Psychological Reports, 2005, 97, 867-874. © Psychological Reports 2005

SIMULTANEOUS MULTIPLE STRESSORS IN THE ENVIRONMENT: PHYSIOLOGICAL STRESS REACTIONS, PERFORMANCE, AND STRESS EVALUATION[1]

CLARA MARTIMPORTUGUÉS-GOYENECHEA AND LUIS GÓMEZ-JACINTO

Málaga University

Summary.—Interactive effects of two environmental stressors when simultaneously present, i.e., noise and crowding, were analyzed. Four experimental conditions with two intensities of stress for each stressor (high versus low) were created. The stressors were concurrently introduced in laboratory conditions and their effects analyzed using several methodological approaches. More intense and negative effects were expected when the two highest intensities of noise and crowding concurred. 40 people (20 men and 20 women) participated in a study with a 2 × 2 factorial design. Analysis showed an increase in the measures of hemodynamic, endocrine, and neuroendocrine values of participants after being exposed simultaneously to noise and crowding. Similarly, their performance on complex tasks decreased, and they reported a subjective increase in stress. Capacity to cope was indicated by a statistically significant lower mean on the Dimension of Stress scale, tolerance of frustration during the multiple stress condition.

The classic review of Evans and Cohen (1987) on environmental stress highlighted the importance of analyzing not only the additive effects of multiple intensities of stressors, but their multiplicative effects as well. However, since then there has been little research on how different environmental stressors interact. According to Lepore and Evans (1996), this is because most studies have approached this issue as stressful life events, for which only additive effects are analyzed. However, people cope with multiple environmental stressors which interact with each other, creating effects which differ from the simple addition of their individual effects. As Lepore and Evans (1996) pointed out, "social, psychological, and biological effects of coping with one stressor may influence a person's ability to cope with concurrent or subsequent stressors" (p. 355). These authors also differentiated between the additive and the multiplicative effects of multiple stressors, suggesting five combinations of environmental stressor effects.

Consider the simple case of two stressors, A and B, which gives two main effects (A and B), an additive effect (A+B), and two multiplicative effects (A × B) which can be attenuated or potentiated. Bearing in mind these considerations, study is needed of the interactive effect of multiple stressors

[1]Send enquiries to Clara Martimportugués-Goyenechea, Departamento de Psicología Social, Facultad de Psicología, Campus de Teatinos, Universidad de Málaga, 29071-Málaga, Spain or e-mail (cmartimportu@uma.es).

on behavior and health to avoid bias of estimations based only on simple or aggregate effects of stressors.

Thus, Maxwell (1996) has shown that chronic exposure to a crowded environment in the home and in child care centers has negative effects on children. The combination of these two densely crowded environments increases behavioral disturbance more than exposure to a single crowded setting. Therefore, it appears there is little adaptation to crowding. Maxwell (1996) stated that such results are "consistent with the Cohen, Evans, Stokols, and Krantz (1986) contextual perspective on stress, suggesting that behavioral response to a stressor in one setting can be moderated by stressful conditions in another setting" (p. 506).

Similarly, Evans, Allen, Tafalla, and O'Meara (1996) reported greater negative effects and posteffects in both stressors when they used noise and a social stressor as sequential sources of environmental stress. In both studies authors noted the adaptive cost of stress (Cohen, *et al.*, 1986): coping with the continual demands of multiple environmental stressors is associated with tiredness and decreases personal and social resources. This translates into less capacity to cope with further environmental stress and greater negative consequences to health.

Also consider that (1) ecological covariation between natural multiple stressors is the norm; (2) people are continuously exposed to multiple environmental stressors; and (3) isolation of specific stressors can understimate their effects within their ecological context (Evans, *et al.*, 1996). Then it is clear the study of stress in context should take into account the effect the demands of environmental covariations make on people and their coping capacity.

This study follows the theoretical and methodological approach of Evans, *et al.* by examining the interactive effects of two simultaneous environmental stressors, noise and crowding. We created four experimental conditions with two intensities of stressor (high vs low) presented concurrently in a laboratory to provide multimethodological evaluation of their effects. Effects were predicted to have greater intensity and be more negative if high noise and high crowding were simultaneous.

Method

Participants

The participants were 40 university students in their first year of psychology, 20 men and 20 women ages 18 to 25 years. Participation was rewarded with credit points for their introductory psychology course.

Procedure

Four random groups with a 2×2 factorial design were created (*ns* of 5 men and 5 women). Crowding was defined as social density in the experimental room: high density (8 people) and low density (2 people). Noise was operationalized by using a continuous recording at 95 dBA with a wide spectrum of frequencies, that included different types of environmental noise recorded in Madrid (Carles & López Barrios, 1995).

Before starting the experiment, the participants were told that a blood specimen would be taken and analyzed by qualified personnel from the University Hospital of Málaga (Hospital Clinico de Málaga) to establish hormone level. Once the heart-rate baseline was established, the experiment began. Foregoing breakfast, participants worked from 8 a.m. to 11 a.m.

In the waiting room participants were told about the duration of the test and given brief information regarding general procedures. In the laboratory, heart-rate baseline was measured; then attention tests were given over 30 min. During this time, the heart rate was monitored. Once the task was concluded the clinical staff took a blood sample from each. In another room they completed a 15-min. coping-with-frustration test and completed a questionnaire to assess subjective appraisal of stress. To conclude they were offered a sweet and a glass of juice.

Dependent Measures

Before measuring baseline heart rate, participants rested for 20 min. In the experimental stage, the heart rate was monitored using a Polar Sport Tester 400 during the execution of the task.

Levels in the plasma of neuroendocrine, adrenaline, and noradrenaline were measured. High Performance Liquid Chromatographic assay was used. In a normal healthy person the index has an interval of 30–100 pg/ml for adrenaline and 60–400 pg/ml for noradrenaline.

Three endocrine hormones were analyzed: adrenocorticotrophic hormone (ACTH), cortisol, and beta-endorphin. The Immulite 2000 Analyzer was used for the quantitative measurement of cortisol and ACTH in EDTA plasma. The values of cortisol in a normal healthy person are usually between 5 and 25 ml/gm. The quantitative determination of human beta-endorphin levels in EDTA plasma was carried out by a two-site immunoradiometric assay. The normal values are below 29.

Cognitive performance was assessed via a concurrent dual-task paradigm combining a focused attention task with another task involving simultaneous focused attention and category search (Smith, 1990, 1992).

In this task a group of five letters were presented on the center of the screen of the computer. The target letters, A and B, appeared with other letters or several distractor symbols: $, &, #. In addition, these letters were presented on a background of changing colors. The participant had to respond by typing the letter B when the letter B appeared fourth in the group of letters and typing A when the letter A appeared second. At the same time numbers from 1 to 9, chosen at random, were shown on the screen. The participant had to press the space bar when an odd number appeared. The duration of the test was 30 min. Reaction times were recorded in milliseconds.

After-effect measurements were taken after exposure to the stressor using a conceptual replica of Glass and Singer's unsolvable puzzles (1972). Participants were given two types of puzzles, very difficult manipulation tasks and unsolvable written ones to be done in 10 min., but participants were told they could give up at any time and start a new one during the 10 min. they had been assigned, or they could just give up before time was finished. Once a puzzle was abandoned, the participants could not go back to it. After-effects were evaluated based on the total number of attempts participants made with both types of puzzle. More attempts were interpreted as less tiredness after exposure to stressors (Glass & Singer, 1972).

To assess subjective stress, an adaptation of the Dimension of Stress Scale (Vitaliano, Russo, Weber, & Celum, 1993) of 20 items about the conditions of the task, unfamiliarity, control of the situation and the task was given.

Results

The analytic strategy is similar to the one proposed by Evans, *et al.* (1996). Comparisons were made between the mean of the Crowding-Noise condition (multiple stress) and the means of the other conditions. When this comparison was significant, means of the other three experimental conditions (Crowding-No Noise; No Crowding-Noise; No Crowding-No Noise) were compared. If the differences were significant in the first comparison but not in the second one, this meant that our hypothesis was supported. Such a procedure is useful when there is an *a priori* hypothesis and when the interaction tests have reduced statistical power (Kirk, 1982; Cohen, 1988). Contrary to Evans, *et al.*'s analyses, comparisons were carried out with nonparametric tests, since the sample was small and not all parametric assumptions could be ensured. The first comparison was made using a Mann-Whitney U test and the second with the Kruskal-Wallis H test, which uses a χ^2 index.

Table 1 shows the means and standard deviations for the nine dependent variables. According to the hypothesis, there should be a higher concentration of neuroendocrine and endocrine hormones in the multiple stress condition than in the other three conditions; heart rate and reaction time should also be greater in the first condition than in others. There should be fewer attempts to solve the puzzles in the multiple stressor condition, and participants should report higher mean subjective stress.

This procedure for neuroendocrine measurements showed the difference between the mean of adrenaline in the multiple stressor condition ($M=60$,

TABLE 1
NOISE × CROWDING: MEANS AND STANDARD DEVIATIONS OF MEASURES

Measure		Noise			
		High Crowding		Low Crowding	
		High	Low	High	Low
Adrenaline	*M*	59.99	61.82	50.26	64.53
	SD	17.24	16.85	19.83	22.22
Noradrenaline	*M*	227.63	156.79	129.04	154.68
	SD	63.57	63.48	40.06	75.88
Cortisol	*M*	18.60	16.64	16.75	16.00
	SD	3.04	4.14	4.23	5.38
Adrenocorticotrophic hormone	*M*	15.25	11.75	13.40	10.06
	SD	7.65	4.44	8.60	2.37
Beta-endorphin	*M*	26.21	22.46	21.37	19.10
	SD	9.06	7.06	6.83	6.63
Heart rate	*M*	8.87	4.03	7.70	2.33
	SD	10.48	14.92	7.65	6.71
Reaction time	*M*	2080.10	1611.47	1454.11	1542.90
	SD	1813.40	647.75	238.55	312.84
Unsolvable puzzles	*M*	15.80	23.10	16.30	21.70
	SD	10.16	11.96	12.73	11.33
Subjective stress	*M*	107.79	103.38	92.52	96.31
	SD	14.63	17.56	12.05	16.59

$SD = 17.2$) and the other conditions ($M = 58.9$, $SD = 20.1$) was not statistically significant ($U = 136$, $p = .33$), although the direction of the difference was consistent with the hypothesis. Differences were found for noradrenaline ($U = 50$, $p = .001$). A higher concentration of noradrenaline was found in the multiple stressor condition ($M = 227.6$, $SD = 63.6$), while the mean for the other three conditions was significantly lower ($M = 146.8$, $SD = 60.8$) as hypothesised. The Kruskal-Wallis test showed no significant differences among the three experimental conditions without multiple stressors [$\chi_2^2(N = 30) = .96$, $p = .61$].

The following results refer to endocrine measures: cortisol, adrenocorticotrophic hormone, and beta-endorphin. The difference between with and without multiple stressors for mean cortisol is small ($M = 18.60$, $SD = 3$; and $M = 16.46$, $SD = 4.5$, respectively; $U = 106$, $p = .08$). Nevertheless, the direction is always consistent: the maximum level of this hormone is produced in the multiple stressor condition. The differences among the three experimental conditions without multiple stressors are not statistically significant [$\chi_2^2(N = 30) = .42$, $p = .80$]. The differences between the other two hormones were larger. For adrenocorticotrophic hormone, the mean differences with and without multiple stressors ($M = 15.25$, $SD = 7.6$; $M = 11.73$, $SD = 5.7$, respectively) were significant ($U = 102$, $p = .05$), but not for the three conditions with no multiple stressors [$\chi_2^2(N = 30) = .93$, $p = .62$]. For beta-endorphin the results were similar ($U=99$, $p=.06$), with a mean for the multiple stressor condition ($M=26.2$, $SD=9.1$) which is higher than the mean of the other conditions without multiple stressors ($M=21.0$, $SD=6.8$). No significant differences were found among the other three conditions, as indicated by the Kruskal-Wallis test [$\chi_2^2(N=30)=1.64$, $p=.44$].

The means for heart rates shown in the table are differential scores obtained after subtracting the baseline heart rate from the value obtained during the experiment (Llabre, Spitzer, Saab, Ironson, & Schneiderman, 1991; Karmack, Jennings, Debski, Glickman-Weiss, Johnson, Eddy, & Manuck, 1993). The same pattern occurs and further supports our hypothesis that the heart rates of people exposed to simultaneous environmental stressors are higher ($M=8.9$, $SD=10.5$) than for those exposed to any of the other three conditions [$M=4.7$, $SD=10.31$; $U=98$, $p=.05$; $\chi_2^2(N=30)=2.09$, $p=.35$].

With respect to performance of the concurrent dual task, reaction times during this complex task were greater in the multiple stress condition ($M=2080.1$, $SD=1813.4$) than for the other three conditions ($M=1535.9$, $SD=430.77$), although the mean difference was not significant ($U=113$, $p=.13$). The differences were also not significant among the three conditions with no multiple stressors [$\chi_2^2(N=30)=.94$, $p=.62$]. Although weaker, the direction of results is consistent with our hypothesis.

After-effects were analyzed using the unsolvable puzzles. Once again, participants made fewer attempts to solve the task after experiencing the multiple stress condition ($M=15.8$, $SD=10.2$) than after experiencing any of the other three conditions ($M=20.3$, $SD=12$), although this comparison was not statistically significant [$U=110$, $p=.11$; $\chi_2^2(N=30)=3.18$, $p=.20$].

Table 4 also shows the means and standard deviations for participants' subjective evaluation of environmental stress. As expected, those exposed simultaneously to high noise and crowding reported more stress ($M=107.8$, $SD=14.6$) than those exposed to the other three conditions [$M=97.4$, $SD=15.7$; $U=95$, $p=.04$; $\chi_2^2(N=30)=2.83$, $p=.24$].

Discussion

Results for these hormones suggest that the sympathetic and adrenal systems are triggered in the presence of two simultaneous stressors of noise and crowding. The levels of noradrenaline suggest the active involvement of the sympathetic nervous system which is in charge of activating the organism for immediate action and in which this hormone is a neurotransmitter. This is why it appears in the plasma faster. It seems that the activation of the adrenal endocrine system in situations of stress which are not life threatening is slower so a longer exposure time to both stressors would have been required to record significant means for adrenaline. The levels of beta-endorphin were significant when the subjects were exposed to both stressors. Ising (1983) reported that urine catecholamines showed a pattern similar to noradrenergic activation in his work of exposure to traffic noise.

The release by the body of opium-like substances, beta-endorphin for example, depends on the perception of distress or pain as well as on the person's mood. This hormone depends on the severity of the stressor, its duration, and the actual stimulus as well as on the metabolic demand (Schwartz & Kinderman, 1992). Analysis suggested intensity of both stressors rather than their duration had the greatest effect on stimulating this hormone. An increase in exposure might have yielded a larger discrepancy in those conditions of intense stress.

Cortisol presented its highest values when both stressors were simultaneously present, and it is likely that, had the exposure been longer, comparisons for cortisol would have been statistically significant. One of the main characteristics of this hormone is it begins to rise slowly and does not go above basal levels until some time has passed. Thus, the effects of simultaneous environmental stressors suggest a particular physiological pattern, the most important being an increase in endocrine activity and also a more moderate increase in neuroendocrine activity. These data are supported by the increase in heart rate.

We also observed that the difficulty of the dual task required longer reaction times from participants, since it required the higher integration of several sources of focused attention and categorical search (Easterbrook, 1959; Smith, 1990).

Analysis of after-effects of adaptation showed no statistically significant differences. However, the direction was consistent with the hypothesis. Subjects reported less coping with frustration for the multiple stressor condition. Crowding surpassed noise in psychological effects on accumulated tiredness. The physiological rates follow a pattern of stimulation that matched the psychological report of "worn-out" as indicated by the number of tries in each experimental condition.

The last variable analyzed, the subjective assessment of environmental stress, was higher when both stressors were present simultaneously. This, once again, supports the hypothesis that the simultaneity of the two environmental stressors exerts a potentiating effect. These results are consistent with those obtained by Evans, *et al.* (1996), which served as a reference for this experiment. Two or more stressors presented in sequence or simultaneously index greater effects for subjects than those expected from their simple addition.

Rather than analysing independent effects of each stressor, focus should be on interactions between stressors to check how they really work in everyday life, given that people have to cope on a daily basis with noise, pollution, crowding, heat, and many other environmental stressors typical of urban surroundings.

REFERENCES

CARLES, J. L., & LÓPEZ BARRIOS, I. (1995) "Latidos": escenas sonoras de Madrid. In R. Elias Mamou, M. Rüsenberg, H. U. Werner, F. Lopez, J. L. Carles, & I. López-Barrios. Abrúndo la cuidad del sol habitado: Madrid como Materia Sonora. Zwerg Productions, CD ZP 9501.

COHEN, J. (1988) *Statistical power analysis for the behavioral sciences.* (2nd ed.) Hillsdale, NJ: Erlbaum.

COHEN, S., EVANS, G. W., STOKOLS, D., & KRANTZ, D. S. (1986) *Behavior, health, and environmental stress.* New York: Plenum.

EASTERBROOK, J. A. (1959) The effect of emotion on cue utilization and the organization of behavior. *Psychological Review*, 66, 183-201.

EVANS, G. W., ALLEN, K. M., TAFALLA, R., & O'MEARA, T. (1996) Multiple stressors: performance, psychophysiological and affective responses. *Journal of Environmental Psychology*, 16, 147-154.

EVANS, G. W., & COHEN, S. (1987) Environmental stress. In D. Stokols & I. Altman (Eds.), *Handbook of environmental psychology*. Vol. 1. New York: Wiley. Pp. 571-610.

GLASS, D. C., & SINGER, J. E. (1972) *Urban stress: experiments on noise and social stressors.* New York: Academic Press.

ISING, H. (1983) *StreBreaktionen und Gesundheitsrisiko bei Verkehrslärmbelastung.* Berlín: Dietrich Reimer. (Wa Bo Lu Berchte)

KARMACK, T., JENNINGS, J., DEBSKI, T., GLICKMAN-WEISS, E., JOHNSON, P., EDDY, M., & MANUCK, S. (1993) Reliable measures of behaviorally evoked cardiovascular reactivity from a PC-based test battery: results from student and community samples. *Psychophysiology*, 29, 17-28.

KIRK, R. (1982) *Experimental design.* (2nd ed.) Belmont, CA: Brooks/Cole.

LEPORE, S. J., & EVANS, G. W. (1996) Coping with multiple stressors in the environment. In M. Zeidner & N. S. Endler (Eds.), *Handbook of coping: theory, research, applications.* New York: Wiley. Pp. 350-377.

LLABRE, M., SPITZER, S., SAAB, P., IRONSON, G., & SCHNEIDERMAN, N. (1991) The reliability and specificity of delta versus residualized change as measure of cardiovascular reactivity to behavioral challenges. *Psychophysiology*, 28, 701-711.

MAXWELL, L. E. (1996) Multiple effects of home and day care crowding. *Environment and Behavior*, 28, 494-511.

SCHWARTZ, L., & KINDERMAN, W. (1992) Changes in beta endorphin levels in response to aerobic and anaerobic exercise. *Sports Medicine*, 13, 14-27.

SMITH, A. P. (1990) Effects of noise and task parameters on dual cognitive vigilance task. In D. Brogan (Ed.), *Proceedings of the First International Conference on Visual Search.* London: Taylor & Francis. Pp. 129-130.

SMITH, A. P. (1992) Noise and aspect of attention. *British Journal of Psychology*, 82, 313-324.

VITALIANO, P. P., RUSSO, J., WEBER, L., & CELUM, C. (1993) The Dimensions of Stress Scale: psychometric properties. *Journal of Applied Social Psychology*, 23, 1847-1878.

Accepted November 15, 2005.