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The impact of auditory white noise on semantic priming

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ABSTRACT

It has been proposed that white noise can improve cognitive performance for some individuals, particularly those with lower attention, and that this effect may be mediated by dopaminergic circuitry. Given existing evidence that semantic priming is modulated by dopamine, this study investigated whether white noise can facilitate semantic priming. Seventy-eight adults completed an auditory semantic priming task with and without white noise, at either a short or long inter-stimulus interval (ISI). Measures of both direct and indirect semantic priming were examined. Analysis of the results revealed significant direct and indirect priming effects at each ISI in noise and silence, however noise significantly reduced the magnitude of indirect priming. Analyses of subgroups with higher versus lower attention revealed a reduction to indirect priming in noise relative to silence for participants with lower executive and orienting attention. These findings suggest that white noise focuses automatic spreading activation, which may be driven by modulation of dopaminergic circuitry.

1. Introduction

The presence of environmental noise can impair cognitive performance in healthy adults (Wright, Peters, Ettinger, Kuipers, & Kumari, 2014). However, under some conditions the addition of a particular type of noise, such as white noise, has the capacity to enhance signal processing. The influence of white noise appears to be related to its stochastic property (having a random probability distribution that can be analyzed statistically but cannot be predicted precisely). Accordingly, the process by which white noise enhances signal processing is called stochastic resonance or stochastic facilitation (McDonnell & Ward, 2011).

Auditory white noise and its ability to elicit stochastic resonance has been shown to benefit various aspects of cognition, particularly for those with lower attention capacity. Research indicates that white noise can improve cognitive performance in children with attention deficit hyperactivity disorder (ADHD) (Baijot et al., 2016; Soderlund, Sikstrom, & Smart, 2007) as well as children rated as less attentive by school teachers (Helps, Bamford, Sonuga-Barke, & Soderlund, 2014; Soderlund, Sikstrom, Loftesnes, & Sonuga-Barke, 2010). Improvements to go/no-go task reaction time in white noise have also been shown to correlate with self-rated attention levels in healthy adults (Sikstrom et al., 2016). Of note, the findings in this field include benefits to the processing of auditory stimuli. Soderlund et al. (2007) found auditory white noise improved memory performance in children with ADHD, despite noise being delivered at 81 dB and task stimuli at 80 dB. Similarly, Soderlund et al. (2010) found that memory performance in children with lower attention improved with 78 dB of white noise and task stimuli delivered at 86 dB. Comparatively, research suggests that white noise can worsen performance on some cognitive tasks for children rated by teachers as having average attention (Soderlund et al., 2010) or high attention (Helps et al., 2014). The impact of white noise on cognitive performance may be consistent with the moderate brain arousal model (Sikstrom & Soderlund, 2007). The model suggests that the brain functions optimally when it is moderately aroused and operating at moderate neural Signal to Noise Ratios (SNRs). People with low attention could have low neural noise. Adding moderate levels of white noise could optimize their neural SNR and improve cognitive performance. In contrast, people with high attention could already have higher neural noise. Adding moderate levels of white noise could worsen their neural SNR and hinder cognitive performance.

The moderate brain arousal model (Sikstrom & Soderlund, 2007) also postulates that individual differences in neural noise are linked to differences in dopamine signaling. Thus, dopamine could play a key

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role in mediating an individual's responsiveness to the presence of white noise during cognitive performance. Recent neuroimaging research provides further support for a link between dopamine and the impact of white noise on cognition. Rausch, Bauch, and Bunzeck (2014) presented white noise to healthy adults during the encoding phase of a recognition memory task. They observed small improvements in subsequent recognition memory performance relative to when the memory task had been performed in silence. Rausch et al. did not observe the same improvement with either a pure tone (a periodic signal) or the sound of a running horse played backwards (a non-stochastic, noise-like signal), suggesting that the effects were specific to the stochastic properties of white noise and not to general auditory stimulation. In a further fMRI experiment with the same recognition memory task, Rausch et al. found that white noise was associated with decreased sustained activity and increased event-related activity within the substantia nigra and ventral tegmental area. They also observed an increase in functional connectivity between those regions and the superior temporal sulcus. Rausch et al. proposed that white noise modulates attention and improves memory formation by enhancing phasic dopamine release and modulating activity within the superior temporal sulcus.

The introduction of white noise does not appear to benefit cognitive performance for all tasks. For instance, white noise has been shown to impair memory performance in healthy adults when presented during the maintenance phase of a working memory task, and to have no impact if presented during the other phases of the task or continuously throughout task performance (Herweg & Bunzeck, 2015). The manner in which attention modulates the effects of white noise on cognitive performance is also difficult to predict. Helps et al. (2014) found that a shift from low to moderate levels of white noise induced a decline in performance on non-executive function tasks for highly attentive children, whereas a shift from a low to a moderate level of white noise improved performance on executive function tasks for low attentive children. The authors noted that such findings could be explained by a differential impact of white noise on executive relative to non-executive tasks, as well as factors relating to differences in stimulus modality and the range of white noise used across the different tasks.

Despite such findings, the notion of a possible causal link between dopamine and the effects of white noise on cognition prompts the need to investigate whether dopamine and white noise have similar effects on cognitive function. Recently, Angwin et al. (2017) demonstrated that white noise facilitated novel word learning in healthy adults. This followed Shellshear et al.'s (2015) demonstration that dopamine facilitated word learning in a similar population. While Angwin et al. (2004) and Kischka et al. (1996) have demonstrated that dopamine modulates semantic processing in healthy adults, no matching studies have been conducted on the effects of white noise on semantic processing.

Semantic priming tasks are frequently used to assess lexical access. Semantic priming refers to the faster recognition of a target word when preceded by a related prime word (e.g., tiger-stripe) relative to an unrelated prime word (e.g., table-stripe). Such effects can be attributed to automatic spreading activation (Collins & Loftus, 1975; Neely, 1977), whereby recognition of the prime leads to the partial activation of other related words in the semantic network via spreading activation. Conscious processes involving pre-lexical expectancies or post-lexical semantic matching strategies can also induce semantic priming effects under some conditions (Neely, 1991).

To date, there have been several studies documenting the neuromodulatory role of dopamine on semantic processing. Kischka et al. (1996) gave healthy adults either levodopa or a placebo and measured both direct and indirect semantic priming effects. Direct semantic priming was measured via word pairs with a direct semantic relationship (e.g., black-white), whereas indirect priming was measured via word pairs that were only related via an intermediate word (e.g., 'summer-snow' is related via the mediating word 'winter'). Kischka et al. observed significant priming effects for directly related word pairs at a short (250 ms) and long (700 ms) stimulus onset asynchrony (SOA) for both the levodopa and placebo groups. In contrast, indirect semantic priming was evident only for the placebo group at the longer SOA. The researchers suggested that dopamine reduced spreading activation within the semantic network, thereby eliminating the indirect but not the direct priming effects.

Subsequent evidence has provided further support for the notion that dopamine is capable of dampening weaker signals in the semantic network. In a divided visual field study, Roesch-Ely et al. (2006) observed a trend towards reduced indirect semantic priming for targets presented to the right visual field (left hemisphere) for participants on pergolide (a D1/D2 agonist) relative to a placebo. Other studies of semantic priming in healthy adults have shown that levodopa reduces priming for subordinate meanings of ambiguous words (Copland, Chenery, Murdoch, Arnott, & Silburn, 2003; Copland, McMahon, Silburn, & de Zubicaray, 2009). Taken together, these findings are generally consistent with a neuromodulatory influence of dopamine on semantic processing that focuses spreading activation and dampens the activation of weak or indirect associations. Such focusing of activation could be consistent with dopamine's proposed impact on the neural signal to noise ratio (SNR) during information processing, whereby dopamine has the capacity to enhance salient signals and dampen weaker signals within neural networks (Cepeda & Levine, 1998; Servan-Schreiber, Printz, & Cohen, 1990).

Changes to semantic priming have also been observed in populations with dopaminergic dysregulation. Parkinson's disease, a condition associated with striatal dopamine depletion, has been associated with various changes to semantic processing including the prolonged activation of subordinate meanings for ambiguous words (Copland, 2003; Copland, Chenery, & Murdoch, 2001; Copland, Sefe, Ashley, Hudson, & Chenery, 2009). Similarly, schizophrenia, another condition associated with dopaminergic pathology, is also associated with changes to semantic processing. Specifically, schizophrenia patients with formal thought disorder have been shown to exhibit hyper-priming relative to healthy controls (Henik, Nissimov, Priel, & Umansky, 1995) and increased priming for indirect associations (Spitzer, Braun, Hermle, & Maier, 1993). It has been proposed that decreased dopaminergic function in patients with formal thought disorder may lead to less focused activation within semantic networks (Spitzer et al., 1993). In contrast, those without formal thought disorder have demonstrated patterns of semantic priming similar to healthy controls (Ruiz, Soler, Dasí, Fuentes, & Tomás, 2018; Spitzer et al., 1993).

In summary, research has shown that white noise can influence cognitive performance, and that these effects are potentially mediated by attentional capacity and dopaminergic mechanisms. Given that dopamine has been shown to focus semantic activation and reduce priming for weak or indirect associations, white noise may therefore be expected to have a similar impact on semantic priming. The present study used an auditory semantic priming task to investigate the effects of white noise on direct and indirect semantic priming in healthy adults. Some previous studies have shown that dopamine impacts semantic priming at short SOAs (Copland et al., 2003; Copland, McMahon, et al., 2009), whereas others have demonstrated changes at longer SOAs (Kischka et al., 1996; Roesch-Ely et al., 2006). Accordingly, both a short (250 ms) and a long (750 ms) inter-stimulus interval (ISI) were used in the present study in order to best capture the potential effects of white noise on priming.

It was hypothesized that white noise would focus activation within the semantic network, leading to a reduction of indirect semantic priming. The influence of attentional capacity was also examined, given previous findings that the effects of noise on various cognitive tasks may be modulated by attention.