American Journal of Epidemiology
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Vol. 150, No. 1
Printed in U.S.A.

Adverse Work and Environmental Conditions Predict Occupational Injuries

The Israeli Cardiovascular Occupational Risk Factors Determination in Israel (CORDIS) Study

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This study was designed to test whether the total objective adverse work and environmental conditions, expressed as the ergonomic stress level (ESL), would predict occupational injuries over a 2-year period. The study population consisted of 4,096 men from 21 factories in six industrial sectors who were studied as part of the Israeli Cardiovascular Occupational Risk Factors Determination in Israel (CORDIS) Study, 1985–1987. The ESL (assigned four levels, 1–4) was based on an ergonomic assessment which covered 17 risk factors pertaining to safety hazards, overcrowding, cognitive and physical demands, and environmental stressors. The ESL was found to be a highly reliable measure and stable over a period of 2–4 years. The incidence of injuries among workers in low ESL conditions (level 1) was 10.3%. It increased with higher ESL's: 11.7% in level 2 (relative risk (RR) = 1.13, 95% confidence interval (CI) 0.86–1.50); 21.6% in level 3 (RR = 2.09, 95% CI 1.68–2.62); and 23.8% in level 4 (RR = 2.31, 95% CI 1.85–2.88). After adjustment for age, job experience, educational level, managerial status, and occupational status (white/blue collar), injury occurrence was significantly elevated for those at level 3 (adjusted odds ratio (OR) = 1.46, 95% CI 1.12–1.91) and level 4 (adjusted OR = 1.81, 95% CI 1.39–2.37) but not for level 2 (adjusted OR = 0.87, 95% CI 0.65–1.18). The authors conclude that adverse work and environmental conditions, objectively assessed, can predict occurrence of occupational injuries. *Am J Epidemiol* 1999;150:18–26.

accidents, occupational; environmental health; occupational health; risk; safety; stress; work; wounds and injuries

Occupational injuries are commonly conceived to be a product of worker error and/or unsafe worker behavior, organizational factors, and objective risk in the work environment (1–4). However, few studies have attempted to determine the independent predictive value of adverse objective occupational factors for work-related injuries. Most of the reports in this area have been done post hoc. To pinpoint causative occupational factors, they usually examined injured workers or accident data, often without control groups (5–10). Many used worker self-reports or relied on job titles to obtain measures of the work environment (1, 11, 12), a practice prone to misclassification bias (13). In some studies, even the injury data were based solely on self-reports (1, 5), which are subject to recall bias (13). In three case-control studies summarized by Saari and Lahtela (14), no consistent association was found between risk factors at the workplace and accident occurrence, while in a study by Hoyos and Ruppert (15), the general scores on the Safety Diagnosis Questionnaire only correlated moderately with the frequency of serious accidents but not with that of the less serious accidents. Thus, it is still unclear whether the objective risk factors standardly assessed in the work environment are predictive of occupational accidents. Gaining such knowledge remains a challenge to occupational injury epidemiology (13).

Many attempts to characterize hazardous environments have focused mainly on safety features (10, 16). Yet, there is increasing evidence that environmental stressors such as high ambient noise levels (17, 18), heat (19, 20), and poor lighting (21) may also be precipitating factors for occupational injuries. Other possible contributors are high physical effort (10, 22), overcrowding (23, 24), and cognitive demands, such as a need for sustained attention (25). Although these factors are known to be present simultaneously in a typical work environment (13, 26, 27), their additive effect on injury risk has so far been barely studied. Such an additive effect on injury risk is theoretically expected. Many researchers have reasoned that the combination of a physically demanding job, active safety hazards, and environmental stressors is overloading and distracting, and requires more

Received for publication November 16, 1997, and accepted for publication November 4, 1998.

Abbreviations: CI, confidence interval; ESL, ergonomic stress level; OR, odds ratio; RR, relative risk.

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"spare" mental capacity of the worker than is available (28).

The present study evolved from our pilot study among male workers (29), which showed that a composite measure of adverse work and environmental conditions termed the ergonomic stress level (ESL) and comprising four dimensions—body motion and posture, physical effort, active hazards, and environmental stressors—was predictive of injury occurrence even after correction for age and other possible confounders. The present study was conducted on a large sample of white- and blue-collar male workers in 21 industrial plants in Israel. A detailed objective assessment of their work environment that covered 17 risk factors pertaining to safety hazards, cognitive and physical job demands, and environmental stressors was performed by independent raters. To our knowledge, no such endeavor has been attempted before. The aims of the study were: 1) to examine whether an aggregate measure of the ESL, based on the above work environment assessment, predicts injury occurrence over a 2-year period; 2) to determine the relative contribution to injury prediction of each of the different factors of the aggregate ESL.

MATERIALS AND METHODS

Study population

The study population consisted of 4,316 men who had participated in the Israeli Cardiovascular Occupational Risk Factors Determination in Israel (CORDIS) Study (30) in 1985–1987. The men were from 21 industrial plants throughout Israel and were screened on site and free of charge for cardiovascular disease risk factors. Six industrial sectors were represented: metal work, textiles, light industry, electronics, food manufacturing, and plywood. Approximately 80 percent of the workers were classified as blue collar (see reference 30 for more details) and the remainder as white collar. Employees at one or two factories were examined each month. Throughout the study period, ergonomic evaluations were independently performed for different plants at different times. The response rate was around 60 percent. Failure to comply was largely due to technical and logistic factors rather than worker refusal to participate. A total of 222 subjects were excluded from the present study because of missing ergonomic data. Thus, the final sample consisted of 4,096 men (3,229 blue-collar workers and 867 white-collar workers) of mean age 42.8 years (range 20–65 years). Mean job experience was 10.1 years (range 1–44 years), and mean educational level was 10.1 years (range 6–15 years). Twenty-four percent were in managerial positions.

Work environment evaluation

Following a pilot study (described below), two experienced observers (who had taken part in the pilot study) evaluated the 640 work stations of the 21 plants in which the study participants were employed. The evaluation was performed using the Ergonomic Stress Inventory (detailed below). Convergent validity of the observers' ratings was obtained by asking workers and supervisors to evaluate the same work environments.

Pilot study and inter-observer agreement

The Ergonomic Stress Inventory comprised 70 items, compiled from published checklists for safety and ergonomic evaluations. The reliability of the work environment evaluation was tested by applying the inventory to 56 work stations in six plants that did not participate in the main study. Four experienced observers independently rated all stations. Eight items for which inter-observer agreement was less than 50 percent were deleted. Thus, the final inventory consisted of 62 items for which high levels of agreement were ascertained. The median value was 0.97, using Ebel's test (31).

The Ergonomic Stress Inventory and its subscales

The 62 items, all rated on a 4-point scale, covered a multitude of adverse work and environmental conditions mentioned earlier. The empirical extraction of the different risk factors (subscales) was completed as follows. First, items were transformed into normal scores to overcome the uneven distribution of item rankings across the work stations. Second, items were grouped into subscales, based on theoretical considerations. Third, the subscales were modified empirically. This modification was guided by the outcomes of cluster analysis (using the SAS VARCLUS procedure in the SAS package) (32) and item analysis (using the SAS CORR procedure), which yielded 17 risk factors (subscales): active hazards; falling hazards; passive hazards; poor controls and safety guards; lack of protection; lack of hazard warnings and escape routes; physical effort; physical discomfort; overcrowding; need for sustained attention; noise intensity; noise disturbance; impact noise frequency; climate discomfort; climate severity; lighting problems; and vibration. The subscales, the number of items in each, and their internal consistency (Cronbach's alpha) or item correlation (in case of two items per subscale) are given in the Appendix. The internal consistency coefficient of the entire inventory was 0.95.

Scoring. Each participant was assigned two types of scores: 1) a global 4-point ESL score, which was his average score across the 62 items of the Ergonomic Stress Inventory, and 2) a 4-point score corresponding to empirical quartiles assigned to each of the 17 subscales of the inventory.

Consistency of ratings over time

Two to four years after completion of the study, we returned to nearly half of the work stations ($n = 115$) in 11 plants. These were evaluated by the same observers. The test-retest correlation of the global ESL was 0.75.

Injury data

Injury data were compiled at the end of the study from all the injuries registered at the participating factories over a period of 2 years (1986–1987) which resulted in at least one day's loss of work and which were recorded in the workers' personal records. By law, injuries that result in 3 days or more of work loss must be reported to the National Social Security, and those that result in 2 days or less of work loss were likely to be underreported. Of the injuries reported, all were found in the workers' personal records. However, the full personal records available at the end of the study were of those workers who were still employed at that time. Reasons for leaving the factory were not accessible. Thus, workers involved in accidents that resulted in death or injuries sufficiently severe to make return to work impossible were not included in the study.

Confounding variables

The two major possible confounders repeatedly mentioned in the literature are age and job experience (13, 33, 34). Others suggested are educational level (13) and occupational (white/blue collar) status (1, 12, 35). These variables were controlled for in a subsequent test of the link between the ESL and injury occurrence. Also controlled for was managerial status (managers vs. workers), a variable whose significance had not been studied previously. We assumed that managers and workers would differ in types of tasks performed, responsibility, and experience, and in job and environmental characteristics; thus, managerial status may be yet another possible confounder.

Data analysis

Linear logistic regression analysis was used to test the association between the global ESL (including each of the 17 factors in the Ergonomic Stress Inventory) and risk for injury occurrence (0 = not injured, 1 = injured once or more times). The odds ratio for each factor was also adjusted for an ESL score based on the remaining 16 factors. Finally, stepwise (forward inclusion) logistic regression was used to determine the significant factors that constituted independent predictors of injury risk. Their additive contribution to predicting injury risk was compared with that of the full ESL score based on the 17 risk factors of the Ergonomic Stress Inventory. Differences between means were tested by t-test. Intercorrelations between scores on subscales of the Ergonomic Stress Inventory were examined by Pearson's correlations.

RESULTS

The correlations matrix between scores on subscales of the Ergonomic Stress Inventory is presented in table 1. Some of these correlations were quite high (37.5 percent were ≥0.50), particularly those among active hazards and falling hazards, passive hazards, poor controls and guards, and lack of protection. As expected, high correlations were also found between noise intensity and noise disturbance and frequency of impact noises, and between climate discomfort and climate severity. The high correlations between scores on the Ergonomic Stress Inventory subscales justified our combining them into a total ESL score representing the overall measure of the work and environmental conditions at a given work setting.

The number of workers employed at each ergonomic stress level and those that sustained one injury or more during the 2-year study period are presented in table 2. The percentages of injuries were greater with increased ESL and were particularly high for workers in levels 3 and 4. Workers in level 3 had a relative risk of 2.10 (95 percent CI 1.68–2.62) for becoming injured compared with men in level 1. For workers in level 4, the relative risk was 2.32 (95 percent CI 1.86–2.88).

Table 2 also presents the numbers of workers and injuries within strata of other potential predictors. No significant differences in injury risk were observed for age, educational level, and job experience. On the other hand, workers were found to have higher risk than managers (relative risk (RR) = 1.35, 95 percent CI 1.14–1.60), and blue-collar workers were found, as expected, to have much higher risk for being injured than white-collar workers (RR = 4.02, 95 percent CI 3.04–5.32). Further analysis showed that blue-collar workers were subject to poorer work and environmental conditions than the white-collar workers, as reflected by the significant differences (standard errors) in the average ESL's (2.8 (0.02) vs. 1.6 (0.2), $p < 0.0001$).

Logistic regression analysis controlled for age, job experience, educational level, managerial status, and

TABLE 1. Intercorrelations* among subscales of the Ergonomic Stress Inventory (*n* = 4,096), the Israeli CORDIS† Study, 1985–1987

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Active hazards	–	0.74	0.71	0.68	0.67	0.62	0.47	0.53	0.50	0.21	0.59	0.64	0.61	0.48	0.54	0.24	0.13
2. Falling hazards		–	0.58	0.51	0.60	0.63	0.52	0.45	0.58	0.08	0.51	0.63	0.54	0.50	0.54	0.28	−0.02
3. Passive hazards			–	0.57	0.64	0.69	0.35	0.48	0.42	0.26	0.49	0.59	0.55	0.55	0.55	0.27	0.11
4. Poor controls and safety guards				–	0.52	0.52	0.28	0.43	0.32	0.20	0.51	0.55	0.46	0.25	0.29	0.16	0.02
5. Lack of protection					–	0.62	0.37	0.39	0.39	0.17	0.53	0.54	0.42	0.51	0.56	0.28	0.10
6. Lack of hazard warnings						–	0.33	0.38	0.43	0.13	0.42	0.53	0.51	0.42	0.46	0.33	0.04
7. Physical effort							–	0.32	0.34	0.10	0.45	0.54	0.34	0.33	0.42	0.16	0.15
8. Physical discomfort								–	0.46	0.48	0.39	0.54	0.57	0.38	0.35	0.15	−0.07
9. Overcrowding									–	0.16	0.35	0.44	0.34	0.36	0.32	0.22	0.05
10. Need for sustained attention										–	0.28	0.31	0.29	0.19	0.16	0.10	0.07
11. Noise intensity											–	0.84	0.64	0.48	0.49	0.25	0.27
12. Noise disturbance												–	0.77	0.54	0.55	0.29	0.19
13. Impact noise frequency													–	0.45	0.47	0.23	0.19
14. Climate discomfort														–	0.82	0.46	0.19
15. Climate severity															–	0.38	0.21
16. Lighting problems																–	0.17
17. Vibration																	–

* Correlation coefficients >0.05 are significant at $p = 0.0001$ level.
† Cardiovascular Occupational Risk Factors Determination in Israel.

TABLE 2. Relative risks (RR) for occupational injury in the 2-year follow-up (1986–1987), by ergonomic stress level and other predictors, the Israeli CORDIS* Study, 1985–1987

Variable	No.	% Injured†	RR	95% CI‡
Ergonomic stress level				
Level 1	874	10.30	1.00	
Level 2	711	11.67	1.13	0.86–1.50
Level 3	1,201	21.57	2.09	1.68–2.62
Level 4	1,310	23.82	2.31	1.85–2.88
Age (years)				
<40	1,921	18.38	1.00	
≥40	2,175	17.98	0.98	0.86–1.11
Job experience (years)				
<8	1,999	17.96	1.00	
≥8	2,097	18.36	1.02	0.89–1.16
Education (years)				
<12	2,519	21.24	1.00	
≥12	1,577	13.25	1.60	1.38–1.86
Managerial status				
Managers	975	14.46	1.00	
Workers	3,121	14.32	1.33	1.13–1.58
Occupational status				
White collar	867	5.65	1.00	
Blue collar	3,229	21.52	3.80	2.88–5.05

* Cardiovascular Occupational Risk Factors Determination in Israel.
† One or more injuries.
‡ CI, confidence interval.

occupational status was used to estimate odds ratios for injury occurrence associated with different ESL's (table 3). Although some of these potential confounding variables were not found to be significant in the univariate analysis, they were included in the regression analysis because of their reported significance in earlier research. The results for the ESL replicated those obtained in the univariate analyses. Levels 3 and 4 of the ESL were associated with 1.46 (95 percent CI 1.12–1.91) and 1.81 (95 percent CI 1.39–2.37) increased risk for injury, respectively. The only other significant variable was occupational status (odds ratio (OR) = 3.55, 95 percent CI 2.50–4.81).

The next step in the analysis was to determine the particular factors in the Ergonomic Stress Inventory that were significantly associated with injury occurrence. First, we studied the univariate data derived from fitting 17 models of logistic regression for the 17 factors of the Ergonomic Stress Inventory (table 4). Second, we attempted to determine the specific contribution of each risk factor beyond all the others. This is quite difficult to do because of the high collinearity among the study variables. Entering all 17 factors into one logistic regression would yield unstable estimated

TABLE 3. Odds ratios and 95% confidence intervals (CI) for *injury occurrence in the 2-year follow-up (1986–1987)*, by ergonomic stress level adjusted for age, job experience, educational level, managerial status, and occupational status, the Israeli CORDIS* Study, 1985–1987

Variable	Odds ratio	95% CI	*p* value
Ergonomic stress level			
Level 1	1.00		
Level 2	0.87	0.65–1.18	0.13
Level 3	1.46	1.12–1.91	0.03
Level 4	1.81	1.39–2.37	0.002
Age (years)	0.99	0.98–1.00	0.37
Job experience (years)	0.99	0.98–1.01	0.89
Education (years)	0.98	0.96–1.02	0.52
Managerial status†	1.02	0.82–1.27	0.81
Occupational status‡	3.55	2.56–5.00	0.0001

* Cardiovascular Occupational Risk Factors Determination in Israel.
† Managers = 1, workers = 0.
‡ Blue collar = 1, white collar = 0.

regression coefficients (36). To overcome this problem, we calculated the adjusted odds ratio for each of the 17 factors after controlling for reduced ESL score based on the remaining 16 variables. Sixteen out of the 17 hypothesized risk factors turned out to be associated with increased injury risk in the univariate analysis with odds ratios ≥1.2 (table 4). Twelve risk factors remained independently associated with injury occurrence in the multivariate analysis with odds ratios different from unity. Ten risk factors were positively associated with injury risk, while two risk factors, lack of hazard warnings and lighting problems, appeared to be protective.

Thus, the results of the multivariate analysis showed that, among the risk factors studied, 60 percent independently contributed to increased injury risk. In an attempt to verify this finding, we applied stepwise logistic regression to the data. The significant factors were: active hazards, need for sustained attention, overcrowding, physical effort, and climate discomfort, all of which had an additive effect on injury occurrence (see table 5). These five factors were also the ones that were positively associated with injury occurrence in the multivariate analysis results presented in table 4.

Finally, we computed two ESL scores: ESL-S, based on a short subscale comprised of these five factors; and ESL-L, based on a longer subscale comprised of the other 12 factors. Both scores were regressed onto injury data. ESL-S was predictive of injury occurrence (RR = 1.46, 95 percent CI 1.31–165), whereas the ESL-L did not have any further contribution (RR = 1.02, 95 percent CI 0.92–1.15). The percentages of injuries associated with the four levels of the ESL-S were 9.99, 11.11, 21.64, and 25.00, respectively, which were similar to the ones obtained with the full scale (see table 2). Furthermore, computing the adjusted odds ratios for the different levels of the short ESL-S by using the same analytical procedure as in table 3 yielded similar results (level 2, OR = 0.79, 95 percent CI 0.57–1.10; level 3, OR = 1.62, 95 percent CI 1.24–2.14; level 4, OR = 1.89, 95 percent CI 1.45–2.48).

TABLE 4. Logistic regression results for predicting injury occurrence by each of the 17 risk factors in the Ergonomic Stress Inventory, the Israeli CORDIS* Study, 1985–1987

Risk factor	Odds ratio	95% CI†	*p* value	Adjusted‡ odds ratio	95% CI	*p* value
Active hazards	1.39	1.29–1.49	0.0001	1.16	1.05–1.28	0.003
Falling hazards	1.28	1.20–1.36	0.0001	1.08	0.99–1.17	0.099
Passive hazards	1.27	1.19–1.36	0.0001	1.05	0.96–1.15	0.26
Poor controls and safety guards	1.24	1.14–1.35	0.0001	0.99	0.89–1.10	0.87
Lack of protection	1.34	1.23–1.47	0.0001	1.02	0.91–1.15	0.75
Lack of hazard warnings	1.24	1.14–1.35	0.0001	0.86	0.76–0.96	0.010
Physical effort	1.35	1.24–1.47	0.0001	1.21	1.09–1.33	0.0005
Physical discomfort	1.23	1.15–1.32	0.0001	1.00	0.92–1.10	0.91
Overcrowding	1.45	1.30–1.62	0.0001	1.18	1.04–1.34	0.001
Need for sustained attention	1.30	1.19–1.42	0.0001	1.17	1.06–1.29	0.0008
Noise intensity	1.34	1.25–1.44	0.0001	1.14	1.04–1.24	0.0042
Noise disturbance	1.36	1.27–1.47	0.0001	1.18	1.07–1.31	0.013
Impact noise frequency	1.21	1.14–1.30	0.0001	1.00	0.89–1.06	0.56
Climate discomfort	1.28	1.20–1.37	0.0001	1.10	1.02–1.20	0.020
Climate severity	1.30	1.27–1.39	0.0001	1.09	1.00–1.20	0.048
Lighting problems	1.07	0.99–1.17	0.084	0.89	0.81–0.99	0.029
Vibration	1.19	1.05–1.34	0.007	1.16	1.02–1.32	0.016

* Cardiovascular Occupational Risk Factors Determination in Israel.
† CI, confidence interval.
‡ The odds ratio for each factor was adjusted for the ergonomic stress level score based on the remaining 16 factors.

TABLE 5. Results of stepwise logistic regression for disclosing the most significant risk factors in the Ergonomic Stress Inventory, the Israeli CORDIS* Study, 1985–1987

Risk factor	Odds ratio	95% CI†
Active hazards	1.20	1.09–1.31
Need for sustained attention	1.18	1.07–1.31
Overcrowding	1.17	1.03–1.34
Physical effort	1.13	1.02–1.25
Climate discomfort	1.10	1.01–1.18

* Cardiovascular Occupational Risk Factors Determination in Israel.

† CI, confidence interval.

DISCUSSION

The prime undertaking and novelty of the present study of a large cohort of male industrial workers from 21 plants was the objective evaluation of job conditions and work environment by experienced observers. The evaluation covered 17 factors, pertaining to safety hazards, environmental stressors, overcrowding, and cognitive and physical demands. Scores for the 17 factors were combined into an aggregate score of ergonomic stress level (ESL), which represents an objective and global measure of the work and environmental conditions in a given work station.

Our major hypothesis was supported. The ESL was found to be predictive of occupational injuries during a 2-year period, even after controlling for several potential confounders. Increased frequency of injuries was particularly apparent among workers in levels 3 and 4, with odds ratios of 1.46 and 1.81, respectively, compared with those in level 1. Because we were unable to include fatal injuries or those that caused disabilities severe enough to necessitate termination of work, it is possible that the association between the ESL and occupational injuries is even somewhat stronger than found here. Our findings support and extend the results of previous cross-sectional studies that found evidence of an association between injuries and safety hazards (10, 16), work characteristics (10, 22–25), and environmental stressors (17–21). In contrast, in their case-control study, Saari and Lahtela (14) did not find that environmental characteristics predicted accidents. However, in their study, they used simple job descriptions, and had no detailed evaluation of the work environments. Further longitudinal prospective studies using comprehensive ergonomic assessments are needed to corroborate our results.

The finding that the ESL remained a significant predictor of injury occurrence even after occupational status was controlled for is particularly important. Blue-collar workers had an injury incidence nearly four times that of white-collar workers. Although blue-collar workers may differ from white-collar workers in many aspects other than ESL that are relevant to injury risk (e.g., educational level, risk perception, and safety practices), the ESL was found to be predictive of injury risk over and above the potential confounding factors embedded in the occupational status.

The results of the univariate analysis (table 4) revealed that all of the Ergonomic Stress Inventory factors except one (lighting problems) were predictive of accident occurrence. This reflects mainly the aforementioned high intercorrelations among the Ergonomic Stress Inventory subscales and the total ESL, and demonstrates yet again that, in the typical work environment, adverse job and environmental conditions coexist (13). Work stations typified by a high level of active safety hazards may often be overcrowded, and have such hazards as high ambient noise levels and bad lighting. The implication is that workers in such work stations are subjected to a multitude of harsh conditions, which have a cumulative effect on injury risk.

The relatively high degree of collearity among the 17 factors in the Ergonomic Stress Inventory make it difficult to determine which of them is most significant in predicting the outcome studied. High degree of collinearity among predictor variables, as observed in this study, can cause unstable regression coefficients (36). This may have led to the inverse association of injury occurrence for two of the factors, observed after adjustment for the ESL score based on all other factors. The results of the stepwise logistic regression, controlling only for the factors which significantly added to the model, suggested that the number of independent factors may be reduced to five. These were: active hazards, need for sustained attention, overcrowding, physical effort, and climate discomfort. The ESL-S based on these five factors was comparable with the total ESL in predicting injury occurrence.

It was interesting to note that although all the safety hazards studied (namely, active hazards, falling hazards, passive hazards, faulty controls and safety guards, and lack of protection) were strongly associated with injury occurrence in the univariate analysis, only active hazards proved to be a significant predictor in the stepwise logistic regression. It is likely that all the other safety hazards are more latent, and that their manifestation is dependent on the circumstances. Other important risk factors examined here have been shown to be related to injury risk in other studies. These risk factors were overcrowding (23, 24), physical effort (10, 22), and climate discomfort (19, 20). By contrast, the significance of the need for sustained attention has hardly been explored. To our knowledge, only one study (25) has examined this issue, and it had a similar finding. The results of the present study warrant further exploration of injury risk in tasks requiring sustained attention.

We are aware, however, that the above list of five important work and environmental factors may be specific to our sample of workers, factories, and industrial sectors. Different risk factors may prove important in other industries, and in other cultural settings. Future studies should also include women, for whom yet other factors may predict injury risk. Furthermore, we have referred to the ergonomic evaluation performed by experienced raters as objective in the sense used by Frese and Zapf (37), namely that the data were not based on workers' self-reports, which are subject to cognitive and emotional errors. The convergent validity of the observers' ratings was ascertained through its congruence with workers' and supervisors' evaluations. Some of the risk factors, such as overcrowding or need for sustained attention, were based on direct measures. Other risk factors, such as active hazards, falling hazards, and poor controls and guards, were based on expert ratings. The ability to make such judgments depends on proper training of observers, which could also vary in different settings. Estimates of environmental stressors such as noise intensity, climate discomfort, climate severity, lighting problems, and vibration can be supplemented by physical measures of ambient noise level, ambient temperature, illumination, and vibration. Evaluation of these parameters requires extensive sampling, at different times of the day, on different days, and preferably in different seasons. Thus, it would be interesting, in further studies, to correlate expert rating of the environmental stressors with physical measurements. It is unknown and theoretically unclear, however, whether direct physical measurement of ambient noise level, ambient temperature, illumination, and vibration would be equally effective, superior, or inferior in the prediction of injuries than expert rating of the environmental stressors as used in this study.

Finally, the participation rate of 60 percent may have introduced a certain bias. As noted earlier, failure to comply was largely due to technical and logistic factors rather than workers' refusal to participate. There is some likelihood that those who volunteered to participate in the study were healthier than those who did not. Healthier volunteer effect has been demonstrated with regard to mortality in the general population (38), but not in workers (39). The existence of such a bias and how it might effect the results is unclear.

In conclusion, this study has met some of the methodological challenges pointed out by Veazie et al. (13), namely the use of longitudinal study design and a multi-firm nationwide survey to evaluate multiple exposure. It demonstrated that the composite measure of objective negative work and environmental conditions as expressed by the ergonomic stress level (ESL) is predictive of occupational injuries occurrence over a 2-year period. Furthermore, the ESL measure was found to be stable over time. These findings, if replicated in other working populations, suggest that work-related injuries can be proactively reduced by modifying potential risk factors in the work environment, as identified by the Ergonomic Stress Inventory. The availability of data on the objective environment in future studies may help to establish the contribution of other factors—behavioral, personal, and organizational—to injury risk. These may make an independent contribution or may interact with any of the 17 factors in the Ergonomic Stress Inventory.

ACKNOWLEDGMENTS

This study was supported by a grant from the Committee of Preventive Action and Research in Occupational Health of the Ministry of Labor and Social Welfare.

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APPENDIX

Subscales of the Ergonomic Stress Inventory

Following are the subscales, the number of items in each, and their internal consistency (Cronbach's alpha) or item correlation (in case of two items per subscale).

1. Active hazards (8 items), e.g., "danger of getting trapped in machines/materials/piping/cords," "unguarded sharp angles, protruding parts especially at eye level or below knee-level." Cronbach's alpha = 0.75.
2. Falling hazards (9 items), e.g., "faulty/unsafe ladders, stairs or passages," "danger of slipping (wetness, oils, shavings)." Cronbach's alpha = 0.77.
3. Passive hazards (5 items), e.g., "danger of getting locked in rooms, etc.," "danger from faulty connections (power lines, piping)." Cronbach's alpha = 0.64.
4. Poor controls and safety guards (4 items), e.g., "poor planning of controls and handles (improperly marked function and direction of handles, poor readability of displays)," "machines can be accidentally started while being serviced or opened." Cronbach's alpha = 0.76.
5. Lack of protection (4 items), e.g., "lack of standard guards wherever required," "personal devices uncomfortable, difficult to use." Cronbach's alpha = 0.86.
6. Lack of hazard warnings and escape routes (6 items), e.g., "lack of clear hazard warnings," "escape routes nonexistent or improperly marked." Cronbach's alpha = 0.91.
7. Physical effort (3 items), e.g., "strenuous physical demands (magnitude)," "strenuous physical demands (frequency)"; "typical length of spell (minutes) (very short (<10 minutes), short (10 minutes), long (60 minutes), very long (most of shift))." Cronbach's alpha = 0.87.
8. Physical discomfort (3 items), e.g., "uncomfortable seating/standing position," "typical period of time spent in an unnatural posture imposed by work conditions (very short to very long; same definition as in factor 7)," "strained/unnatural motions (frequency)." Cronbach's alpha = 0.84.

9. Overcrowding (employees/equipment). Ranking based by percent of void (vacant) space per the maximal space capacity (without people or equipment): 4) very overcrowded, ≤50 percent; 3) overcrowded, 60 percent; 2) slightly overcrowded, 70 percent; 1) not overcrowded, ≥80 percent.
10. Need for sustained attention (1 item) (very short to very long; same definition as in factor 7).
11. Noise intensity (2 items), "perceived intensity of continuous noise," "perceived intensity of impact noise." ($r = 0.52$).
12. Noise disturbance (2 items), "annoyance due to continuous noise," "annoyance due to impact noise" ($r = 0.62$).
13. Frequency of impact noise (1 item), very low (<1 per minute), low (1–4 per minute), high (5–15 per minute), very high (>16 per minute).
14. Climate discomfort (3 items), "annoyance due to temperature," "annoyance due to air currents," "annoyance due to other climatic conditions." Cronbach's alpha = 0.59.
15. Climate severity (4 items), e.g., "contribution of process heat to workplace temperature," "adequacy of ventilation and air conditioning." Cronbach's alpha = 0.83.
16. Lighting problems (3 items), e.g., "lighting intensity relative to requirement," "contrast between work-area illumination and requirement, glare." Cronbach's alpha = 0.72.
17. Vibration (3 items), "perceived intensity of whole-body vibration," "perceived intensity of hand-and-arm vibration," length of exposure period (very short to very long; same definition as above). Cronbach's alpha = 0.84.