been investigated in terms of its deleterious consequences. Early work by Broadbent found that noise interfered with vigilance (Broadbent, 1951), response speed (Broadbent, 1957), and mental arithmetic (Broadbent, 1958). Similar findings have since been reported using many different tasks and subject populations (Smith, 1989). However, irrelevant noise may also facilitate performance, particularly during monotonous, repetitive tasks (Smith, 1989; Suter, 1989). Indeed, as initially proposed by Yerkes and Dodson (1908) and expanded upon by Zentall and Zentall (1983), the effect of task-irrelevant stimuli may depend on task difficulty, as appropriate levels of stimulation may be required for optimum performance.

The neuronal processes that underlie the proposed interaction between task difficulty and distraction have not been well characterized. Insight into this process can be gained, however, by examining two variants of an attention task, the Sustained Attention to Response Task (SART), which may be comparable except for their respective difficulties. In the SART, a subject is shown a series of numbers and instructed to press a button when he sees any number except for “3”; if he sees a “3,” the subject is instructed to withhold from responding. The task has a much lower frequency of “3’s” than other numbers; thus the primary task objective is to inhibit the natural tendency to button press after each stimulus presentation (O’Connell et al., 2004). The Fixed version of the SART, in which targets are presented (one at a time) in numerical order and the stop target is therefore predictable, is easy and requires fewer trial-by-trial attentional resources. The Random version, in which numbers are presented in random order, requires the subject to more fully process each stimulus to perform the task accurately and is therefore more difficult, requiring higher attentional load.

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Behavioral evidence for increased processing is an increase in reaction time for the Random SART.

fMRI studies have characterized the functional neuroanatomy of the Fixed and Random SART. Both versions have shown involvement of a frontal–parietal attention network that includes the dorsolateral prefrontal cortex (DLPFC) and inferior parietal lobule (Fassbender et al., 2004). DLPFC activation in particular is associated with top-down control processes as demonstrated via neuroimaging in other attention tasks (Banich et al., 2000; Cohen et al., 1998; Hager et al., 1998; Sturm et al., 1999). The Random SART showed additional activity in the inferior frontal gyrus and basal ganglia, likely reflecting its additional demands on response inhibition. The Random SART also showed increased activity in visual cortex, reflecting its demands on sensory processing (Fassbender et al., 2004).

A later imaging study used randomly presented "alerting tones" during the Random SART, and showed deactivation of the frontal portion of the attention network despite no change in performance (O'Connell et al., 2011). The decreased activation in this area was interpreted to reflect decreased need for top-down attentional control due to the cueing, alerting effect of the tones. In addition, increased activity in the left DLPFC with tones was observed during a control task in which the subject was instructed to press after *every* stimulus, suggesting an "orienting" response to the tones (Corbetta & Shulman, 2002; O'Connell et al., 2011).

Decreased activity in the DLPFC with tones during the Random SART suggests that exogenous stimulation may reduce demands on cortical attention networks. However, a number of questions remain. The tones in the O'Connell et al. (2011) study were task-relevant; it is unclear if task-irrelevant stimulation would have the same effect on Random SART-associated activity. In addition, the neurobiological effects of task-irrelevant auditory stimulation during tasks of comparatively low difficulty, such as the Fixed SART, are unknown. Finally, the alerting tones in the O'Connell et al. (2011) study were intermittent (every 8–12 s) and of the same frequency (2 kHz) and duration (30 ms); it is unclear whether constant noise would have the same effect, or conversely increase the burden on attentional processing. Indeed, based on previous studies that examine the effect of cross-modal distraction on attention, one might predict that constant noise would increase response in areas crucial for processing the attended modality (Langner et al., 2011; Roland, 1982).

In the present study, using functional magnetic resonance imaging (fMRI), we compared the neurophysiological effects of task-irrelevant "urban noise" stimulation on the Random and Fixed SART. The "urban noise" is a mixture of talk radio, music, and conversation one might find on a crowded city street, and is designed to mimic real-world sounds (Tregellas, Ellis, Shatti, Du, & Rojas, 2009). We formulated two hypotheses: (1) Relative to Fixed SART, Random SART would additionally recruit areas important for attentional, inhibitory, and sensory processing, because the Random version is more difficult and requires more resources than the Fixed version; (2) a significant Task × Noise interaction would be observed in areas important for attentional and sensory processing (e.g. the DLPFC and visual cortex), suggesting that the effect of noise may differ depending on attentional load.

2. Methods

2.1. Subjects

Twenty-seven healthy subjects participated in this study. Mean age was 37.07 (SD = 12.68), 13 females, 14 males. Subjects provided written informed consent approved by the University of Colorado Institutional Review Board.

2.2. Task design

fMR images were obtained while subjects performed the Sustained Attention to Response Task (SART). Subjects were shown single-digit numbers presented one at a time, and instructed to press a button after every number except for the number "3," in which case subjects were asked to withhold responding. The SART consisted of two conditions, Fixed SART and Random SART (Fig. 1). In the Fixed, or 'Ordered' condition, the numbers were presented in order, so the subject could predict when the no-go stimulus, or "3" will appear; in the Random condition, the numbers were presented pseudo-randomly. The subject was asked to respond as quickly and accurately as possible to help induce attentiveness.

SART stimuli were presented as a block design, with 'Ordered' and 'Random' blocks pseudo-randomly interspersed throughout a session (Fig. 1). All stimuli were presented through MR-compatible goggles (Resonance Technology, Inc.). A 2.3 s identifier cue (i.e. Ordered (Fixed) or Random) was presented before the first block, as well as each time the block switched from Ordered to Random (or vice-versa). The length of each block was 12.65 s. Blocks that were preceded by an instruction had 9 trials; blocks that were not preceded by an instruction had 11 trials, thus making each block equal in duration. Each trial consisted of a 250 ms stimulus (the single-digit number) followed by a 900 ms intertrial interval; during the intertrial interval a fixation cross was presented to orient the subject. Number font was pseudo-randomized (40, 72, 94, 100, 120 type) as to increase the difference in feature detection processing requirements between Fixed and Random SART. Due to the predictability of Fixed SART, subjects may be able to correctly respond or withhold responding reflexively to the presence of any visual stimulus; however, the unpredictability of Random SART requires subjects to focus on specific stimulus features before making the appropriate response. Each session consisted of 56 blocks of trials and lasted for approximately 12 m. Baseline data was collected from a 37.95 s fixation period at the beginning and end of each session, and two 12.65 s fixation sessions near the middle. Subjects were given a brief practice session outside of the scanner to introduce them to the task parameters.

To determine the effect of noise distraction on the functional neuroanatomy of the SART, we overlaid previously developed 80 dB "urban white noise" distractors (Tregellas et al., 2009) during half of the blocks. Noise was presented in the magnet through MR-compatible headphones (Resonance Technology, Inc.). The "urban white noise" consisted of a mixture of audio clips, including segments of radio shows, classical music pieces, and background conversation (described fully in Tregellas et al., 2009). Volumes of all of these elements were mixed so that no one element was readily identifiable. The subjective experience of the sound mixture was that of standing in a busy crowd of people, in which multiple conversations were occurring, with a low level of indistinguishable background music and other sounds one might experience in a busy urban setting.

The primary performance measure on the SART was percent commission errors, defined as the percent of incorrect responses on no-go trials, i.e. the percent of button presses following presentation of the number "3." Pilot studies were first conducted outside the scanner to ensure that noise would not affect any performance measure. fMRI data could then be analyzed without the potentially contaminating effects of performance differences.

2.3. MR parameters

Functional scans were collected using a clustered volume approach as described previously (Edmister, Talavage, Ledden, & Weisskoff, 1999; Tregellas et al., 2009). Use of the clustered volume approach allowed stimuli to be presented while minimizing