Neurocase (2006) **12**, 228–231

ISSN: 1355-4795 print / 1465–3656 online
DOI: 10.1080/13554790600878887

Psychology Press
Taylor & Francis Group

The Effect of Auditory Stressors on Cognitive Flexibility

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Stress is known to activate the noradrenergic system which may have a modulatory influence on cognitive flexibility. We investigated whether an auditory stressor would thus affect performance on cognitive flexibility. A task utilizing cognitive flexibility and two memory tasks were presented in both stressful and non-stressful condition. In the stressful condition performance was impaired for the cognitive flexibility task but not for the memory tasks, arguing against the stressor serving as a general distracter. These findings suggest that stress caused by an auditory stressor may negatively impact performance on more complex tasks requiring a rapid search of the semantic and lexical associative networks.

Introduction

The physiological stress response is marked by increases in norepinephrine (NE) and cortisol (CORT) activities (Lovallo & Thomas, 2000). Stressful stimuli activate the noradrenergic system (Ward *et al*., 1983). Despite the large amount of stress research focusing on the catecholamines epinephrine and norepinephrine, as well as research directed at the effects of corticosteroids, it is not yet fully apparent how these neurochemical events affect cognition (Skosnik *et al*., 2000). The majority of efforts to date have focused on how stress affects memory and attentional processes. The effects of stress on more complex aspects of cognition, such as cognitive flexibility and creativity, need to be further refined.

As a form of fluid intelligence (Cattell, 1963), cognitive flexibility, for the purposes of this research, encompasses the ability to inhibit strong response preferences in order to explore alternative solutions in problem-solving through searching the 'possible solutions network', and are typically solved in an all-or-none insight manner (Beversdorf *et al*., 1999; Beversdorf *et al*., 2002). Research indicates that stress impairs cognitive flexibility (Martindale and Greenough, 1973). Although the underlying mechanism has not been determined, our previous research suggests that the NE system may modulate cognitive flexibility in semantic networks (Beversdorf *et al*., 1999).

The measure of flexibility of semantic and lexical associative networks utilized in this study is the compound remote associates (CRA) task (Bowden and Beeman, 1998, 2003). In this task three words are presented and a fourth word must be generated which is related to the first three. For example, the participant is presented with the words "cream", "skate", and "water" simultaneously. They must generate a word that could form a compound word with all three of these targets. In this example, the word "ice" would be the correct word, forming "ice cream", "ice skate", and "ice water". This task demands cognitive flexibility, as in order to know that "ice skate" is a word, a search of the lexical associative network is necessary to obtain the correct response. In addition, accessing semantic associative networks may be advantageous in this task where the associated words are also related by meaning (e.g., ice and skate, ice and water). This is explained by the network model of lexicon organization where different concepts, or semantic features of words, are represented as nodes. Nodes closely associated with each other are interconnected in the network. If a presented word activates one particular node, this activation spreads through the semantic associative network, lowering the threshold of neighboring nodes (Collins and Loftus, 1975).

One stressor commonly encountered in real world settings that can be readily reproduced in the laboratory is the effect of loud noise. In industrial settings higher noise levels have been shown to reduce quality of work (e.g., Broadbent and Little, 1960). Noise has also been shown to impact cognitive processes such as attention and memory (Matthews *et al*., 2000). Task strategy is also affected, with noise increasing speed but reducing accuracy thus leading to more errors, an effect sometimes attributed to an increase in arousal level. Noise also may cause stress-related effects as a result of emotional irritation and annoyance that induce physiological responses (Langdon, 1985). Evidence suggests that 90dB of white noise is of sufficient intensity to affect cognitive task performance (e.g., Broadbent, 1971; Oishi *et al*., 1999). Some research has shown that noise actually benefits cognitive processes, not only improving speed of performance (Hockey and Hamilton, 1970; Davies and Jones, 1975;

Received 22 August 2005; accepted 19 June 2006.

This research was supported by grants from the National Institute of Neurological Disorders and Stroke (NINDS, K23 NS043222) and the National Institute of Drug Abuse (NIDA, R21 DA015734) to D.Q. Beversdorf.

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Poulton, 1979), but also selective attention (Chajut and Algom, 2003).

The aim of this study was to examine the impact of an auditory stressor on cognitive flexibility. We hypothesized that because the auditory stress would impair the participants' ability to conduct a rapid, broad search of the semantic and lexical associative networks, performance on the cognitive flexibility task would be negatively impacted whereas the memory tasks would not.

Method

Participants

Thirty-two (16 males and 16 females) normal, healthy adults with a mean age of 25.08 ± 8.34 years participated in this study. Participants were excluded if there was a history of dyslexia, learning difficulty, or if English was not their primary language. Participants were recruited via advertisements posted around the University campus. All aspects of the study were performed in accordance with the Institutional Review Board of The Ohio State University.

Procedure

Participants completed three different cognitive tests in two randomized counterbalanced conditions, a stress condition and a no-stress condition. The two visits took place 1–2 weeks apart. During the stress condition an auditory stressor of 90dB of continuous white noise was administered via headphones. The participants were exposed to the stressor for the duration of each of the three tests with relief in between tests for instructions. In the no-stress condition headphones were worn by participants without input of noise.

At each session, participants were given one of two versions of the compound remote associates task (CRA; Bowden and Beeman, 1998, 2003) in order to assess cognitive flexibility. As described previously, the CRA task involved the generation of a word associated with three presented words. The solution word is related to the triad of words by formation of a compound word (e.g., cream, skate, water = ice). The participant was allowed seven seconds per triad for 30 triads, and solution latency and number of problems solved were recorded.

At each session participants were also given one of two versions of the Hopkins Verbal Learning Test (HVLT; Brandt, 1991) and the Rey-Osterrieth Complex Figure Test (CFT; Rey, 1941; Osterrieth, 1944) in order to assess verbal and visuo-spatial memory as comparisons to the cognitive flexibility task. Due to the nature of our stressor, the HVLT words were presented visually in our experiment (three free-recall trials of a 12-item list of semantically categorized words followed by a recognition test; scores from the first recall trial were subsequently scored for analysis). The CFT was scored for accuracy of copying and 30 minute recall of the complex figure (Rey, 1941; Osterrieth, 1944; Spreen and Strauss, 1998).

Results

A within group t-test for the CRA task showed that the white noise stressor significantly decreased the participants' number of correct responses compared to their performance in the no-stress condition. Additionally, the stressor showed increased solution latency compared to the control condition.

For verbal memory (HVLT), within group t-test results of the first recall trial revealed no significant difference in performance between the conditions. Therefore, white noise did not hinder the participants' memory for visually presented sequential word lists. Similarly, within group t-test results for the visuo-spatial memory test, CFT, revealed no significant change in performance in the reproduction of complex figures between conditions. All participants performed at ceiling on copying the figure in both conditions. Therefore, the auditory stressor did not compromise visuo-spatial processing or memory. Mean scores for solution latency and accuracy for the cognitive tasks in the stress and no-stress conditions are shown in Table 1.

Therefore, as expected, there was a significant effect of noise on the CRA task, a measure of cognitive flexibility. Participants demonstrated increased solution latency and more solution errors in the stress condition than the no-stress

Table 1. Mean solution latencies and accuracy scores for the cognitive measures

Measures	Stress condition (SD)	No-Stress condition (SD)	t	Significance
CRA				
Correct (max = 30)	5.50 (3.52)	12.26 (6.06)	7.01	p = .000
Time (s)	263.38 (30.95)	231.39 (48.81)	3.01	p = .005
HVLT				
Recall (max = 12)	7.66 (1.45)	7.29 (1.67)	1.20	p = .238
CFT				
Copy (max = 36)	34.69 (1.49)	34.71 (1.35)	.10	p = .919
Recall (max = 36)	28.92 (5.79)	29.22 (6.43)	.51	p = .612

Note. SD = Standard Deviations.

condition. There was no significant effect for the comparison memory tasks, HVLT and CFT.

Discussion

White noise significantly increased response times and decreased the number of correct responses for the compound remote associates (CRA) task. Whereas auditory stimulation has a significant effect on cognitive flexibility, this is not the case for other types of tasks such as those involving memory processes. The lack of an effect on memory also suggests that the findings due to auditory stress are not reflective of a generalized distracter effect.

Increased solution latency for the CRA task in the stress condition supports our prediction that white noise would impede cognitive flexibility. Noradrenergic activation caused by noise-induced arousal perhaps mediates this process wherein high arousal stimulates an increase of norepinephrine (NE) activity that has the effect of limiting access to the network of possible solutions (Beversdorf *et al*., 1999, 2002). Future studies could help to support the role of the noradrenergic system by measuring NE levels in blood or elsewhere in the body during such stressors, as compared to other potential factors such as cortisol levels.

In addition, according to the inverted U curve hypothesis (Yerkes and Dodson, 1908), when not already excessively aroused, arousal is believed to narrow a broad attention span to focus on an immediate task. However, performance on the CRA would be negatively impacted as it requires a broad search of the semantic and lexical associative networks for which this increased focus due to increased arousal may be deleterious. In contrast, performance on the memory tasks could be improved by moderate arousal assuming the participants' arousal levels were in the mild to optimal range within the inverted U during these tasks.

Previous research indicates that for short-term memory tests of a nonsequential nature (such as the CFT), continuous irrelevant sound such as white noise presents only a modest challenge to memory testing (LeCompte, 1994), and may not cause interference with performance (Jones *et al*., 1990). Another type of noise stressor could have a significant impact on these tasks. For instance, noise in the form of irrelevant speech has shown robust deleterious effects on serial memory (Colle and Welsh, 1976), although this could be due to distraction caused by the relevance of the words heard rather than the noise of the speech itself. Also, noise administered on a wide range of frequencies (i.e., broadband noise), which is also fluctuating and irrelevant, markedly impaired short-term memory for visual-verbal and visuo-spatial items (Tremblay *et al*., 2001).

One possible confound in this study could be that the cognitive flexibility test was a timed test. Future work will be necessary to disentangle the interaction between stress and performance on timed versus untimed cognitive flexibility tests. Also, the possibility that the CRA task necessitated more effort than the memory tasks rather than more demand on cognitive flexibility cannot be excluded. The CRA task may have required increased resources to suppress the effects of the white noise and subsequently had a greater negative impact on performance. Further investigation will be necessary to exclude this possibility.

Although our results indicate that the noise stressor caused an impairment in the cognitive flexibility task (CRA), we expect a more powerful stressor could exert more consistent influence on performance for the memory tasks, and other types of tasks, due to a greater shift on the inverted U curve. Furthermore, the continuity of the noise throughout the tasks may have contributed to participant acclimation. Future studies could examine this with an aperiodic and unpredictable noise stressor. Also, perhaps a more comprehensive simulation of field setting stress conditions with more psychological stressors, such as social stressors, may have a greater impact on memory and other cognitive processes. Reich and Zautra (2002) suggest that under high-stress, emotionally intensive conditions cognition is inhibited, producing oversimplified processing. According to the dynamic model of affect, only when arousal creates strong affect in response to the stimulus does impairment of cognition occur (Reich and Zautra, 2002). When personal stressors arise that necessitate action, cognitive flexibility, the function that normally enables appropriate planning, may break down as we observed in the CRA task.

Future research may also benefit from the consideration of a perceived stress scale, possibly in combination with an affect measure, to determine the psychological impact of noise stress on cognitive flexibility performance. This may also provide information about noise susceptibility, which may influence the degree of psychological and physiological response to the auditory stressor. Pharmacological modulation studies of the NE system and other neural stress pathways (including cortisol) for tests of cognitive flexibility performance will help to expose the underlying biological substrates and mechanisms responsible for the present findings, and may lead to interventions for improving performance on such tasks.

References

Beversdorf DQ, Hughes JD, Steinberg BA, Lewis LD, Heilman KM. Noradrenergic modulation of cognitive flexibility in problem solving. NeuroReport 1999; 10: 2763–2767.

Beversdorf DQ, White DM, Chever DC, Hughes JD, Bornstein RA. Central β-adrenergic modulation of cognitive flexibility. NeuroReport 2002; 13: 2505–2507.

Bowden EM, Beeman MJ. Getting the right idea: Semantic activation in the right hemisphere may help solve insight problems. Psychological Science 1998; 9: 435–440.

Bowden EM, Beeman M. Aha! Insight experience correlates with solution activation in the right hemisphere. Psychonomic Bulletin & Review 2003; 10: 730–737.

Brandt J. The Hopkins Verbal Learning Test: Development of a new memory test with six equivalent forms. Clinical Neuropsychologist 1991; 5: 125–142.

Broadbent DE. Decision and stress. London: Academic Press, 1971.

Broadbent DE, Little EAJ. Effects of noise reduction in a work situation. Occupational Psychology 1960; 34: 133–140.
Cattell RB. Theory of fluid and crystallized intelligence: A critical experiment. Journal of Educational Psychology 1963; 54: 1–22.
Chajut E, Algom D. Selective attention improves under stress: Implications for theories of social cognition. Journal of Personality and Social Psychology 2003; 85: 231–248.
Colle HA, Welsh A. Acoustic masking in primary memory. Journal of Verbal Learning and Verbal Behavior 1976; 15: 17–31.
Collins AM, Loftus EF. A spreading activation theory of semantic processing. Psychological Review 1975; 82: 407–428.
Davies DR, Jones .M. The effects of noise and incentives upon attention in short-term memory. British Journal of Psychology 1975; 66: 61–68.
Hockey GRJ, Hamilton P. Arousal and information selection in short-term memory. Nature 1970; 226: 866–867.
Jones DM, Miles C, Page J. Disruption of reading by irrelevant speech: Effects of attention, arousal, or memory? Applied Cognitive Psychology 1990; 4: 89–108.
Langdon FJ. Noise annoyance. In: Tempest W, editor. The noise handbook. London, England: Academic Press, 1985; 143–176.
LeCompte DC. Extending the irrelevant speech effect beyond serial recall. Journal of Experimental Psychology: Learning, Memory and Cognition 1994; 20: 1396–1408.
Lovallo WR, Thomas TL. Stress hormones in psychophysiological research: Emotional, behavioral, and cognitive implications. In: Cacioppo JT, Tassinary LG, Berntson GG, editors. Handbook of psychophysiology (2nd ed). Cambridge, England: Cambridge University Press, 2000; 342–367.
Martindale C, Greenough J. The differential effect of increased arousal on creative and intellectual performance. Journal of Genetic Psychology 1973; 123: 329–335.
Matthews G, Davies DR, Westerman SJ, Stammers RB. Human performance: Cognition, stress and individual differences. E. Sussex, England: Psychology Press, 2000.
Oishi K, Kamimura M, Nigorikawa T, Nakamiya T, Williams RE, Horvath SM. Individual differences in physiological responses and type A behavior patterns. Journal of Physiological Anthropology and Applied Human Science 1999; 18: 101–108.
Osterrieth PA. Le test de copie d'une figure complexe: Contribution a l'tude de la perception et de la memoire [Copying a complex figure: Contributions to the study of perception and memory]. Archives de Psychologie 1944; 30: 203–353.
Poulton EC. Composite model for human performance in continuous noise. Psychological Review 1979; 86: 361–375.
Reich JW, Zautra AJ. Arousal and the relationship between positive and negative affect: An analysis of the data of Ito, Cacioppo, and Lang. Motivation & Emotion 2002; 26: 209–222.
Rey A. L'examen psychologique dans les cas d'encephalopathie traumatique [The psychological examination of cases of traumatic encephalopathy]. Archives de Psychologie 1941; 28: 286–340.
Skosnik PD, Chatterton RJ, Swisher T, Park S. Modulation of attentional inhibition by norepinephrine and cortisol after psychological stress. International Journal of Psychophysiology 2000; 36: 59–68.
Spreen O, Strauss E. A compendium of neuropsychological tests (2nd ed). New York, NY: Oxford University Press, 1998; 349–353.
Tremblay S, MacKen WJ, Jones DM. The impact of broadband noise on serial memory. Changes in band-pass frequency increase disruption. Memory 2001; 9: 323–331.
Ward MM, Mefford IN, Parker SD, Chesney MA, Taylor CB, Keegan DL, Barchas JD. Psychosomatic medicine 1983; 45: 471–486.
Yerkes RM, Dodson JD. The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology 1908; 18: 459–482.