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The Interactive Effect of Chronic Exposure to Noise and Job Complexity on Changes in Blood Pressure and Job Satisfaction: A Longitudinal Study of Industrial Employees

Samuel Melamed
National Institute of Occupational and Environmental Health

Yitzhak Fried
Wayne State University

Paul Froom
National Institute of Occupational and Environmental Health

The hypothesis of this study was that noise exposure level and job complexity interact to affect changes in blood pressure (BP) levels and job satisfaction over 2–4 years of follow-up. Results showed that among workers exposed to high noise, those with complex jobs showed increases in BP that were more than double shown by those with simple jobs. Under low noise exposure, there was a small increase in BP for workers with complex jobs but about a 3-fold increase in workers with simple jobs. The prevalence of elevated BP showed a similar trend. Job satisfaction increased among workers with complex jobs but was much less in those exposed to high noise. It was concluded that exposure to occupational noise has a greater negative impact on changes in BP and job satisfaction over time among those performing complex jobs. In contrast, job complexity had a clear beneficial effect for workers exposed to low noise.

In recent years, considerable effort has been directed toward investigating the possible effects of chronic exposure to noise on the cardiovascular system, especially on the risk of hypertension. Interest in the effects of chronic exposure to noise has two major sources. First, it is recognized that high ambient noise is one of the most prevalent environmental stressors in the workplace. North American research has shown that the percentage of workers exposed daily to harmful noise of over 85 dB(A) ranges between 30% and 60% across industries (Deguise, 1988; Franks, 1990). In certain industries, the percentage may reach as high as 70%–95%. Second, laboratory studies have fairly consistently shown that acute noise exposure, even at moderate levels of around 80 dB(A), has cardiovascular and autonomic effects that are manifested by increased vascular resistance (Andren, Hansson, Bjorkman, Jonsson, & Borg, 1979; Sawada, 1993), heart rate (Andren et al., 1979; Sawada, 1993), blood pressure (Andren et al., 1979; Harrison & Kelly, 1989; Sawada, 1993), and stress hormones (Miki, Kawamorita, Araga, Musha, & Sudo, 1998).

However, in contrast to the laboratory findings, field studies have found no consistent association between occupational noise exposure and risk for hypertension and other cardiovascular diseases (Babisch, 1998; Kristensen, 1989; A. Smith, 1991). Weak correlations, no correlations, and even negative correlations between noise exposure and these endpoints have been found in over 50% of these studies (Kristensen, 1989).

These inconsistent findings may be explained by three reasons, two methodological and one conceptual. First, the inconsistent results reflect the general difficulty in generalizing from the effects of laboratory stressors on blood pressure to the effects of chronic stressors on long-term elevation of blood pressure (Harshfield et al., 1988; Pickering & Gerin, 1988; Van Engeren & Sparrow, 1989). Factors that cause acute changes in blood pressure may be different from those that contribute to chronic changes (Schwartz, Pickering, & Landsbergis, 1996).

Second, deficiencies in research design have been noted in a high proportion of studies of occupational

Samuel Melamed, Department of Occupational Health Psychology, National Institute of Occupational and Environmental Health (NIOEH), Ra'anana, Israel; Yitzhak Fried, Department of Management, School of Business Administration, Wayne State University; Paul Froom, Department of Epidemiology, NIOEH.

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Correspondence concerning this article should be addressed to Samuel Melamed, Department of Occupational Health Psychology, National Institute of Occupational and Environmental Health, P. O. Box 3, Ra'anana, Israel 43100. Electronic mail may be sent to melameds@ioh.org.il.

noise and its effects (e.g., Babisch, 1998; Kristensen, 1989; Thompson, 1993). Most of the studies were cross-sectional or retrospective in nature, usually with no record of exposure history and of hearing protector use. No control was made in many studies for other negative work and environmental conditions. Furthermore, in many studies, no direct measure of noise was available, and the evidence of hearing loss among the study's participants inferred the existence of such exposure. The more methodologically rigorous studies (e.g., those that controlled for possible confounding variables) have reported lower associations between noise exposure and blood pressure levels (Thompson, 1993).

Third, it is conceivable that the inconsistent associations between noise and blood pressure are due to the effect of moderators. One such moderator is job complexity. Jobs higher in complexity typically require the use of greater cognitive capacity compared with jobs lower in complexity. The information overload model argues that individuals' capacity for information processing is limited (e.g., S. Cohen, 1980). Stressors such as noise increase cognitive load because they require a share of cognitive capacity in addition to that allocated to job requirements. For simple jobs (i.e., jobs of low complexity), the cognitive demands are low, so that the effect of noise on job performance is likely to be relatively small. In contrast, high ambient noise is likely to produce cognitive overload on complex jobs that impose high cognitive demands and thus decrease performance on such jobs (e.g., Baron, 1994; S. Cohen, Gary, Evans, Stokols, & Krantz, 1986; Kryter, 1994). Moreover, increased cognitive overload is likely to lead to adverse psychological (e.g., lower job satisfaction) and physiological (e.g., higher blood pressure) reactions. This association between increased cognitive load and physiological responses has been demonstrated in numerous laboratory studies (e.g., Callister, Suwarno, & Seals, 1992; Fournier, Wilson, & Swain, 1999; Svebak, 1982; Veltman & Gaillard, 1993, 1996, 1998).

The literature has also provided more direct support for the expected joint effect of noise and cognitive difficulty on physiological reactions. Specifically, in a series of experiments, exposure to recorded noise (factory, aircraft, or traffic) in combination with mental task performance (binary-choice test) resulted in increased blood pressure compared with exposure to recorded noise alone (Mosskov & Ettema, 1977a, 1977b). Similar results were obtained in other studies (Carter & Beh, 1989; Ray, Brady, & Emurian, 1984) but not in all (Wu, Huang, Chou, & Chang, 1988). The combination of noise and cognitive task performance was also associated with increased muscle tension (Hanson, Schellekens, Veldman, & Mulder, 1993) and increased heart rate, norepinephrine, and cortisol levels (Tafalla & Evans, 1997). The proposed explanation of these and other noise effects invoked the information overload model mentioned above. Furthermore, these findings further corroborate the general association between increased cognitive overload and physiological responses.

It is difficult, however, to extrapolate from these laboratory studies to occupational situations involving long-term exposure to ambient noise. Most of the studies cited were conducted on small groups of participants, and the experimental manipulations typically lasted less than 0.5 hr. To our knowledge, besides one (not well described) Russian study (cited in Welch, 1979), no other field studies, either longitudinal or cross-sectional, have examined the effect of chronic exposure to occupational noise on physiological outcomes among employees with cognitively demanding versus nondemanding jobs. Thus, it remains unknown whether chronic noise exposure would have a negative effect on the cardiovascular system of employees, particularly those holding complex (cognitively demanding) jobs.

We hypothesized that chronic exposure to ambient noise would interact with job complexity to affect blood pressure levels over time. We expected that increased blood pressure would occur primarily among workers performing complex jobs under high ambient noise exposure.

In addition, we tested the hypothesis, also derived from the information overload model, that the combination of high ambient noise exposure and high job complexity would also have a negative effect on job satisfaction over time. We focused on job satisfaction because it is conceived to be a job-related affect. Previous research has shown that the proportion of variance in this variable that is explained by adverse job characteristics is much higher than that explained for more general affects such as anxiety, depression, or irritation (French, Caplan, & Harrison, 1982). Job satisfaction was found to be negatively associated with occupational noise exposure in several cross-sectional studies (Melamed, Luz, & Green, 1992; Verbeek, van Dijk, & de Vries, 1986). In line with this reasoning, we hypothesized that exposure to noise would mainly affect the job satisfaction of those performing complex jobs. No study has examined the long-term interactive effect of noise exposure and job complexity on this outcome. We tested the two hypotheses in a longitudinal study of industrial employees, followed up between 2 and 4 years.

The present study was designed to overcome some of the methodological deficiencies mentioned earlier. Its particular strength, besides its longitudinal design, was in focusing on workers who were likely to have fairly stable work environment conditions throughout the follow-up period. These were workers who remained at the same work station during the whole study period (see Method section). This best controls for the possible confounding effect of third variables and permits a claim of causal effect. According to Zapf, Dormann, and Frese (1996, p. 148), for longitudinal research the stability of third variables over time is crucial. Of particular importance here was our confirmation of the stability of noise exposure at the individual level over time (see Method section), which ensures chronicity of the noise exposure.

Method

Study Population

The study participants were 1,831 workers, ages 20–60 years, who participated in the two waves of the CORDIS (Cardiovascular Occupational Risk Factors Determination in Israel) follow-up study (see Green & Harari, 1995), conducted in 21 industrial plants 2–4 years apart ($M = 2.6$ years). A detailed description of the types of plants that were sampled is presented elsewhere (Melamed et al., 1992). Excluded from this sample were 42 workers with chronic diseases (diabetes, myocardial infarction, angina pectoris, and stroke) that might affect blood pressure levels and other cardiovascular endpoints. Of these workers, 282 had missing values on one or more of the study variables. Thus, the sample was reduced to 1,507 workers distributed across 161 work stations. *Work station* was defined as a group of workers employed in similar physical work and environmental conditions (e.g., control room operators, office workers, or workers employed in a given work process). Of these, 700 changed their work station during the follow-up period. Because by doing so, they are likely to have also changed their noise exposure levels and other work and environmental conditions, they were not included in the study sample. Thus, the final sample consisted of 807 workers (451 men and 356 women) who remained in the same work station throughout the follow-up period. Their mean age was 44.00 years (range = 22–62 years), their mean tenure was 9.97 years (range = 0–36 years), and their mean level of education was 10.50 years (range = 4–15 years). Sixty-seven percent were blue-collar and 33% were white-collar workers.

Measures

Noise exposure level. Multiple noise measurements were taken. At Time 1 (T1), ambient noise levels at each work station were measured using a Quest sound level meter Type SL-215 (area sampling; Quest Electronics, Oconomovoc, WI), tripod-mounted and adjusted to a height of 150 cm from the floor. Noise levels were sampled twice a day (morning and afternoon) in winter and in summer. Each sampling period lasted 0.5 hr, during which 5 to 10 readings were taken (depending on noise fluctuations). Results were noted in dB(A) and were averaged for each worker across four sampling periods. The average intercorrelation between noise levels in the four sampling periods at T1 was >.90. Noise exposure level was defined by the geometric mean exposure across the four samplings. At Time 2 (T2), 2–4 years later, we returned to 115 work stations and again measured the ambient noise level. Noise exposure levels were measured during 1 day in summer and in winter, using a Quest M-27 noise-logging dosimeter. The correlation between the noise levels sampled twice during T2 was .89. Results were noted in Leq and were averaged for each worker for the two sampling periods at T2.

Stability of exposure levels over time. The noise exposure level was found to be highly stable; the correlation between noise levels measured twice (2 to 4 years apart) at the same work stations was .86. Therefore, in all analyses we used the noise levels measured at T1.

Ambient temperature. Hourly outdoor dry temperature readings (°C) for each day of the year for the regions of the study were obtained from the National Meteorological Institute, Beit Dagan, Israel.

Job complexity. Job complexity was assessed by averaging an expert's ratings of two items. The first item, *task complexity*, provided an overall assessment of the number of elements, decisions, skill level, independence, and sophistication of the employee's job. Rating ranged from 1, representing a very simple job, to 4, representing a very complex job. The second item, *task variety*, assessed the diversity of tasks in a given job. Ratings on this item also ranged from 1, representing no diversity, to 4, representing high diversity. These items, which correlated .87, were part of the job analysis conducted on the 480 jobs held by the employees in the 21 plants sampled. Other work characteristics included in the job analysis were type of work (repetitive work or work underload), pay system, type of service/production processes, and other general characteristics (e.g., rotation or team work). Job analyses were performed by an experienced rater who observed workers in the same jobs for 1 day. The reliability of the ratings was evaluated in a pilot study that focused on 48 jobs in two plants from two different industries. Ratings were made by three independent raters who observed workers in the same job on 2 separate days. Interrater agreement assessed by kappa statistic (J. Cohen, 1977) had a median value of .91.

Inspection of the job complexity scores revealed a bimodal distribution with two distinct clusters of high and low scores. On the basis of this finding and given that the study hypotheses were specifically formulated in terms of low and high job complexity, we dichotomized job complexity into low and high on the basis of median split of the score distribution (scores 2–4 and 5–8, respectively).

Physical examination. Workers were examined in a nonfasting state between 7:00 a.m. and 4:00 p.m. in a quiet, air-conditioned room at the factory site. Blood pressure was measured three times following a 5-min rest using a standard mercury sphygmomanometer (Baummanometer), the cuff of which was placed on the workers' right arm. Systolic blood pressure corresponded to the first Korotkoff sound and diastolic blood pressure to the fifth. The participant was supine during the first measurement and sitting upright for the next two measurements. The average of the second and third measurements was used in the analysis. This measurement procedure should produce a valid assessment of blood pressure (see, e.g., Fried, 1988; Fried, Rowland, & Ferris, 1984).

Job satisfaction. Job satisfaction was measured by the Satisfaction With Work subscale of the Job Description Index (JDI; P. C. Smith, Kendall, & Hulin, 1969). This subscale had the highest correlation with other measures of well-being (Meir & Melamed, 1986) and with withdrawal behavior (Muchinsky, 1977). The scale consisted of 18 items, with a response scale of *yes* = 3, *?* = 1, or *no* = 0. Two hundred forty-one workers did not complete the JDI at T1, mainly because of language difficulties or because they were absent at the time of administration. An additional 221 workers did not complete the JDI at T2, because of specific requests of some factories to shorten the questionnaire battery. In these factories, only the medical questionnaires were administrated.

Confounding variables. The major potential confounding variables are age, sex, body mass index (weight in kilograms/[height in meters]^2), and a family history of hypertension, which is known to be associated with increased risk for hypertension (Schwartz et al., 1996). Other possible confounding variables included tenure at the department, which might reflect history of exposure to environmental and job stress but also acquired coping strategies (Zapf et al., 1996); use of hearing protection devices (HPDs) to attenuate noise exposure; and ambient temperature (Kristal-Boneh, Harari, Green, & Ribak, 1995). These variables were controlled for in the subsequent tests of the link between noise exposure, job complexity, and blood pressure elevation over time. Finally, an additional potent confounding variable is the presence of workers in white-collar and blue-collar jobs in our study sample. White- and blue-collar workers might differ not only in the complexity of their jobs but also in the exposure to noise and to other adverse work and environmental conditions (as indicated in recent analysis of CORDIS data; see Melamed, Yekutieli, Froom, Kristal-Boneh, & Ribak, 1999). Thus, we also controlled for this variable in the data analysis. Detailed descriptions of white-collar and blue-collar jobs have been presented elsewhere (Melamed, Ben-Avi, Luz, & Green, 1995; Melamed et al., 1992; Melamed et al., 1999).

Results

The intercorrelations among the key study variables are presented in Table 1. The main finding here is a significant association between the predictor variables and the outcomes. Noise exposure levels correlated positively with systolic blood pressure levels at T2 and negatively with job satisfaction at T1 and T2. Job complexity correlated positively with job satisfaction at T1 and T2. Another noteworthy finding is the negative correlation between noise and job complexity. This suggests that those employed in noisy environments tend to also have more simple jobs. Furthermore, as expected, the white/blue-collar

Table 1
Means, Standard Deviations, and Correlation Matrix for Key Study Variables (N = 807)

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Systolic blood pressure, T1	122.8	16.21	—	.74**	.01	.36**	.26**	−.16**	.14**	.04	−.02	.06	.70**	.55**	.06
2. Diastolic blood pressure, T1	77.5	9.9		—	.04	.34**	.26**	−.18**	.10*	.03	−.01	.00	.56**	.60**	−.03
3. Job satisfaction, T1[a]	28.5	9.7			—	.00	−.01	−.12*	.03	−.23**	.22**	−.29**	.01	.04*	.54**
4. Age	44.0	10.4				—	.27**	−.19**	.06	.09*	.03	.03	.41**	.29**	.06
5. Body mass index	26.3	4.5					—	.02	.07*	.05	−.03	.08*	.31**	.32**	−.02
6. Gender[b]	1.44	0.5						—	.00	−.29**	−.15**	−.09*	−.17**	−.13**	−.25**
7. Family history of hypertension[c]	0.31	0.5							—	−.07*	.02	−.02	.11*	.10*	−.03
8. Noise	71.5	11.1								—	−.32**	.59**	.09*	.01	−.13*
9. Job complexity[d]	1.53	0.5									—	−.37**	−.05	−.01	.38**
10. White/blue collar[e]	1.66	0.5										—	.07*	.03	−.27**
11. Systolic blood pressure, T2	124.7	16.7											—	.74**	−.04
12. Diastolic blood pressure, T2	79.4	10.1												—	−.01
13. Job satisfaction, T2[f]	27.3	9.7													—

Note. T1 = Time 1; T2 = Time 2.
[a] n = 666. [b] 1 = man, 2 = woman. [c] 0 = no, 1 = yes. [d] 1 = low, 2 = high. [e] 1 = white collar, 2 = blue collar. [f] n = 285.
* $p < .05$. ** $p < .001$.

Table 2
*Moderated Multiple Regressions of Blood Pressure (BP) Percentage Change [(Time 2 − Time 1) * 100/Time 1] on Time 1 Blood Pressure Value, Control Variables, Noise Exposure Level, and Job Complexity (N = 787)*

Step and variable	Systolic BP change B	SEB	β	ΔR^2	Diastolic BP change B	SEB	β	ΔR^2
Step 1: Controls				.19*				.24*
Time 1 BP (mmHg)	−0.28*	0.02	−.45		−0.62*	0.04	−0.52	
Age (years)	0.21*	0.04	.22		0.12*	0.04	0.11	
Gender	0.91	0.72	−.05		−1.11	0.82	−0.05	
Body mass index (kg/m^2)	0.34*	0.76	.16		0.50*	0.08	0.19	
HPD use (yes/no)	1.41	1.16	.04		−1.61	1.32	0.04	
Family history of hypertension	0.17	0.71	.01		0.92	0.81	0.04	
Ambient temperature (°C)	−0.76*	0.34	−.08		−1.39*	0.40	−0.13	
Job tenure (years)	−0.00	0.05	−.00		−0.04	0.05	−0.03	
White/blue collar	1.40	0.75	.07		1.43	0.86	0.06	
Step 2: Main effects				.00				.00
Noise [dB(A)]	0.04	0.04	.04		0.04	0.04	−0.04	
Job complexity (low/high)	−1.08	0.72	−.05		−0.44	0.83	−0.02	
Step 3: Interactions				.01*				.01*
Noise × Job Complexity	0.22*	0.06	.78		0.19*	0.07	0.57	

Note. For systolic blood pressure change, final model $F(12, 774) = 17.96$, $p < .001$, total $R^2 = .20$, adjusted $R^2 = .19$. For diastolic blood pressure change, final model $F(12, 775) = 21.78$, $p < .001$, $R^2 = .25$, adjusted $R^2 = .24$. *B* indicates unstandardized regression coefficients; β indicates standardized regression coefficients. HPD = hearing protection device.
* $p < .05$.

variable correlated positively with both the predictor and the outcome variables. On the one hand, it correlated negatively with job complexity and positively with noise exposure levels. On the other hand, it correlated positively with systolic blood pressure at T2 and negatively with job satisfaction at both T1 and T2. Thus, this variable may be a possible confounder in this study. Finally, inspection of the mean scores presented in this table reveals that both systolic and diastolic blood pressure increased by 2 mmHg at T2, which is consistent with the expected increase in blood pressure with age. Job satisfaction, however, decreased over time.

To directly test the major hypothesis that the interaction between chronic noise exposure and job complexity predicts blood pressure change over time, we used percentage change from the baseline because it is a more stringent measure from the physiological point of view. This is because at the start of real hypertension disease, the vessel lumen becomes narrowed and a proportionally high blood pressure rise is needed to keep the blood flow constant. Thus, percentage pressure change [(blood pressure T1 − blood pressure T2)/blood pressure T1] served as an outcome variable. This hypothesis was tested through moderated hierarchical multiple regression models in which possible confounding variables were controlled. A review by Aguinis, Peterson, and Pierce (1999) supported the use of moderated multiple regression as the method of choice for estimating moderating effects in applied psychology. Entered in Step 1 were all possible confounding variables: age, gender, body mass index, job tenure, family history of hypertension, HPD use, ambient temperature, and white/blue-collar category. Also entered in this step was T1 (baseline) blood pressure value. To test the main effect of noise (continuous variable) and job complexity (low/high),[1] we entered these variables in Step 2 in addition to all variables in Step 1. Finally, the interactive effect of noise exposure and job complexity on blood pressure change was tested in Step 3. In this step, the interaction term was entered, along with all the variables in the previous step. The results of this analysis are presented in Table 2.

The results show no main effect of either noise or job complexity on systolic or diastolic blood pressure percentage change (Step 2). However, a significant interactive effect of noise by job complexity on both

[1] We have tried, in a preliminary analysis, to enter job complexity as a continuous variable, but this yielded less favorable results, probably because of the true bimodal distribution of the job complexity scores.

systolic and diastolic measures of blood pressure was found even after adjusting for several control variables. Entering this interaction term in Step 3 resulted in a significant, albeit low (1%), increment in R^2. Thus, the results supported the first hypothesis. It should be added, however, that a small amount of explained variance in stressor–outcome relationship is to be expected in longitudinal studies. For an extensive discussion of this issue, see Zapf et al. (1996).

The interactive effect of noise by job complexity on the adjusted percentage change in systolic and diastolic blood pressure is presented in Figure 1. As predicted, among workers exposed to high noise levels, systolic blood pressure increased by a much higher percentage (6%) in those with high job complexity compared with those with lower job complexity (2%). The opposite trend was evident among workers exposed to low noise levels. There was no change in systolic blood pressure for workers with high job complexity. However, a relatively large increase (4%) was observed in workers with low job complexity.

A somewhat unexpected result was the beneficial effect of noise on workers with low job complexity. The percentage of increase in systolic blood pressure was much lower among those exposed to high noise levels (2%) than those exposed to low noise levels (4%). Possible reasons for this occurrence are discussed later. A similar trend was observed for diastolic blood pressure. All results are in the same direction. However, the beneficial effect of noise for workers in low complex jobs was even more pronounced here (see Figure 1, right).

Moderated hierarchical multiple regression analysis, similar to that described above, was used to test the hypothesis concerning percentage change in job satisfaction. Three irrelevant control variables—family history of hypertension, body mass index, and the ambient temperature—were excluded. The results are presented in Table 3. Significant main effects of job complexity, in the expected direction, were observed even after controlling for possible confounding variables (Step 2). Also significant was the Noise × Job Complexity interaction (Step 3: incremental R^2 of 2%). Thus, the second hypothesis was also supported.

The interaction for percentage change (adjusted scores) in job complexity is depicted in Figure 2. This time, the main effect of job complexity is clearly evident. Job satisfaction increased over time among workers with high job complexity. However, job satisfaction decreased over time in workers with low job complexity. The increase in job satisfaction in the former group was much lower (3%) among the subgroup of workers exposed to high noise levels compared with workers exposed to low noise levels (9%). A large reduction in job satisfaction (−34%) was observed among workers with low complexity jobs who were exposed to low noise levels. A much smaller reduction (−13%) was observed among those exposed to high noise levels.

The final analysis focused on the prevalence of elevated blood pressure in the study sample. Elevated blood pressure was defined as either systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg and/or antihypertension medication use. The purpose of this analysis was to test whether the interaction of noise exposure levels (low/high) and job complexity can predict the prevalence[2] of elevated blood pressure. A cutoff point of 80 dB(A) was used to dichotomize noise exposure levels into high and low. The selection of this cutoff point was based on previous findings that this was the threshold for detecting the effect of noise on blood pressure levels (e.g., Fogari, Zoppi, Vanasia, Marasi, & Villa, 1994). The effect of the interaction between noise exposure and job complexity on risk for elevated blood pressure was tested through logistic regression analysis that controlled for the same possible confounders mentioned earlier. The results are presented in Table 4. Noise exposure level was found to interact with job complexity in predicting risk for elevated blood pressure (odds ratio [OR] = 2.66, 95% confidence interval [CI] = 1.11–6.35).

To understand the meaning of this interaction, we examined the percent prevalence of elevated blood pressure in four groups of workers defined by noise exposure levels and job complexity. The results, presented in Table 5, were consistent with the trend observed for the blood pressure percentage changes shown in Figure 1. The highest prevalence of elevated blood pressure was observed among workers in complex jobs who were exposed to high noise levels. Workers exposed to high noise levels but performing simple jobs had a lower prevalence of elevated blood pressure. The reverse was observed among workers exposed to low ambient noise. Among these workers,

[2] In a preliminary analysis, we examined whether this interaction would predict the incidence (new cases) of elevated blood pressure during the follow-up period. However, the small number of new cases (n = 65) during a follow-up period of 2–4 years did not provide enough statistical power to test the above possibility.

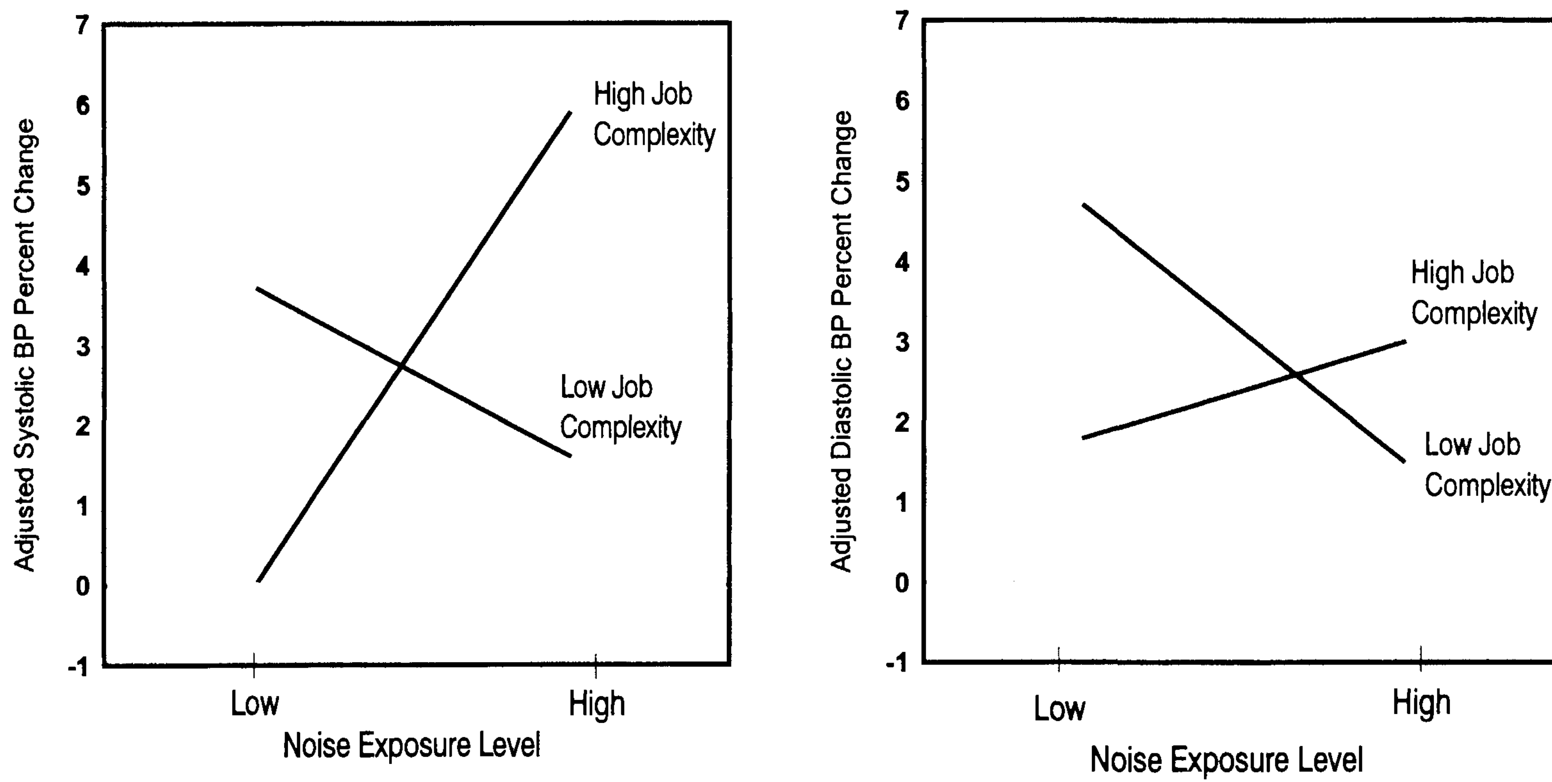

Figure 1. The interaction between noise exposure levels and job complexity in the prediction of percentage change over time of systolic and diastolic blood pressure (after adjusting for several possible confounding variables). BP = blood pressure.

Table 3
*Moderated Multiple Regression of Job Satisfaction Percentage Change [(Time 2 − Time 1) * 100/Time 1] on Control Variables, Noise Exposure Levels, and Job Complexity (N = 246)*

Step and variable	Job satisfaction change B	SEB	β	ΔR^2
Step 1: Controls				.25*
Time 1 job satisfaction	−2.26*	0.26	−.50	
Age (years)	−0.11	0.29	−.02	
Gender	−9.83*	5.50	−.11	
HPD use (yes/no)	−2.59	8.85	−.02	
Job tenure (years)	0.50	0.39	.09	
White/blue collar	−20.60*	5.20	−.23	
Step 2: Main effects				.04*
Noise, in dB(A)	−0.04	0.32	−.01	
Job complexity (low/high)	22.72*	6.23	.25	
Step 3: Interaction				.02*
Noise × Job Complexity	−1.30*	0.63	−0.96	

Note. Final model $F(9, 236) = 13.87$, $p < .001$, total $R^2 = .31$, adjusted $R^2 = .30$. B indicates unadjusted regression coefficients; β indicates standardized regression coefficients. HPD = hearing protection device.
* $p < .05$.

the lowest prevalence of elevated blood pressure was observed in those having complex jobs.

Discussion

To our knowledge, this is one of the few longitudinal studies on the effect of chronic exposure to industrial noise on blood pressure levels. This is also the only study that examined in a natural field setting the interactive effect of ambient noise and job complexity on changes in blood pressure and job satisfaction. Regression analysis results revealed that after several potent confounding variables were controlled for, neither noise exposure levels nor job complexity was associated with blood pressure change over time. This finding concerning noise replicates the negative results obtained in most retrospective longitudinal studies (e.g., Hessel & Sluis-Cremer, 1994; Hirai et al., 1991). Yet, there are a few retrospective longitudinal studies with positive findings (e.g., Deyanov, Mincheva, Hadjiolova, & Ivanovich, 1995; Talbott, Gibson, Burks, Engberg, & McHugh, 1999). To our knowledge, there are no field studies of the long-term effect of job complexity on blood pressure levels; hence we cannot tell whether our finding concerning job complexity can be generalized. Nevertheless, the results of this controlled study suggest that noise exposure levels or job complexity alone are poor predictors of blood pressure change over time.

However, as hypothesized, the complexity of the workers' jobs turned out to have a significant moderating effect on the association between chronic noise and blood pressure. The results show a significant interactive effect of noise exposure levels and job complexity on both systolic and diastolic blood pressure changes over time. This significant interactive effect was evident even after controlling for nine possible confounding variables: baseline systolic blood pressure values, age, sex, body mass index, tenure, family history of hypertension, HPD use, the ambient temperature, and white/blue-collar category. As mentioned previously, our recent analysis of the CORDIS data has shown that compared with white-collar workers, blue-collar workers are exposed to a wider range and magnitude of adverse work and environmental conditions, namely, safety hazards, overcrowding, cognitive and physical demands, and environmental stressors (Melamed et al., 1999). Thus, the fact that the results remained significant even after controlling for white/blue-collar category further reinforces the significance of our findings.

Plotting these interactions revealed that among workers exposed to high ambient noise levels, a threefold adjusted increase in systolic blood pressure was observed in those performing complex jobs compared with those performing simple jobs. A corresponding twofold increase was observed for the adjusted percentage changes in diastolic blood pressure.

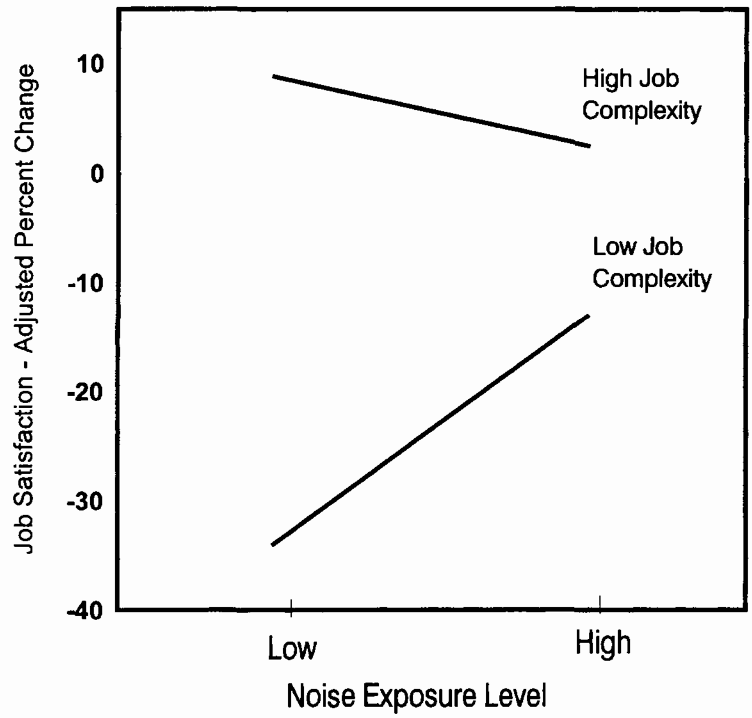

Figure 2. The interaction between noise exposure levels and job complexity in the prediction of percentage change in job satisfaction (after adjusting for several possible confounding variables).

Thus, the present work showed for the first time in a controlled field study that the adverse interactive effect of noise exposure and task complexity on physiological outcomes, observed in laboratory studies (see introduction), generalizes to the work environment. This finding may partly explain the reason for the inconsistent results of previous studies on the effect of chronic noise exposure on blood pressure levels. As mentioned earlier, because these studies failed to consider the type of jobs the exposed workers were performing, the degree of job complexity may have influenced the results. Further follow-up studies are needed to confirm the findings of the present study and to determine whether the adverse effects of noise on the cardiovascular system will be more pronounced in workers performing cognitively demanding jobs.

At the same time, the present findings also showed the existence of a beneficial effect of job complexity in blood pressure change in workers exposed to low levels of ambient noise. There was a minor adjusted change in systolic and diastolic blood pressure among workers with high job complexity but about a threefold increase in the percentage change in both systolic and diastolic blood pressure in workers with low job complexity. Complementary results were observed when we examined the prevalence of elevated blood pressure in the worker sample. Logistic regression results indicated that the interaction of noise exposure levels (high/low) and job complexity (high/low) was associated with increased risk for elevated blood pressure (adjusted OR = 2.66, 95% CI = 1.11–6.15), even after controlling for several possible confounding variables. The highest prevalence of elevated blood pressure was observed among workers in complex jobs exposed to high ambient noise (31%). This compares with the prevalence of 22% in workers in noncomplex jobs. Among workers exposed to low noise levels, however, those employed in complex jobs had the lowest prevalence of elevated blood pressure (20%), whereas among those with simple jobs the prevalence was 23%.

Table 4
Logistic Regression for Predicting Blood Pressure Elevation by Noise Exposure Level and Job Complexity and Their Interaction

Variable	Odds ratio	95% CI	*p*
Noise (low/high)	0.22	0.05–0.82	.025
Job complexity (low/high)	0.31	0.09–1.06	.061
Noise × Job Complexity	2.66	1.11–6.35	.027
Age (years)	1.09	1.07–1.11	.0001
Gender	0.85	0.55–1.32	.48
Body mass index (kg/m^2)	1.14	1.09–1.19	.0001
HPD use (yes/no)	2.13	1.11–4.02	.02
Ambient temperature (°C)	0.83	0.67–1.02	.089
White/blue collar	1.07	0.65–1.75	.78
Family history of hypertension	1.40	0.93–2.08	.09

Note. CI = confidence interval; HPD = hearing protection device.

Taken together, the findings lead to two conclusions. First, exposure to occupational noise has a greater effect on changes in blood pressure over time among those performing complex jobs. These workers also showed the highest prevalence of elevated blood pressure. Second, job complexity, in contrast, had a clear beneficial effect for workers exposed to low noise levels. This was manifested in no change of systolic blood pressure and in a small percentage change in diastolic blood pressure over time (which likely reflected the typical rise of blood pressure with age) and in the lowest prevalence of elevated blood pressure.

This latter finding is rather novel. Job complexity is considered by industrial/organizational psychologists to be a positive job characteristic. Higher job complexity is associated with greater job challenge and stimulation, and it is typically expected to affect employees' psychological well-being and motivation (e.g., Fried & Ferris, 1987; Hackman & Oldham, 1976). Previous studies have demonstrated the beneficial effect of this job characteristic on attitudinal and behavioral outcomes, such as job performance and productivity, creativity, and intention to leave (e.g., Fried & Ferris, 1987; Oldham & Cummings, 1996; Oldham, Kulik, Ambrose, Stepina, & Brand, 1986; Sparrow & Davies, 1988). The present findings show for the first time that among those with favorable environmental conditions, such as low ambient noise levels, job complexity may be a protective factor associated with reduced risk for cardiovascular disease.

Table 5
Percentage Prevalence of Elevated Blood Pressure Among Workers Classified by Noise Exposure Levels and Job Complexity

	Low noise exposure		High noise exposure	
Job complexity	*N*	%	*N*	%
Low	246	22.8	120	21.7
High	337	19.6	85	30.6

These findings are particularly revealing because of the general failure of prior studies to demonstrate a clear association between work stress and health indicators (e.g., Briner & Reynolds, 1999; S. Cohen & Williamson, 1992; Lazarus & Folkman, 1984; Pollock, 1988). Several researchers have pointed out that this failure is due to the profound methodological shortcomings of studies in the area of organizational stress, particularly the reliance on cross-sectional designs and self-report data (e.g., Briner & Reynolds, 1999; Frese & Zapf, 1988; Jex & Beehr, 1991). The present study overcomes these methodological weaknesses and thus contributes to the current literature.

Other important findings of this study are concerned with the attitudinal outcome of job satisfaction. Noise exposure was found to negatively correlate with job satisfaction at both T1 and T2. This is consistent with the findings of other studies (Melamed et al., 1992; Verbeek et al., 1986). Job complexity, as expected, was positively correlated with this outcome as found in other studies (Ganzach, 1998; Hackman & Oldham, 1976). Plotting the interaction of noise exposure by job complexity on job satisfaction change over time revealed that exposure to high noise levels offsets the positive effects of job complexity on job satisfaction. This finding is congruent with the trend observed for blood pressure change, namely, higher elevation of both systolic and diastolic blood pressure, compared with those exposed to low noise levels. However, among workers exposed to low noise levels, those with complex jobs not only showed increased job satisfaction over time but also had minor changes in blood pressure at T2. Those with simple jobs manifested a decrease in job satisfaction over time and had higher percentage change in blood pressure. This similarity in findings for the psychological and physiological outcomes is important, as it has not often been found in other studies (Frese & Zapf, 1988; Fried, 1988; Kasl, 1996). It can serve as mutual validation of both outcomes.

Integration of all the findings suggests that the anticipated positive role of job complexity, suggested by organizational behavior and organizational psychology scholars, is manifested only under favorable environmental conditions, such as low ambient noise. One other study making a similar suggestion was conducted by Oldham, Kulik, and Stepina (1991). This study showed that the combination of job complexity and overcrowding was associated with reduced job satisfaction. Additional studies are needed to determine whether the present findings can be replicated and extended to other negative environmental conditions, such as high ambient temperature or bad lighting. At the same time, the findings here support the assertion that performance of complex jobs under high ambient noise levels may impose high attentional demands and may be stressful (Baron, 1994; S. Cohen et al., 1986; Kryter, 1994). The stressfulness of such a combination was manifested here by less improvement of job satisfaction over time, increased blood pressure levels, and higher prevalence of elevated blood pressure beyond that attributable to increased age. Further research is needed to cross-validate this finding and to determine if it generalizes to other stress indicators, both behavioral (e.g., impaired performance and high absence rate) and physiological (e.g., elevated levels of stress hormones, increased ambulatory blood pressure levels, and reduced heart rate variability).

Yet another important finding of this study is that the effects of noise exposure on employee physiological and attitudinal outcomes were obtained at moderate noise exposure levels. In our sample, 30% were exposed to noise levels ≥80 dB(A). Further inspection of the data revealed that of these, only 46% were exposed to noise levels ≥85 dB(A). Thus, our findings are consistent with those of others (e.g., Fogari et al., 1994) in indicating that the adverse effects of noise on employees can be observed at levels lower than those [≥85 dB(A)] considered to be harmful according to the noise regulations.

A somewhat unexpected finding here for workers in simple jobs was the beneficial effect of being exposed to moderate levels of ambient noise. Compared with their counterparts who were exposed to low ambient noise, they showed much lower blood pressure change over time (in particular diastolic blood pressure) and considerably less reduction in job satisfaction. One possible explanation for the benefits of noise for low complexity jobs, which often may be monotonous and boring, is the arousal theory (Broadbent, 1971; Kryter, 1994; Loeb, 1986). Exposure to moderate noise levels may be arousing and offset the understimulation associated with the boredom and monotony likely to be experienced in simple jobs. We should emphasize, however, that most of the beneficial effects of noise were obtained in laboratory conditions and focused on task performance. Positive effects were obtained either with "white" (broadband random) noise or music. The beneficial effect of moderate industrial noise exposure observed here with physiological and attitudinal outcomes is rather novel, and it is unclear whether it can be accounted for by the arousal theory. Another viable explanation for the above finding is self-selection of jobs. Those in simple jobs who selected to work in noisy environments may have been healthier and more resilient to stressfulness of simple jobs. However, this self-selection cannot be explained in terms of the control variables examined here (such as initial T1 blood pressure values, family history of hypertension, body mass index, blue vs. white collar, etc.). The above results were obtained after controlling for all these possible confounders. Thus, if self-selection was operating here, it may be manifested in variables other than those examined by us. At any rate, the above finding is certainly interesting and deserves further exploration and validation in future studies.

The strength of this study is in its longitudinal design, in the examination of workers who remained in the same work station throughout the follow-up period, and in the use of objective measures of noise exposure levels, job complexity, and blood pressure. The only subjective measure was job satisfaction. We therefore have minimized cognitive biases (for elaboration, see Frese & Zapf, 1988). However, it is appropriate to note some limitations of our study. First, the assessment of noise exposure could have been improved if we had used personal dosimeters at T1 as we did at T2 and sampled the exposure to noise four times a year rather than twice. Second, it would have been desirable to record job changes, if there were any, to assess changes in job complexity. This would have allowed us to obtain more precise results. Third, our follow-up period was too short to have a sufficient number of new cases of elevated blood pressure to be able to test if our predictor variables and their combination would predict incidence of the above endpoint. Finally, because we obtained job satisfaction data for only a third of the workers, we do not know if our results can be generalized to the entire sample.

In conclusion, despite the limitations noted above, this field study contributes to the literature in several ways. It highlights the significance of taking into account the complexity of the jobs performed when studying the effect of chronic noise exposure on employees' outcomes. It demonstrates that job complexity may be beneficial or detrimental to workers' well-being, depending on the conjunction of favorable versus unfavorable environmental conditions. It shows that, given favorable environmental conditions, the beneficial effects of job complexity may extend to health outcomes. Finally, the findings suggest that workers in simple jobs may benefit from exposure to moderate noise levels.

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